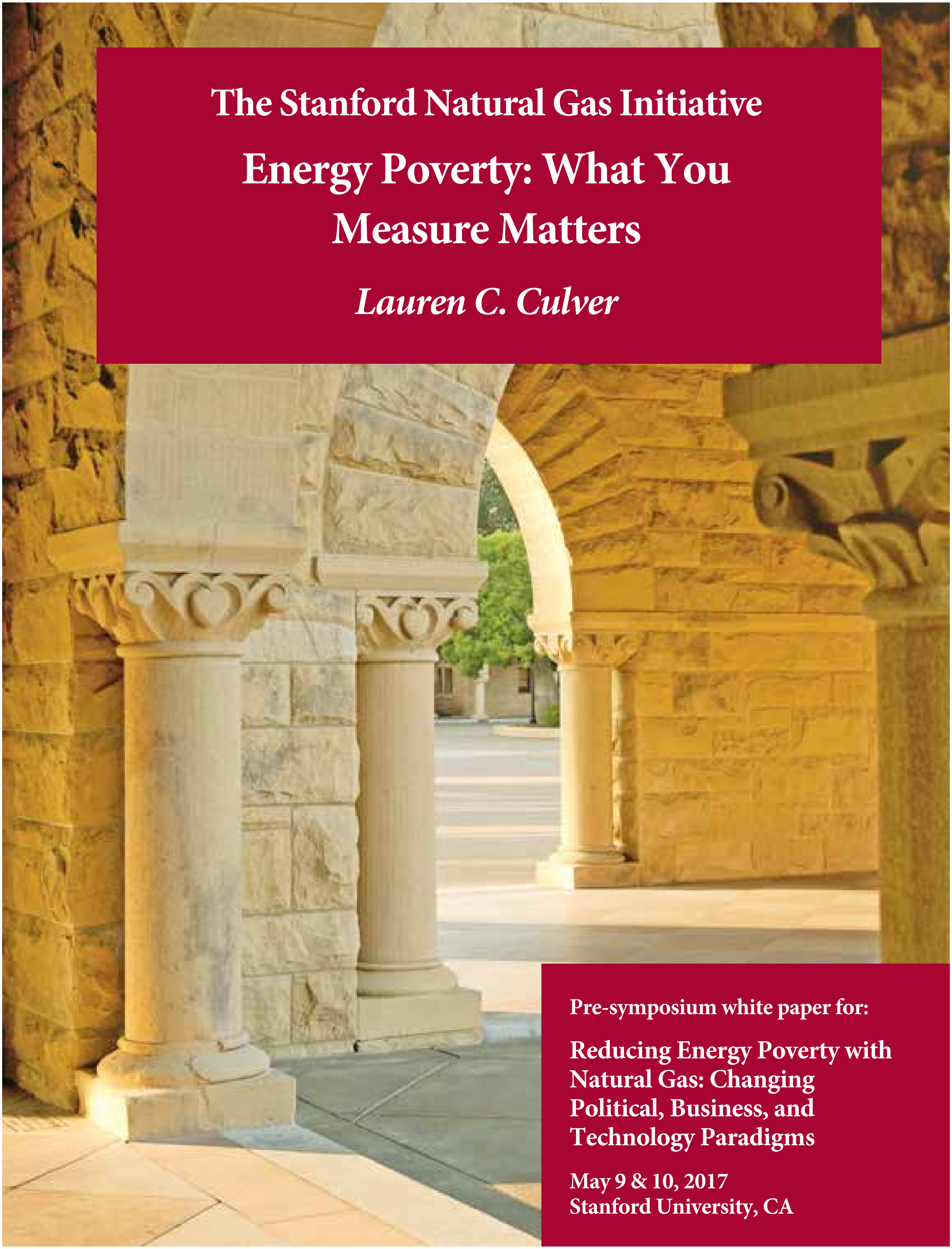

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Energy Poverty: What You Measure Matters

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Energy Poverty: What You Measure Matters

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There is no one metric for energy poverty because there is no single, universally-accepted understanding of what it is to be below the energy poverty line. Unlike nutritional poverty, which can be defined in terms of a minimum daily caloric intake, there is no absolute reference for what fulfills a minimum level of basic energy needs. And unlike measurements of income poverty, like the World Bank's $1.90 per day, which is a relative measure based on the purchasing power parity of the poorest countries in the world denominated in currency (Ferreira et al., 2015), there is no common, fungible unit of energy from which people derive utility directly. Without an objective reference for energy poverty, many energy poverty metrics have been developed to help scholars and practitioners understand energy poverty and measure progress towards its elimination.

This paper will review some of the metrics that have been developed. The paper is organized as follows. The first section begins with a discussion of the lack of energy services as an accepted understanding of energy poverty, but one that cannot be directly used as a metric. The next section summarizes energy poverty metrics developed for different audiences, highlighting their strengths and constraints. These measures of energy poverty are classified into four approaches: 1) energy access 2) energy inputs, 3) outcomes of energy use, and 4) the quality of energy delivered. The third section reviews several proposed composite metrics that combine elements of the previous four approaches. Users of these metrics should be aware of the strengths and limitations of each energy poverty metric and their usefulness for different purposes. More research is needed to understand the relative influence of energy services in different sectors on development and economic growth, and then to establish an energy poverty line based on the most basic basket of energy services and the minimum threshold of each energy service.

Energy Services: What We Wish to Measure

There is widespread agreement that in measuring energy poverty we would like to reflect the level of energy services actually experienced by households and businesses. The UN Secretary General's Advisory Group on Energy and Climate, for example, frames the goal of eliminating energy poverty as providing "a basic minimum threshold of modern energy services for both consumption and productive uses. Access to these modern energy services must be reliable and affordable, sustainable and where feasible, from low-GHG-emitting energy sources (Advisory Group on Energy and Climate Change, 2010)."

Energy services, such as lighting, cooking, space heating and cooling, refrigeration, process heat, mechanical power, mobility, and communication, are the productivity and human welfare goals of primary energy consumption. Framing energy poverty in terms of energy services underscores the fact that people do not consume energy directly, but need energy in every aspect of their lives to alleviate the drudgery of poverty and to support socio-economic development. Implied in the definition, "access to energy services" requires a source of fuel or electricity, but also that the energy is available when needed and a household can afford both the energy and energy-consuming technology that provides a service.

