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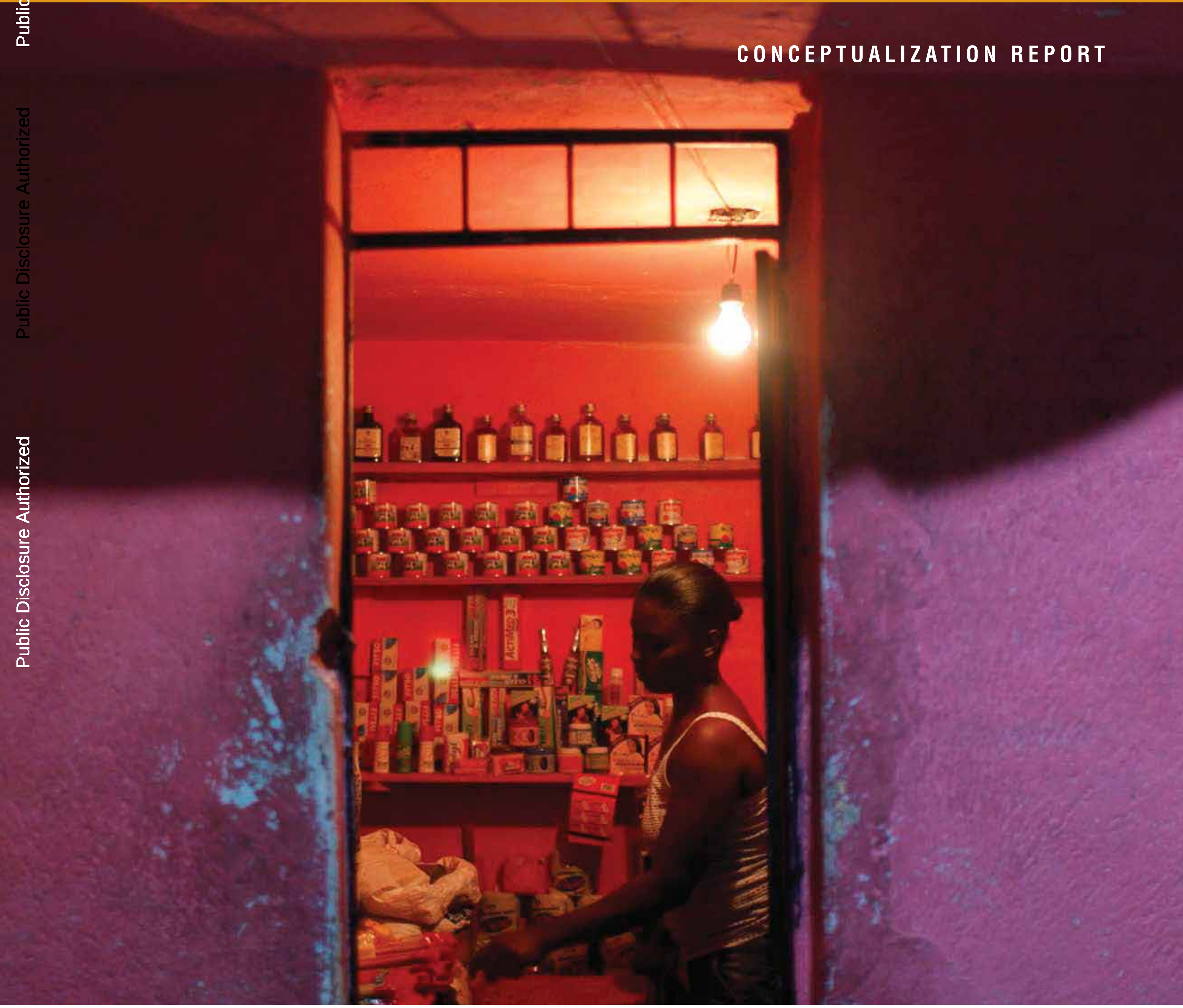
Energy Sector Management Assistance Program

SUSTAINABLE
ENERGY FOR ALL

TECHNICAL REPORT 008/15

BEYOND CONNECTIONS
Energy Access Redefined



CONCEPTUALIZATION REPORT

ESMAP MISSION

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Energy Sector Management Assistance Program | The World Bank


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FOREWORD

Access to energy is vital to economic, social and human development. To be meaningful for households, productive enterprises and community facilities, the energy supply supporting that access must have a number of attributes: it must be adequate in quantity, available when needed, of good quality, reliable, convenient, affordable, legal, healthy, and safe.

Access to this sort of energy changes lives. It can reduce human effort, enhance comfort and enable telecommunications, education and better heathcare, while also extending useful waking hours. It can reduce the time spent on the drudgery of fuel gathering, benefiting women and girls in particular, and curb the health-damaging impacts from smoky cookstoves.

Access to a reliable and quality energy supply can also boost productivity and economic activity which can in turn create opportunities for jobs and incomes. It can facilitate the delivery of education, health services, e-governance, and improve public safety on the streets. This is why universal access to energy by 2030 is one of the three goals of the Sustainable Energy for All (SE4All) initiative.

This new report from the SE4All Knowledge Hub—*Beyond Connections: Energy Access Redefined*—conceptualizes a new multi-tier framework for defining and measuring access to energy. Binary metrics such as whether a household has an electricity connection, and whether a household cooks with non-solid fuels don't help us understand the phenomenon of expanding energy access and how it impacts socioeconomic development. This report heralds a new definition and metric of energy access that is broader—it covers energy for households, productive engagements and community facilities, and focuses on the quality of energy being accessed.

How does that alter our conception of the challenge of universal energy access? *Beyond Connections* shows that the access challenge is not just limited to the 1.1 billion households that lack electricity connections. It is as much a challenge for the hundreds of millions of households around the world with poor and unreliable electricity supply. The goal of universal access must also cover energy for household cooking and heating and for productive engagements and community facilities.

While our understanding of the universal energy access challenge has expanded, so has our understanding of what's needed to meet this challenge. There are many ways to expand energy access—from electricity grid to off-grid solutions like solar lanterns, solar home systems and mini-grids, and improved cookstoves and clean fuels. Equally, improvements in supply through generation, transmission and distribution strengthening, and demand management through energy efficiency measures all contribute to energy access.

The multi-tier framework underlying *Beyond Connections* will prove to be a tool for measuring and goal-setting, investment prioritization, and tracking progress. It will help us capture the multiple modes of delivering energy access from grid to off-grid, including the wide range of cooking stoves and fuels. It will also help reflect the contributions of various programs, agencies, and national governments toward achieving the SE4All goals.

In a follow-up report, we will learn methodologies for applying this framework to projects, programs and country contexts. Experience from pilots in a number of countries will help demonstrate the methodologies in action. Eventually, the rollout of a global multi-tier survey will give us much finer detail on the quality of energy access across all countries.

Beyond Connections changes the paradigm of measuring energy access. We commend this report as another vital tool in our quest for sustainable energy for all.

