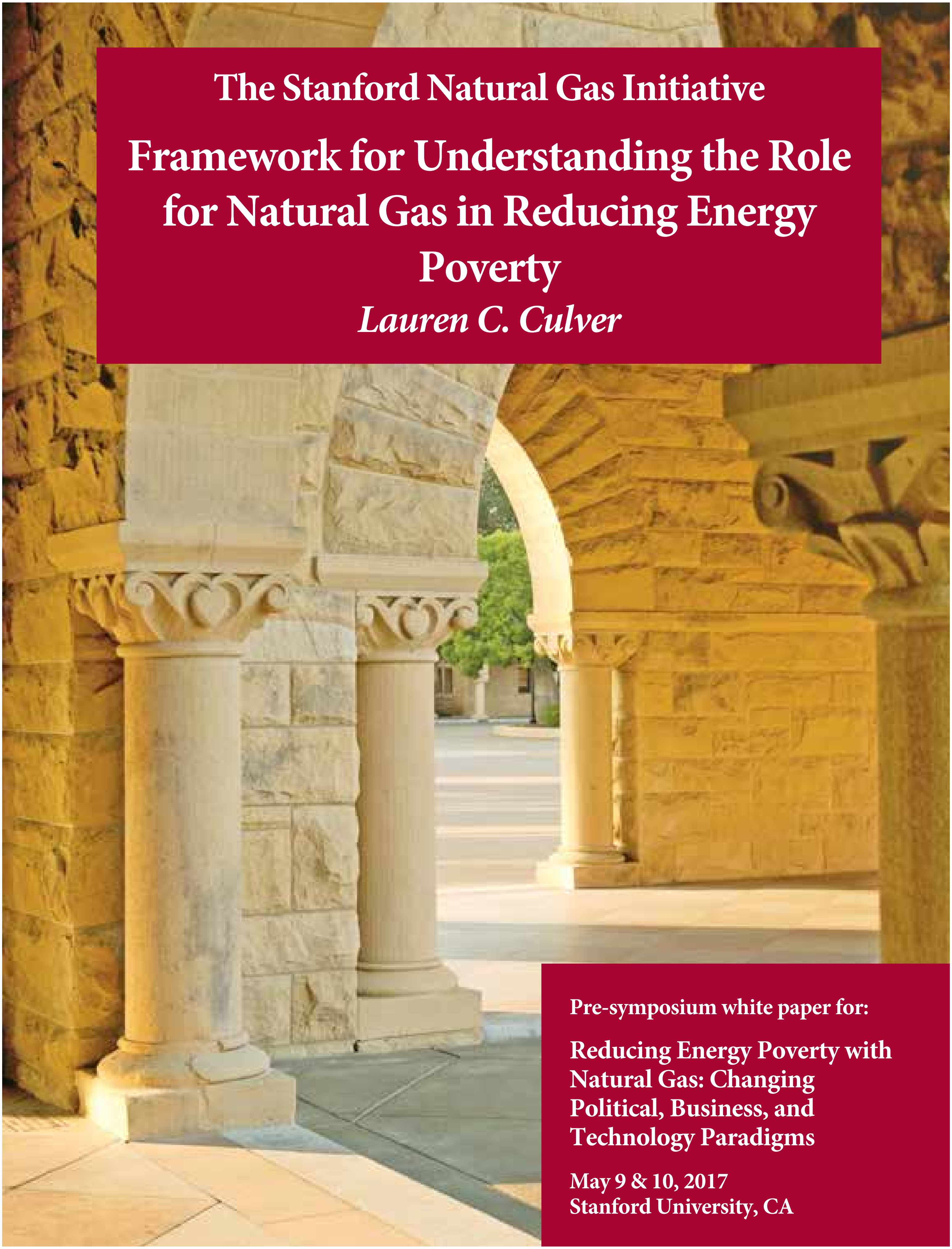

The Stanford Natural Gas Initiative

Framework for Understanding the Role for Natural Gas in Reducing Energy Poverty

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Pre-symposium white paper for:

Reducing Energy Poverty with Natural Gas: Changing Political, Business, and Technology Paradigms

May 9 & 10, 2017
Stanford University, CA

A Framework for Understanding the Role for Natural Gas in Reducing Energy Poverty

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March 2017

Energy poverty is the lack of "a basic minimum threshold of modern energy services for consumption and productive uses (Advisory Group on Energy and Climate Change, 2010)[1]." The energy poor include 2.9 billion people that cook with traditional biomass fuels, 1.1 billion without a connection to an electricity network, predominately in in South Asia and Sub-Saharan Africa as summarized in Table 1, and 1 billion people with inadequate electricity (IEA and World Bank, 2015; IEA, 2011). Energy poverty forces people to survive on energy that is poor quality, high cost, and hazardous to human health (IEA and World Bank, 2015).

Energy poverty is a barrier to development (Modi et al., 2005; Advisory Group on Energy and Climate Change, 2010; UNDP and WHO, 2009), economic growth (Granoff et al., 2015; Elias and Victor, 2005), and international security (Sovacool, 2014; Bazilian, Sagar, et al., 2010). Without reliable electricity in the home, life comes to a standstill every day when the sun goes down. Children study by dim candlelight or kerosene lamp, and many schoolchildren attend school without electricity (Practical Action, 2013). Women and children spend hours each day collecting sticks or dung to cook over inefficient fires, leaving little time for going to school

[1]Energy services are the desired outputs of energy use: light, boiling water, heat, refrigeration, mechanical power, mobility, communication etc. Modern energy often refers to non-solid fuels, but can generally be thought of as energy that is convenient and not harmful to human health. Electricity, natural gas, and liquified petroleum gases (LPG) are considered modern. Energy services like light, air conditioning, and cooking are considered consumptive. In contrast, energy for "productive uses" enhances productivity and generates income.

Region	Population without electricity (millions)	Urban population without electricity (%)	Rural population without electricity (%)	Population using traditional biomass (millions)	Population using traditional biomass (%)
Sub-Saharan Africa	632	37	81	792	81
China	0	0	0	453	33
India	244	4	26	819	63
Developing Asia	287	4	26	603	55
Latin America	22	2	15	65	14
Middle East	18	2	22	8	4

Table 1: Population without electrification and relying on traditional biomass for cooking (IEA, 2016a).

or starting a business (WHO, 2006). Indoor air pollution from kerosene lighting and cooking without modern fuels results in 4 million premature deaths each year and countless respiratory ailments (WHO, 2006). It is estimated that use of polluting fuels like wood and coal cost society $123 billion each year in terms of health, environmental, and economic costs (Bhatia and Angelou, 2015). A third of health facilities in Africa do not have electricity and even more have unreliable electricity supply that compromises refrigeration of vaccines and medicines (Practical Action, 2013). Energy shortages are an impediment to economic growth in agriculture, manufacturing, and enterprise (Practical Action, 2010; Asafu-Adjaye, 2000; Ramachandran, Gelb, and Shah, 2009; G8 Energy Ministers, 2009). Poverty and lack of education create a vicious cycle leading to unemployment, idleness, and social discontent. While there is weak evidence that violent extremism is caused by poverty, as many vicious attacks are perpetrated by the affluent, poverty is a powerful precursor for instability. "Ample energy supply is not an automatic guarantee of smooth economic advance, social progress, and political stability; it is indisputably, their essential precondition. (Smil and Knowland, 1980)."

