21ST MARCH, 2014

IGC EVIDENCE PAPER

ENERGY, GROWTH, AND DEVELOPMENT

Energy, Growth, and Development

Michael Greenstone (MIT and IGC)[1]

Executive Summary

Achieving reliable, widespread access to electricity will be transformative for many developing countries. It has significant effects on how households apportion their time and which methods and inputs are applied by productive enterprises. However, much of the world's population remains without this reliable access or the benefits generated from it. This paper outlines many of the questions behind why this remains the case. Each section of the paper covers a specific issue and focuses on what research has found, where research is currently being conducted, and where further research is required. All of this is directed at understanding the forces that are standing in the way of efficient and inclusive energy markets in these developing countries and also what are their root causes.

This paper covers four main topics: (i) improving the reliability of grid services, (ii) rural electrification, (iii) energy efficiency, and (iv) minimizing the external costs of energy consumption. These each address the main outstanding questions on these topics in the economics literature and also the specific questions which the IGC believes are most pressing for sustainable development. Each section also covers the implications of these questions for continuing economic development and, where possible, what the potential ways forward for research are.

E.1 Improving the Reliability of Grid Services

In the majority of developing countries, there are many customers actually connected to the electricity grid, but the quality of service remains poor. They experience rolling blackouts, electricity rationing, and reduced service. The unreliability and/or limited availability of electricity dramatically reduces its value and potential uses to both households and businesses. There are three main topics in this section, which separately deal with the value of this service to consumers, reducing losses of electricity from the grid, and incentivizing high quality service from the supply side. These are undoubtedly linked, and the grouping along these lines is admittedly loose for some questions.

[1] Michael Greenstone is Director of the IGC Energy Research Programme. He is grateful to Aaron Weisbrod (LSE and IGC) for excellent research assistance.

It is important to establish as much as possible about the demand for a reliable service of electricity so that investments can be effectively prioritized. This allows for more accurate assessment of both objective and relative net social gains when looking at potential projects for improvement. Quantifying the actual willingness to pay for high-quality service is quite difficult in practice, but the actual effects on households are potentially quite large however, making much of their work and leisure time more efficient. Similarly, the effects on production are also significant. It can be used as a direct input in production or to increase the efficiency of the current human and capital inputs already being utilised (or both). Additionally, increasing the reliability of electricity allows producers to stop the use of other makeshift measures, such as costly diesel-based generators. The willingness to pay for the current electricity services appears to remain low in many developing countries however. What remains to be investigated is not only how to improve these services, but also if improving them will raise the willingness to pay sufficiently to profitably sustain that quality of service.

A major factor in the way of these high-quality energy markets developing is electricity theft. For an electricity grid, there are normal transmission and distribution losses (technical losses) and then the losses from non-payments or overt theft (non-technical losses). In some developing countries, these non-technical losses can be very significant. This has serious impacts on the profitability of electricity firms in these markets, discouraging generation, investment, and entrance into the market. This means that these losses often have to be borne by paying customers or local governments to try and retain profitability. Some countries have been successful in reducing these losses, but concrete and tested strategies are yet to emerge. Technologies such as pre-paid cards could be helpful for this. Additionally, privatization or schemes by which companies can target regions where payment is higher may also prove helpful. These are potential measures, but the effectiveness of these (and others) are yet to be rigorously tested.

In order to achieve a reliable high-quality electricity service, there will have to be significant investments in the quality of the electricity infrastructure. This includes generation plants, and both transmission and distribution infrastructures. Additionally, it has been noted that there are many cases where companies deliberately produce below capacity. The question then becomes how to we incentivize the necessary investments and generation to meet local demand for high-quality electricity service. Partnering with local governments (commonly known as public-private partnerships or PPPs) could be helpful for this. Alternatively, there may be other government regulations or strategies that could induce these investments. Reducing the non-technical losses described above may also prove a significant step in the right direction. Additionally, it remains to be seen how the series of new oil and gas finds across much of the developing world will affect these sectors. What is important is that we need to actively investigate different strategies that can induce this investment and generation as these supply-side investments must be the cornerstone of establishing these well-functioning electricity markets.

E.2 Rural Electrification

Connecting rural areas to electricity can often provide some acute problems. At the heart of this lie the problems of connecting these areas and retaining profitability. The reality is that these are areas where the willingness (or ability) to pay is exceptionally low, the population density is low, and the costs of infrastructure investments and operation are often high. These areas are also those where electrification can prove most transformative, if it can be encouraged.

The use of the electricity in these rural areas will affect which potential solutions are best suited to the problem. Whether households will use the electricity for consumption or production will determine the needs for both the amounts of electricity and the required timing of peak supply. It is not this clear cut however, as the amount of electricity available will surely affect the way in which it is used. If the electricity would be used first and foremost for production, then it is more likely to require larger amounts of electricity and possible grid connections must be explored. If it will be used primarily for household consumption and small amounts are valuable, then smaller micro-grids may be more appropriate, at least in the short-term.

Rural uptake of electricity sometimes remains low once the region is connected. This is because rural consumers often use a portfolio of fuel sources, even when electricity is available. This results from a variety of factors, including low incomes and switching costs to electricity (e.g. the need to purchase appliances). It is therefore important to also explore how to encourage uptake once the connections are established. Additionally, it is necessary to investigate how rural electrification can be used to improve the effectiveness of both public goods and government services as well as also advance the economies of whole regions.

Electricity firms are hesitant to engage in rural electrification projects because of their reduced profitability. This means that these projects often require encouragement. It is possible that PPPs may have a role to play here. Either way, it is clear that policy will play an important role here. Policies to reduce theft and losses as well as make the electricity more affordable are likely important first steps in many cases. It is possible that stopgap measures until areas are electrified, such as mini-grids and solar panels, may be cost-effective for the short-term. This would also help develop the market for consumers and work on overcoming switching costs before full-scale grid connections are attempted. These stopgap measures should only be considered if they move us closer to long-term goals, as they do not constitute satisfactory long-term solutions themselves.

E.3 Energy Efficiency

It is often the case that investments that would increase energy efficiency remain unmade, despite their potential social and private gains. This is a problem found in all countries, not just developing ones, but is of particular importance in developing countries because they will constitute the major growth in future global energy demand in the coming years. As a result, any gains in energy efficiency that can be promoted in these countries may turn out to have quite significant effects, especially for meeting global carbon-emission and pollution-reduction targets.

One of the explanations for this is the well-documented difference between the private and social costs of these investments. As in some cases the private benefits to a firm do not outweigh the costs of the investment, despite substantially larger social benefits that could result, and therefore are not made naturally by the private sector. As a result, these investments often need to be encouraged.

An interesting observation with energy efficient investments is what is called “the rebound effect”. This is where energy saving technologies lowers the costs of generation, which should be at least partially passed onto consumers in the form of lower prices. These lower prices can actually lead to more electricity being consumed as it becomes more affordable. This can partially offset some of the savings in generation. This effect has generally been found to be quite low in developed countries, but could be higher for developing countries.

There are cases however where these investments can remain profitable, but are still not made. There are many differing explanations for this in the literature including: (i) slow diffusion of technologies, (ii) imperfect information, (iii) uncertainty, with large variations in energy prices mean that large, illiquid, non-reversible investments are perceived as risky, (iv) costs of purchase and adoption (i.e., fixed costs considerations versus the lower marginal costs), (v) the existence of a subset of firms or consumers that do not use enough energy to warrant costly investments, despite the investments making sense in the aggregate, and (vi) differences between the potential returns from the engineering models and the real-world returns. The explicit causes of this underinvestment have yet to be researched thoroughly in a developing country context, but remain an important route of investigation for future research.

E.4 Minimising the External Costs of Energy Consumption

The rapid development in many developing countries has led to large increases in the consumption of energy. An unfortunate side effect has been large increases in pollution and declines in these nations' environmental quality. This has profound implications for the sustainability of future levels of growth in these countries.

These pollutants can be very harmful to peoples' health and welfare, but populations are often hesitant to invest in reducing these externalities. It is important to establish both (i) what the willingness to pay for reducing these effects actually is in these communities and (ii) why they generally appear to be so low. It is likely that both information problems and low levels of income play significant parts here. Free-riding behavior and social concerns may also be at play here. What is important is to find their root causes and then how to shift them towards more sustainable valuations.

So far, there have been few serious attempts to reduce pollution in developing countries. Pollution is currently allowed to remain high in many of these countries due to weak institutional environments and limited resources. It is therefore critical to determine which regulatory structures and policy strategies can be effective at promoting investments in reducing these externalities.

Climate change is a force that will significantly affect developing countries, especially as in most cases these are the ones that are most vulnerable to and least able to guard against these changes. Additionally, it is likely that rising international pressure to control carbon emissions may affect growth trajectories. It is becoming increasingly critical to both understand the effects that these climate changes will have on local developing economies and also to determine strategies that prove most effective in mitigating these effects.

E.5 Conclusion

This paper concludes with a brief overview of certain areas where research could help to further inform policy on these issues. These focus on the major questions and studies in these areas that are yet to be answered. There are questions of demand, and the need to begin to define what exactly are individuals' willingness to pay for high-quality energy services, both for those connected and those not currently connected (primarily in rural areas). Additionally, there exists a need to discover which strategies are effective for incentivizing behaviours which are conducive to profitably providing these services. There are then various questions for how to effectively incentivise the necessary investments in the electricity grid to develop the capabilities to provide this service to as many consumers as possible. Similarly, questions of how to incentivise energy efficiency investments and how to reduce the externalities associated with increased energy consumption, such as pollution and climate change, are also discussed.