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ABBREVIATIONS

AC	alternating current
ACCES	African Clean Cooking Energy Solutions
AGECC	Advisory Group on Energy and Climate Change
ALRI	acute lower respiratory infection
BLEENS	biogas, liquefied petroleum gas, electricity, ethanol, natural gas, and solar
BLEN	biogas, liquefied petroleum gas, ethanol, and natural gas
CCT	controlled cooking test
CFL	compact fluorescent lamp
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
COPD	chronic obstructive pulmonary disease
CVD	cardiovascular disease
DHS	Demographic and Health Survey
EC	European Commission
EDI	Energy Development Index
EEA	European Environmental Agency
EFA	Education for All
EISD	Energy Indicators for Sustainable Development
EnDev	Energizing Development Program
ERC	energy results chain
ERT	emission rate target
ESI	Energy Supply Index
ESMAP	Energy Sector Management Assistance Programme
EUEI	European Union Energy Initiative
FRES	Foundation Rural Energy Services
GDG	Guidelines Development Group
GDP	gross domestic product
GHG	greenhouse gas
GIS	geographic information system
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GTF	Global Tracking Framework
H&A	human and animal
HPCO	high-power carbon monoxide
HPTE	high-power thermal efficiency
IAEA	International Atomic Energy Agency
IAQ	indoor air quality
ICT	information and communication technology
IEA	International Energy Agency
IER	integrated exposure response
IHDS	India Human Development Survey
IMF	International Monetary Fund
ISO	International Organization for Standardization
IWA	International Workshop Agreement
KBT	kitchen-based test
kgoe	kilograms of oil equivalent
kJ	kilojoule
kW	kilowatt
kWh	kilowatt hour
LED	light-emitting diode
lmhr	lumen-hour
LPCO	low-power carbon monoxide
LPG	liquefied petroleum gas
LPSC	low-power specific consumption
LSMS	Living Standards Measurement Survey
LT	low tension
LV	low voltage
MDG	Millennium Development Goal
MEPI	Multidimensional Energy Poverty Index
NGO	nongovernmental organization
NO_x	nitrogen oxides
PCIA	Partnership for Clean Indoor Air
PM	particulate matter
PPEO	Poor People's Energy Outlook
QA	quality assurance
RME	renewable motive energy
RPM	revolutions per minute
RTE	renewable thermal energy
SAIDI	system average interruption duration index
SAIFI	system average interruption frequency index
SARA	Service Availability and Readiness Assessment
SCADA	supervisory control and data acquisition
SDG	Sustainable Development Goal
SE4All	Sustainable Energy for All
SHS	solar home system
SO_x	sulfur oxides
SUM	stove-use monitor
T&D	transmission and distribution
TEA	Total Energy Access
ToD	time of day
UAE	United Arab Emirates
UN	United Nations
UNDATA	United Nations Statistic Database
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
USAID	U.S. Agency for International Development
USDOE	U.S. Department of Energy
WBT	water-boiling test
WHO	World Health Organization

All currency in United States dollars (USD or US$), unless otherwise indicated.

TERMINOLOGY

Access to energy services: The ability of an end user to utilize energy services (such as lighting, phone charging, cooking, air circulation, refrigeration, air conditioning, heating, communication, entertainment, computation, motive power, etc.) that require an energy appliance and suitable energy supply.

Access to energy supply: The ability of an end user to utilize an energy supply that can be used for desired energy services.

Affordability of energy supply: An attribute of energy supply that implies ability of the end user to pay for energy needed for a defined package of energy consumption. Affordability encompasses one-time connection charges, energy charges, capacity charges, maintenance charges, and replacement charges. The affordability of energy access is a function of the defined package, the price of energy (including all the above-mentioned charges), and the user's income level. Energy supply is considered to be affordable when the cost of energy for a defined package of energy consumption does not exceed a normative percentage of the household income.

Appliances (also called end-use devices): Equipment, powered by electricity or other energy sources, that accomplish some function or task to deliver an energy service (e.g., light bulb, electric fan, cookstove, refrigerator, radio, washing machine, x-ray machine, drilling machine, etc.).

Attributes of energy supply: Characteristics of energy supply that influence its usability for various energy services. Eight key attributes have been selected for the purpose of defining and measuring energy access: capacity, affordability, availability, reliability, quality, health and safety, legality, and convenience.

Availability of energy supply: An attribute of energy supply that implies ability to draw energy when needed for use of energy services. Availability is measured as the time and duration of supply. Availability of electricity can be measured as the time during the day (and night) when electricity is available, or the total number of hours when electricity is available each day. Fuel availability can be measured as number of days per year during which the fuel is available, or whether a secondary fuel is used to address lack of availability of a preferred fuel. Availability of electricity supply is often more important during the evening hours, especially for lighting needs. Therefore, evening supply may be sometimes treated as a separate indicator of availability of electricity supply.

BLEENS-equivalent cooking solutions: Cooking solutions that deliver household air pollution performance similar to BLEENS (biogas, LPG, electricity, ethanol, natural gas, and solar) solutions are called BLEENS-equivalent solutions.

BLEENS cooking solutions: Biogas, LPG, electricity, ethanol, natural gas, and solar cookers are cooking solutions that typically deliver high performance in terms of reducing household air pollution—often (although not always) regardless of the type of cookstove used—and are collectively called BLEENS. These cooking solutions are often considered "modern" or "clean" solutions.

Capacity of energy supply: An attribute of energy supply that relates to the quantity of energy made available to the user. It can be measured as a combination of total energy available over a period of time and the maximum power (rate of energy delivery) that can be used. For example, for electricity, capacity can be measured as the maximum power available (in watts) or the total energy available each day (in watthours). Similarly, capacity of fuel-based energy supply can be measured as the quantity of fuel available each day.

Clean cookstoves: Cookstoves that produce significantly less household air pollution than traditional three-stone open-fire stoves and meet a specified emission standard are often called clean cookstoves. Clean cookstoves may also be called advanced cookstoves.

Convenience of energy supply: An attribute of energy supply that relates to the time and effort involved in securing, processing, and using the energy source (such as fuels).

Efficient cookstoves: Cookstoves that use less energy to deliver a given amount of usable heat compared to traditional three-stone open-fire stoves and meet a specified efficiency standard. Efficient cookstoves may also be called improved cookstoves.

End user: The ultimate consumer who requires energy for desired energy services at any locale—a household, productive enterprise, or community institution.

Energy access: The ability of the end user to utilize energy supply that is usable for the desired energy services. Improvement in energy access is achieved through enhancement of the usability of the energy supply with improvement in attributes. Energy access can be defined either inclusive or exclusive of use of appliances. When defined inclusive of appliances, it is called access to energy services, and when defined exclusive of appliances, it is called access to energy supply.

Energy applications: The set of five categories—lighting, information and communication technology (ICT) and entertainment, motive power, product and water heating, and space heating—into which energy services have been codified in order to allow energy access to be measured in terms of its ability to support these applications.

Energy carrier or energy source: A substance or means that can be used to produce mechanical work or heat or to operate chemical or physical processes. Energy sources (or energy carriers) include fuels and renewable energy sources that are harnessed directly as well as grids and mini-grids powered by fossil fuels and renewable energy sources. They provide energy supplies that are used by end users to utilize energy services.

Energy poverty: The state of being deprived of certain energy services or not being able to use them in a healthy, convenient, and efficient manner, resulting in a level of energy consumption that is insufficient to support social and economic development. Although energy poverty can be measured using binary indicators (by specifying a minimum package of energy services or minimum amount of energy use), it is in reality a continuous variable encompassing deprivation on a range of energy services.