In recognition of the threat energy poverty poses to human dignity, economic development, and global security, eliminating energy poverty has moved to the forefront of international policy (Bazilian, Nussbaumer, Cabraal, et al., 2010; UNGA, 2012; UNGA, 2014). The United Nations' Sustainable Development Goal 7.1 is the culmination of international commitment to address energy poverty establishing a goal to achieve universal access to affordable, reliable, and modern energy services by 2030 (UNGA, 2015). However, without new efforts to alleviate energy poverty, the absolute number of energy poor is expected to rise as population growth outpaces investment in energy infrastructure (IEA, 2011).

Despite recognition of both the ills caused by a lack of energy and the commitment to increase access to energy, there is disagreement on what is required to eliminate energy poverty. This disagreement is the result of unresolved questions in three distinct areas of scholarship. First, there is no universal metric for energy poverty (Culver, 2017; IEA and World Bank, 2015; Nussbaumer, Bazilian, and Modi, 2012; Pachauri and Spreng, 2011). Second, there is no agreement on how much energy is needed to escape energy poverty (Wolfram, Shelef, and Gertler, 2012; Lee, Miguel, and Wolfram, 2016; Gertler et al., 2016; Bazilian and Pielke, 2013; Elias and Victor, 2005). Finally, there is no consensus on whether reducing energy poverty conflicts with climate change mitigation (IEA, 2011; Lucas et al., 2015; Calvin et al., 2013; Chakravarty and Tavoni, 2013; Sanchez, 2010). The consequence of these lingering debates is a thin basis for a rigorous discussion about the role of different energy technologies and fuels in the fight against energy poverty. Indecision about which kinds of energy supply investments are most appropriate affects national policy-makers, multilateral development banks, and private investors. The current ambiguity risks delaying investment and raising the cost of financing energy projects further perpetuating energy poverty.

The purpose of this paper is to synthesize ongoing debates around energy poverty to highlight the implications for policy and investment; to present a framework, based on the literature, for evaluating the appropriateness of different energy solutions for meaningfully reducing energy poverty; and to apply the framework to assess the prospects for natural gas to contribute to meaningful and sustainable reductions in energy poverty.

The paper is organized as follows. The first section will unpack three scholarly debates that contribute to uncertainty for policy and investment. The second section will propose six attributes of energy that are necessary and sufficient for characterizing the contribution of various energy supply options to reducing energy poverty. The third section will use the energy attribute framework to specifically assess how expanded use of natural gas could contribute to reductions in energy poverty[2]. Natural gas is found to be a promising fuel for reducing energy poverty, and recommendations are made for future technology and policy development as well as academic research.

Investment Ambiguity Stems from Underlying Debates

In this section we will look at three unresolved areas of scholarship related to energy poverty: (1) energy poverty metrics, (2) energy requirements for development, and (3) the interaction of policies to advance energy poverty reduction and climate change mitigation. These unsettled debates underpin continued controversy about the role of different fuels and energy technologies in addressing energy poverty.

No Universal Metric for Energy Poverty

Recalling the definition provided earlier, energy poverty is the lack of "a basic minimum threshold of modern energy services for consumption and productive uses (Advisory Group on Energy and Climate Change, 2010). While there is consensus on this as a definition, there is no universal approach to measuring it (Culver, 2017; Nussbaumer, Bazilian, and Modi, 2012; Pachauri and Spreng, 2011). Unlike nutritional poverty, for example, there is no objective level of energy that delineates a minimum for survival.

In the absence of a theoretical basis for an energy poverty metric, it is difficult to develop a robust measure. First, energy services cannot be

[2] The paper highlights some unique opportunities and challenges to the viability of natural gas as a means of reducing energy poverty. There are many more obstacles facing expansion of energy in low and middle income countries through the grid or through mini-grid technologies that are not unique to natural gas. These challenges are common to all fuels and energy technologies that are being developed to serve the energy poor. Similarly, there are many opportunities that will have significantly expand energy supply in every sector. The absence of a discussion of these issues does not reflect their unimportance. Each of these topics is the subject of considerable work that could not be treated adequately here: Pay-as-you-go energy services(Moreno and Bareisaite, 2015); Super efficient appliances (Phadke et al., 2015; Global LEAP, 2015; Buskirk, 2015); Targeted assistance programs (Rawlings and Rubio, 2005; Dhand, 2014); Governance (Desai and Jarvis, 2012); Pricing; Finance (SE4ALL, 2015); No credit sector serving poor (Karlan et al., 2014); Utility viability (Trimble, 2016; Eberhard et al., 2011); Technology standards; Fossil fuel and fertilizer subsidies (Coady, Parry, et al., 2015; Coady, Flamini, and Sears, 2015; Victor, 2009); Grid extension and connection policy.

understood in fungible units and exchanged. Unlike money, which can be spent flexibly to meet a household's needs, an excess of energy service, like

Energy Services

Uses of energy, called energy services, include lighting, cooking, space heating and cooling, refrigeration, process heat, mechanical power, mobility, communication, and entertainment etc.

Lack of energy services does not lend itself to a metric for energy poverty that is easy to interpret because:

- Energy services cannot be substituted for each other.
- There is no agreement on which energy services are fundamental.
- Defining the poverty level for each energy service is arbitrary.

light, cannot meet the need for another energy service, like boiling water.

Second, there is no consensus on which energy services are basic. Light and heat are surely essential energy services, but there are many other important household uses of energy, including energy for productive uses such as mobility, refrigeration, or mechanical power that can bring crops to market, pump water, sharpen farm equipment, and process crops (ex. corn threshers, rice dehuskers, presses, etc.)[3].

Energy services for agriculture and small enterprises are central to enhancing productivity and supporting a livelihood. Declining rural poverty, rather than urban poverty, has been responsible for recent reductions in the poverty rate (World Bank, 2008). Many of the poorest people in the world are farmers. Rural farmers account for three quarters of the extreme global poor (UNDP, 2007). The agricultural sector has tremendous potential to drive economic growth and alleviate extreme poverty, and "improving the productivity, profitability and sustainability of smallholder farming is the main pathway out of poverty in using agriculture for development (World Bank, 2008)." Improvements in agricultural efficiency as well as rural growth that allows diversification of the economy

[3]Practical Action (2010) and Sovacool et al. (2012) provide a review of rural energy needs beyond cooking and lighting.

may be increasingly important because of the agricultural sector's vulnerability to climate change (DFID, 2014).

Energy services beyond the household are also relevant to development. Energy services for community facilities like hospitals and schools are needed to serve the broader economy. A measurement of energy poverty could capture the delivery of energy services for industry, enterprise, and transportation of goods and people. In modern economies these households, industry, and the transport sector consume energy at an equal order of magnitude. Which household and non-household energy services should be considered essential for escaping energy poverty?

Assuming agreement on the basket of basic energy services, it is then difficult to draw a poverty line for each of those energy services. For example, is energy poverty less than 100 lumen hours of light each day or 200 lumen hours?

Energy access, typically defined as a connection to the electric grid and use of modern cooking fuels or stoves, is commonly used as a proxy to discuss energy poverty. However, this term is misleading because it reduces modern energy service delivery to access to an electricity network and access to modern cooking fuels. An electricity connection does not guarantee useful energy is available to produce needed energy services. By focusing on cooking and electricity, energy access does not capture household energy consumption used productively to generate income. Energy used in economic activities such as commercial and industrial operations and in public spaces like schools, hospitals, and street lighting are also not included in energy access.