1. Introduction

It is nearly impossible to overstate the role of access to reliable energy as a critical determinant of growth. Greater access to reliable energy transforms lives and economies in an almost uncountable number of ways including: income generation; greater economic specialization; and more enjoyable leisure; substitution of labour with capital that increases productivity; creation of small businesses and enterprises; facilitating the reallocation of household time (especially by women) from energy provision to improved education; protection from extreme temperatures; access to greater market size due to lower transportation and communication costs; and potential health improvements due to reduced indoor smoke, cleaner water, and improved refrigeration (Lipscomb, Mobarak, and Barham, 2013; Dinkleman, 2011; Toman and Jemelkova, 2003; Barreca et al. 2012; Jensen, 2007; Suri et al., 2012). Furthermore, the EIA projects that nearly all of the world's growth in energy consumption will come from non-OECD countries (see Figure 1) and Wolfram et al. (2012) suggest that these projections may understate developing countries' likely growth in energy consumption.

Despite energy's multitude of benefits and projected growth in consumption, access to reliable energy remains a major impediment to economic growth around the world. Approximately 1.2 billion people live without access to electricity. About 2.8 billion people still rely on solid fuels, such as wood, charcoal, animal waste, and coal for heating and cooking, leading to high levels of indoor air pollution (World Bank, 2013). Even among those that are connected to the grid, a high fraction has intermittent and unreliable access to electricity. The scale of the challenge is evident in the figures for average per capita electricity consumption, which was 13,325 kWh in the US in 2010 but just 626 kWh in India and 122 kWh in the Indian state of Bihar (*CIA World Factbook* 2010; Government of Bihar). That is, the energy consumption of citizens in Bihar is less than 1% of that in the US, which severely constrains their productive potential.

Policy plays a central role in increasing access to energy and promoting energy choices that maximise growth. With respect to access, there are important issues around impediments to the construction of the necessary energy infrastructure. Furthermore, in many countries, state and privately owned energy suppliers are required to achieve a multitude of goals (e.g., redistribution) in addition to supplying energy, which impedes their ability to recover costs and earn a profit. As a result, they frequently do not have the incentives to provide a steady supply of electricity to their customers.

With respect to energy choices, policy rarely reflects that the full costs of energy consumption include both the private costs of producing energy and, especially in the case of fossil fuels, the external costs which include shortened lifespans (Chen et al., 2013; Lim et al., 2012; Muller et al., 2011) and a changing climate. Developed and developing countries throughout the world find it challenging to make their energy usage decisions on the full social (i.e., the sum of the private and external) costs, and predominantly base decisions on the private costs alone. Too often, the result is elevated rates of morbidity and mortality that restrict growth. Figure 2 summarizes recent research in the US that makes clear the wide variability in the full costs of different sources of electricity (Greenstone and Looney, 2012).

The IGC Energy Research Programme aims to answer the fundamental policy questions at the centre of energy and growth that focus on how to increase access and minimise the social costs of energy consumption. In the remainder of this document, we review four of the leading areas for energy research that could identify policy interventions that increase growth and advance economic knowledge: (i) improving the reliability of grid services, (ii) rural electrification, (iii) energy efficiency and (iv) minimising the external costs of energy consumption. Each of these areas are divided into subsections and are dealt with separately. These sections are focused on the questions surrounding many of these issues and where future research can help inform policy solutions.

2. Improving the Reliability of Grid Services

A lot of attention is paid to the 1.2 billion people without access to electricity with the assumption being that these people are not connected to the grid. However, a surprising number of these people are connected to the grid but electricity does not flow to the feeders and transformers in their areas. Further, many hundreds of millions of people are connected to the grid but live with electricity outages and irregular service that severely constrain their access to electricity. Irregular and unpredictable access to electricity makes it very challenging for households and businesses to do the planning and make the investments that are the foundation of growth.

In many countries, the poor and erratic state of electricity delivery reflects a choice by distribution companies not to provide regular service because they are unable to recoup the costs of the electricity generation. In India, for example, distribution companies are responsible for getting electricity from the power grid to customers and billing those customers for their consumption. The main problem in the Indian power sector is that as much as half of power drawn from the grid — in Bihar, 45% — is not paid for and is counted opaquely as “aggregate technical and commercial losses” (AT&C), attributable mainly to power that is unmetered, unbilled, or pilfered. Part of these losses is a consequence of redistribution policies (e.g., many farmers are given free electricity) but a high proportion is due to an inability to recover payment for services rendered. Wolak (2008) estimates that the distribution companies in India have annual losses that exceed 1% of GDP. So although power is cheaply available in the wholesale market, the huge losses and poor financial condition of the distribution companies and the poor state of power supply are a single interlinked problem which constrains economic growth.

Although the exact details often differ, India is not unique in having high rates of electric power losses in its transmission and distribution systems. In fact, as the World Bank has detailed in its indicators, almost all of South Asia, large parts of Africa, and many other low-income regions all struggle with this problem.[2] Governments often put an emphasis on increasing generation capacity as a solution; however, this misses the fundamental instability of systems where losses are high regardless of the level of transmission and where the revenue generated is limited. Indeed, these factors constrain attempts to increase supply. Ultimately, part of the problem stems from governments' desire to achieve multiple policy goals through their ownership or regulation of the energy sector, although social norms and politics also play important roles.

The development of growth-enhancing and sustainable energy distribution policies require the identification of empirically-tested approaches that can work in the presence of real world political constraints. Three general foci stand out for their economic and policy relevance: (i) demand-side valuation of the quality of energy supply, (ii) incentivising the fiscally solvent supply of energy, and (iii) supply-side development. While this division of topics is helpful, there are important interactions between these different areas of research and in the policy responses to these issues. The IGC Energy Research Programme is dedicated to building a new knowledge base in these areas. Credible policy solutions will need to draw on research in a number of areas given the interactions between different areas of potential intervention.

2.1 Demand-Side Valuation of the Quality of Energy Supply

It goes without saying that both households and industries benefit from a constant and reliable flow of accessible energy. Understanding the value that consumers place on accessible and reliable energy is critical to the formulation and prioritization of policy. In situations of limited resources, time, and capabilities, it is necessary for policymakers to ensure that their efforts are directed towards those activities where the gains are greatest for the long-term growth of the country. Therefore, it is important to gain an idea of the value of reliable, high-quality energy services across sectors, regions, and consumer groups in order to both determine (i) what public and private costs would result in net social gains for these sectors and communities, and (ii) which of these groups would receive the largest social gains from improvements in the quality of their energy supply.

In the absence of perfectly-functioning markets, it is difficult to infer the valuations of energy accessibility and reliability by simply observing the prices paid for the service. This is due to theoretical and data concerns, issues of imperfect information, price dispersion, heterogeneous preferences, corruption, as well as the many uses of electricity for both households and industry. Further, willingness to pay for a kWh of electricity is likely to vary with the reliability of the service such that a kWh is worth more in settings where electricity is supplied continuously relative to cases where it is only available infrequently. This is because the set of viable uses is substantially larger when electricity is supplied continuously than when service is intermittent.

There are many ways in which the use of energy for production purposes (i.e., both industrial and agricultural) can affect output and by extension economic growth. Energy is often used as a

[2] Available at: http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS (Accessed 03 December 2013)

direct input in production, but, as energy is itself produced, it acts as an intermediate good in the chain of production. Toman and Jemelkova (2003) develop a simple model that incorporates these interactions.[3] The model highlights how, in markets defined by limited access to physical and human capital and to energy, the value of expanding the energy provided to industrial production must be balanced with the opportunity cost of the physical and human capital used in energy production. This balance does go both ways, however, and it can equally be the case that large output gains can be achieved by reallocating human and physical capital to the generation of larger amounts of higher-quality energy services in cases where energy is currently constrained.

Beyond use as a direct input, energy often also enhances the productivity of various other inputs. The availability of reliable energy has direct implications for the choice of capital inputs in the production process and therefore the adoption of more advanced levels of technology. Unreliable energy provision hinders, and in some cases prevents, the uptake of energy-intensive capital inputs. Increased energy access can therefore lead to increased productivity of other inputs, allowing for more advanced and efficient techniques of applying the inputs and for the shift to more productive technologies. Indeed, there have been a number of studies over the years, such as Jorgenson (1984), Worrell et al. (2003), and Murillo-Zamorano (2005), which have found that increased energy usage in production leads to general increases in total factor productivity. These studies demonstrate that the gains from increased energy inputs go beyond the value of energy as a production input. These positive spillover and multiplier effects of energy production highlight the importance of establishing reliable systems for energy provision.

Another example of the productivity effects of unreliable energy sources is the use of smaller personal or private backup generators. A World Bank report published in 2002 chronicled extensive use of diesel generators by farmers for their pump sets. This use took place despite the fact that the energy cost of subsidized electricity was considerably below that of diesel. Diesel generator usage, however, was necessary to ensure that crop yields would not be undermined by irregular electricity services.[4] This is a common trend across many developing countries, as Adenikinju (2003) described in Nigeria, where frequent unpredictable blackouts caused many private entities to turn to inefficient self-generation, significantly increasing both their entry and operational costs.[5] The use of smaller generators is still prevalent, even in areas that are or could easily be connected to the national power grids. These generators constitute a significant capital investment that, in the presence of reliable electricity provision, could be reallocated to other more productive use. In general equilibrium terms, being forced to rely on diesel generators also places firms in regions/countries where energy supply is unreliable at a competitive disadvantage relative to those in regions/countries where energy supply is reliable.