Energy results chain: The series of causal linkages between energy investments and their socioeconomic development impacts. It entails a seven-step causality chain (inputs, intermediate outputs, outputs, intermediate outcomes, outcomes, intermediate impacts, and impacts) with reducing attribution of results to the energy intervention due to external factors increasingly coming into play at each step.

Energy services: Amenities that are delivered through the use of energy when converted into light, sound, heat (or cold), motion, signal, etc. Energy services encompass lighting, cooking, air circulation, refrigeration, air conditioning, heating, communication, entertainment, computation, motive power, etc.

Energy supply: The provision of energy regardless of the availability of end-use equipment.

Fuels: Any material that stores energy that can be extracted through a combustion process to perform mechanical or heating work. Fuels are often classified in three types: solid (wood, coal, dung, etc.), liquid (diesel, kerosene, LPG, etc.), and gaseous (natural gas, biogas, etc.).

Health attribute: An attribute of energy supply that relates to the risk of adverse health consequences from the use of energy. This attribute is particularly important for fuel-based energy for cooking and heating.

Improved cookstoves: Cookstoves that use less energy to deliver a given amount of usable heat and produce less indoor and overall air pollution compared to traditional three-stone open-fire stoves, but may or may not meet any specified emission or efficiency standards.

Legality of energy supply: An attribute of energy supply implying that in using the energy supply, the end user is not indulging in any activity proscribed by law.

Locales of energy use: The broad locations of end use of energy for availing energy services. Locales of energy use include households, community institutions, and productive enterprises.

Motive power: An application of energy that pertains to delivery of linear or rotatory motion as the output. Motive power typically requires electrical motors or engines as the appliances for converting electricity or fuels, respectively, into motion.

Quality of energy supply: An attribute of energy supply that implies correct level and stability of voltage (and frequency) in case of electricity, and absence of adulteration (including excessive moisture) in case of fuels so that desired combustion characteristics can be achieved.

Reliability of energy supply: An attribute of energy supply that entails absence of unpredictable outages of energy supply. It is measured by the frequency and length of unpredictable outages.

Safety: An attribute of energy supply that relates to the risk of injury from the energy supply.

Stacking: The use of multiple energy solutions (such as different fuels) to meet a single energy need.

Usability of energy supply: The potential to use energy supply when required for desired energy services. Usability can be enhanced by improving the attributes of energy supply, such as capacity, availability, reliability, affordability, safety, convenience, etc.

EXECUTIVE SUMMARY

Access to energy is a key enabler of socioeconomic development. Energy is needed for multifarious applications across households, productive uses, and community infrastructure. "Universal access to modern energy by 2030" has been proposed as one of the three key pillars of the Sustainable Energy for All (SE4All) program, an initiative co-chaired by the United Nations (UN) Secretary General and the World Bank President. Achieving this goal would require a wide range of interventions by various agencies. The success of such interventions depends in part on the ability to assess the level of access to energy—both for planning and investment, and, later, for tracking progress. Therefore, an approach that captures the contribution of all of these efforts, as well as encompasses quantity and quality aspects of improvements, would be required. SE4All's *Global Tracking Framework* (GTF) 2013 report introduced multi-tier frameworks for measuring energy access. It identified tasks for improved measurement of energy access over the medium term, including further development of the multi-tier frameworks. This report is a culmination of the multi-agency effort on developing multi-tier frameworks to fulfill the mandate suggested by the GTF 2013 report.

CONCEPTUAL BACKGROUND

The concept of access to energy does not lend itself to an easy definition. In the past, access to energy usually was considered synonymous with household access to electricity. It has been defined variously as a household electricity connection, an electric pole in the village, and an electric bulb in the house. However, these definitions do not take into account the quantity and quality of electricity provided. There are many instances where connected households receive electricity at low voltage, for limited hours, during odd hours of the day (or night), and with poor reliability. Further, this approach does not address the questions of affordability of energy and legality of connection. A definition of energy access based on household electricity connection also ignores energy for cooking and heating needs, as well as for productive engagements and community facilities.

To develop a comprehensive definition and measurement approach for energy access, the key concepts underlying this phenomenon must be examined. Some of these key concepts are:

1. **Access to energy can mean many things.** The distinction between *access to energy supply, access to energy services,* and *actual use of energy* must be clearly reflected in the definition of energy access. The definition should also capture the phenomenon of access achieved through stacking of multiple energy solutions.
2. **Socioeconomic development is the primary objective of expanding energy access.** The services that energy provides are critical ingredients for socioeconomic development, including the achievement of Sustainable Development Goals (SDGs).
3. **Access to energy is needed at multiple locales.** Socioeconomic development requires increased use of energy services across households, productive engagements, and

community facilities. At the household level, access to energy encompasses electricity as well as cooking and heating solutions. Access to energy for productive engagements increases income, productivity, and employment, while delivering higher quality and lower priced goods. Access to energy for community infrastructure (such as schools, health facilities, and government offices) can lead to substantial improvements in service delivery, human capital, and governance.

4. **Access pertains to *usability of supply* rather than *actual use of energy*.** The usability of energy is the potential to use the available energy supply when required for the applications that a user needs or wants. The energy provided should have all the necessary attributes for use in these applications. The actual use of energy may be constrained by exogenous factors despite an adequate access to energy supplies. Further, after adequate access to an energy supply is achieved, the actual use of energy generally increases gradually over time. To get a complete picture of energy access, both usability of energy supply and actual use of energy should be measured.
5. **Attributes of the energy supply affect the usability of energy for desired services.** The attributes of energy include capacity (adequacy), availability, reliability, affordability, quality, legality, health impact, safety, and convenience, among others. The definition and measurement of access to energy should focus not only on the number of users benefitting from improved energy access, but also the nature and degree of that improvement across various attributes.
6. **Improvement in energy access refers to a continuum of improvements in attributes of energy supply**. Improvement in energy access is not a single-step transition from lack of access to availability of access. Instead, it is a continuum of increasing levels of energy attributes. This forms the basis of a multi-tier conceptualization of energy access to reflect the continuum versus a binary conceptualization.
7. **For standalone energy solutions, the collective attributes of the energy supply and conversion device are taken into account.** Standalone devices such as solar lanterns and cookstoves deliver a complete energy service (lighting or cooking) rather than just energy supply. In such a case, the collective attributes of the energy supply and the conversion device should be taken into account when examining energy access.
8. **All interventions in the energy sector can contribute to improved access by moving users to higher levels of attributes.** Such interventions not only include new household electricity connections and delivery of clean cookstoves, but other projects such as power generation, transmission, gas pipelines, liquefied petroleum gas (LPG) bottling, mini-grid systems, solar home systems, biogas projects, fuel-wood plantations, and briquette manufacture, among others. In addition, soft aspects such as policy formulation, credit mechanisms, market structuring, regulatory reforms, institutional capacity development, consumer services enhancement, loss-reduction measures, efficiency improvement, and other aspects may also contribute to enhanced access to energy.