While not objectively quantified, the reader can imagine some level of energy consumption that provides a basic set of energy services each above a certain threshold of minimum use. Below this level of consumption is energy poverty. Above the poverty line is a level of energy consumption that can be considered "meaningful." There is growing recognition that this meaningful energy consumption is greater than the energy consumption of a household that just meets the requirements of energy access. While an objective, theoretical definition of energy poverty may not be feasible, practitioners would benefit from the development of universal standards for both the basket of energy services within and outside the household that are to be considered basic energy services and thresholds of consumption or services that define the poverty line (Pachauri, 2011). Until there is agreement on per capita energy consumption that is meaningful, we will not be able to say what energy demand in the aggregate should be or will be - the next subject of ongoing debate.

Outstanding questions about energy demand and economic growth

The absence of a universal metric for energy poverty is not purely an academic matter. It has consequences for the expected energy demand in low and middle income countries. Currently, there is no consensus on 1) a normative amount of energy consumption that development policymakers should aspire to or 2) how economic growth and energy demand actually increase in response to middle class income growth and pro-poor growth policies, including expanding energy access.

The Ambition Gap

Delivering adequate energy to provide basic, minimum energy services is a much greater task than expanding electricity connections or providing technologies that deliver a subset of energy services. In a debate about the aims of energy policies and investments in low and middle income countries, Bazilian and Pielke (2013) warn against the possibility that universal energy access could be achieved without attendant benefits of socioeconomic development, something the authors describe as an "ambition gap." The ambition gap, in energy units, is the difference between a meaningful level of energy consumption, that required to realize development targets, and the minimal electricity used when households are first connected to the grid or standalone system.

Ambition Gap

Delivering adequate energy to provide basic minimum energy services to all is a much greater task than simply expanding electricity connections or providing technologies that deliver a subset of energy services. The difference between these levels of investment is called the ambition gap.

Depending on assumptions about the scope of basic energy services the ambition gap can be very large. In the United States, the basket of energy services that might be considered basic is expansive, and the threshold of what would be minimal usage is relatively high. This is reflected in average annual per capita energy use of 13,000 kWh/year (*BP Statistical Review of World Energy* 2016). In contrast, in Germany that number is 8,000 kwh/year. Germany likely has the same basket of basic services but greater energy efficiency. In North Africa annual per capita consumption is less than 2,000 kWh/year which likely reflects a smaller basket of basic energy services and less usage. However, even using North Africa as the aspirational level of development suggests a very large ambition gap when compared to the 100 kWh/year often assumed for those granted energy access (IEA, 2015b; Modi et al., 2005; Bazilian, Economy, et al., 2014).

The policies and investments that would best deliver 100 kWh/year to the energy poor may be very different from the policies and investments needed to drive economic growth. Those concerned with an ambition gap fear that institutions will spend their efforts on incremental solutions that may only deliver "poverty management" rather than the transformational policies that could deliver sustainable development (Bazilian and Pielke, 2013). "Such low ambitions risks becoming self-fulfilling, because the way we view the scale of the challenge will strongly influence the types of policies, technologies, levels of investment and investment vehicles that analysts and policy makers consider (Bazilian and Pielke, 2013)." Not everyone agrees that the ambition gap may be detrimental to policy. Some argue that small, distributed systems providing light and phone charging are an important first step in building customers that will expand their energy consumption over time (Craine, Mills, and Guay, 2014).

Pro-poor and Middle Class Growth

While the ambition gap is a debate about the goals, there is also no consensus about what is happening in the present. Our current understanding of the relationship between energy demand and economic growth is limited. Energy demand in low and middle income countries is particularly poorly understood. There is no consensus on the amount and types of energy associated with escaping poverty and moving into the middle class. While energy and economic development are inextricably linked, the connections between them are complex and imperfectly understood. Elias and Victor (2005) reviews the evidence for causality at the national level where the evidence is the strongest. Despite the strength of the relationship it is not clear if energy poverty is a symptom or a cause of poverty.

There has been a dramatic increase in energy demand in the last two decades driven by growth in low and middle income countries, but this growth was not anticipated by energy forecasters. Demand growth in low income countries has been underestimated because current understanding of the relationship between energy demand growth and income level is limited. Wolfram, Shelef, and Gertler (2012) has shown that the relationship between energy demand and income growth changes based on which segment of the population is benefiting from economic growth. If the bottom income quartile grows wealthier, then energy demand grows faster than per capita income. If the top income quartile becomes wealthier, then energy demand grows half as fast as per capita income. This difference may be one explanation for persistent underestimation of energy demand growth.

The energy demand of a rising middle class is also the subject of greater investigation. As incomes rise households are likely to buy more and more appliances for daily comforts and productive uses: televisions, irons, refrigerators. Not only will household energy demand rise, but the economy will need additional energy to produce and transport more goods. Policies for pro-poor growth, those that target people living in poverty, may result in faster energy demand growth than is currently being forecast (Gertler et al., 2016; Lee, Miguel, and Wolfram, 2016).

The ongoing normative debate about the level of per capita demand which we should aspire to deliver to the energy poor as well as a lack of understanding about what is driving energy demand today in low and middle income countries has implications for institutions and investments. As discussed in the following section, a misunderstanding of the scale of demand may lead to overly optimistic conclusions about future greenhouse gas emissions.

No Agreement on Link Between Energy Poverty Reduction and Climate Change Mitigation

There are differences of opinion on whether energy poverty can be solved independently from climate change. Energy modelers have approached the question, but have not provided a conclusive answer. Energy modeling to explore policy options to arrest climate change do not deliver universal energy access without additional targeted interventions directed to the energy poor

(IEA, 2011; Lucas et al., 2015; Calvin et al., 2013). Some studies show that energy policies directed at climate mitigation raise the price of energy and, therefore, reduce consumption in the developing world (Calvin et al., 2013).

Energy modeling has also been used to investigate what is required to achieve universal access and then examine the resulting emissions. Many of these models conclude that universal access to energy can be provided to billions of people with poor or no access to energy today with a negligible impact on emissions (Chakravarty and Tavoni, 2013; Pachauri, Ruijven, et al., 2013; Bazilian, Nussbaumer, H. H. Rogner, et al., 2012; IEA, 2011; Sanchez, 2010). If correct, this would imply that energy poverty and climate change policies could be set independently of one another. However, the model results are based on assumptions about energy demand and energy supply that are still debated. The model results have been criticized because they assume 1) the energy poor will consume minimal energy or 2) the energy supply will 'leapfrog' fossil fuel use in favor of carbon-free solutions - or both.

Demand-side assumptions

Modeling results that suggest that universal energy access can be achieved with minimal emissions are sensitive to assumptions about energy consumption. The IEA, which assumes rural and urban areas' annual per capita consumption will be 50 kWh and 100 kWh respectively, projects a 1% increase in global energy demand and a 0.7% increase in emissions (IEA, 2011). Sanchez (2010) found a 1.6% increase in global emissions, but only assumed 35 kilograms of LPG and 120 kWh of electricity per capita each year. Chakravarty and Tavoni (2013) uses a much higher 10GJ per capita (roughly 2700kWh) and finds a 7% increase in global energy demand and increased emissions.

The scale of emissions is driven by the amount of energy consumed. One's beliefs about the level of energy the energy poor will or should aspire to consume in the future is the driving factor. "If one assumes that billions will remain with levels of energy consumption an order of magnitude less than even the most modest definition of modern access, then one can understand the oft-repeated claim that universal energy access can be achieved with essentially no increase in the global emissions of carbon dioxide (Bazilian and Pielke, 2013)."