[3] Toman and Jemelkova (April 2003): p. 4.
[4] ESMAP (2002): pp. 23-24.
[5] Adenikinji (2003): p. 1529.

Given the large gap between the cost of grid electricity and the cost of diesel as an energy source the magnitude of this competitive disadvantage can be considerable.

In addition to its contribution to production, energy also helps to increase the welfare of households that are hooked up to the grid. While some of these gains are related to the above considerations, such as increased wages through increases in labour productivity and reduced time spent on domestic labour-intensive power generation, there are other separate leisure-enhancing considerations. Generally, increased access to reliable and affordable power benefits households in numerous ways, including the increased use of time-saving appliances, lighting that allows activities later into the evening, and the use of energy-reliant leisure goods (e.g., televisions, radios, etc.).

The existence of multiple equilibria is a well-known theoretical possibility in economic markets. There often exist both optimal “good” and sub-optimal “bad” equilibria and economic policy may play a role in determining equilibrium outcomes. Economies can become stuck in bad equilibria, leading to inefficient and sub-optimal market outcomes. In many developing countries, energy provision remains patchy at best with large numbers of customers paying little-to-nothing for the service. An important area for investigation is thus whether this is the result of these energy markets becoming stuck in a self-enforcing bad equilibrium with poor service and a low willingness to pay for the substandard service. There is already preliminary evidence that many consumers in developing countries would be willing to pay more for regular and reliable service. There are many potential gains from investigating whether this is the case and then if it is possible to shift these markets to equilibria with more beneficial outcomes. The key questions are whether increasing the quality of service provision would increase the consumers’ willingness to pay for the service and whether increased levels of quality would result in a sufficiently large paying customer base to make energy provision fiscally sustainable.

2.2 Incentivising the Fiscally Solvent Supply of Energy

The energy sectors in developing countries frequently generate large losses. These losses can be divided into two general categories: (i) ‘technical losses’, where power is lost through general transmission, distribution, leakages, blackouts and system failures, and similar outlets, and (ii) ‘non-technical losses’, where losses occur from theft, inability to collect funds, inefficient metering practices, and other aspects not directly related to the technical operation of the grid. Many interventions have focused on incentives to reduce technical losses in order to provide improved access to electricity for those connected to the grid. Non-technical losses, however, present a major challenge in the large majority of developing countries.

Although this problem has been observed within many developing regions around the world, it remains most glaring in Sub-Saharan Africa and South Asia. Indeed, a World Bank Background Paper for their Energy Sector Strategy (2009) stated that, in Sub-Saharan Africa, only 50% of generated electricity was actually paid for, primarily driven by low rates of electricity being actually billed and low levels of collection.[6] Non-technical losses undermine the sustainability of the distribution companies. Ultimately, the costs of this stolen electricity are borne by paying customers, the firms themselves, and, in some cases, local governments. And where these losses are significant, they may be a significant source of competitive disadvantage not only because firms face higher energy prices but also because electricity firms do not raise the revenue necessary to ensure a reliable supply of energy.

The overt theft of electricity often occurs through the direct tapping into of power lines by third parties, manipulation of power meters or unmetered use. There are, however, further elements that help to entrench the problem of electricity theft. Corruption and the inability to adequately monitor and bill for electricity usage also play important roles. Corruption can come from various different arenas. Golden and Min (2012) found in the Indian state of Uttar Pradesh that not only was electricity theft significant, but the losses were larger prior to elections and followed an "electoral cycle", indicating that efforts to crack down on non-technical losses are likely reduced in favour of promoting pre-election goodwill.[7] Corruption can be found in other aspects of the collection process as well, relating to the motivations and incentives of specific collectors, consumers, and officials.

Unfortunately, beyond observing that some countries have successfully combatted this problem, there is little structured research into specific methods and strategies for reducing these non-technical losses. There are large potential gains from understanding the roots of and solutions to this persistent problem, especially in cases where large-scale sweeping measures prove prohibitively costly. How can we convince individuals to refrain from this behavior what combinations of carrots (e.g., service quality, easier payment modes, incentives for faithful meter reading) and sticks (e.g., disconnections) are most effective at doing so, and how can collusion and corruption be prevented in these contexts?

There are technologies that may help reduce these non-technical losses. A good example of these are inexpensive smart meters that utilize prepaid cards, which could help to monitor theft, incentivise and reduce the cost of collections, and constitute a relatively cost-effective solution. These and similar technologies do present potential solutions that could help reduce these costs, but it remains to be thoroughly investigated which ones prove the most promising and how and where best to use them. There are large potential gains from developing strategies for governments that effectively promote the use of these technologies due to the knock-on effects of reduced costs on both the profitability of energy provision and the subsequent investments by utility companies in the supply system.

There is evidence that privatization has proven effective in mitigating some of these problems in past cases. However, there are notable cases where the problem has not been solved by privatization and also where nationalized utility companies have been able to make significant

[6] World Bank (2009): p. 9.

[7] Golden and Min (2012): pp. 22-23.

headway.[8] This highlights the importance of understanding exactly where these successful privatizations have drawn their transformative power from and how this can be adapted and adopted by government-run utility companies. Further understanding the measures that have proven particularly effective would be a good first step towards developing strategies to counteract this problem.

2.3 Supply-Side Development

The quality of service provision is ultimately down to the service providers themselves and their incentives to invest in, maintain, and expand the capacity and reliability of their energy and production infrastructure. This is driven primarily by the profitability of these activities. This still holds for state-run utility companies, although the incentives in these cases can be more complicated. For elected politicians, persistent loss-making by state-run utility companies can make their continued operation increasingly undesirable. Many of the issues discussed in the previous sections, namely willingness to pay and power theft, feed directly into these supply-side considerations.

Therefore, the question is how to incentivise local utility firms to improve their service. Many utility companies in developing countries suffer from both a lack of infrastructure and underinvestment in existing infrastructure. This lack of infrastructure does not necessarily imply a lack of reach of the system, but rather a limited set of diversified transportation routes, safeguards, backup technologies, and a lack of generation capacity, especially during peak demand hours. A lot of investment in the upgrading of energy grids involves large outlays of capital into illiquid infrastructure investments. As a result, the primary factors that drive these investment decisions are often profitability, perceived risk, and distributional considerations. However, it is not always the case that the poor quality of energy provision is the result of infrastructure deficiencies. It can also be due to distributors deliberately selling below their full operating capacity.

The previous sections have covered some of the aspects of consumer behavior that reduce the profitability of supply, such as theft and low willingness to pay. A first important question is whether reducing these tendencies is sufficient to induce utility firms to increase the quality of their supply. There are many aspects of these issues that make answering this question potentially quite difficult. First, it may be difficult to identify those regions where these tendencies are prevalent. Additionally, even where it is possible to identify those regions, it is important to understand if firms are able to target the areas where these tendencies are less prevalent and investments in quality more profitable. If it is possible for firms to actively engage in this type of targeting, then it gives these firms a way of selectively investing in expanding the quality of supply while hopefully maintaining profitability (or at least minimising losses). This produces very positive incentives for consumers as it rewards good behavior while punishing bad, hence increasing the probability that this behavior can be reduced in order to encourage

[8] World Bank (2009): pp. 19-23.

investment in the quality of supply in that area. In practice, however, this type of targeting may prove quite difficult.

Government policymaking can have substantial effects on firms' investment and supply decisions. If policymakers have the ability to encourage the investments necessary to make energy provision accessible and reliable, then there is the potential for large productivity and welfare gains. Examples of these are tax reforms, public-private partnerships, subsidization of tariffs and heightened enforcement efforts on the part of the government. Research on whether potential policy and regulatory structures can be used to facilitate increased investments in upgrading and expanding the current energy supply infrastructure is a core focus of energy research that has the potential to be transformative in terms of encouraging increases in firm productivity and in aggregate economic growth. It will also be important to determine which reforms are both necessary and complementary to these efforts. The most appropriate and efficient ways of achieving these improvements will likely vary on a case-by-case basis.

Many developing countries have also significantly ramped up their activities in exploration and production (E&P) activities. For example, many areas in Sub-Saharan Africa are now developing large oil and natural gas finds, which provide a potentially important opportunity for increasing economic growth in these countries. These finds provide many of the countries with the prospect of increased revenues in the near future that could be used to make the investments necessary to achieve these service improvements. Alternatively and more ambitiously, it is possible to start using these resources for domestic energy generation, especially in cases where the finds are significant and could form the basis of a domestic market, such as in Tanzania's recent natural gas finds.[9] The Côte D'Ivoire is a good example of a nation that uses its significant natural gas reserves entirely for power generation – over 60% of total electricity generation in the Côte D'Ivoire is done from natural gas.[10] Other options include the extremely successful sovereign wealth fund model (made famous by Norway). These finds do provide an opportunity to help bolster these relatively underdeveloped energy sectors and it will be increasingly important in the future to investigate what are the most effective ways to harness these resource finds to encourage economic growth in these countries.

The benefits of a well-run productive energy sector are significant. As described above, many energy sectors in developing countries remain underdeveloped and as a result, fail to provide reliable service to consumers. A successful research programme in this area has the potential to identify how the energy sector might be remade from a constraint on growth to a source of it.