While there is agreement in principle that energy poverty is a lack of energy services, it is very difficult to make this definition measurable and, therefore, useful. First, energy services cannot be measured in a fungible unit. While light from a light bulb, heat to boil water, and pumping water to irrigate crops can be converted into common energy units, interpreting the sum of those numbers is problematic. A surplus of one energy service, for example light, could not be substituted for another energy service, like water pumping.

Second, there is no universally accepted basket of basic energy services. To distinguish the energy poor from those who are not, one must define a basket of basic energy services and the minimum amount of each service needed. Lighting and cooking are typically included in the set of basic energy services. However, there is no standard on whether to include energy services like refrigeration, heating or cooling, agricultural processing, or mobility in the basket of basic needs.

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.

After having chosen which energy services are necessary, measuring energy poverty based on energy services is further complicated by the arbitrariness of defining the minimum level of each energy service identified as basic. For example, surveys have shown that 100 lumen hours per person per day (4 hours of light at 25 lumens) "satisfies" the poor in Asia and Africa (Bhatia and Angelou, 2015). Would 90 lumen hours per person per day be unacceptable? Why not 125 lumen hours per person per day? Any normative definition for basic needs is subjective and will vary based on geography and culture.

Practitioners would benefit from the development of 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. Baskets determined at the national level would be useful for program management and national policy making, but not international benchmarking. For now, there is no consensus on a household's minimum energy needs or, more importantly, the process by which we would agree on those needs.

Four Ways to Measure Energy Poverty

As a minimum basic level of energy services cannot be measured in an objective and fungible way, many alternative ways of measuring energy poverty have been developed. In this section we review several metrics, categorized by whether the approach to measurement is based on an observation of energy access, the energy input, the outcomes of energy use, or the quality of energy delivered.

Approach 1: Energy Access

Energy access is commonly used as a proxy for energy poverty because of the conceptual difficulties of measuring energy services just described. Energy access is an observation about households' access to both electricity and cooking fuels. The first component of energy access is electricity access, also called the electrification rate. The electrification rate is defined as the percentage of the population with a connection to an electric network.[1] The second component of energy access is access to modern cooking services provided by liquified petroleum gas (LPG), electricity, biogas systems, or high efficiency biomass cookstoves. The number of households with access to modern cooking is defined as the complement of the percentage of the population that uses traditional fuels like fuelwood, charcoal, crop residues, or dung (IEA, 2011).

Strengths

Energy access is easy to measure and easy to communicate. The energy access metric is convenient for data collection because of its binary nature, "having/not having an electricity connection" and "having/not having access to non-solid fuels." Several international organizations, including the International Energy Agency (IEA), the World Bank Group, the World Health Organization (WHO), and the United Nations Development Program (UNDP), maintain a dataset on both access to electricity and use of traditional fuels developed from a combination of nationally reported data and their own survey information (IEA, 2016; IEA, 2011; World Bank, 2016; UNDP and WHO, 2009).

[1] An electric network can be the national grid or a mini-grid powered with a diesel generator or renewable energy. A solar home system is not typically considered electrification.

Limitations

Energy access is used as a measure of energy poverty because of its simplicity, but its simplicity gives rise to critique. By assessing access to cooking and electricity, the implication is that electricity provides all of the energy services needed for development besides cooking.

First, energy access only includes household energy use. The use or lack of electricity in commercial enterprises, heavy industry, street lighting, and public buildings like schools and hospitals is not reflected in the energy access metric despite their importance to economic and social development.

Second, energy access does not consider other kinds of energy use such as for mobility or mechanical power necessary for transforming resources into food and products with the aid of machines within households. To support income generation, energy must be available for productive uses in industry and agriculture (Brew-Hammond and Kemausuor, 2009). "Mechanical power helps alleviate drudgery, increase work rate and substantially reduce the level of human strength needed to achieve an outcome, thus increasing efficiency and output productivity, producing a wider range of improved products, and saving time and production costs (Bates et al., 2009)." Mechanical power, when not produced by human power, is produced from the conversion of fuel or electricity into motion as in steam, diesel and gas engines, small turbines, and electrical and hydraulic motors. In the context of low income countries, applications include pumps, stationary engines, farm equipment sharpeners, corn threshers, rice dehuskers, and presses.

Third, energy access does not capture the quality of the energy. Quality measures reflect the usability of the energy connection. Quality adjusts for the common reality of a home that is connected to the grid, but does not have power. Measures of quality include the availability, reliability, adequacy, affordability, convenience, and safety (Bhatia and Angelou, 2015; Culver, 2017). For electricity, availability and reliability reflect the number of hours a day electricity is provided and whether those hours are in the evening when they are most needed. Adequacy typically relates to voltage fluctuations that might burn out appliances and power requirements to support multiple appliance use.[2] Affordability typically relates to the price of electricity or the price of fuel, although sometimes it includes the cost of

[2]Power (ex. kW) is energy (ex. kWh) per unit time. An appliance may require high power, high energy, or both. For example, a hair dryer requires high power, but uses little energy. A refrigerator uses lots of energy, but does not require high power.

appliances. Convenience and safety may relate to both the collection and use of energy.

Approach 1: Energy Access

energy access = access to the grid + access to modern cooking fuels
Data on energy access is relatively easy to collect and understand, but it does not capture important aspects of energy poverty:

- Energy access does not consider energy used outside the household
- Energy access does not measure all forms of household energy use
- Energy access may not result in energy useable for energy services
- Energy access does not account for households that continue to use traditional fuels even with "access" to modern fuels

Lastly, calculations of energy access based on the percentage of the population using traditional fuels like wood, crop residue, or dung for cooking does not consider the factors behind consumer behavior. This obscures the differences between causes of energy poverty. Households that use traditional fuels is an imperfect proxy for the number of households that do not have access to modern cooking services. Many households use modern cooking fuels while continuing to use biomass fuels - a practice called fuel stacking (Masera, Saatkamp, and Kammen, 2000).

A theory called the energy ladder suggests that as wealth grows households progress from inefficient, polluting fuels to fuels that require less labor, burn more efficiently, and alleviate indoor air pollution. (Leach, 1992; Sathaye and Tyler, 1991). The theory implies that households use the most sophisticated fuels they can afford and, therefore, biomass fuels are solely the 'energy of the poor.'