Supply-side assumptions

One can conclude that energy poverty and climate change can be solved simultaneously by assuming a relatively high proportion of renewable solutions is adopted, but there is no consensus on the role renewables, especially decentralized renewables, in the energy systems of low and middle income countries (Casillas and Kammen, 2010; Deichmann et al., 2011; IEA, 2011; Szabó et al., 2013). Costs of renewable energy technologies declined dramatically in recent years, and will continue (IEA, 2015a). This has lead some scholars to argue that low-cost renewables will allow low and middle income countries to avoid investments in grid-based fossil fuel generation, and rely on distributed renewable electricity to provide sustainable energy without sacrificing economic growth - this is the idea of leap frogging (Levin and Thomas, 2016).

Those skeptical of leap-frogging the grid in favor of distributed renewables do not have reservations about the viability of renewable power. They do, however, perceive it as unrealistic to deliver meaningful energy services to the energy poor with distributed renewables alone. Mini-grid systems do not have high enough wattage to run many desirable appliances (Lee, Miguel, and Wolfram, 2016). Lighting and phone charging can be achieved through commercially viable solar home systems and super efficient LEDs, but high power and higher energy applications cannot realistically be met with these systems. In the future more super efficient appliances will be available(Global LEAP, 2016). However, equipment for productive uses in agriculture and enterprise has not been a focus of innovation.

A tradeoff

As laid out so far, assumptions about energy demand and supply determine whether energy access and climate change policies can be pursued independently or whether tensions between the two objectives need to be actively managed. Without clarity on which energy services must be provided to escape energy poverty, then the necessary capabilities of supply technologies are undefined. Perpetuating the possibility of leapfrogging without being circumspect about the limitations in energy services delivered by some decentralized electricity solutions obscures the emissions that may come with expanding meaningful energy services to the energy poor. Those that set comparatively high goals for energy consumption and those that expect much higher demand than currently forecast, must grapple with how to attract investment to adequately supply energy that is both appropriate for the energy poor and low-carbon.

There are repercussions of an unrealistic assessment of future energy consumption. Without an accurate estimation of the types and amounts of energy needed, an important discussion of the scale of energy infrastructure and the environmental and climate impacts is preempted. Underestimates in demand may lead to underinvestment in supply resulting in future shortages or price spikes that are particularly painful for the poor (Wolfram, Shelef, and Gertler, 2012). And the consequences of an unrealistic assessment of the carbon intensity of supply that can realistically provide a minimum of basic energy services could be a miscalculation about global emissions.

If the two objectives cannot be pursued independently, strong coordinated action will be required. Governments need to provide clear, long-term policy signals to reduce investment risk. The institutions that deliver infrastructure, technologies, and finance may need to reposition to effectively manage the tradeoff. Many development organizations have dual remits of reducing poverty and reducing emissions, but they do not have transparent mechanisms for balancing these goals. For example, Moss, Pielke, and Bazilian (2014) criticizes the U.S. Overseas Private Investment Company for their policy that restricts support for fossil fueled power investments rather than consider climate change and poverty reduction as two equal goals (Kammen, 2014; Levi, 2014). More work needs to be done to understand how energy poverty and climate change mitigation policies may work together or against each other.

Summary

This section has reviewed the challenge of measuring energy poverty, the emerging understanding about future energy demand, and the uncertainty of the climate impact of ending energy poverty. There is no consensus on the basket of energy services which are fundamental nor a defined energy poverty line for each of those energy services. Without consensus on a meaningful level of energy consumption, it is difficult to make assumptions about what demand in low and middle income countries might be or should be in the future. Without clarity on the scale of energy demand that will result from less energy poverty, it is difficult to understand the extent of the conflict between energy poverty and climate change policies.

Can climate change and energy poverty policy be pursued independently?

International commitments to reduce energy poverty and mitigate climate change may be in conflict. Conclusions of whether there is a tradeoff that needs to be managed is driven by assumptions about supply and demand in the analyses. Some influential assumptions include:

- The energy consumption above the normative energy poverty line
- The effect of pro-poor growth policies on the energy demand of the poorest
- The appliance driven energy demand of the growing middle class
- The percentage of energy consumption that can be met with renewable energy

The connection between these three debates is significant. *The energy required to support even meager development opportunity for the energy poor is considerably more than the energy associated with providing household energy access. Acknowledging the amount of energy truly required to meaningfully reduce energy poverty makes it of utmost importance to think carefully about the ways to scale energy supply while restraining climate forcing emissions.* Without a proper view of the range of energy that may be needed, supply decisions may result in 'poverty management' or greater vulnerability among the global poor.

Six Attributes of Energy Supply to Reduce Energy Poverty

In the previous section we saw that incomplete understanding of energy poverty results in disagreement about which fuels and energy technologies to invest in to reduce energy poverty. Ambiguous criteria for energy supply affects national policies for infrastructure and subsidies for fossil fuels and renewable energy and creates new pressures for multilateral development banks allocating their capacity and resources. Policy uncertainty inflates private investors'calculations of risk, which delays investment and raises cost of capital prolonging energy shortages. This section outlines six necessary and sufficient attributes meaningful and sustainable energy, based on existing literature. It is intended as a framework to evaluate the advantages and limitations of various energy supply options seeking to reduce energy poverty to build a foundation for transparent decisions about energy investment priorities.

Quality Attributes Approximate Energy Services

As modern energy services, especially for productive uses, cannot be measured and aggregated coherently, the attributes of energy that are required to support meaningful energy services can be assessed instead (Bhatia and Angelou, 2015; Practical Action, 2014). Energy should be adequate, available, affordable, convenient, and clean-burning. The attributes must be defined in the context of an application such as centralized electricity generation, distributed electricity generation, cooking and heating, process heat, and transportation.

- *Adequate: Good enough energy?* Adequate energy means it is capable of delivering the needed energy service. In electricity generation, adequacy would be measured in terms of power capacity and voltage stability; for cooking and heat, adequacy would be measured in terms of the heat rate. Systems that are designed to deliver lighting or phone charging services would not be adequate to operate high power appliances like irons, refrigerators, or agricultural processing equipment like presses and grinders.

- *Available: Enough energy?* Available energy can be obtained or used at a national or wholesale level. Whether energy is available to the customer is considered separately as convenience. In the power sector, the number of hours of electricity generated each day, particularly hours in the evening for household and during the working day for businesses, measures convenience. For energy services provided from fuels like cooking, heating, and transportation the availability is measured in terms of fuel availability. Energy that is not available because of geography, lack of investment, or lack of fuel cannot provide energy services.

- *Affordable: Cheap enough?* Affordable energy is both absolute and relative. When a consumer has multiple supply options the affordability of energy is relative to the alternative. For example, whether LPG is competitive with firewood. For the global poor, especially, energy must also be inexpensive in an absolute sense on a unit basis such as $ per kilowatt hour.

- *Convenient: Around when needed?* Convenient energy occurs in a place and time that is useful. The distribution of a fuel or energy carrier is central. The proximity of an electricity connection and the number of disruptions each day are distribution issues that affect convenience for the consumer. Cooking and heating also require distribution networks that are proximately located and reliable. For biomass fuels, convenience would also account for fuel collection time and ease of using the appropriate stove.