---

[9] Ledesma (March 2013): pp. 20.

[10] "Cote D'Ivoire: Ramping Up Electricity", Oxford Business Group (March 2013): available at: http://www.oxfordbusinessgroup.com/economic_updates/c%C3%B4te-divoire-renforcement-des-capacit%C3%A9s-de-production-d%C3%A9lectricit%C3%A9#english

3. Rural Electrification

Past studies suggest that the benefits of rural electrification are significant (e.g. Khandker 1996; Martins 2005; World Bank 2008; Dinkelman 2011). These benefits include the expansion of economic activities including the setting up of new firms, access to new technologies, increased opportunities for entrepreneurial activities, reductions in labour intensive domestic tasks, improved lighting quality and improvements in indoor air quality. Women and children receive many of the gains of rural electrification, as they often benefit disproportionately from improved indoor living conditions and increased appliance use (Dinkelman 2011). Power can also have a transformational effect on local productivity by allowing entrepreneurs, vendors and farmers to access new and more efficient technologies. Refrigeration for use in retail businesses as well as in manufacturing and service firms (for example, milk chilling in dairy businesses) is an example of a technology that spreads quickly when rural electrification occurs. Self-generation of power, through diesel generators, for example, may be prohibitively expensive to make use of these technologies viable and thus act an impediment to structural change in the countryside.

These benefits notwithstanding, rural electrification programmes face formidable challenges. Historically, rural electrification project developers face a tradeoff between securing financial viability and reaching disadvantaged households. For economic reasons, rural electrification initiatives have focused disproportionately on communities located close to roads and the existing grid infrastructure. It is estimated that extending grid infrastructure to a village located 15 km out of range requires an investment of nearly $150,000, which is not cost-effective in areas where population density is low or the willingness and ability to pay for power is low. Further, in a recent study, researchers found that when a village is electrified, higher income households benefit significantly more than their poorer counterparts, because poorer households find the connection fees prohibitive (Khandker et al., 2012).

Finally, many rural electrification programmes have been rendered unsustainable due to poor commercial management. As a result, concerns have surfaced about the long-run financial viability of rural electrification projects. A recent World Bank study suggests that the long-term success of a rural electrification initiative depends critically on the ability to charge tariffs that cover operations and maintenance costs (Barnes and Foley, 2004). In response, many governments and private sector actors have effectively decided that it is infeasible to serve rural areas with the grid and have turned to local or mini-grids that rely on renewables or alternative energy sources such as bio-gas, solar, and wind. The end result is that vast swathes of the rural parts of developing countries remain without electricity.

Two primary research areas stand out for their economic and policy relevance in the area of rural electrification are: (i) willingness to pay, focusing on defining and quantifying (where possible) the value of rural electrification to a country's populace, the uses of electricity and its uptake, and (ii) sustainability of supply, focusing on how to incentivise the electrification of these rural areas.

3.1 Willingness to Pay

As discussed above, the potential of rural electrification for improving welfare in these communities is immense. The benefits of this connectivity are as varied as they are significant, and range from on an individual level up to community-wide benefits and beyond. However, each of these benefits needs to be separately investigated before they can be viewed as whole for the purposes of cost-benefit analyses or similar exercises.

On a private level, the benefits of being connected to electricity grids can be quite transformative. One of the largest benefits relates to efficiencies in the use of time. Electrification allows for the use of appliances and other time-saving mechanisms, but also advantages for the poorest of households in developing countries. A large amount of power generation in the most impoverished developing countries still relies on very time-and-labour-intensive methods, such as biomass (e.g., wood stoves) and coal.[11] Beyond the health effects of these methods, they require large human energy and time inputs relative to the use of electricity.

While it is apparent that there is demand for electrification in the majority of rural developing regions, the nature of this demand remains less apparent. As electricity can be used as an input into either production processes or consumption goods, the demand for particular forms of electricity will be critically dependent on how electricity is utilized in these rural regions. Therefore, the division between production and consumption usage will critically affect how electrification is valued, depending on many elements such as its scale and its timing. For example, if it is used for production, electricity offered in late evenings will be less valuable than electricity offered during the day. Likewise, in cases where electricity is used primarily for consumption, electricity service primarily in the evenings will be more valuable than during the day, when agricultural activity is undertaken. These distinctions are important in assessing valuations of electricity from alternative sources (e.g., solar which is available only during the day versus grid electricity). This is also related to the reaction of consumers to increases in the quality of service as discussed in the previous section.

The willingness to pay will also depend critically on the quantities of power required at any given time. This will be determined largely by the prioritization of uses for electricity by rural consumers. Since, for example, a toaster uses significantly less power than advanced irrigation machinery, the benefit of electrification for producers and consumers will be determined largely by the wattage offered. Appropriate understanding and prioritization of uses will therefore be important in ensuring that investing in rural electrification is targeted efficiently, especially where the electricity generated and funded available for investment are limited.

Therefore, if consumers will primarily use electrification for consumption and household goods, then it is likely that kWhs will be highly valued at first and then experience diminishing returns

[11] Heltberg (2004): pp. 869-871.

in the marginal benefit of each additional unit. In this case small-scale grid solutions may be ideal, and solutions that are alternatives to the connection to the larger national grids may be effective. However, if electricity would ideally be used for productive processes by consumers, then it is possible that kWhs of electricity will demonstrate increasing marginal benefits to individuals until enough kWhs are available for the full operation of the desired production mechanisms and only then start to decrease. This second case also produces potential switching behavior where, at low levels of electricity offered, consumers may first use the power for leisure and consumption, but switch to using it for production once their access reaches the required scale. This switching threshold, if it does indeed exist, would produce a more complicated marginal benefit curve, which would substantially increase the importance of the scale of electricity provision alongside the access of the provision. In these cases access to larger-capacity electricity production, as is usually available in national grids, will be more important in order to maximise the positive impact of rural electrification.

These examples illustrate how differing potential uses for electricity by rural households affect both producer and consumer valuations of electricity and the relative viability of different rural electrification strategies. They are, however, not meant to be exhaustive. Grid electricity, for example, can often prove more expensive to rural consumers than traditional, more labour-intensive methods of wood-burning, kerosene, and candle usage for personal household consumption. In other words, electrification can prove cost-saving for production inputs, but be a more expensive alternative for personal household consumption. Therefore, even when electricity is consumed by households, it is often used in conjunction with these other labour-intensive fuel sources.[12] This is especially so in very poor rural areas where it is not always possible to monetize an individual's leisure time, making production of energy through labour-intensive methods that requires less monetary cost increasingly attractive. In fact, the household choices around fuel consumption in rural areas in developing countries appears to be far more complicated than simple transitional ladder models, with the reality being that households often adopt a basket of fuels for consumption from both the traditional (wood and kerosene) and the more advanced (electricity and gas).[13] Additionally, the cost of electricity usage is often increased by the costs of the household investments necessary to start using the electricity, such as appliances and connection fees, which can often prove prohibitively costly. As a result, electricity uptake post-electrification in many rural areas can be lower than expected, with only partial usage of electricity occurring as well as appliance ownership and alternative fuel usage proving significant factors of uptake.[14]

In addition to private valuations for individual and personal electricity usage, there are more overarching public goods elements of rural electrification. While it is very likely that spillovers from network effects do exist, what is less clear is the magnitude of these spillovers, in which cases and contexts they are strongest, and how they can be effectively utilized to maximise the

[12] Davis (1998): p. 208.
[13] Heltberg, (2004): pp. 871, 885.
[14] Louwa et al. (2008): pp. 2813, 2816.

welfare gains from the rural electrification. Public goods can obviously be enhanced by rural electrification as well – a benefit that should be taken into account when comparing the social benefits and costs of such initiatives. Examples of these can range from direct goods such as street lights, to things less overtly visible, such as improvements in the capabilities of local public servants and reductions in crime rates.

Finally and importantly, rural electrification can have significant effects on the whole dynamics of the regions where electrification occurs. As discussed above, access to improved production techniques and technologies will translate into potentially significant productivity and scale increases. Similarly, increases in the consumption of both electricity-reliant goods and other products (due to increased leisure and income effects) may also affect trade and migration patterns in these cases. It is imperative that the size, scale, and nature of these general equilibrium effects be taken into account with any rural electrification policy as they have a profound effect on the benefits and spillover effects of rural electrification.

Investigating these more significant shifts may prove quite difficult, but the advantages of doing so are also quite large. Energy usage affects almost all aspects of the economy and it is natural that its effects would be far reaching. General equilibrium modelling could be potentially quite informative where it is not prevented by the lack of available data. More concentrated studies of the effects of improved energy access on labour markets, structural change, trade promotion, urbanisation, and other topics will also be critical to informing cost-benefit analyses and optimal policymaking. It will be important to investigate all of these and other effects of improved energy access as their spillover and feedback effects are likely to be varied and significant. This will allow policymakers to not only weigh the costs and benefits of such programmes, but to also take actions to maximise the benefits and mitigate the potentially negative effects of improving energy access.

3.2 Sustainability and Supply

The electrification of many rural areas in developing countries is constrained by the simple fact that the costs of these extensions are often higher and the population density is often lower in these areas. This reduces the probability of recuperating the costs of these investments compared to those in more densely populated areas. As a result, energy firms are often hesitant to engage in large-scale rural electrification and most of this rural electrification has remained confined to areas close to the existing grids. In the more difficult cases, it is often necessary to find ways of increasing the profitability of these projects or to seek alternative solutions, whether temporary or permanent, in order to facilitate these investments.