Empirical studies on fuel use challenge the energy ladder theory showing that fuel switching depends on the price of fuels, security of supply, and cultural, social or taste preferences (Hiemstra-van der Horst and Hovorka, 2008; Van Der Kroon, Brouwer, and Van Beukering, 2013; Barnes, Krutilla, and Hyde, 2004). Even when modern fuels may be available and affordable, traditional fuels may be free. Households that cannot rely on electricity or LPG to be available and affordable, may continue to use a traditional cooking system. In many cases people are not well informed about the health risks of the indoor air pollution (Practical Action, 2016). In Indonesia, it was found that some women, the primary beneficiaries of modern cooking fuels and stoves, were willing to purchase the modern cooking system, but male household decision makers would not agree to purchase more expensive systems (Durix, Carlsson Rex, and Mendizabal, 2016). Instead of climbing the ladder, incomplete fuel switching and or multiple fuel use is common in households especially in urban households (Arnold, Kohlin, and Persson, 2006; Hiemstra-van der Horst and Hovorka, 2008).

Observing "access" to modern energy for cooking by surveying use of traditional fuels also fails to provide any information on the root cause of the energy poverty. In rural areas, incidence of energy poverty is higher than that of income poverty, suggesting that distribution of modern fuels and stoves is the central issue. Here "access" is the problem. However, in urban areas energy poverty and income poverty are more closely aligned pointing to affordability as the primary concern for combating energy poverty (Khandker, Barnes, and Samad, 2012).

These deficiencies in the energy access metric give rise to a serious critique that energy access fails to reflect "the full extent of the energy access gap (Bates et al., 2009)." Scholars suggest that using a simple energy access metric creates an ambition gap - the difference between the the amount of energy that might be used once "access" is provided and the amount of energy that is commensurate with real improvements in both human welfare and economic productivity (Bazilian and Pielke, 2013).

Ambition Gap

Delivering adequate energy to provide universal basic minimum energy services is a much greater task than simply expanding electricity connections or providing technologies that deliver a subset of energy services. The difference between these goals is called the ambition gap. The ambition gap can be thought as the difference in the minimal electricity used when a household is first connected to the grid and the more significant amount of energy consumed to reach a minimum level of productivity and quality of life. Delivering a meaningful amount of energy to support development may require institutions and investments of a different character than that needed to increase energy access.

An ambition gap suggests there is a danger that "as the world is rushing to reach the universal access target, the purpose behind the target — having energy services provided in sufficient quantity and quality to trigger desired development outcomes — may be lost (Bhatia and Angelou, 2015)." Using energy access as the metric for energy poverty influences energy development programs to adopt an approach focused on expanding access to basic lighting and improved cookstoves. Solar home systems have improved the lives of many, but are not the "end goal (Craine, Mills, and Guay, 2014)." When the point is to make decisions trying to increase development, Pachauri (2011) warns against choosing a metric that is "merely convenient and instrumental."

Approach 2: Measuring Inputs

Because of the challenges of measuring energy services and the limitations of using energy access as a surrogate, many scholars have approached the definition of energy poverty through the lens of inputs of energy, measured either in terms of energy consumed or in terms of income spent on energy[3]. The assumption is that if one has energy, then one has energy services. Input-based metrics differ based on whether energy consumption is measured in units of energy or units of income and on how the energy poverty line is set. While the energy inputs into a household or an economy can be measured easily and consistently, the threshold that identifies the energy poor is not consistent across time or geography.

Energy input in units of energy

Primary energy, final energy, and useful energy have all been used to measure energy consumption. Using primary energy, one can look at per capita national energy consumption. The energy poverty line can be set by calculating the average per capita national energy consumption for countries that are classified as poor - either by a measure of national income or the Human Development Index (Goldemberg and Johansson, 1995). Essentially this method defines energy poverty as the per capita energy consumption within poor countries. Per capita energy consumption captures energy use throughout the economy, but it cannot explain the

[3] When looking at calculations of energy consumption take heed of whether the total is for a household or an individual and how many people are assumed to be in a household.

distribution of energy use within the economy, and therefore, cannot explain how many energy poor there are in a particular country or in what ways they are energy poor. Figure 1 shows the top twenty-five energy poor countries by these metrics and compares them to metrics of energy access. The energy poor are identified differently.

Using final energy, other approaches have been taken. Foster, Tre, and Wodon (2000) defined the energy poverty line as the average final energy consumption of the households whose total incomes fall within ten percent of the national poverty line. Essentially defining energy poverty as the amount of energy used by poor households. Barnes, Khandker, and Samad (2011) identifies the energy poverty threshold as the energy consumption at the income level at which consumption does not increase with income. Below this line households'energy consumption is the level of energy necessary for a minimum quality of life.

Goldemberg, Johansson, et al. (1987) calculated the minimum energy needs based on a back calculation of the energy that would be required to supply a normative set of basic energy services. This common calculation not only depends on which and how much energy services you think are necessary, but also on assumptions about the size and efficiency of the technologies used (lightbulb, stove). Using this method means the threshold of energy poverty will change over time as appliance efficiency improves and as the goals of human development change [4].

Rather than reducing basic energy services to a single sum, Pachauri and Spreng (2004) proposes the Energy Access-Consumption Matrix. The matrix combines the physical availability of different kinds of energy (rows) with the amount of each kind of energy consumed (columns). In each cell, the population with each quantity of energy consumed and fuel use is counted, providing information about the distribution of useful energy (Pachauri, Mueller, et al., 2004; Pachauri and Spreng, 2004). The poverty line is subjectively drawn as a frontier across the matrix.

Measuring total primary or final energy consumption is helpful for thinking about national and global changes in energy demand and making comparisons, but the poverty line will change in time and geography because of improvements in the efficiency of appliances and the energy

[4] A similar approach was used by Modi et al. (2005) which is the basis for the International Energy Agency's assumptions of 50 kilowatt-hours (kWh) of electric consumption per year per capita in rural areas and 100 kWh per year per capita in urban areas (IEA, 2015).