- *Clean-burning: Degrading the air?* Clean-burning energy does not degrade air quality and is, therefore, not harmful to human health. Any combustion activities whether for power generation or heat, should be evaluated on the resulting ambient or indoor air pollution. Energy that lowers the quality of air endanger the well-being and productivity of the energy poor.

Together these first five attributes reflect the idea that a sufficient quantity of energy must be delivered when it is needed, cleanly and conveniently, at a low enough price and with enough quality to support the desired application, for example, to operate household appliances and farm equipment. Investments in energy supply options that do not provide all five attributes will result in energy services that should be recognized as either incremental or unsustainable.

Low-Emission Attribute for Sustainable Poverty Reduction

Global energy consumption produces two thirds of global greenhouse gas emissions. Arresting dangerous anthropogenic interference with the climate will require net zero greenhouse gas emissions by 2100 (IPCC, 2014). Most of the IPCC climate mitigation scenarios require global emissions to peak around 2030, the same year of the UN targets to eliminate extreme poverty and provide universal access to energy. At the 2015 United Nations Framework Convention on Climate Change Conference of the Parties (UNFCCC COP21) climate negotiations in Paris, countries pledged nationally determined contributions that outlined actions individual countries would take to reduce or limit the growth of emissions.

The poor are particularly susceptible to the physical impacts of climate change. Those lacking access to modern energy services will find it all the more difficult to adapt to drought, flood, and heat-waves that will cripple agriculture, contribute to further epidemics, and increase mortality. (Birol, 2014) The U.S. Department of Defense describes the effect of climate change on security as a threat multiplier "that will aggravate stressors abroad such as poverty, environmental degradation, political instability, and social tensions — conditions that can enable terrorist activity and other forms of violence (DoD, 2014)." Even with a rise of only 2°C in global mean temperature, changes to the environment after 2030 may result in sending 720 million poor people back into poverty by degrading human health and the environment (Granoff et al., 2015). Eliminating energy poverty by 2030 will only be sustainable, if the efforts to address energy poverty are carried out within a broader international commitment to mitigating climate change.

- *Low-emission: Changing the climate?* To meet climate mitigation targets, middle and low income countries need to rapidly reach their peak emissions and then begin to reduce them. This emissions trajectory will conflict with countries' aspirations for economic growth if energy supply is not low-emission.

Considering Energy Supply Investments

In this section we proposed a total of six attributes of energy supply investments that are necessary and sufficient to meaningfully and sustainably reduce energy poverty. *Investments that do not make energy adequate, available, affordable, convenient, and clean-burning risk establishing a system that prolongs poverty. Further investments that are not low-emission will exacerbate climate change increasing the number of global poor and working against the initial goals of increasing development, growth, and security.* This framework could be the basis for discussion about appropriate energy solutions without presupposing the best fuels or technologies. Many energy supply options should be considered for their ability to provide meaningful and sustainable energy to reduce energy poverty. The appropriate solutions will be different across applications and across countries each with different starting points and different opportunities.

Prospects for renewable energy investments are improving, but in many markets today renewable energy does not deliver all six of the attributes of meaningful, sustainable energy. In most markets, renewable energy only provides adequate solutions in the electricity sector. Geothermal and hydro power generation are not available everywhere. In distributed applications the intermittency of wind and solar makes energy inconvenient and often the capital costs make it untenable to invest in systems that can deliver adequate energy for many productive uses (Wolfram, Shelef, and Gertler, 2012). In centralized systems, the intermittency can be managed, but low capacity factors mean that for a given capital investment the electricity generation is a fraction of what it might have been for a thermal power plant (IEA, 2015a). Where energy shortages are rampant, the emission-free character of renewable energy should be balanced with a prolonging of energy deficits.

Many countries seeking to increase access to modern energy at an affordable cost are turning to the least expensive fuel - coal. This includes countries with ambitious renewable energy programs. In Asia, 50% of new generation capacity has been renewable energy and the other 50% coal-fired power (IEA, 2016b). Using the framework to assess coal would reveal the adequacy of coal in many sectors of the economy, but unambiguously dangerous climate forcing emissions and air pollution. In the next section natural gas is evaluated in detail.

Applying the Framework to Understand Opportunities for Natural Gas to Reduce Energy Poverty

This paper has established that climate and poverty goals may be in conflict and that to make investments that recognize both of these goals equally, investments in energy supply should be evaluated based on how they deliver energy that is adequate, available, affordable, convenient, clean-burning, and low-emission. Many energy supply options should be considered for the contribution they can make to different dimensions of energy poverty. Here we will focus our assessment to natural gas. In low income countries the use of renewable energy is expanding rapidly, but emissions will continue to rise because of growth in consumption of fossil energy, especially coal (IEA, 2016b). Recent changes in natural gas markets and technologies make gas an increasingly viable option for low and middle income countries, but it will be incumbent on each country to have policies in place that encourage efficient investment in energy infrastructure to capitalize on global trends.

In this section we will look at the contribution natural gas could make to reducing energy poverty by examining the *adequacy* of natural gas in urban electricity, rural electricity, cooking, heat, petrochemicals, and transportation; the role of global resources and technology in the *availability* of gas; the role of markets and technology in the *affordability* of gas; the role of distribution infrastructure in the *convenience* of natural gas; the *clean-burning* quality of natural gas.; and the life-cycle *emissions* of natural gas;.

Adequate

Natural gas[4] is a versatile fuel used for centralized power generation, distributed power generation, cooking, household heating, industrial process heat, petrochemical production, and transportation.

Natural gas is used to generate electricity for urban households and industry in combustion turbines for power generation. Households and industries in cities are expected to grow and account for most of global income growth (Deichmann et al., 2011; New Climate Economy, 2014; World Bank, 2010). Improving the quality of grid electricity will promote growth and development in urban areas. Solutions that leverage the existing grid may also be the best way to address the energy poverty of the peri-urban poor. The peri-urban poor, on the outskirts of urban centers, may be relatively easily reached by grid extension with sizable impacts on reducing energy poverty. Grid extension may not reach rural areas for decades, and in some remote areas the grid is not likely to arrive at all, therefore, using natural gas for power generation for rural households is

[4]Natural gas is a mixture of lightweight hydrocarbons including methane, ethane, propane, and butane. Methane is the dominant molecule by volume and is a gas at standard temperature and pressure. When natural gas is processed liquid petroleum gases - ethane, propane, and butane - are separated from the methane.

considerably more complicated than in urban environments. However, generators and micro-turbines make it possible to produce electricity from natural gas apart from a centralized grid. The technology and business models for small scale gas-fired power generation may not yet exist. Additional technology development is required to run equipment used in agriculture or small enterprise and mobility directly on cylinders of natural gas.

Uses of Natural Gas

Natural gas is a versatile fuel used in the following sectors globally:

- Centralized power generation
- Distributed power generation
- Cooking
- Heat
- Industrial process heat
- Petrochemicals
- Transportation

Natural gas is an excellent fuel for cooking and household heating because it is fast-response, high-heat, and combusts cleanly and efficiently. In urban areas, gas can be delivered by city gas pipeline networks or in cylinders. In rural areas, cylinders of liquid petroleum gas (LPG) are most practical. LPG stoves accommodate culturally rooted cooking practices and are, therefore, more likely to be adopted and deliver social benefits than other improved cookstove designs (Durix, Carlsson Rex, and Mendizabal, 2016).