OVERARCHING FRAMEWORK

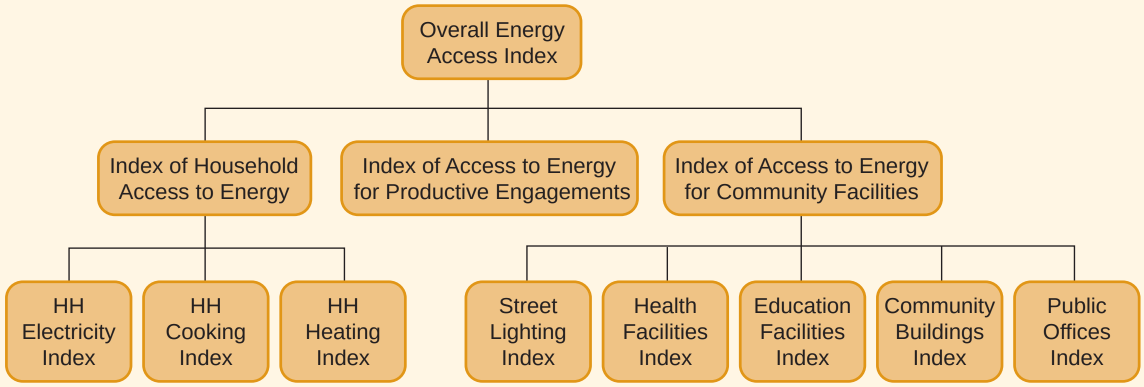
The broad areas of energy use—(i) households, (ii) productive engagements, and (iii) community facilities—are termed as the *locales of energy access.*

For the household locale, the proposed multi-tier framework examines (i) access to electricity, (ii) access to energy for cooking solutions, and (iii) access to energy for space-heating solutions as three separate sub-locales. Separate multi-tier frameworks are defined for each of these components. Separate indices of energy access are calculated for each of the components, defined as the average tier rating across households in the given area adjusted to a scale of 100. The overall index of household access to energy may be calculated as the average of the three sub-locale indices (Figure ES.1). This overall index involves an apples-to-oranges aggregation across sub-locales and is less meaningful than the individual indices.

For the productive engagements locale, the proposed multi-tier framework examines the energy supply vis-à-vis critical energy applications. Measuring energy needs for productive uses is a complex challenge. There are multiple types of productive enterprises, encompassing different scales of operation, varying degrees of mechanization, a multitude of energy applications, and a variety of energy supplies. Further, it is not possible to set norms of energy needs for different enterprises or applications to measure energy access deficits. Also, lack of adequate energy access may not be the only constraint to functioning and expansion of the productive enterprise, which may be constrained by raw materials, capital, land, skilled manpower, markets, transportation, government licenses, or other inputs. Specifying minimum energy needs of different types of enterprises would be a very

FIGURE ES.1

Hierarchy of Energy Access Indices



Note | HH = household

cumbersome approach. Also, it is important to capture energy needs of small and micro enterprises and productive engagements in the informal sector, which are often not reflected in enterprise surveys that tend to focus on large enterprises.

To address these challenges, an approach based on surveys of individuals for their key productive engagements and energy needs is proposed. Under this approach, energy access for productive engagements is aggregated across individuals, thus eliminating the need for reflecting the relative scale of operations of different enterprises. Although this approach may suffer from less-accurate reporting about energy needs of individuals working in larger enterprises, it would be better suited for most countries where an overwhelmingly high proportion of people work in informal or micro- and small-scale enterprises. An index of access to energy for productive uses for any given geographical area can be calculated as the average tier level across all individual respondents in that area, adjusted to a scale of 100. In addition, sub-indices can also be calculated for various productive activities (e.g., small shops, artisans, or agriculture) by taking the average of tier levels across respondents engaged in those activities.

For the community facilities locale, five sub-locales need to be considered—(i) health facilities, (ii) educational facilities, (iii) street lighting, (iv) government buildings, and (v) public buildings. Access to energy for each sub-locale can be determined based on surveys of either the users of the facility or the providers of the facility. The former requires a survey of households, whereas the latter requires a survey of the relevant community institutions. Whereas the former can only yield subjective and limited information, more detailed information can be obtained from the latter. Multi-tier frameworks are defined for each of the sub-locales, and separate indices are calculated based on the average tier rating for each sub-locale, adjusted to a scale of 100. The overall index of access to energy for community facilities is calculated as the average of indices across the five sub-locales.

For any geographical area, an overarching index of access to energy can be calculated as the average of the indices across the three locales—households, productive uses, and community facilities.

Household Locale

Household Access to Electricity

Binary metrics for tracking access to household electricity fail to capture the multifaceted nature of access to electricity. Binary measurement of electricity access is usually based on whether a household has a grid connection. However, poor electricity supply from the grid may limit its usefulness. Use of electricity may also be constrained by its affordability. Illegal connections may cause significant financial losses to the utility, while also increasing the risk of accidents. Further, electricity access through off-grid standalone and mini-grid solutions needs to be tracked in addition to grid connections, according suitable weights based on the amount and quality of electricity delivered.

Access to electricity is measured based on technology-neutral multi-tiered standards where successive thresholds for supply attributes allow increased use of electricity appliances. The key attributes relevant for household electricity are: (i) capacity, (ii) duration (including daily supply and evening supply), (iii) reliability, (iv) quality, (v) affordability, (vi) legality, and (vii) health and safety. The multi-tier standards for household access to electricity supply are summarized in Table ES.1.

A separate multi-tier framework can be defined for access to electricity services. A gradually improving electricity supply enables increased and improved access to electricity services. Therefore, a second matrix measuring access to household electricity services mirrors the supply matrix, based on the type of appliances used in the household (Table ES.2). It is possible for a household to obtain different tier ratings across access to electricity supply and access to electricity services—reflecting either availability of appliances despite poor supply or inability to afford appliances (or high electricity consumption) despite adequate supply.

A third multi-tier framework is defined for electricity consumption. This framework is closely aligned with tiers of electricity services. The thresholds for annual consumption level at each tier are based on the indicative hours of use for select appliances. A consumption-based metric cannot accurately reflect the diversity of appliances actually used by the household, nor appropriately account for energy efficiency. Also, tiers of consumption are distinct from tiers of energy services, which are different still from tiers of energy supply (Table ES.3).

Access to lighting using stand-alone devices requires separate attention. Many of these devices do not meet the Tier 1 threshold, but may yet contribute significantly to improved access. This is discussed separately in the next section.

Data for populating the multi-tier frameworks can be obtained through demand-side and supply-side measurements. Demand-side measurement involves collecting data from electricity users through household energy surveys and the use of sensor-based instrumentation. Supply-side measurement can use utility or project and program data. However, in the developing country context, utility data may suffer from several deficiencies.

Results can be compiled and analyzed to produce an energy access diagnostic. Data can be dissected to analyze different attributes of electricity supply for a disaggregate analysis. The lowest tier among all attributes determines the overall access to electricity tier for the household. A single-number index representing the level of access to household electricity supply may be compiled based on the multi-tier matrix. Respective indices of access to electricity supply, services, or consumption can be defined as the average tier rating across all households in the given area. The indices and disaggregated data may be compared across countries or any geographic area (subnational, regional, and worldwide). Similarly, the indices and data may be compared over time to track progress.