	Population without access to electricity		Population without access to clean cooking		Per Capita Primary Energy (GJ/person)		Per Capita Final Energy Consumption (GJ/person)		Per Capita Electricity (kwh/person)		Per Capita GDP (2011 USD PPP)	
1	India	269,144,593	India	808,693,811	Mali	4.9	Mali	3.6	Burundi	15	Somalia	305
2	Nigeria	74,698,739	China	609,594,812	Niger	5.4	Central African Republic	3.7	Benin	16	Dem. Rep. Congo	640
3	Ethiopia	67,702,865	Bangladesh	138,326,166	Central African Republic	6.5	Niger	4.0	Togo	16	Burundi	717
4	Bangladesh	62,723,984	Nigeria	126,438,009	Chad	7.0	Malawi	4.0	Niger	18	Malawi	750
5	Dem. Rep. Congo	58,763,410	Pakistan	104,727,487	Malawi	7.6	Comoros	4.5	Chad	19	Liberia	782
6	Tanzania	41,202,916	Indonesia	101,075,166	Rwanda	8.2	Chad	4.9	Guinea-Bissau	20	Niger	860
7	Kenya	32,758,093	Ethiopia	90,171,086	Gambia	8.6	Rwanda	5.0	Burkina Faso	32	Central African Republic	912
8	Uganda	28,970,961	Dem. Rep. Congo	66,773,275	Madagascar	8.7	Madagascar	5.3	Somalia	34	Mozambique	948
9	Sudan	25,432,291	Philippines	51,964,802	Afghanistan	8.8	Gambia, The	6.0	Afghanistan	34	Guinea-Bissau	1193
10	Myanmar	25,030,541	Myanmar	48,696,276	Bangladesh	8.9	Kiribati	6.2	Rwanda	37	Guinea	1197
11	Mozambique	20,534,877	Tanzania	46,585,245	Comoros	9.0	Bangladesh	6.3	Sierra Leone	39	Ethiopia	1212
12	Madagascar	18,860,487	Vietnam	43,464,464	Kiribati	9.0	Djibouti	7.1	Central African Republic	39	Togo	1294
13	North Korea	17,442,672	Kenya	35,662,771	Burundi	9.3	Afghanistan	8.0	Comoros	57	Madagascar	1360
14	Afghanistan	16,944,278	Uganda	34,494,902	Djibouti	9.8	Senegal	8.2	Madagascar	67	Uganda	1370
15	Niger	15,096,229	Sudan	27,189,046	Burkina Faso	10.6	Burkina Faso	8.2	Ethiopia	73	Comoros	1460
16	Burkina Faso	14,417,416	Mozambique	24,755,737	Lao PDR	11.6	Sierra Leone	8.7	Guinea	76	Rwanda	1463
17	Angola	14,291,948	Afghanistan	23,935,736	Yemen	11.6	Burundi	8.7	Uganda	80	Mali	1477
18	Malawi	14,161,793	North Korea	22,793,850	Solomon Islands	11.7	Solomon Islands	8.8	Liberia	84	Burkina Faso	1516
19	Yemen	12,837,851	Nepal	21,876,203	Tajikistan	12.0	Yemen	9.0	Cambodia	97	Gambia	1563
20	Philippines	12,002,165	Madagascar	21,847,846	Myanmar	12.2	Somalia	9.7	Mali	111	Sierra Leone	1566
21	Mali	11,987,576	Ghana	21,257,887	Dem. Rep. Congo	12.2	Sao Tome and Principe	10.3	Haiti	112	Zimbabwe	1570
22	Chad	11,901,675	Mexico	18,489,722	Sierra Leone	12.5	Mauritania	10.3	Dem. Rep. Congo	113	Tanzania	1579
23	Zambia	11,524,283	Niger	17,074,959	Uganda	12.5	Philippines	10.4	Botswana	117	Haiti	1585
24	Pakistan	11,353,104	Cote d'Ivoire	17,067,077	Senegal	12.5	Tonga	10.5	Tanzania	119	Kiribati	1675
25	South Sudan	10,424,723	Cameroon	16,909,538	Cameroon	13.5	Tajikistan	10.8	Equatorial Guinea	126	Benin	1687
	Total in Top 25	900,209,470	Total in Top 25	2,539,865,873	Average in Top 25	9.8	Average in Top 25	7.3	Average in Top 25	62	Average in Top 25	1227
									Average Per Capita GDP (USD) for electricity poorest countries	3120	Average Per Capita Electricity (kwh/person) for income poorest countries	115
	Global Total	1,086,126,107	Global Total	2,916,099,116	Global Average	91.0	Global Average	51.4	Global Average	3892	Global Average	17960

Figure 1: Top twenty-five energy poor countries ranked by different metrics (World DataBank, 2012).

service needs in different environments. Even with agreement on a basket of energy services and their thresholds, it will not necessarily translated into a fixed input of energy because of different operating conditions.

Approach 2: Energy inputs

Energy consumption or the amount of money spent on energy is used to measure energy poverty. The data is easy to collect, but there is no consensus on how to define the energy poverty line. While measuring energy inputs is useful in cross-country comparisons, it is less meaningful for managing policies or investments to reduce energy poverty.

Energy input in units of income

Using inputs to evaluate energy poverty is not limited to measuring energy consumption. Scholars have also looked at measures of income to define energy poverty. One method is to measure the amount of money a household spends on energy and define poverty as those households that spend above a fixed percentage of their income (Foster, Tre, and Wodon, 2000). Reddy (2003) added to this approach by also including the amount of income spent on the appliances necessary to use the energy in the percentage of income spent on energy. Hammond et al. (2007) looked at the absolute level of expenditure on energy.

Methods based on expenditure inputs are problematic for a few reasons. First, the results vary considerably between countries, between urban and rural areas, between income groups, and by personal choice. Second, these measures are sensitive to the cost and efficiency of the appliances and fuels in use. Third, the poor commonly pay more per unit of energy than the wealthy(Dutt and Ravindranath, 1993). This obscures the usefulness of the metric for policy design and management. As an illustration, if a household were to gain access to the grid, they might pay a lower price per unit energy allowing them to increase their consumption. Their improvement in energy services would not be observed if their energy expenditures were to remain constant.