Industry combusts natural gas directly in industrial boilers for process heat or combined heat and power. Industry also uses natural gas as a feedstock for fertilizer and petrochemicals. Globally, natural gas is used in the transportation sector as compressed natural gas (CNG) , LPG, and liquified natural gas (LNG) to move people and goods by two stroke engine, light duty vehicle, taxi fleets, public bus systems, trucking, and shipping.

Available

The availability of gas is the result of economic incentives to produce natural gas and the availability of technology to deliver gas where it is needed. The availability of gas to low and middle income countries is affected both by the global natural gas system and domestic infrastructure and policy choices.

Global environment

A natural gas revolution is unfolding globally with the United States at the center. After years of preparing for declining natural gas production, new technologies for producing directly from the source rock - including horizontal drilling and hydraulic fracturing - caused a dramatic increase in U.S. gas production. As supply increased, natural gas hub prices steadily declined, sustained by production cost declines through technology improvements. With lower gas prices, natural gas fired power plants became more profitable to operate than coal fired power plants in many U.S. electricity markets. This fuel switching in the power sector brought U.S. carbon dioxide emissions from power generation to its lowest level in a decade (EIA, 2016).

Natural gas price declines also led to a change in U.S. production strategy. As the price of gas declined, development turned to regions with wet gas. Wet gas contains higher fractions of ethane, propane, and butane, collectively referred to as LPG. Increased LPG and methane production led to a resurgence in petrochemical manufacturing and exports to international markets (Braziel, 2015).

The changes in the natural gas market in the United States are just the beginning. Natural gas production is distributed globally as shown in Figure 1. As of 2015, there are 187 trillion cubic meters (tcm) of natural gas resources globally compared to 3.5 tcm current consumption (*BP Statistical Review of World Energy* 2016). Reserves, which reflect natural gas that is technically and economically recoverable, will continue to grow as technology improves to make conventional and unconventional gases including shale gas, tight gas, and coal bed methane more accessible globally.

Local conditions

Globally there is enough gas to meet the needs of the developed countries and low and middle income countries, but sufficient gas on global markets

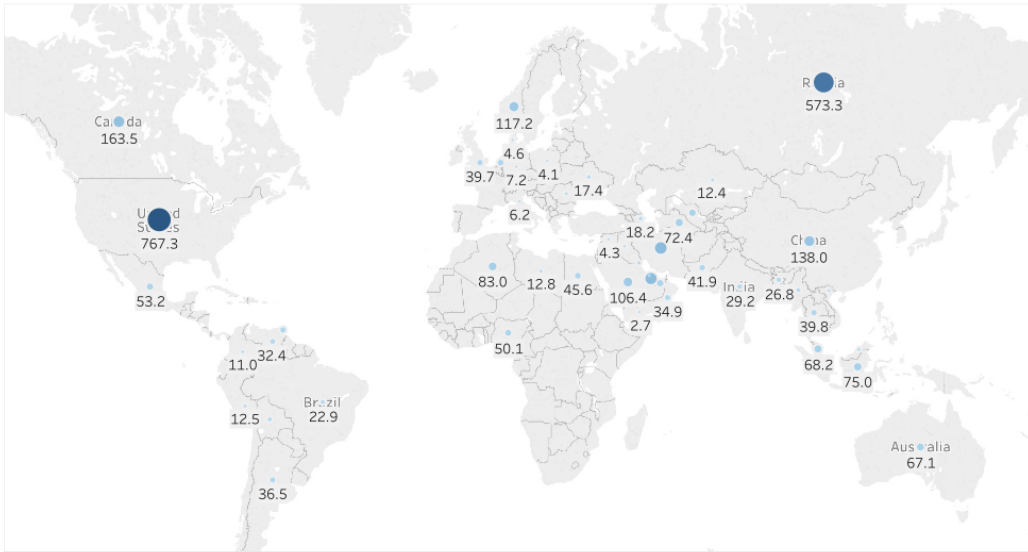

Figure 1: Natural gas production in 2015 (billion cubic meter) (*BP Statistical Review of World Energy* 2016).

will not always mean a specific country will have the gas it needs. Local availability relies on domestic infrastructure and policy choices.

As a gas, transportation and storage requires specialized infrastructure. Gas importing countries must invest in international pipelines or LNG import and regasification facilities. Additional infrastructure is needed to distribute the gas to consumers. This may be a pipeline distribution network or specialized vehicles and storage containers required to move and store natural gas that has been compressed or liquified at cryogenic temperatures. Some countries, particularly island and archipelago nations, have been pursuing small scale LNG. LNG infrastructure is typically designed to carry large volumes to lower costs by economies of scale. In many cases, these large volumes are more than a low income country can absorb in local markets. Small scale technology development - small scale LNG for transport, micro turbines to generate power, and other distributed small scale uses of gas - has been slow.

Some low and middle income countries have domestic gas resources. Investment to produce these resources could provide a double benefit of supplying natural gas without the additional costs of transportation and regasification and by generating revenue through taxes and royalties.

Domestic resources, however, do not automatically mean gas is available. In order to get the full benefits, domestic resources must be managed well. Investment conditions must be globally competitive to attract the limited resources of upstream companies. Domestic obligations, a requirement that gas producers sell a volume of gas to the domestic market, generally at a price below the international price, is a common disincentive for investment.

Local gas availability is also affected by policies. Third party access requirements are necessary to efficiently utilize infrastructure. Regulated prices facing the producers and distributers of gas lead to underinvestment in infrastructure to produce gas and stifle imports of gas that must be purchased at international prices and then sold at a loss. Many countries use poorly designed energy subsidies - for natural gas and for electricity - to control the prices faced by consumers (Coady, Parry, et al., 2015; Coady, Flamini, and Sears, 2015). These subsidies promote inefficient use of fuel, often benefit the wealthy more than the poor, and contribute to unviable electric utilities. Unless the price of imported gas and electricity generation and distribution can be recovered by consumer tariffs, import infrastructure will be unbuilt or unused. In lieu of domestic obligations and subsidies, revenue from domestic production and safety net payments to defer the cost of energy can be distributed to the poorest citizens through direct subsidy payments. Direct payments do not distort the incentives for domestic production or efficient energy consumption and can make energy more affordable for the poor.

Affordable

The affordability of gas for consumers in low income countries is driven by the global market for natural gas, the costs of delivering the gas, and its competitiveness at the point of end use.

Global environment

Natural gas can be a very affordable fuel. Globally production costs for natural gas are \$1-\$4 per mmbtu (H.-H. Rogner et al., 2012). Transporting gas by pipeline is inexpensive, but is limited by geography and carries with it commercial and geopolitical risks especially in the case of a single seller and single buyer of gas. Transporting natural gas as LNG carries additional costs for liquefaction, transportation, and regasification which can add from

$1 - $5 per mmbtu to the price of the commodity[5] (Stokes and Spinks, 2016). Improvements in technology and an increasingly competitive market will result in a reorganization of the global LNG market and will apply downward pressure on both the traded price and the costs associated with delivering LNG.

Even before the first LNG cargo left the lower 48 states, global LNG markets had begun a transformation. As U.S. domestic production displaced the need for projected U.S. imports of LNG, cargoes were redirected to Asian and European markets. The increased liquidity in global LNG markets exerted downward pressure on LNG prices at European hubs while Asian customers faced high oil-indexed prices. Since Asian customers began to question the hallowed long-term contract based on an oil index, buyers have been more selective about the terms they are willing to accept such as contract length and destination clauses. While the majority of LNG contracts are still oil-indexed and long-term, short-term LNG trading especially by aggregators based on hybrid indexes and on spot and short-term contracts now make up thirty percent of LNG trade or 75 mtpa of the total LNG supply of around 250 mtpa (Corbeau, 2016). Gas trade that is more beneficial to buyers is expected to evolve further with 180 bcm of new LNG export capacity, including U.S. projects indexed to Henry Hub.