TABLE ES.1

Multi-tier Matrix for Measuring Access to Household Electricity Supply

			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	1. Peak Capacity	Power capacity ratings[28] (in W or daily Wh)		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
				Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
		OR Services		Lighting of 1,000 lmhr/day	Electrical lighting, air circulation, television, and phone charging are possible			
	2. Availability (Duration)	Hours per day		Min 4 hrs	Min 4 hrs	Min 8 hrs	Min 16 hrs	Min 23 hrs
		Hours per evening		Min 1 hr	Min 2 hrs	Min 3 hrs	Min 4 hrs	Min 4 hrs
	3. Reliability						Max 14 disruptions per week	Max 3 disruptions per week of total duration <2 hrs
	4. Quality						Voltage problems do not affect the use of desired appliances	
	5. Affordability					Cost of a standard consumption package of 365 kWh/year < 5% of household income		
	6. Legality						Bill is paid to the utility, pre-paid card seller, or authorized representative	
	7. Health & Safety						Absence of past accidents and perception of high risk in the future	

TABLE ES.2

Multi-tier Matrix for Measuring Access to Household Electricity Services

	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Tier criteria		Task lighting AND Phone charging	General lighting AND Phone Charging AND Television AND Fan (if needed)	Tier 2 AND Any medium-power appliances	Tier 3 AND Any high-power appliances	Tier 2 AND Any very high-power appliances

TABLE ES.3

Multi-tier Matrix for Measuring Household Electricity Consumption

	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Annual consumption levels, in kWhs		≥4.5	≥73	≥365	≥1,250	≥3,000
Daily consumption levels, in Whs		≥12	≥200	≥1,000	≥3,425	≥8,219

Household Access to Lighting and Phone Charging

Modern lighting and phone charging are important first steps toward improved household electricity access. Electricity offers hundreds to thousands of times more affordable lighting than fuel-based lighting (on the basis of cost per lumen-hours) but still fails to reach over a billion people. For households that are just starting to climb the energy ladder, lighting and mobile phone charging are critical first applications. Access to modern lighting extends useful hours of the day, and also improves public health and safety. It reduces the economic burden of costly (on the basis of per lumen-hour) fuel-based lighting, while also delivering superior quality of light. Access to mobile charging improves social connectivity, enhances financial inclusion and economic activity, facilitates emergency assistance, and supports broader development by providing a platform for mobile governance.

Fractional measurement between Tiers 0 and 1 is used to reflect less than Tier 1 access. To reflect the benefit of pico-solar and other small-scale devices that contribute improved lighting but may not meet Tier 1 standards, fractional measurement is used between Tier 0 and Tier 1.

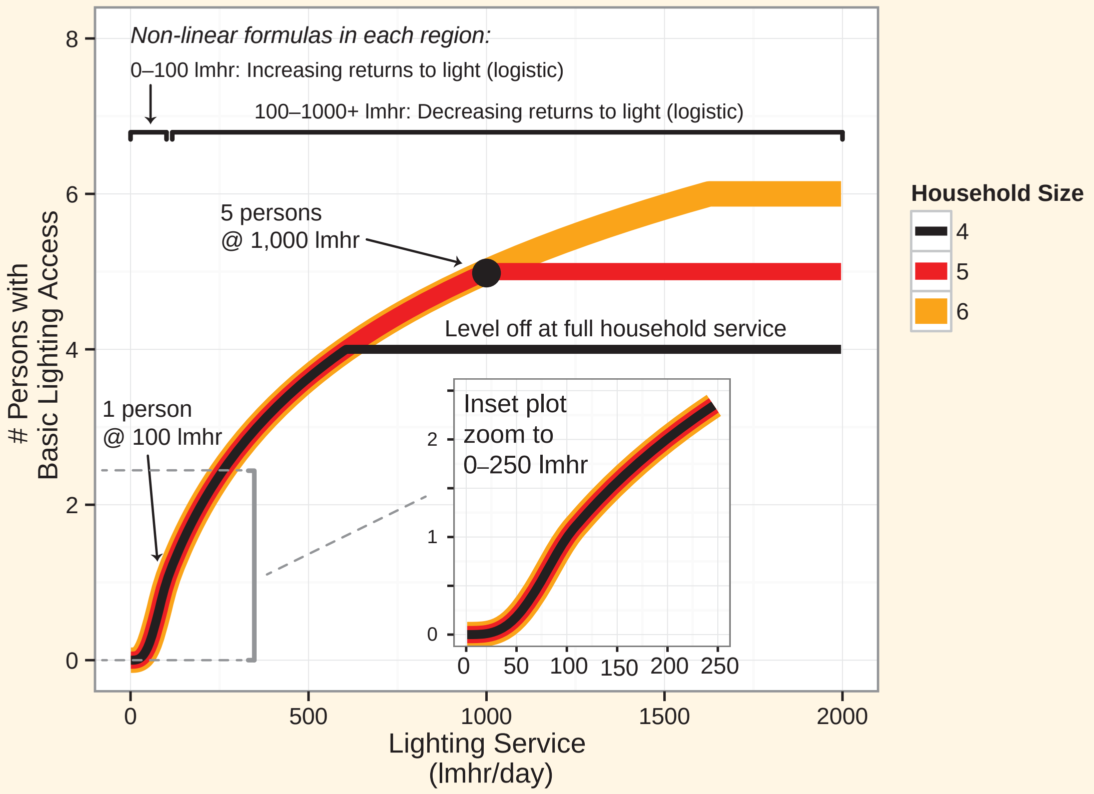
Lighting is an excludable good, while phone charging is a common good. Small amounts of light is usually difficult to share physically among multiple members of a household. As a result, access to light using entry-level lighting solutions is often an individual rather than household service. Mobile telephony, on the other hand, is treated as a common good because the benefits of phone charging access are often shared within the household.

The three core benchmark levels of lighting service are at 0, 100, and 1,000 lumen-hours per day. Data collated by Lighting Global reveals that over 90 percent of people across Africa and India are satisfied with brightness levels around 25 lumens, and use of about 4 hours each evening. Based on the observation that low-level lighting is an individual service, a benchmark is placed at 100 lumen-hours for meeting the needs of one person. Use of a shared light source simultaneously by multiple persons can reduce its utility because it is difficult to spatially distribute light across more than one person. Thus, there are declining access returns on additional light as more people are served, up to a full household of 5 being served by 1,000 lumen-hours. This represents another benchmark level for lighting. Two different mathematical functions are used to link the benchmarks, as shown in Figure ES.2.

Energy for phone charging is defined in terms of watt-hours of electricity. Full credit for phone charging access is given if available supply can charge approximately one phone every day, whereas partial (two-thirds) credit is given if one phone can be charged every three days. In the event the phone recharging service is only available in the neighborhood, one-third credit is given.

FIGURE ES.2

Implications of the Tier 1 Framework for a Household of Five Using a Single Light Source with a Range of Performance Characteristics and Different Levels of Access to Mobile Charging



For devices from 0–100 lmhr/day	For devices from 100–1,000 lmhr/day	Total number of persons served in the household
A logistic function	*A logarithmic function*	*A summation function*
$P_l = d\left(1 - \frac{1}{1 + (\frac{L}{e})^f}\right)$ where: P_l = number of persons served with lighting service by the device L = quantity of available light (lmhr/day) $d = 2$ $e = 100$ $f = 3.3$	$P_l = 0 < h_{base} \times \log10\left(\frac{L}{a} + b\right) - c < h$ where: P_l = number of persons served with lighting service by the device L = quantity of available light (lmhr/day) $a = 95$ $b = 0.732$ $c = 0.0515$ $h_{base} = 5$ h = household size	Sum for all the light sources in a household: $P_{tot} = \max\left(\sum_i^{All} P_{l,i},\ h\right)$ $T_l = \frac{P_{tot}}{h}$ where: P_{tot} = number of persons served with lighting service in total h = household size T_l = effective tier for lighting

Relative weightage of lighting and phone charging is specified. A weighted average tier score is calculated across lighting (70 percent weight) and phone charging (30 percent weight). This tier score is used as the tier rating of households that do not have access to any higher level electricity supply solutions.