The reality is that rural electrification projects can produce large welfare gains for rural citizens, but often yield low profits. In these situations, public-private partnerships (PPPs) are commonly used to subsidize the project so that it becomes sufficiently profitable for private enterprises to undertake while still remaining a “good deal” for public governing bodies. Some interesting work has been done on PPPs to date, but further research on how to structure these agreements, and make them more effective, could turn the PPP into an exceptional tool for overcoming these problems.

The government will have a large role to play in making these projects profitable regardless of whether PPPs are used. The first step is to establish the conditions required to make these projects profitable and then how to structure these investments so as to maximise this profitability. An example for this is that electrification of a series of individual villages may prove prohibitively costly, but a cluster of the same villages may not. This is because, due to the costly transmission infrastructure associated with these investments, the electrification of individual villages generates significant positive cost externalities (or spillovers) for nearby villages by allowing them to share many of the same fixed costs, thereby raising the profitability of each individual village electrification. As a result, large-scale and clustered electrification projects may prove to be significantly more viable investments. It will therefore be important to determine how to identify these potentially viable methods of investment and also which government policies can be effective in then drawing investment to these projects.

In some cases, direct connections to the grid will simply be prohibitively costly for the time being and the question will turn to how to choose and implement viable electrification measures in the meantime. There may be off-grid solutions in the forms of village-specific or smaller-scale separate grids that can bridge this gap. While these are temporary solutions and far from ideal, the investment costs are likely to prove lower for these projects which may then increase the long-term profitability of such ventures. This is important since often, as Davis (1998) points out in the South African case, large levels of electricity usage is necessary for rural electrification projects to provide positive net present value returns to utility companies.[15] It is noted, however, that electrification in rural areas often does not lead to switching to the use of electricity right away due to significant switching costs for the household.[16] It is therefore possible that these stopgaps can be used to first develop the demand for electricity in these rural areas and then, when the demand is sufficiently developed, make connection to the large-scale national grids a more economically viable investment.

The questions surrounding these potential stopgap methods are still critical to investigate. Such methods are only worth using if they are relatively economically viable compared to the alternative of larger-grid connection and actually sufficient to meet the demands of the targeted rural consumers or at least promise to make the necessary long-term investments more viable in the medium-term. Therefore, it is critical to consider to what extent off-grid power solutions can substitute for grid power in terms of its effect on current living standards and growth. Importantly, if these solutions do have the potential to raise welfare, how far can they bring these welfare increases before they reach their operating capacities and then, how far do they bring us towards adopting more permanent long-term solutions? This remains important as the desirability of these projects may be questionable if they don’t help bring

[15] Davis (1998): p. 208.

[16] Louwa et al. (2008) p. 2816.

these areas towards a long-term solution and allow for only lower grades of rural electrification.

As mentioned previously, electricity theft and generally low levels of payment for the power consumed remains an important consideration for encouraging the supply of these services. The challenge of trying to limit these losses will likely prove critical in making rural electrification profitable and ultimately appealing to utility companies. The unfortunate reality is that, in many cases, electricity theft and non-payment can be both common and acceptable, cementing itself as the norm. It is in these cases that it becomes important to understand the nature of these social norms and how they can be shifted. It is possible, for example, that smart meters with pre-paid cards can prove effective in overcoming these issues. Alternatively, there can be successes using certain tools to disincentivise this behavior and shift these social norms away from these practices. The effectiveness of these various solutions remains to be rigorously tested however.

4. Energy Efficiency

The future of global energy use and carbon emissions depends almost entirely on the growing energy demand in the developing world. The Energy Information Administration forecasts that energy consumption will grow 14% from 2007 to 2035 in non-OECD countries but 4% in OECD countries—a figure that recent research suggests is an underestimate (Wolfram et al., 2012). There is a widespread belief that there are tremendous opportunities for low-cost or even negative cost energy efficiency investments (Alcott and Greenstone, 2012). Thus any evidence on the viability of mass-scale energy-efficiency initiatives in the developing world may be important both for increasing the rate of economic growth through more efficient energy usage and for reducing the external costs of energy consumption.

In addition to the importance of energy efficiency for growth, it is the climate policy for which there is near universal support across the income and political distributions. Reports of the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change (IPCC) have long stressed the importance of energy efficiency in any climate change mitigation strategy. Further, the head of the U.N. Climate Change Secretariat recently hailed energy efficiency as "the most promising means to reduce greenhouse gases in the short term."[17] This favoured position is based on the poorly-tested idea that energy-efficiency investments are a low-cost or even no-cost form of abatement. The presumption is that such investments will save firms enough money on energy bills to be profitable outright.

Recognising the need to reduce carbon emissions to mitigate the rate of climate change, global climate policy-makers have pushed funding for carbon emissions abatement and mitigation initiatives. The goal of transferring $30 billion from developed to developing economies, set in

[17] De Boer, Yvo (August 28, 2007), available at: http://www.reuters.com/article/idUSL2836333720070828.

Copenhagen, was raised to $100 billion less than a year later in Cancun.[18] This transfer, a combination of public and private investments, can only succeed if it significantly and reliably checks emissions growth. Policies to increase energy-efficiency, ranging from technology mandates and building codes to efficiency credits and energy audits, are some of the most favoured abatement options in the near term. For example, McKinsey & Co. has argued that industrial energy efficiency offers some of the lowest carbon abatement costs of any available technology – in fact it yields positive returns (Nauclér and Enkvist, 2009).

Economists have heard, and often rebuked, such claims before (Joskow and Marron, 1992). A long literature in economics demonstrates that neither consumers nor firms adopt all technologies that appear profitable in engineering analyses of costs and benefits (Jaffe and Stavins, 1994a). The reasons cited for this failure to adopt vary. Market failures may prevent firms from learning about efficient technologies, or a lack of capital, skilled labour, and other inputs may inhibit adoption. Most basically, real-world returns to energy-efficiency investments may not match their predicted returns.

The research areas that stand out for their economic and policy relevance on this topic can be generally divided into two groups: (i) the return on efficient energy, which focuses on the returns to energy-efficient investments and why the uptake of these investments appears to be so much lower than would be expected, and (ii) incentivising efficient energy investments, which focuses on potential methods for encouraging these investments.

4.1 Return on Efficient Energy

The potential benefits of adopting energy-efficient technologies are generally well-established. These returns are quite varied, ranging from private firm production efficiencies to village-wide, nation-wide and world-wide benefits resulting from pollution reduction. The uptake of these technologies has remained quite low relative to their potential in both developed and developing countries and low take-up is seen as a significant constraint on economic growth. In addition, continued use of inefficient technologies despite the large potential returns of these investments, results in continued high levels of water and air pollution.

A plausible explanation is that the returns to such investments justify their costs, but the private (firm) returns to such investments remain a fraction of the total social returns. In fact, there are many energy sources that provide high levels of private returns, but also result in high social costs, such as coal-burning plants. It is in these cases that switching to more efficient sources may lead to low or negative private returns even though they result in large net gains in social returns. The social costs are not taken into account by the private individuals, leading to high external costs and inefficient outcomes. Greenstone and Looney (2012) present a series of calculations along these lines which shows many of these relevant comparisons in the context of electricity generation in the United States. Coal, for example, has private costs of 3.2₵/kWh,

[18] Wall Street Journal (December 11, 2010), available at: http://online.wsj.com/article/SB10001424052748703518604576012922254366218.html

but has a social cost of 8.8₵/kWh. On the other hand, conventional natural gas has higher private costs of 4.9₵/kWh, but lower social costs of 6.0₵/kWh.[19] There is an analogous case for energy-saving technologies as well, both for households and industries, where the costs of implementation do not necessarily reflect the social costs of the investments.

Another noteworthy element of energy-efficiency investments is the "rebound effect", which reduces the energy savings from such investments. This effect is largely grounded in microeconomic principles, stating that energy-efficiency investments will reduce the cost of energy production which should transmit into lower prices for consumers and hence higher demand for consumption. As a result, the energy saved from such investments may be partially eroded by increased demand for energy as a result of the lower prices passed on by the reduced costs. Greening et al. (2000) conducted an extensive survey of rebound effect investigations focusing on the United States and found that generally these effects were "low-to-moderate" and largely below 30-50%.[20]

In developing countries, however, the effect may be considerably larger. First, it is possible that there is significant unsatisfied demand for energy such that any energy saved would be offset by increased demand, resulting in very high rebound effects. Secondly, as the consumers in developing countries likely spend a larger portion of their income on energy, decreases in the price of energy could lead to large income effects which could then further increase energy consumption, again leading to larger rebound effects. Citing these factors, Van den Bergh (2011) argued that developing countries are more likely to experience large rebound effects and noted the potential implications for growth and development.[21] Papers such as Roy (2000), which found potentially high rebound effects for lighting in rural India, provide preliminary evidence that this might be the case, but there remains little rigorous research on the topic for developing countries.[22]

It is evident that more research on the returns to energy efficiency investments in developing countries is necessary. This research should make clear that the private and social returns can differ. With respect to the rebound effect, increases in consumption reflect gains in individual welfare that may be counterbalanced by increased negative externalities and sorting out the magnitudes of these two effects is an important area for future research.