Approach 3: Measuring Outcomes

The third approach to measuring energy poverty is based on the outcomes of energy poverty. Implied in this approach is that without modern energy services people will experience bad outcomes, and therefore, if improved outcomes are measured, then energy poverty has been reduced. There are three ways in which the outcomes of energy poverty have been used as a metric. First, the individual impacts of energy use that are characteristic of the energy poor can be measured. For example, one could measure health impacts like the number of respiratory infections or kerosene burns treated. Alternatively, one could measure environmental impacts like deforestation rates. These measures are problematic because they conflate the dependent and independent variables that might be used to study the efficacy of programs.

Second, the outcomes of energy poverty can be measured in terms of opportunity costs. Mirza and Szirmai (2010) look at several dimensions of opportunity cost such as time lost when gathering fuel that may have otherwise been spent at school or engaged in a productive enterprise. The opportunity cost will differ among communities depending on the distance to the source of biomass fuels.

Approach 3: Outcomes of energy poverty

Outcomes of energy poverty that could be measured include:

- Health impacts
- Environmental impacts
- Opportunity cost
- Absence of choice

Outcomes of energy poverty capture the essence of the poverty to be alleviated. However, they are not easily measured and aggregated numerically.

Finally, energy outcomes can be measured in terms of available choice. Sen (1999) argues that poverty is defined by the absence of choices and opportunities to live a basic human life. The focus on choice is based on Sen's capability approach to defining poverty, centered around the moral significance of individuals' "beings and doings" rather than the more common utilitarian definitions. In line with this broader thinking about poverty, the Asian Development Bank has defined energy poverty as the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development (Masud, Sharan, and Lohani, 2007). By this definition, when a household has a choice to exercise about their energy services, that household has escaped energy poverty.

Like energy services themselves, outcomes are not measured in units that can be meaningfully added and interpreted. Data collection for health and environmental impacts is straightforward, but designing data collection for opportunity costs and choice is daunting.

Approach 4: Quality of Energy Delivered

The World Bank developed the Multi-Tier Framework (MTF) to improve upon the simple, binary measure of energy access by assessing the attributes of energy supply as a way to more closely measure the energy services needed to support household and business development (Bhatia and Angelou, 2015). The underlying assumption is that energy services require, not just an electricity connection and not just energy, but a certain quality of energy that can be described by various attributes. If the delivered energy has the prescribed attributes, then energy services are being provided. The MTF is the most sophisticated energy poverty metric based on the quality of energy delivered. The MTF assesses the quality of energy in several domains: household energy, energy for productive uses, and community energy. The household energy index is further divided into electricity, cooking, and space heating. For each type of end use there are several attributes of quality. For example, the MTF assesses electricity based on seven attributes of quality: capacity, duration (including daily supply and evening supply), quality[5], reliability, affordability, legality, and health and safety. For each attribute a quantitative or qualitative threshold is set establishing five tiers of access, as shown in Figure 1.

For electricity, Tier 1 access is the provision of 1,000 lumen hours and cell phone charging for at least four hours a day, of which at least one hour must be in the evening. Tier 1 could be met with many solar home systems

[5] Quality as an attribute refers to voltage stability.

Attributes	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Peak capacity (W)	-	>3	>50	>200	>800	>2000
Resulting Wh per user	-	>12	>200	>1000	>34,000	>82,000
Duration (hours)	-	≥ 4	≥ 4	≥ 8	≥ 16	≥ 23
Evening supply (hours)	-	≥ 1	≥ 2	≥ 3	≥ 4	≥ 4
Reliability (disruptions/wk)	-	-	-	-	14	3
Quality	-	-	-	-	✓	✓
Affordability	-	-	-	✓	✓	✓
Legality	-	-	-	-	✓	✓
Health and Safety	-	-	-	-	✓	✓

Table 1: Multi-tier framework to define access to electricity services (Bhatia and Angelou, 2015)

available today. Tier 5 is 23 hours of reliable electricity, provided legally at a cost of less than 5% of household income. This quality of electricity is not provided by the grid in many countries.

The multi-tier index for household electricity has additional parallel assessments. In addition to the seven attributes of electricity quality, there is a multi-tier matrix for annual consumption, daily consumption, and access to energy-intensive energy services. The overall tier assignment is determined by the lowest tier assignment of each of the attributes among the assessments.

Like the multi-tier matrix described for electricity there is a multi-tier matrix for cooking, space heating, productive uses, street lighting, health facilities, education facilities, community buildings, and public offices. For example, for cooking Tier 1 requires high air quality and high efficiency. Tier 2 adds a requirement for convenient fuel collection. Tier 4 adds requirements for year round fuel availability and affordability.

All of the assessments of energy end uses are aggregated in a simple mathematical average as an index describing energy access in each domain which are then further aggregated to provide the overall energy access index as shown in Figure 2.

Strengths

The MTF should prove useful for tracking progress toward achieving international energy access targets and leveling the playing field for

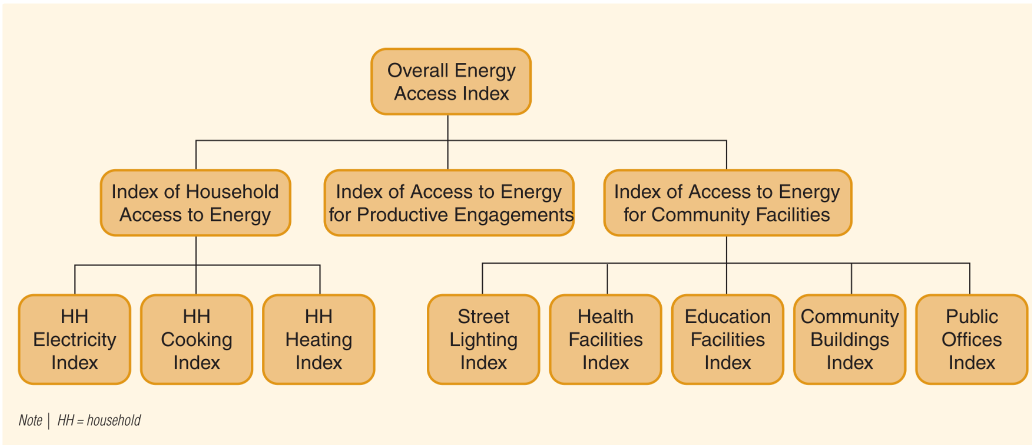

Figure 2: Hierarchy of Energy Access Indices (Bhatia and Angelou, 2015)

different technology and business solutions to contribute to reducing energy poverty. Capturing the quantitative and qualitative aspects of energy services allows a distinction between a solar lantern and a grid connection or between an improved biomass cookstove and LPG use, but also recognizes the incremental benefits of various technologies. Over time the MTF could usefully track progress within countries and inform policy and investment decisions. The MTF includes all aspects of the United Nations' Sustainable Development Goal (SDG) 7.1 for achieving universal access to reliable, affordable and modern energy services by 2030 - reliability, affordability, modernity and an orientation toward energy services (UNGA, 2015). In order to measure progress towards SDG 7.1, a threshold must be set below which will define energy poverty. Practical Action (2014) suggests achieving Tier 3 should be the measure of success for universal access.