Household Access to Cooking Solutions

The multi-tier framework for measurement of access to energy for cooking is based on seven attributes: health (based on indoor air pollution), **convenience** (based on fuel collection time and stove preparation time), **safety, affordability** (including expenditure on cookstove and fuel), **efficiency, quality, and availability.** This report refers to a cooking solution as the combination of a cookstove and a type of cooking fuel taken together. A cooking system includes all cooking solutions being used, as well as the cooking location and ventilation.

Although distinct, **the multi-tier framework for household access to energy for cooking has been defined in a manner that is consistent with the International Workshop Agreement on Cookstoves (IWA) tiers for measuring cookstove performance.** To avoid any confusion with the IWA "tiers" for cookstoves, the proposed multi-tier framework uses the term "levels" for improving echelons of attributes of cooking access. The levels reflect simultaneous increase in attributes related to indoor air quality (for health), convenience, safety, affordability, cookstove efficiency, and fuel quality and availablity. The lowest tier among all attributes determines the overall access to cooking tier for the household. An index of household access to cooking solutions for any given geographical area can be calculated as the average of levels across all households in that area, adjusted to a scale of 100 (Table ES.4).

Data for access to energy for cooking may be collected through demand-side sources (household energy surveys) or supply-side sources (program, project, and manufacturer data). However, data on some attributes and parameters are only feasible from demand-side measurement, such as ventilation, quality of fuel used, convenience, availability, and affordability. Other parameters, such as indoor air quality and efficiency, can be measured better through supply-side data based on testing or through estimation based on mathematical modeling.

Household Access to Space-Heating Solutions

In many households, cooking solutions also serve to meet heating needs. Energy for space heating, however, can be availed through a range of solutions, including electric heating, fuel-based centralized district heating, fuel-based standalone heating, and direct solar heating.

Household access to heating (where needed) is measured using a separate multi-tier framework, and a separate index of access to energy for space heating is calculated (Table ES.5).

TABLE ES.4

Multi-tier Matrix for Measuring Access to Cooking Solutions

ATTRIBUTES		LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
1. Indoor Air Quality	$PM_{2.5}$ (μg/m^3)		[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	< 35 (WHO IT-1)	< 10 (WHO guideline)
	CO (mg/m^3)					< 7 (WHO guideline)	
2. Cookstove Efficiency (not to be applied if cooking solution is also used for space heating)			Primary solution meets Tier 1 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	Primary solution meets Tier 2 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	Primary solution meets Tier 3 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	Primary solution meets Tier 4 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	
3. Convenience:	Fuel acquisition and preparation time (hrs/week)			< 7	< 3	< 1.5	< 0.5
	Stove preparation time (min/meal)			< 15	< 10	< 5	< 2
4. Safety of Primary Cookstove	IWA safety tiers		Primary solution meets (provisional) IWA Tier 1 for Safety	Primary solution meets (provisional) IWA Tier 2	Primary solution meets (provisional) IWA Tier 3	Primary solution meets (provisional) IWA Tier 4	
	OR Past accidents (burns and unintended fires)					No accidents over the past year that required professional medical attention	
5. Affordability						Levelized cost of cooking solution (inc. cookstove and fuel) < 5% of household income	
6. Quality of Primary Fuel: variations in heat rate due to fuel quality that affects ease of cooking						No major effect	
7. Availability of Primary Fuel						Primary fuel is readily available for at least 80% of the year	Primary fuel is readily available throughout the year

TABLE ES.5

Multi-tier Matrix for Access to Space Heating

			LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
ATTRIBUTES	1. Capacity			Personal space around individuals is heated	At least one room has heating		All rooms in the household have heating	
	2. Duration					At least half the time when needed (> 50% of the time)	Most hours when needed (> 75% of the time)	Almost all hours when needed (> 95% of the time)
	3. Quality					Comfortable temperature at least 50% of the time	Comfortable temperature at least 75% of the time	Comfortable temperature all the time
	4. Convenience (fuel collection time in hrs/week)				<7	<3	<1.5	<0.5
	5. Affordability					Cost ≤ 2 times the grid tariff		Cost ≤ the grid tariff
	6. Reliability (number of disruptions/day)					<7	<3	<3 (total duration < 2 hours)
	7. Indoor Air Quality	$PM_{2.5}$ (µg/m^3)		[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	< 35 (WHO IT-1)	< 10 (WHO guideline)
		CO (mg/m^3)					< 7 (WHO guideline)	
	8. Safety						No accidents (burns or unintended fires) over the past year that required professional medical attention	

Access to Energy for Productive Engagements

Productive uses of energy are defined as those that increase income or productivity, referred to as value-adding activities. The wide diversity of productive activities and enterprises makes it difficult to devise a common metric for energy access. There are hundreds of different types of productive uses, with varying scales of operations and varying degrees of mechanization. Each productive use may involve different energy applications and may use energy from different sources. Energy applications can be broadly classified as lighting, information and communication, motive power, space heating, product heating, and water heating. Measurement is also constrained by survey limitations, including the need to address the informal sector.

The proposed multi-tier framework is based on the energy access experienced by individuals in their productive engagements. In the course of a household energy survey, the earning members are identified first. Next, the relevant energy applications are identified based on significant impact of these energy applications on productivity, sales, cost, or quality. Thereafter, the primary energy source for each application is identified and evaluated for the nine key attributes of energy supply.

The multi-tier framework (Table ES.6) is built on nine attributes that determine the usefulness of the supply for each application needed for the productive activity. Access to energy is first assessed for each application separately. The lowest tier among all applications determines the energy access rating for the productive use as a whole. The multi-tier framework captures the multiple attributes that influence access to energy for productive uses, in order to inform policy and investment.

The index of access to energy for productive enterprises is calculated as the average tier rating across the entire sample of individuals surveyed, adjusted to a scale of 100. Additional indices for specific engagements can be calculated by filtering the survey data for respondents engaged in the particular productive use, such as agriculture, small shops, and artisans.

Access to Energy for Community Facilities

Energy for community facilities is fundamental for socioeconomic development. It drives improvements in human capital through education and health services. Street lighting can improve mobility and security and encourage economic and social activity. Energy access in health facilities is a critical enabler of access to health services. Access to energy in education facilities increases the time students spend at school and improves children's and teachers' experience. Access to energy in government buildings enables e-governance, as well as necessary communications. Energy services in community buildings (such as prayer and celebration halls) allow the use of these institutions during evening hours as well.

The wide diversity of community facilities makes it difficult to devise a common measurement approach. Measurement of street lighting has to encompass coverage as well as brightness, whereas that for community institutions needs to reflect a wide variety of energy services and energy sources. The proposed framework captures separately street lighting and energy for community institutions (Tables ES.7 and 8, respectively).