4.2 Incentivising Efficient Energy Investments

There are many technological advances that increase the efficiency of power generation which have experienced low levels of uptake by industry. This is a puzzle as the returns to these investments are potentially quite large, simultaneously reducing generation and social costs. However, this gap between the socially-optimal levels of energy efficiency and those observed,

---

[19] Based on "existing capacity" calculations: Greenstone and Looney (2012): pp. 19-21.

[20] Greening, Lorna, David L. Greene, Carmen Difiglio (2000): p. 399.

[21] Van den Bergh, Jeroen C.J.M (2011): pp. 44-45, 56.

[22] Roy, Joyashree (2000): pp. 434-436.

dubbed "the energy-efficiency gap", remains substantial. There are many differing explanations for this in the literature including: (i) slow diffusion of technologies, (ii) imperfect information, (iii) uncertainty, with large variations in energy prices mean that large, illiquid, non-reversible investments are perceived as risky, (iv) costs of purchase and adoption (i.e., fixed costs considerations versus the lower marginal costs), (v) the existence of a subset of firms or consumers that do not use enough energy to warrant costly investments, despite the investments making sense in the aggregate, and (vi) differences between the potential returns from the engineering models and the real-world returns.[23] As Alcott and Greenstone (2012) point out, if these inefficiencies result from energy use externalities, the remedies are established and straightforward. Solutions such as Pigouvian Taxes or cap-and-trade programmes are obvious choices, even if they are perhaps more difficult to implement in developing countries. If, however, these inefficiencies result from investment inefficiencies, then the solution is less clear cut.[24]

While many of these explanations seem plausible, there is relatively little research into the primary causes of this phenomenon, especially within specific (developing) country contexts. There are major potential gains from further investigation into which of these factors best explain the observed trends and what market structures and household characteristics make energy markets more susceptible to these deficiencies in investments. With regards to policymaking, it also becomes critical to tailor these investigations to each country's contexts with the added aim of ensuring as much external validity as possible while maintaining the necessary specificity for it to inform domestic policy. In some cases, the culprit here is imperfect information (or other market failures) and policy should be enacted in order to try and rectify these failures in information dispersion. There will be other cases where the roots of these gaps lie in behavioral biases that cause individuals or businesses to fail to make profitable energy efficiency investments. Also, in some cases the real world returns may simply not justify the investments. In the cases where they are justified, however, it is first important to investigate what is holding firms and individuals back from making them.

Once the roots of any underinvestment are discovered, the question becomes what are the available and optimal interventions to induce these investments. There are many differing ways to deal with these problems of underinvestment and it is important to consider each of these interventions in turn. Which public sector energy-efficiency programmes have the highest rate of return for consumers and businesses? This is especially important in developing countries where jeopardizing growth is especially costly. It is therefore important to identify the social costs of each ton of carbon and also the most cost-effective methods for carbon abatement. That being said, it is also possible that encouraging energy-efficiency investments can increase, not hinder, growth beyond the cost savings by promoting productivity increases through technological advancement and spillover effects. It is important to identify the policies that allow these efficiencies to be realized.

[23] Jaffe, Adam B., and Robert N. Stavins (1994b): pp. 804-806.
[24] Alcott, Hunt, and Michael Greenstone (2012): p. 4.

5. Minimising the External Costs of Energy Consumption

Most visitors to developing country cities notice the poor environmental quality due to conventional pollutants: their eyes sting, the views are obscured by smog, they experience respiratory problems, and they are advised not to drink the water or bathe in rivers. These casual observations are backed up by the data that reveal much greater concentrations of air and water pollution in developing countries than in developed countries today (or in some cases ever). The available evidence suggests that they lead to large health and productivity losses. For example, Chen et al. (2013) find that a policy that provides free coal for indoor heating leads to dramatic increase in total suspended particulates pollution concentrations and a 5.5 year decline in life expectancy in the north of China. The elevated rates of mortality occur throughout the life cycle and the more than 500 million people living in the north of China are expected to lose more than 2.5 billion life years. Although energy consumption and production are by no means the only source of water pollution and water scarcity, they do contribute to these problems. The recent Global Burden of Disease research suggests that water quality is also an important source of morbidity and mortality in developing countries (World Health Organization, 2008).

Balancing the twin aims of increasing economic growth and minimising the external costs of rising energy consumption requires significant additional research. There are several research areas that are critical for their economic and policy significance: (i) welfare impacts of pollution, (ii) abating pollution and (iii) climate change. Many of these questions centre on estimating the social costs of emissions associated with energy consumption and production and the costs of reducing these emissions. Part of these social costs arise from local pollution but climate change has an international reach and therefore mitigation of the growth and welfare challenges that this problem poses will require involvement of policy makers from a number of countries.

5.1 Welfare Impacts of Pollution

The issues of energy and pollution are becoming increasingly linked in the public eye. China is perhaps the most commonly cited example of this, if only for the extreme levels and concentration of pollution and its growth, which has led it to become the number one producer of carbon emissions. China is a prime example of pollution externalities run amok, with approximately 50% of its water declared unsafe for drinking and just below 25% declared unsafe for even industrial or agricultural use in 2010 by China's Ministry of Environmental Protection.[25] Examples such as this are some of the most visible and far-reaching effects of pollution, but the linkages to growth range from these large-scale effects down to the individual household-specific effects and from productivity decreases, human capital erosion, and

[25] Reuters, "Pollution makes quarter of China water unusable: ministry", 26 July 2010. Available at: http://www.reuters.com/article/2010/07/26/us-china-environment-water-idUSTRE66P39H20100726

sustainability concerns to direct health impacts. The effects can be long-term, for example through their impact on early childhood development.

The effects inevitably vary across countries. For example, rural villagers in Lesotho are more likely to suffer from respiratory problems from burning wood and dung in their small and enclosed homes than from groundwater contamination, whereas the latter is a primary concern for rural villagers in much of China due to the issues described above. This example illustrates how energy choices can have significant negative effects on a population through differing channels – in one case, the damage occurs from an individual's choice (or is internalized) and in the other case, it is primarily the result of the actions of others (externalities).

It remains an unfortunate reality that, in many developing countries, households are exposed to pollutants and contaminants that are both hazardous and avoidable. There are many potential explanations for the persistence of this exposure. First, the lack of reliable information on these topics for many of these rural communities is a likely cause – a prime and related example has been the dearth of information about the HIV/AIDS crisis within many areas of Sub-Saharan Africa. Second, low income households, even when aware of these issues, may not be able to afford the necessary testing or substitutes to mitigate these problems. This has been demonstrated by the pilot work by Van Geen and Singh (2013) on arsenic-contaminated groundwater in India. Despite the severely negative side-effects on continuous exposure to arsenic contaminants, very few people selected had previously had their wells tested and the willingness to pay for such a service fell well short of the costs of the tests.[26] This study has been informative as it has highlighted that many households are willing to pay for the service once informed about the problem, but few are willing or able to spare the money to cover the full costs of the test.

It is therefore important to establish people's willingness to pay for improvements in environmental quality in order to inform policy and make it possible to prioritise and design the interventions necessary to alleviate these problems. It is of utmost importance to understand why these investments are not being made already; it is likely that externalities and free riding are part, but not all, of the answer here. The willingness to pay for these improvements seems often to fall short of the actual benefits. Is the low uptake of environmental measures a result of low valuations by firms and households and if so, why do these appear so low? It is important to understand these root factors as valuations may be affected by the presence of market failures, poor information, weak governance and property rights, multiple risks, and poor policy design, weak implementation and rent seeking, or various other factors, many of which can be rectified if necessary. Alternatively, this reluctance to adopt these clean technologies may be a product of decision-making heuristics and biases.

There are many other potential explanations and it is important to start to pinpoint the driving factors behind these valuations. Basic surveys and randomized controlled trials may be enough

[26] Van Geen, Alexander, and Chander Kumar Singh (2013).

to pinpoint these factors within specific countries. Beyond this, it may also be possible to alter the behavior of the public towards these environmental risks. It may be that providing information or financial support for these investments is enough to drastically reduce the environmental risks, but it will be important to identify the right set of solutions. For example, if reducing environmental pollutants leads to increased long-term productivity and income, the social return to these investments may be larger than people realize and may justify public investments.

5.2 Abating Pollution

To date, there have been few serious attempts to abate air and water pollution in many developing countries. As a result of this, little is known about which methods are successful in these contexts. As the economies of these developing countries continue to grow, issues of air and water pollution will also grow in importance. Strategies to reduce these pollutants must also take into account the often weak institutional environments within which their firms and consumers operate. This is especially so in cases where local governments have relatively limited resources at their disposal for this purpose. The successful abatement of many of these pollutants will hinge on the feasibility and costs of the various potential strategies available.

Therefore, it is important to determine the costs of various strategies for abating air and water pollution in these developing countries. The costs of the technological advancements required to achieve more modern and clean practices observed in many developed countries are likely quite high. One advantage that developing countries do have, however, is the ability to "leap-frog" technologies in their development. Leap-frogging is a phenomenon often observed in developing countries where certain technologies will be skipped as they rapidly catch up to the more advanced technologies already discovered by more developed nations. A famous example of this is the prevalence of cellular phone usage in Sub-Saharan Africa despite a low prevalence of land-line phones. On top of the straight upgrade and restructuring costs accompanying some potential reforms, it is important to take into account the political and time costs of enacting such reforms when attempting to define and quantify their costs.