Natural gas has historically been a volatile fuel. It is unclear as of yet how the volatility of natural gas prices will change as it becomes a more liquid global commodity. In general, diversified supplies and an increasingly liquid market for natural gas trade strengthen security of supply.

The cost of importing natural gas is becoming more cost effective with new floating LNG technology. Floating storage and regasification units (FSRUs) are less capital expensive than onshore options (typically $100 million -$250 million vs. $500 million to $1 billion) and can be operational more quickly (12 months vs 4 years for engineering, procurement, and construction). While countries sometimes pay a premium on regasification on a volume basis, the flexibility that a floating option provides is expanding the number of interested importers. Vessels can be used for regasification and easily converted back to use in transportation if the

[5] Marginal costs for liquefaction, transportation and regasification are on the lower end of this range. Costs which include amortization of the capital expenditure are on the higher end of the range.

buyer is unable or unwilling to purchase the gas.

More supply and lower prices are likely to bring new buyers to the LNG market, many of whom will be low and middle income countries. In the past year Pakistan, Egypt, Ghana, Colombia, and the Philippines have moved to import natural gas through floating regasification units. In the past eight years, ten countries have added more than 20 mtpa of firm demand. This strong growth is expected to continue with 69 projects for 137 mtpa of proposed import capacity under exploration and a projected surplus in LNG ships. A surplus of LNG ships may encourage older ships to convert to FSRUs, creating a more competitive market and contributing to lower prices of delivered natural gas.

Local conditions

While global trends are making natural gas increasingly available and affordable, natural gas has many competitors at the point of final use. The attractiveness of gas differs by sector.

The economics of supplying electricity through the grid are very compelling in dense populations areas. Electricity delivered by the grid can support high power applications and the unit cost of energy does not rise with consumption. In this sector, coal-fired power generation is the competitor to beat. The economics depend on both the relative cost of coal and gas and the relative efficiencies of coal and gas-fired power plants. Gas does not need to be as cheap as coal on a per mmbtu basis because, typically, natural gas fired power plants are considerable more efficient (Zhang, Myhrvold, and Caldeira, 2014). In the United States and Europe, fuel switching is occurring; China and India will continue to use predominately coal unless the coal, gas, and electricity pricing policies are reformed.

In a decentralized setting, sufficiently small gas-fired turbines electricity powering a mini-grid could provide energy to household electric appliances, schools, and hospitals. A small scale turbine, would work against the economies of scale typically pursued in turbine technology, but the unit fuel cost could be affordable. With today's technology, however, the system cost is likely to be prohibitive for the poor. Financing such a system would face barriers similar to that faced by other mini-grid alternatives such as diesel, solar, and small-hydro systems.

In cooking and household heating, natural gas competes with firewood, collected biomass fuels, or electricity. In urban areas heat might also be provided by coal or liquid petroleum products. In this market, affordability is a barrier to natural gas uptake. Even when the fuel itself may be affordable, poor households struggle to afford an LPG stove and cylinder, much less a back-up cylinder for security. Empirical studies have shown that the relative price of LPG to alternatives strongly influences household fuel choice. In urban areas the poor typically pay for firewood or coal or burn trash. In rural areas traditional fuels are often gathered, requiring considerable time and physical exertion, but not money. In cooking and household heating, as well as decentralized power generation and direct uses of gas, the affordability of natural gas solutions will balance on efficient distribution.

In the industrial sector, natural gas competes with biomass, coal, and liquid petroleum products to provide process heat. For petrochemical production, natural gas competes with liquid petroleum products like naphtha or directly imported chemical products. In the transportation sector, gas competes with petroleum products like gasoline and diesel and potentially with electricity in the future. In these sectors natural gas is a desirable and competitive alternative.

Convenient

The convenience of natural gas is highly dependent on the available distribution infrastructure in the form of wires, pipelines, or a network for cylinder refilling. Expanded use of natural gas, delivered by wire through a centralized electricity grid, to reduce power shortages will improve the convenience of energy supply. More reliable electricity will reduce the energy poverty for any household or business connected to the electricity grid. In applications where pipelines deliver gas, natural gas is a very convenient fuel. These applications include centralized electricity generation, industrial use for combustion or feedstock, and city gas for cooking and heating. In most low and middle income countries this infrastructure will be in urban areas, if at all.

Without a connection to the electricity grid or pipeline system, natural gas can be delivered by cylinder. Gas can be delivered to as CNG, LNG, or LPG. These fuels are distributed in cylinders by truck, but are not as convenient to store as liquid fuels. The convenience of gas cylinders, especially in rural areas, is troubled by unreliable or unavailable distribution. Distribution is hampered by poor infrastructure like roads for delivery by truck. LPG distributors have found it difficult to reach economies of scale outside of urban centers. Distribution may improve as applications for small scale gas in rural areas beyond cooking and heating are developed.

Meaningful adoption of natural gas for public, private, or goods transportation will begin in urban areas where economies of scale can be achieved in refueling stations. The convenience of storing liquid fuels and the ubiquity of existing engines that run on gasoline and diesel will dampen adoption of natural gas vehicles.

Clean-burning

Unlike coal and liquid petroleum fuels, natural gas combusts cleanly with negligible emissions of sulfur, mercury, and particulates and relatively less nitrogen oxides. The extensive use of coal in the developing world has lead to untenable levels of air pollution. In power generation, fuel-switching, using natural gas in place of coal-fired power plants or diesel generators, improves air quality. In industry, natural gas boilers release less pollution and emissions than their coal or oil counterparts. Using gas as a transportation fuel would reduce particulate emissions and nitrogen oxides, both an issue in urban centers. In the electricity and industrial sectors, fuel switching is driven by the relative economics of the fuel alternatives as well as any additional cost for complying with local environmental regulations if any exist. In transportation, the relative fuel cost and the relative capital costs both play a role in switching decisions.

Sickening air pollution is not only a product of modern energy use. Cooking and household heating, whether with biomass or coal, degrade both ambient and indoor air quality. Indoor air pollution, a scourge of the energy poor, is caused by use of traditional fuels for cooking and heating and kerosene lighting. The indoor air quality benefits of moving from biomass to natural gas for cooking and household heating are well understood (ESMAP, 2007).

Low-emission

Climate forcing emissions are released throughout the lifecycle of natural gas: production, processing, transportation, distribution, and end use. Because of the global nature of the natural gas system, additional consumption in a low or middle income country will cause emissions both outside a country's borders and within. All emissions have an impact on the global climate system.

Global environment

In combustion, natural gas emits half as much carbon dioxide as coal. However, the net climate benefits of natural gas use to displace other carbon-based fuels will depend on lifecycle emissions of LNG and global fugitive methane emissions. Unlike the other pollutants, fugitive emissions result from leakage. Methane, a greenhouse gas and the molecule that comprises over 90% of processed natural gas, is a more powerful climate forcer than carbon dioxide (IPCC, 2014). Therefore, fugitive methane emissions from the natural gas system, predominately in distribution, erode the relative climate benefit over coal use.