Two different approaches for collecting information are considered: direct assessment through survey of community institutions and indirect assessment through survey of users. Both approaches entail measurement of various attributes of energy supply—capacity, duration, reliability, quality, affordability, legality, convenience, and health and safety—though the survey of users can only

TABLE ES.6

Multi-tier Matrix for Measuring Access to Productive Applications of Energy

				TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	1. Capacity	Electricity	Power		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
			Daily Supply Capacity		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
			Typical Technology		Solar lanterns	Standalone solar systems	Generator or mini-grid	Generator or grid	Grid
		Nonelectric (fuels, RME, RTE, AP, HP)					Available nonelectric energy partially meets requirements	Available nonelectric energy largely meets requirements	Available nonelectric energy fully meets requirements
		Both					No relevant application is missing solely due to capacity constraints		
	2. Availability (Duration) of Daily Supply	Electricity			Min 2 hrs	Min 4 hrs	Half of the working hours (min 50%)	Most of working hours (min 75%)	Almost all working hours (min 95%)
		Nonelectric (fuels, RME, RTE, AP, HP)					Available nonelectric energy partially meets requirements	Available nonelectric energy largely meets requirements	Available nonelectric energy fully meets requirements
		Both					Longer working hours are not prevented solely by lack of adequate availability (duration) of supply		
	3. Reliability							Reliability issues with moderate impact	No reliability issues or little (or no) impact
	4. Quality							Quality issues with moderate impact	No quality issues or little (or no) impact
	5. Affordability							Variable energy cost ≤ 2 times the grid tariff	Variable energy cost ≤ the grid tariff

TABLE ES.6 continued

			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	6. Legality						Energy bill is paid to the utility, pre-paid card seller, authorized representative, or legal market operator	
	7. Convenience						Convenience issues cause moderate impact	Little (or no) convenience issues or little (or no) impact
	8. Health (IAQ from use of fuels)	PM2.5 (μg/m^3)		[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	< 35 (WHO IT-1)	< 10 (WHO guideline)
		CO (mg/m^3)					< 7 (WHO guideline)	
		OR Use of fuels (BLEENS)			Use of non-BLEENS solutions (if any) outdoors or with smoke extraction		Use of BLEENS or equivalent solutions only (if any)	
	9. Safety						Energy solutions caused accidents that did not require professional medical assistance	Energy solutions did not cause any accidents

TABLE ES.7

Multi-tier Matrix for Access to Street Lighting

	STREET LIGHTING	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	1. Capacity		At least one functional street lamp in the neighborhood	At least 25% of the neighborhood is covered by functional street lamps	At least 50% of the neighborhood is covered by functional street lamps	At least 75% of the neighborhood is covered by functional street lamps	At least 95% of the neighborhood is covered by functional street lamps
	2. Availability (duration)		Street lighting functions for at least 2 night hours each day	Street lighting functions for at least 4 night hours each day	Street lighting functions for at least 50% of night hours each day	Street lighting functions for at least 75% of night hours each day	Street lighting functions for at least 95% of night hours each day
	3. Reliability					No reliability issues perceived by users	
	4. Quality					No brightness issues perceived by users	
	5. Safety					No perceived risk of electrocution due to poor installation or maintenance	

deliver limited information about select attributes. An important aspect of energy supply is the financial sustainability, which refers to the ability of the community institution to pay for utility bills, fuel, spares, maintenance, and batteries.

An index representing the level of access to energy at each type of community facility may be compiled based on the multi-tier framework. The lowest tier among all attributes determines the overall access tier.

STRENGTHS AND SHORTFALLS OF PROPOSED MULTI-TIER METHODOLOGY

Strengths of the Proposed Methodology

The proposed multi-tier framework enables a comprehensive assessment of energy access, spanning across various locales and attributes. Apart from a comprehensive treatment of energy access measurement, the approach offers the following advantages:

Gap analysis and diagnostic review. The aggregate and disaggregate analysis under the proposed approach enable an energy access diagnostic review that provides insights into possible interventions that would enable enhanced access. An energy access diagnostic report can be prepared using the survey information, which can then be used for planning, investment prioritization, and program design.

Foundation for establishing energy access targets and multifarious analytics. The multi-tier measurement of energy access forms the foundation for establishing realistic targets for achieving universal access. It also enables extensive analytics that can provide further insights into energy access-related aspects. Socioeconomic benefits of energy access can be estimated based on the energy access index. For example, socioeconomic benefits resulting from Tier 1 access would be different from benefits resulting from Tier 4 access.

Information on gender aspects. The multi-tier approach provides information on several gender-related aspects, including:

- Ownership and regular use of various electrical appliances in the household, by gender of household members
- Use of various standalone lighting devices, by gender of household members
- Gender of household members who frequently prepare meals and who obtain cooking fuel
- Gender of household members who use mobile phones
- Various aspects of cooking, including time spent in obtaining cooking fuel and preparing fuel, and level of satisfaction with the cooking solution
- Indoor air quality that usually affects the health of women and children
- Availability of street lighting in the neighborhood area, facilitating mobility, especially for women
- Energy access for productive uses by gender of working household members
- Energy access for health facilities, facilitating child delivery

TABLE ES.8

Multi-tier Matrix for Measuring Access in Community Infrastructure (Survey of Institutions)

				TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	1. Capacity	Electricity	Power		Min 3 W	Min 50 W	Min 200 W	Min 800 Wa or Min 2 KWb	Min 2kWa or Min 10kWb
			Daily Supply Capacity		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
			Typical Technology		Solar lanterns	Standalone solar systems	Generator or mini-grid	Generator or grid	Grid
		Nonelectric (fuels, RME, RTE)					Available nonelectric energy partially meets requirements	Available non-electric energy largely meets requirements	Available non-electric energy fully meets requirements
		Both					No relevant application is missing solely due to capacity		
	2. Availability (duration) of Daily Supply	Electricity			Min 2 hrs	Min 4 hrs	Half of the working hours (Min 50%)	Most of the working hours (Min 75%)	Almost all working hours (Min 95%)
		Nonelectric (fuels, RME, RTE)					Available nonelectric energy partially meets requirements	Available non-electric energy largely meets requirements	Available non-electric energy fully meets requirements
		Both					Operating hours and/or provision of services are not restricted solely by inadequate availability (duration) of supply		
	3. Reliability							Reliability issues have moderate impact	No reliability issues or little (or no) impact
	4. Quality							Quality issues have moderate impact	No quality issues or little (or no) impact
	5. Affordability	Variable Energy Cost						≤ 2 times the grid tariff	≤ the grid tariff
		Financial Sustainability						Energy access has not been interrupted due to unpaid utility bills, or lack of budget for fuel purchases, maintenance, spare parts, or batteries during the past 12 months	

TABLE ES.8 continued

Multi-tier Matrix for Measuring Access in Community Infrastructure (Survey of Institutions)

			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	6. Legality						Energy bill is paid to the utility, prepaid card seller, authorized representative, or legal market operator	
	7. Convenience						Time and effort in securing and preparing energy cause moderate inconvenience	Little (or no) time and effort spent in securing and preparing energy and/or little (or no) impact
	8. Health	$PM_{2.5}$ (μg/m^3)		[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	< 35 (WHO IT-1)	< 10 (WHO guideline)
		CO (mg/m^3)					< 7 (WHO guideline)	
		OR Use of Fuels (BLEENS)			Use of non-BLEENS solutions (if any) outdoors or with smoke extraction		Use of BLEENS or equivalent solutions only (if any)	
	9. Safety						Energy supply solutions caused accidents that did not require professional medical assistance	Energy supply solutions did not cause any accidents

a For small facilities (up to three rooms)

b For large facilities (over three rooms)

Flexibility of setting target tiers. The multi-tier measurement of energy access allows governments to set their own targets by choosing any tier above Tier 0. Such targets will depend on the situation in a country, its development status, the needs of its population, and the budget available.