The weakness of the institutional environments in many of these developing countries is a factor that must not be overlooked. The lessened ability of government to both discourage and monitor will lead to a smaller set of available tools for this purpose. It may be the case that some regulatory mechanisms that have been quite successful in other countries may prove infeasible due to their burden on government's time or resources. Currently, it is becoming increasingly important to determine the regulatory structures that will prove most effective in individual developing countries and how their effectiveness can be maximised. This may involve tailoring various currently used regulatory strategies more fully to the developing country context or devising new ones altogether.

These considerations must all feed into the thinking about how to implement achievable policy advice in developing countries. Significant investments will likely need to be made by firms and households in these countries in order to significantly reduce the levels of pollution and their harmful effects. These will likely need to be encouraged and enforced through effective regulation. Some of the required changes will be relatively clear cut; what will be less clear will be the exact costs of the necessary interventions and also precisely which suggested interventions can be both effective at addressing these problems and politically feasible. This will require research and investigation with a developing country focus in order to capture these added complexities, including the incentives faced by local regulators and polluters.

5.3 Climate Change

In addition to the threat to growth posed by conventional pollutants, the release of greenhouse gases from the combustion of fossil fuels, and the resulting changes in the climate, will significantly affect the well-being of citizens in many developing countries. There is also growing evidence that climate change may constrain the productive potential of citizens in these countries. Rising temperatures, for example, may depress not only agricultural yields and wages (Burgess et al., 2013) but may also depress productivity in manufacturing and service sector firms (Dell et al., 2013).

In the coming decades, today's developing countries are expected to be the largest emitters of the greenhouse gases that are causing climate change due to their projected growth in energy consumption. For example, the EIA projects that nearly all of the world's growth in energy consumption will come from non-OECD countries between now and 2040. Indeed, China is already the largest emitter of CO_2 in the world with emissions that exceed US emissions by 50 percent in 2012. There will be increasing international pressure on today's developing countries to reduce emissions and developed countries are likely to seek out opportunities for inexpensive emissions reductions in developing countries. Both of these forces are likely to have significant effects on developing country growth.

Further, climate damages are expected to be significant and indeed existential for some developing countries (e.g., parts of Bangladesh are at risk of disappearing due to sea level rise). Indeed, the greatest damages are projected to occur in today's developing countries, especially those in the tropics. Rising sea levels threaten to reduce the landmass of many coastal nations, in some cases significantly, and destroy freshwater sources. Changes in rainfall patterns threaten agricultural crops, often through too little or too much rain. Temperature fluctuations and desertification threaten to render currently arable land infertile. Unfortunately, these and other trends mean that in many cases, those countries that stand to be most affected by climate change are also those poorest countries least able to afford the significant costs of adapting. Therefore, efforts to mitigate emissions in the present and measures to adapt to a changing climate will be critical to future long-term economic growth.

Our knowledge of what lies ahead from climate change remains very poor. This is especially so in developing countries, where our records and ability to collect detailed data is lower. This does provide an opportunity to measure the effects of shifts in climate on welfare, largely because these are areas where minimal research has yet been conducted. Additionally, it is still to be investigated what the effects of these shifts will have on various developing economies.

The effects will undoubtedly be far-reaching and in order to begin to counteract them, it is important to quantify these effects on various aspects of the economies of developing nations where possible and to try and predict which of these changes will occur and where. The current lack of research, while presenting an opportunity, also presents a profound danger as this makes it more difficult to produce estimates of these losses under different potential scenarios. As a result, further research on these topics will go far towards facilitating effective policymaking with regards to counteracting the adverse effects of climate change.

Regardless of the precise effects on welfare, it is important to lessen these effects through abating carbon and other greenhouse gas emissions. Four examples of measures to achieve this are (i) energy-efficient investments for households and industries, (ii) ecosystem services, (iii) command-and-control regulations, and (iv) market-based emissions trading systems. Unfortunately, there is little research rigorously comparing these methods in the context of developing countries. The reality in many of these countries is that inefficient governance structures and limited available resources will largely dictate what is feasible in terms of passing and enforcing policy and producing effective results. The relative and objective costs and feasibilities of each of these and other potential solutions need to be investigated through in-depth research. Many promising clean energy products have been developed, but it remains to be seen whether or not they will prove effective. When removed from the lab context, various issues such as low uptake, improper or inefficient use, imperfect information or the inability to adapt them to specific contexts can undermine their effectiveness. For this reason, the effectiveness of these solutions in real world applications must be thoroughly investigated.

Beyond reducing emissions now, the effects of climate change have arguably already begun or are, at least, on the very near horizon. Looking at what programmes and policies can help these countries to adapt to the coming changes will constitute interesting research and also do a lot to ensure continued welfare increases in many of these developing countries. Just as developing countries are particularly vulnerable to the effects of climate change, certain groups within these countries, such as children and the elderly as well as small agricultural households, are particularly vulnerable. Policies designed to help countries adapt to the effects of climate change need to take into account the effects that these policies will have on these vulnerable groups. The question will be both which programmes address these needs most effectively and how other programmes can be adapted to address the needs of these groups more fully. Balancing the twin aims of sustaining welfare increases in developing countries through continued economic growth and minimising the social costs associated with the increased energy consumption that goes hand in hand with this growth will be a major challenge going forward.

6. Conclusion

The potential of increasing high-quality energy access for improving livelihoods in these developing countries is undeniable. Throughout the developing world, these energy markets continue to develop and are currently at various different stages of maturity depending upon the region. As these markets develop, it is becoming increasingly important that they do so in ways that are efficient, inclusive, and sustainable. In order to achieve this development, we need to ensure that (i) these grids are reliable and of high-quality, (ii) services are made available to as many individuals as possible, particularly the rural poor, (iii) investing in energy-efficiency is prioritised, and (iv) that the negative effects of energy consumption, such as pollution, are minimized as much as possible. These will require significant policy action in many of these countries, which will in turn require rigorous evidence-based research that will inform on the optimal policies to achieve these goals.

Improving the quality of grid services is of utmost important, especially in urban centres and clusters of production. This is because the costs of unreliable service to businesses can be very high, as they turn to more costly alternatives in order to ensure continuous supply. The uses for this power are varied, but define the value of ensuring a quality of service to consumers. Only by determining the value of high-quality service to different groups of customers can policy be effectively targeted and informed by reliable cost-benefit analyses. This is especially so in developing countries, where financial and institutional resources are often limited. Extending these services to rural areas, many of which are not currently connected, is also of utmost importance. Similarly to above, the uses of this power will determine where the need in these areas is currently greatest and which potential solutions are most viable, which makes it imperative that further studies are undertaken in these areas. Power theft remains a large problem, and while there have been some anecdotal successes in reducing losses due to this practice, developing systematic strategies for tackling this will require more structured research on the topic.

Unfortunately, the investments required in supply infrastructure are costly and take time. While these energy sectors are growing, many investments that could lead to significant rises in social welfare in these countries are often not made, due to profitability concerns, limited resources, or capacity constraints. It is often the case that these investments need to be encouraged through policies that incentivize these investments. This can be difficult however as the institutional environments and markets themselves are still developing and can therefore be quite limited. The best practices in more developed markets, such as some countries in the OECD, and past successes can be informative to some extent. Given the cost and extent of the required investments to make these improvements, it will necessarily require solutions tailored to the markets in these specific developing countries, which remain largely untested currently. As a result, investigating which of these solutions can be effective in incentivizing these investments and increasing their profitability needs to be prioritized as an avenue for research going forward.

This is similar for incentivizing investments in energy efficiency. It remains unclear currently why many of these are not being made in these developing countries, but the potentials for reducing both the social and private costs through these investments remain. If these investments can be encouraged, the effects will be significant for reducing pollution and carbon emissions as well as raising general welfare in these countries. This is why it is becoming increasingly important to investigate what is holding back these investments currently and which are the best strategies to ensure that these investments in efficiency are not made inefficiently. As time goes on, individual countries' and indeed the global community's energy choices will increasingly affect these developing countries' growth paths. With aspects such as accelerated climate change on the horizon, these issues may prove existential for some countries. It is important to be building up a base of rigorous research now on the effects of coming changes in climate and continued pollution in these developing countries, so that this can then lead to experiments and research on how to mitigate these effects as best as possible.

This paper has outlined some of the pressing issues within energy policy in developing countries. The emphasis of this paper has been on what we know and importantly what we still need to know to be able to effectively tailor policy to address these issues. There is currently much exciting work ongoing and their findings are beginning to paint a coherent picture of these issues. Further research is required however to effectively inform on a policy level.

References

Adenikinju, Adeola (2003). "Electric infrastructure failures in Nigeria: a survey-based analysis of the costs and adjustment responses" *Energy Policy*, 31.

Alcott, Hunt and Michael Greenstone (2012). "Is there an Energy Efficiency Gap?" *American Economic Association*, 26(1), January.

Barreca, Alan, Karen Clay, Olivier Deschenes, Michael Greenstone, and Joseph S. Shapiro (2012). "Adapting to Climate Change: The Remarkable Decline in the U.S. Temperature-Mortality Relationship Over the 20th Century" *NBER*, working paper.

Barnes, Douglas and Gerald Foley (2004). "Rural Electrification in the Developing World: A Summary of Lessons from Successful Programs" *World Bank*.