Limitations

The MTF has enriched the definition of energy access, but it is cumbersome and falls short of cleanly measuring energy services. The data collection required to establish several attributes of several dimensions of energy use will be extensive.[6] While the disaggregated data will be very useful for designing targeted policies, the overall index is opaque and may make it

[6]The World Bank piloted data collection in 2015, and began global data collection in 2016.

difficult to communicate progress.

Besides the challenges of using the MTF, the methodology has also been criticized. The creators of the MTF warn of unintended implications of their methodology. First, the metric takes ordinal information about each attribute and converts them into cardinal values. In addition to being mathematically indefensible, the practical implication is it suggests that movement from Tier 4 to Tier 5 is just as meaningful as movement from Tier 1 to Tier 2. This may encourage policies that prioritize moving customers with moderate service to better service over policies that would target the energy poorest.

Approach 4: Multi-Tier Framework

The multi-tier framework (MTF) is the most advanced measure of energy poverty as it comes closest to approximating energy services. The MTF is an improvement on energy access for the following reasons:

- Distinguishes between “access” and useable energy
- Considers energy used in the household, for productive uses, and in community facilities
- Credits incremental energy poverty solutions
- Frames energy poverty in a way that requires ambitious action

The MTF it is not without its challenges. It is complicated, data intensive, and sensitive to arbitrary decisions in its design.

Combining the different domains of energy with a simple average implies that different types of energy have equal importance to development. For example, cooking, electricity, and heating are all weighted equally. Similarly, household energy, productive energy, and community energy are all weighted equally. There is no evidence to support equal weighting. If each domain is equally weighted, policies that target the cheapest way to raise the energy supplied will be favored over those with the most significant development outcomes.

Groh, Pachauri, and Narasimha (2016) provides a detailed critique of the MTF and suggests improvements based on applying the methodology to empirical data collected in Bangladesh. They find the final tier assignment for each type of energy use (ex. community institutions) is very sensitive to subjective thresholds that determine tier assignments within each attribute (ex. Reliability equivalent to Tier 3 is electricity available 50% of the day), and to the decision rule that determines an overall index from the tier assignments for each attribute (ex. the lowest tier sets the overall assignment).

Composite Metrics

While not the focus of this review, metrics can be classified by whether they are single metrics (ex. energy consumption per capita), compound metrics (ex. energy access = yes/no access to electricity and yes/no access to modern cooking fuels), or composite metrics. Composite indices attempt to capture the multiple dimensions of energy poverty in a single number. In this final section we review three composite metrics: the Energy Development Index, the Multidimensional Poverty Index, and the Energy Poverty Index.

The International Energy Agency developed the Energy Development Index (EDI) by calculating an evenly-weighted average of three normalized components: per capita commercial energy consumption; the share of commercial energy in total final energy use; and the electrification rate (IEA, 2015). One criticism of the the EDI is that it explains how a national energy system is maturing, but not the extent of energy deprivation of households (Nussbaumer, Bazilian, and Modi, 2012). The EDI usefully includes commercial energy, but it does not adequately address household energy services as it still focuses on the share of the population with a connection to an electric network.

The Multidimensional Energy Poverty Index (MEPI), frames energy poverty in terms of energy deprivation. MEPI includes cooking, lighting, services delivered by household appliances, entertainment and education, and communication. A deprivation rule is set for each component (ex. Household is energy poor if they do not own a fridge.), then the total number of deprivations is added up. If the total deprivations exceed an arbitrary threshold (ex. three), a household is classified as energy poor. A weighted average of the population that is poor by each category is calculated. The index is the product of the incidence of energy poverty and a quantification of its intensity (Nussbaumer, Bazilian, and Modi, 2012). This index gives a comprehensive understanding of national household energy poverty in a single number, but excludes energy for productive uses and energy use beyond the household.

Mirza and Szirmai (2010) developed the Energy Poverty Index (EPI) which is the average of the energy shortfall, a percentage of the minimum basic level of energy consumption, and a measure of the inconvenience of energy. The inconvenience measure includes the frequency of buying or collecting a source of energy, distance from household travelled, means of transport used, household member's involvement in energy acquisition, time spent on energy collection per week, household health, and children's involvement in energy collection. The inconvenience of each fuel is determined following the methodology of the Human Development Index (UNDP, 1990). These inconveniences by fuel are aggregated in a weighted average based on percentage of that fuel in household energy consumption. In comparison to the EDI and MEPI, the EPI is very sensitive to energy poverty in cooking fuels. Households with electricity but without LPG remain energy poor because of the opportunity costs associated with gathering traditional biomass. This metric captures the importance of the usability of energy beyond access, but is focused on narrow household energy needs.

Composite metrics

Composite metrics combine different types of information about energy poverty into a single number. Example composite metrics include:

- Energy Development Index (EDI)
- Multidimensional Energy Poverty Index (MEPI
- Energy Poverty Index (EPI)

These metrics do not necessarily avoid shortcomings of the four approaches discussed, and can be difficult to interpret.

In an evaluation of composite energy poverty metrics, Nussbaumer, Bazilian, and Modi (2012) explain that the methodological soundness of composite indices is questionable, but that if developed properly these metrics can be useful. Indeed, composite metrics can combine any number of the four approaches to measuring energy poverty into a single number that is easy to compare across time and across nations. While the composite indexes helpfully reduce many facets of energy poverty into a single number, the justification of what energy uses were included, the relative importance among them, and the threshold that defines the energy poor are arbitrarily set by the authors and then obscured through the reduction to an index. To date, no composite metric has garnered consensus.