As with all fuels and energy technologies, emissions are released throughout the lifecycle (G. a. Heath et al., 2014; O'Donoughue et al., 2014). Natural gas production, processing, LNG supercooling, LNG transportation, and heat for regasification all require energy. Carbon dioxide emissions are a byproduct of these processes, the carbon intensity of which will depend on its efficiency and the source of electricity. While the electricity source may vary, it is often based on diverting and combusting natural gas.

Fugitive methane emissions in production, distribution, and the LNG value chain is the subject of considerable research (Lyon et al., 2016; EPA, 2016; Hutchins and Morgan, 2016; Zavala-Araiza et al., 2015; Jackson et al., 2014; Brandt et al., 2014; Skone, 2014; Alvarez et al., 2012; Howarth, Santoro, and Ingraffea, 2011). Recent studies using top-down measurements of atmospheric methane concentrations and bottom up measurements aggregating individual sources have reported conflicting conclusions (G. Heath et al., 2015). Alvarez et al. (2012) calculates system-wide leakage rates must be below 3.2% to hold an advantage over modern coal plants based on methane and carbon dioxide emissions. Ongoing studies of leakage from production and storage sites, natural gas distribution infrastructure, and the LNG value chain will build our understanding of the high impact opportunities to mitigate leakage and the comparative emissions advantages of natural gas.

Current empirical work provides a greater understanding of the scale of fugitive emissions in the United States, and will lead to experimentation with policy and technology solutions. However, with greater understanding of fugitive emissions rates in the United States, there will still be great uncertainty about the rate of emissions globally. As natural gas production expands to meet new global demand it will matter a great deal whether that supply comes from countries with strict or lax standards for monitoring and remedying leaks. Natural gas production and distribution in low income countries should be required to meet strict standards for fugitive methane emissions to develop their domestic industry.

Local conditions

The climate forcing emissions associated with natural gas at the point of final use depend upon the efficiency of combustion or chemical conversion. To the extent that natural gas is combusted for power generation or industrial demand instead of coal or diesel, the relative emissions of carbon dioxide, sulfur dioxide, and black carbon improve climate change mitigation (Wigley, 2011; Hayhoe et al., 2002). Unfortunately, more natural gas use in the power sector does not unequivocally lead to better climate outcomes because of the risk crowding out centralized renewable power. In the United States, modeling has demonstrated that additional gas-fired power generation effectively pushes out coal-fired power, but also restricts the deployment of renewable energy (Shearer et al., 2014). Researchers are working to better understand the relationship between gas and renewables in the power sector, but their work is currently limited to large existing networks like the United States and Europe. The conclusions may differ in the context of a low income country with insufficient infrastructure and power shortages.

The climate benefits of natural gas that displaces biomass as a household heating or cooking fuel are ambiguous. In theory some biomass is carbon neutral, so switching to natural gas would increase emissions. In practice, however, biomass is not always sustainably harvested. Adding to the uncertainty, incomplete combustion of biomass produces black carbon, a lesser studied contributor to climate change. More research is required to understand the net climate effects of fuel switching in this sector.

Used as feedstock, the greenhouse gas emissions from natural gas depend on the natural gas leakage rates during delivery and storage. Using gas as a transportation fuel reduces particulate emissions and would emits fifteen to twenty percent less carbon dioxide than petroleum based liquids.

Summary

In this section we showed that the global picture for gas availability and affordability is encouraging, but there are challenges for translating that opportunity into meaningful and sustainable energy supply for the energy poor. Natural gas adequately provides a diversity of energy services. A growing global LNG market and floating LNG technologies make natural gas available to a broader number of countries and apply downward pressure to global prices. Deficiencies in distribution, be that grid extension, pipelines, or cylinder re-filling networks, remain serious obstacles expanded use of natural gas, but when in place deliver a convenient fuel. While the clean burning quality of natural gas improves ambient air quality and reduces indoor air pollution, poor management of fugitive methane emissions could eliminate the climate benefits of this low-carbon fuel.

Using natural gas, expanding power generation is the biggest opportunity by megawatts to reduce energy poverty because it addresses two major concerns in the power sector that affect households and industry: air pollution from coal-fired generation and power shortages. Natural gas improves the hours and quality of grid electricity and, in a system with many coal-fired power plants, lowers the carbon intensity of power generation and improves the air quality. Increasing the number of grid connections and the quality of electricity as a means to provide energy to those who previously did not have access has a relatively small impact on emissions and a large impact on reducing poverty. Improving and expanding electricity for industrial processes, which is important for long-term economic growth, will strain the climate-poverty tradeoff as industrialization progresses.

Natural gas is a highly desirable modern cooking fuel which is clean burning and efficient and supports a range of cooking preferences. If technologies and business models for rural distribution improved, there would be significant progress is expanding access to modern cooking systems. Successful distribution of natural gas for cooking could increase the viability of natural gas in decentralized electricity generation and other household needs.

Outside the household, natural gas can contribute to growth in an expanded manufacturing and petrochemicals sector and improve mobility of people and goods in a growing economy. More empirical research is needed to clarify where reductions in energy poverty can have the biggest effect on economic growth and development.

Conclusions and Research Agenda

While there is agreement in principle on reducing energy poverty, lack of agreement on the details risks delaying investment and prolonging energy poverty. There is no theoretical basis for a metric of energy poverty, but academics and practitioners could work together to develop consensus on the basket of energy services and the amount of those services that constitutes meaningful energy consumption. A clear articulation of the amount of energy needed to reduce energy poverty in a meaningful way, coupled with empirical studies of energy demand evolution in low and middle income countries, would clarify future demand. Clarity about which energy services must be met to escape energy poverty would resolve what characteristics of energy supply are required. A better understanding of the size of demand and the nature of supply needed, would sharpen analysis of policy and investment seeking to reduce energy poverty and mitigate climate change.

Realizing human development goals will require energy beyond the home - in schools and hospitals. Turning modern energy services into economic growth will require energy that can support income generating activities in industry, agriculture, and enterprise. With this level of energy consumption, investments to mitigate climate change must be integrated with those to reduce energy poverty.

The framework presented here suggests a transparent way to evaluate energy supply investments to meaningfully and sustainably reduce energy poverty. Applying the framework to natural gas has shown many reasons for low and middle income countries to consider expanding consumption of natural gas, and technologies and policies could make the potential even greater.

Research Agenda

This review highlighted many outstanding questions about how energy demand will evolve in low and middle income countries and whether natural gas will be a viable option for meaningfully reducing energy poverty. Further research could address the questions below, and many others.

- The relationship between energy demand and economic growth in low and middle income countries
- The interaction between global climate policy and pro-poor growth policies
- The competition between coal and gas in the power sector of low income countries
- Prices that stimulate investment and create sustainable demand
- The relative importance of different energy services for poverty reduction
- Technology or business model innovations to enable gas use for pro-poor growth
- How fugitive emissions scale with natural gas production and consumption in the developing world
- The relationship between fugitive emissions in the United States and in low income countries
- The competitiveness of LPG for cookstoves
- The climate benefits of more LPG use in cookstoves
- The ability of countries to absorb gas in their economies
- The competition between gas and renewables for power investments

Recommended Readings

Energy Poverty Practical Action (2014), Bhatia and Angelou (2015), and Halff, Sovacool, and Rozhon (2014)

The Ambition Gap Bazilian and Pielke (2013)

Natural Gas Markets Braziel (2015) and Corbeau (2016)

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