Burgess, Robin, Olivier Deschenes, Dave Donaldson, and Michael Greenstone (2013). "The Unequal Effects of Weather and Climate Change: Evidence from Mortality in India'' mimeo LSE and MIT.

Chen, Yuyu, Avraham Ebenstein, Michael Greenstone, and Hongbin Li (2013). "Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy" *PNAS*, 110(32).

Davis, Mark (1998). "Rural Household Energy Consumption" *Energy Policy*, 26(3).

Dell, Melissa, Benjamin Jones, and Benjamin Olken (2013). "What Do We Learn from the Weather? The New Climate-Economy Literature" Forthcoming, *Journal of Economic Literature*.

Dinkelman, Taryn (2011). "The Effects of Rural Electrification on Employment: New Evidence from South Africa" *American Economic Review*, 101(7), December.

ESMAP (2002). "Energy Strategies for Rural India: Evidence from Six States" *ESMAP Report*. Available at: https://www.esmap.org/node/1030 (Accessed 06 November 2013)

Golden, Miriam and Brian Min (2012). "Theft and Loss of Electricity in an Indian State" *IGC Working Paper*, 12/0060, February.

Greening, Lorna, David L. Greene, and Carmen Difiglio (2000). "Energy efficiency and consumption – the rebound effect – a survey" *Energy Policy,* 28.

Greenstone, Michael and Adam Looney (2012). "Paying Too Much for Energy? The True Costs of Our Energy Choices" *Daedalus*, 141(2), Spring.

Heltberg, Rasmus (2004). “Fuel switching: evidence from eight developing countries” *Energy Economics,* 26.

Jaffe, Adam and Robert Stavins (1994a). “The Energy Paradox and the Diffusion of Conservation Technology” *Resource and Energy Economics*, 16(2).

Jaffe, Adam and Robert Stavins (1994b). “The energy-efficiency gap: What does it mean?” *Energy Policy*, 22(10).

Jensen, Robert (2007). “The Digital Provide: Information (Technology), Market Performance and Welfare in the South Indian Fisheries Sector” *Quarterly Journal of Economics*, 122(3).

Jorgenson, Dale (1984). “The Role of Energy in Productivity Growth” *American Economic Review*, 74(2).

Joskow, Paul and Donold Marron (1992). “What does a Negawatt Really Cost? Evidence from utility conservation programs” *The Energy Journal*, 13(4).

Khandker, Shaidur (1996). “Role of Targeted Credit in Rural Non-Farm Growth” *The Bangladesh Development Studies*, 24(3).

Khandker, Shahidur R., Hussain A. Samad, Rubaba Ali, and Douglas F Barnes (2012). “Who benefits most from rural electrification? evidence in India” *World Bank*, working paper.

Ledesma, David (2013). “East Africa Gas – The Potential for Export” *Oxford Institute for Energy Studies*. Available at: http://www.oxfordenergy.org/2013/03/east-africa-gas-the-potential-for-export/

Lim, Jong-Soo and Yong-Gun Kim (2012). “Combining carbon tax and R&D subsidy for climate change mitigation” *Energy Economics*, 34(3), December.

Lipscomb, Molly, A. Mushfiq Mobarak, and Tania Barham (2013). “Development Effects of Electrification: Evidence from the Topographic Placement of Hydropower Plants in Brazil.” *American Economic Journal: Applied Economics*, 5(2).

Louwa, Kate, Beatrice Conradie, Mark Howells, and Marcus Dekenah (2008). “Determinants of electricity demand for newly electrified low-income African households” *Energy Policy*, 36.

Martins, Johan (2005). “The Impact of the Use of Energy Sources on the Quality of Life of Poor Communities” *Social Indicators Research*, 72(3).

Muller, Nicholas, Robert Mendelsohn, and William Nordhaus (2011). “Environmental Accounting for Pollution in the United States Economy” *The American Economic Review*, 101(5).

Murillo-Zamorano, Luis (2005). “The Role of Energy in Productivity Growth: A Controversial Issue?” *The Energy Journal*, 26(2).

Nauclér, Tomas and Per-Anders Enkvist (2009). “Pathways to a low-carbon economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve” *McKinsey Climate Change Special Initiative*, January.

Roy, Joyashree (2000). “The rebound effect: some empirical evidence from India” *Energy Policy,* 28.

Suri, Tavneet, William Jack, and Thomas M. Stoker (2012). “Documenting the birth of a financial economy” *PNAS*, 109(26), June.

Toman, Michael and Barbora Jemelkova (2003). "Energy and Economic Development: An Assessment of the State of Knowledge" *Resources for the Future Discussion Paper* 03-13, April.

Van den Bergh, Jeroen C.J.M. (2011). “Energy Conservation More Effective With Rebound Policy” *Environmental and Resource Economics,* 48(1).

Van Geen, Alexander, and Chander Kumar Singh (2013). “Piloting a novel delivery mechanism of a critical public health service in India: Arsenic testing of tubewell water in the field for a fee” *IGC Policy Note,* 0238, April4. Available at: http://www.theigc.org/sites/default/files/13_0238_POLICYNOTE_V4_LR.pdf

Wolak, Frank (2008). “Reforming the Indian Electricity Supply Industry” Chapter 3 in *Sustaining India’s Growth Miracle.*

Wolfram, Catherine, Orie Shelef, and Paul J. Gertler (2012). “How Will Energy Demand Develop in the Developing World” *Journal of Economic Perspectives*, 26(1), January.

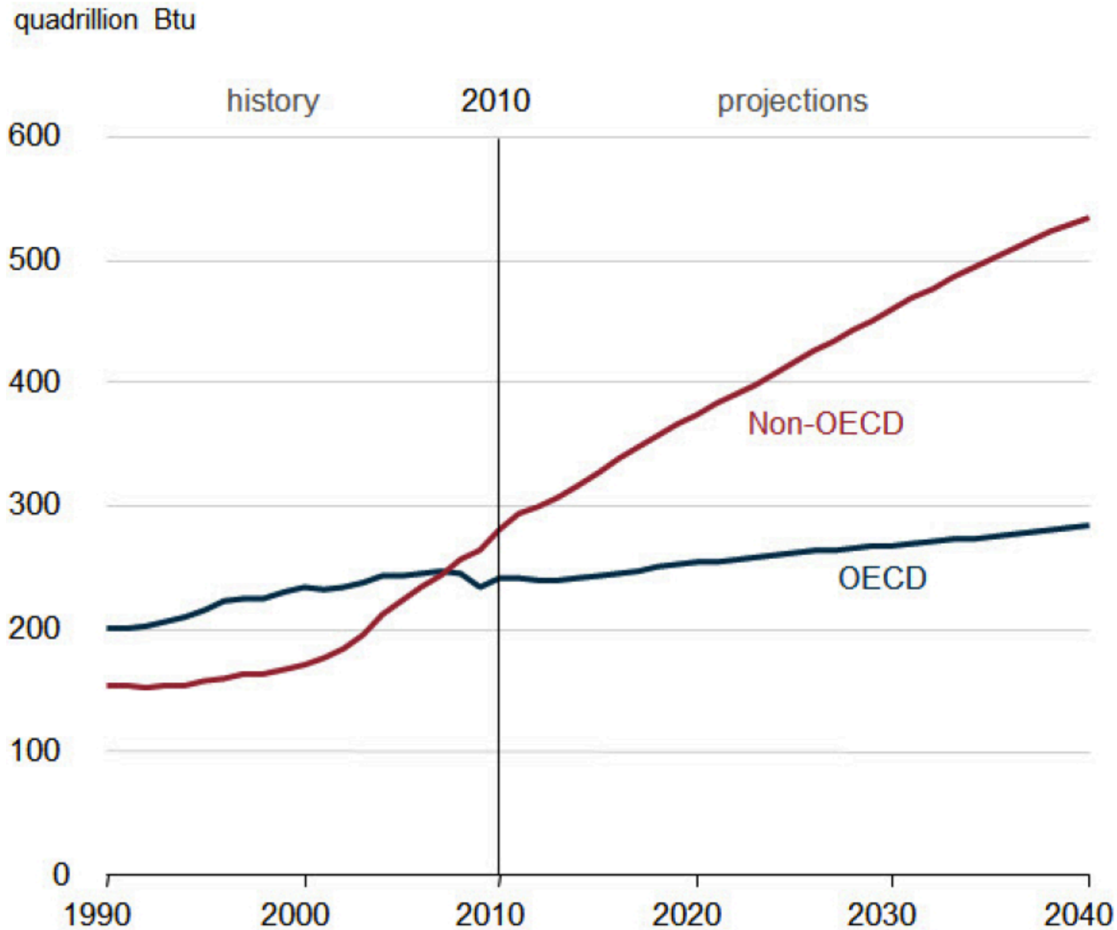
World Bank (2008). “The welfare impact of rural electrification: a reassessment of the costs and benefits” *World Bank*.

World Bank (2009). “Reducing Technical and Non-Technical Losses in the Power Sector” *World Bank Background Paper*, July.

World Bank (2013). "Toward a Sustainable Energy Future for All: Directions for the World Bank Groups Energy Sector" *World Bank,* July.

Worrell, Ernst, John A Laitner, Michael Ruth, and Hodayah Finman (2003). “Productivity Benefits of Industrial Energy Efficiency Measures” *Energy,* 28(11).

Figure 1. World Energy Consumption, 1990 to 2040



Source: EIA, International Energy Outlook 2013

Figure 2. The Private, External and Social Costs of Electricity Generation