Conclusion

We have looked at energy poverty metrics according to whether the definition of energy poverty is based on 1) a binary description of the access a population has to electricity and modern cooking fuels, 2) energy consumption inputs measured in units of energy or currency, 3) the outcomes of energy use, and 4) the quality of energy delivered. All of the metrics are striving to capture the extent of energy services, and in doing so, they tradeoff simplicity, comprehensiveness, and accuracy. A simple metric can be clearly communicated and can facilitate consistent data collection and processing. A comprehensive metric goes beyond simple household energy uses by including energy used in the community and the economy that contribute to human welfare and economic growth. The accuracy of a metric should be judged on its approximation of energy services.

Using a simple binary measure of energy access is easy to understand and the data is available, but it is empirically and theoretically a poor proxy for energy poverty. Quantifying energy poverty based on energy consumption is an approach that cleanly captures all types of energy use in a single metric, but it is sensitive to many arbitrary, unstable assumptions. Metrics that have defined energy poverty based on the outcomes of energy consumption in terms of health impacts, environmental impacts, opportunity costs, or the absence of choice are attractive for their focus on the conditions of poverty, but data collection is burdensome and outcomes generally cannot be combined into a single metric.

Evaluating the quality of energy for different types of energy use is currently the best approximation of access to energy services. While considering each category of energy use (electricity, cooking, productive uses, etc) independently provides clear information, it will be cumbersome to make comparisons on the basis of several indices at one time. However, trying to reduce several indices into a single number by averaging measures such as cooking access, productive use, and hospital electricity is not transparent and may be misleading. While composite metrics are a conceptually attractive way to combine the strengths of each of the four measurement categories, doing so may produce a metric that is neither meaningful nor easy to interpret.

Bensch (2013) contrasts several metrics reviewed here with a common data set to test the consistency between the metrics and their sensitivities to small changes in the arbitrary decisions made by the developers. Of the metrics tested by Bensch (2013), each identified the energy poor differently. This result accentuates the policy implications of metric design. Different understanding about who the energy poor are and why they are poor will lead to different policy decisions and ultimately different infrastructure choices.

Additional basic understanding is needed to advance energy poverty metric development. Without a theoretical reference for an energy poverty line, all the methods described are subject to the arbitrary assumptions and decisions of scholars. Metric development would benefit from consensus on the basket of energy services that are basic needs and the poverty line for each of those energy services. Additional work would then be needed to provide the intellectual foundation for integrating different types of energy services into a single metric. More empirical work is needed to demonstrate the relative development benefits of delivering different types of energy services (ex. lighting, cooking, productive uses, community uses, industrial uses) and whether the relative benefits change with development.

In the absence of a single metric, practitioners must critically evaluate existing metrics and make a selection based on their particular aims. If your purpose is education or communication, simplicity and transparency may be more important than accuracy. If your purpose is cross-country target setting and progress checking then a more comprehensive measure of energy poverty would be desirable. Describing and diagnosing which households or regions are energy poor is most important for national policy design and management, so a cumbersome metric may be worth the effort. Targeted investment decisions may trade off comprehensiveness and transparency for analytic rigor and consideration of data availability. Metrics users must be cognizant of the blind spots and assumptions in existing energy poverty metrics to understand how different energy technologies are reflected and how well increases in a metric will predict real reductions in energy poverty.

Conclusion

Tradeoffs between simplicity, comprehensiveness, and accuracy are inherent in energy poverty metric design. Consider your aims to decide the appropriate balance among:

- Simplicity - for clear communication and consistent data collection
- Comprehensiveness - capturing basic energy services within and outside the household
- Accuracy - reflecting the usability of energy to deliver energy services

Research Agenda

This review highlighted many outstanding questions about creating and using metrics for energy poverty. Further research could address the questions below, and many others.

- In achieving development goals, what is the relative importance of energy use among energy in households, community spaces, and for productive uses in small enterprise and industry?
- In achieving development goals, what is the relative importance of types of household energy services: lighting, cooking, cooling, agricultural processing, etc.?
- How might advanced data techniques be used to identify the energy poverty line or the basket of basic energy services?
- Which attributes of energy quality have the biggest potential for improvement by expanded use of natural gas? How might that change in urban and rural communities?
- Which attributes of energy quality have the biggest impact on poverty reduction? How might that change in urban and rural communities?
- How might various energy poverty metrics reflect expanded use of natural gas?

Recommended Reading

For more about energy services and measures of energy access and energy services:

- Practical Action (2014)
- Bhatia and Angelou (2015)
- Pachauri (2011)
- Bazilian and Pielke (2013)

Other reviews of energy poverty metrics can be found in the following articles:

- Groh, Pachauri, and Narasimha (2016)
- Bensch (2013)
- Nussbaumer, Bazilian, and Modi (2012)
- Pachauri and Spreng (2011)

References

Advisory Group on Energy and Climate Change (2010). *Energy for a Sustainable Future*. Tech. rep. New York: United Nations, pp. 1–24.

Arnold, J. E. M., G. Kohlin, and R. Persson (2006). "Woodfuels, livelihoods, and policy interventions: Changing Perspectives". In: *World Development* 34.3, pp. 596–611.

Barnes, D. F., S. R. Khandker, and H. A. Samad (2011). "Energy poverty in rural Bangladesh". In: *Energy Policy* 39.2, pp. 894–904.

Barnes, D. F., K. Krutilla, and W. Hyde (2004). *The Urban Household Energy Transition: Energy, Poverty, and the Environment in the Developing World*. Tech. rep. Energy Sector Management Assistance Program, World Bank Group, pp. 1–115.

Bates, L. et al. (2009). *Expanding Energy Access in Developing Countries: The Role of Mechanical Power*. Tech. rep. Practical Action and the United Nations Development Programme, p. 56.

Bazilian, M. and R. Pielke (2013). "Making Energy Access Meaningful". In: *Issues in Science and Technology* Summer 201, pp. 74–79.

Bensch, G. (2013). *An Empirical Comparison of Energy Poverty Indices for Sub-Saharan Countries*. Tech. rep. Ruhr Economic Papers #464, pp. 1–53.

Bhatia, M. and N. Angelou (2015). *Beyond Connections Energy Access Redefined*. Tech. rep. Washington, D.C.: Energy Sector Management Assistance Program, World Bank Group, pp. 1–244.

Brew-Hammond, A. and F. Kemausuor (2009). "Energy for all in Africa - to be or not to be?!" In: *Current Opinion in Environmental Sustainability* 1, pp. 83–88.

Craine, S., E. Mills, and J. Guay (2014). *Clean Energy Services for All: Financing Universal Electrification*. Tech. rep. June 2014. Sierra Club, pp. 1–14.

Culver, L. (2017). *A Framework for Understanding the Role for Natural Gas in Reducing Energy Poverty*. Tech. rep. Stanford, CA: Natural Gas Initiative, Stanford University, pp. 1–39.

Durix, L., H. Carlsson Rex, and V. Mendizabal (2016). "Contextual Design and Promotion of Clean Biomass Stoves : The Case of the Indonesia Clean Stove Initiative". In: *Livewire* 64, pp. 1–12.

Dutt, G. S. and N. H. Ravindranath (1993). *Bioenergy: Direct applications in cooking*. Washington, DC: Island Press, pp. 1–1177.

Ferreira, F. H. G. et al. (2015). *A global count of the extreme poor in 2012: data issues, methodology and initial results*. Tech. rep. World Bank Group, pp. 1–68.

Foster, V., J.-P. Tre, and Q. Wodon (2000). *Energy prices, energy efficiency, and fuel poverty*. Tech. rep. September 2000. World Bank Group, pp. 1–7.

Goldemberg, J., T. B. Johansson, et al. (1987). *Energy for Development*. Tech. rep. Washington, D.C.: World Resources Institute, pp. 1–73.

Goldemberg, J. and T. B. Johansson (1995). *Energy as an instrument for socio-economic development*. Tech. rep. New York: United Nations Development Programme, pp. 1–80.

Groh, S., S. Pachauri, and R. Narasimha (2016). "What are we measuring? An empirical analysis of household electricity access metrics in rural Bangladesh". In: *Energy for Sustainable Development* 30.9, pp. 21–31.

Hammond, A. et al. (2007). *The next 4 billion: Market size and business strategy at the base of the pyramid*. Tech. rep. Washington, D.C.: World Resources Institute and International Finance Corporation, pp. 1–149.

Hiemstra-van der Horst, G. and A. J. Hovorka (2008). “Reassessing the 'energy ladder': Household energy use in Maun, Botswana”. In: *Energy Policy* 36.9, pp. 3333–3344.

IEA (2011). *Energy for All: Financing access for the poor*. Tech. rep. Paris: International Energy Agency, pp. 1–52.

— (2015). *World Energy Outlook 2015: Methodology for Energy Access Analysis*. Tech. rep. Paris: International Energy Agency, pp. 1–8.

— (2016). *WEO Energy Access Database*. Tech. rep. International Energy Agency.

Khandker, S. R., D. F. Barnes, and H. A. Samad (2012). “Are the energy poor also income poor? Evidence from India”. In: *Energy Policy* 47, pp. 1–12.

Leach, G. (1992). “The energy transition”. In: *Energy Policy* 20.2, pp. 116–123.

Masera, O. R., B. D. Saatkamp, and D. M. Kammen (2000). “From linear fuel switching to multiple cooking strategies: A critique and alternative to the energy ladder model”. In: *World Development* 28.12, pp. 2083–2103.

Masud, J., D. Sharan, and B. N. Lohani (2007). *Energy For All: Addressing the Energy, Environment, and Poverty Nexus in Asia*. Tech. rep. Asian Development Bank, pp. 1–123.

Mirza, B. and A. Szirmai (2010). *Towards a New Measurement of Energy Poverty: A Cross-Community Analysis of Rural Pakistan*. Tech. rep. United Nations University, pp. 1–41.

Modi, V. et al. (2005). *Energy Services for the Millennium Development Goals*. Tech. rep. Millenium Project, United Nations Development Programme, World Bank Group, Energy Sector Management Assistance Programme, pp. 1–116.

Nussbaumer, P., M. Bazilian, and V. Modi (2012). “Measuring energy poverty: Focusing on what matters”. In: *Renewable and Sustainable Energy Reviews* 16.1, pp. 231–243.

Pachauri, S., A. Mueller, et al. (2004). “On measuring energy poverty in Indian households”. In: *World Development* 32.12, pp. 2083–2104.

Pachauri, S. (2011). “Reaching an international consensus on defining modern energy access”. In: *Current Opinion in Environmental Sustainability* 3.4, pp. 235–240.

Pachauri, S. and D. Spreng (2004). “Energy use and energy access in relation to poverty”. In: *Economic and Political Weekly* 39.3, pp. 271–278.

— (2011). “Measuring and monitoring energy poverty”. In: *Energy Policy* 39.12, pp. 7497–7504.

Practical Action (2014). *Poor People's Energy Outlook 2014*. Tech. rep. Practical Action, pp. 1–74.
— (2016). *Poor People's Energy Outlook 2016*. Tech. rep. Rugby, UK: Practical Action, pp. 1–90.
Reddy, B. S. (2003). "Overcoming the energy efficiency gap in India's household sector". In: *Energy Policy* 31, pp. 1117–1127.
Sathaye, J. and S. Tyler (1991). "Transitions in Household Energy Use in Urban China, India, the Philippines, Thailand, and Hong Kong". In: *Annual Review of Energy and the Environment* 16, pp. 295–335.
Sen, A. (1999). *Development as freedom*. Oxford University Press, pp. 1–384.
UNDP (1990). *World Development Report*. Tech. rep. New York: United Nations Development Programme.
UNDP and WHO (2009). *The Energy Access Situation in Developing Countries*. Tech. rep. New York: United National Development Programme and the World Health Organization, pp. 1–142.
UNGA (2015). *Resolution adopted by the General Assembly on 25 September 2015*. Tech. rep. New York: United Nations General Assemby, pp. 1–35.
Van Der Kroon, B., R. Brouwer, and P. J. H. Van Beukering (2013). "The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis". In: *Renewable and Sustainable Energy Reviews* 20, pp. 504–513.
World Bank (2016). *World Development Indicators*.
World DataBank (2012). *Sustainable Energy for All*.