Comparison across geographies and over time. The multi-tier approach provides a robust tool for measuring access across various locales of energy use, and comparing them across geographies and over time. The indices of energy access also allow aggregation across geographies, using simple averages.

Shortfalls of the Proposed Methodology

The shortfalls of the proposed methodology are as follows:

Critique of multi-tier approach. The proposed methodology is complex and involves tier thresholds that many practitioners may consider subjective. Also, different attributes are independent of each other, and cannot be assumed to improve simultaneously across tiers. However, there are several examples of use of simultaneously increasing attribute standards that deliver better performance of the system.

Critique of data-collection approach. The complex multi-tier framework requires extensive collection of data, which may not always be affordable. On the other hand, the proposed methodology does not cover some aspects that may be of interest to some practitioners. These aspects can be added into the standard survey instrument as additional modules. To facilitate data collection through various survey opportunities, three different levels of the multi-tier framework are proposed.

Critique of mathematical formulation of indices of energy access. The methodology underlying the indices of access to energy converts ordinal values of different tiers into cardinal values of energy access. This conversion may not be mathematically robust. An analysis of the shortfalls of the underlying methodology and options for addressing them are in the main report.

Simplified Frameworks for Global Assessment

To facilitate the implementation of the multi-tier framework on a global scale, simpler versions can be devised capturing varying amounts of information. Three different levels of the framework can be envisaged: (i) comprehensive framework, (ii) simplified framework, and (iii) minimalistic framework (Table ES.9).

EXPANDING ENERGY ACCESS THROUGH UPSTREAM PROJECTS

Upstream energy projects such as electricity generation and transmission can also be considered as energy access projects, provided that they move households to higher tiers of access by improving deficient attributes in the existing electricity system.

Increased availability of electricity from new generation capacity, rehabilitated capacity, or power imports can improve the duration of supply in areas that may have previously experienced load shedding. Peaking stations (or peaking imports) improve supply during evening hours, which is usually when households find electricity most useful. Further, the supply voltage is also likely to improve as the grid as a whole receives adequate electricity generation. Reliability of the system improves with frequency stabilization resulting from better matching of supply with demand. Reliability also improves with fewer plant breakdowns upon rehabilitation. All of these infrastructure projects enable consumers in the target area benefitting from the additional generation to move from access Tiers 1, 2, 3, and 4 to Tiers 3, 4, and 5.

Similarly, transmission, sub-transmission, and distribution-strengthening projects improve reliability and reduce losses. More importantly, these projects create the necessary infrastructure for connecting new households and supporting higher demand for electricity from already connected ones. They enable unconnected households (typically Tiers 0, 1, and 2) to get connected (typically Tiers 3, 4, and 5), while also enhancing the tier rating of connected households through improved availability, reliability, and affordability of electricity.

TABLE ES.9

Levels of the Proposed Multi-Tier Framework

	COMPREHENSIVE FRAMEWORK	SIMPLIFIED FRAMEWORK	MINIMALISTIC FRAMEWORK
Key Purpose	Detailed survey questionnaire for country-level assessment that can be used for diagnostic review	Reduced number of questions that may be used for global assessment of energy access under SE4All	Minimalist number of questions that may be incorporated in existing household surveys such as the DHS and LSMS
Household Characteristics	Covered in detail, including, inter alia, education, social, occupational, basic income, and expenditure characteristics	Covered in a simplified manner without assessment of income and expenditure	Not covered separately (already covered by existing surveys)
Household Electricity Access	Comprehensive assessment based on all attributes: capacity, duration, reliability, quality, affordability, legality, convenience, safety and health	Simplified assessment based on reduced set of attributes: capacity, duration, reliability, quality	Minimalist assessment based on select attributes: capacity, duration
Household Lighting Access	Comprehensive assessment based on lumen-hours of lighting and phone-charging capability, including use behavior	Simplified assessment based on type of lighting device and phone-charging capability	Minimalist assessment based on use of electrical lighting and phone charging capability
Household Cooking	Comprehensive assessment based on all attributes and information about ventilation, cooking area, conformity to standards, and maintenance	Simplified assessment based on primary and secondary cooking solutions as well as ventilation, convenience and affordability	Minimalist assessment based on type of primary and secondary cooking solutions
Household Heating	Comprehensive assessment based on all attributes	Simplified assessment based on capacity, duration, and convenience of primary heating solution	Not included
Productive Uses	Detailed assessment based on all relevant activities and sources of energy	Simplified assessment based on electricity access	Not included
Community Uses	Detailed assessment based on survey of institutions	Simplified assessment based on household interviews	Not included

CONCLUSION AND NEXT STEPS

The use of multi-tier frameworks for measuring energy access is currently constrained by limited availability of data—mainly in existing household surveys. The Global Tracking Framework (GTF) 2013 Report proposed to implement these multi-tier frameworks over the medium term by alleviating data constraints. It proposed to develop standardized survey instruments, conduct periodic household energy surveys, analyze the data to assess various aspects of energy access, and make such data available in the public domain. Apart from multi-tier tracking of energy access, such surveys could potentially serve the data needs of multiple stakeholders, including governments, regulators, utilities, project developers, civil society organizations, developmental agencies, financial institutions, appliance manufacturers, international programs, and academia. The detailed frameworks and survey instrument presented in this report pave the way for wider use of multi-tier measurement by strengthening the availability of data, as envisaged in the GTF 2013.

A four-pronged approach is suggested for strengthening the availability of data for monitoring progress on expansion of energy access:

1. **Incorporation of the minimalistic framework into existing household survey questionnaires.** Existing household surveys such as the Demographic and Health Survey (DHS) and the Living Standards Measurement Survey (LSMS) cover a wide range of information pertaining to multiple sectors, and offer limited space for energy-related questions. The minimalistic framework has been specifically formulated to leverage the limited space for additional questions in existing household surveys such as the DHS and LSMS. This minimalistic approach needs to be implemented by expanding existing household surveys through a dialogue with the International Household Survey Network.
2. **Global survey to establish baseline for SE4All.** To establish the multi-tier baseline for the purposes of SE4All, a global survey would be required, covering at least the top 30 to 40 energy access-deficit countries, and representing about 80 to 90 percent of the binary energy access-deficit population. This global household survey would be centrally administered through a suitable survey agency that has outreach in the selected countries. Such a global survey is likely to be constrained in terms of length of the questionnaire and the sample size in each country (in view of the costs involved). The simplified multi-tier framework and survey instrument would be used for this survey. The survey is being planned for 2016, and necessary funding is being arranged for the same. Similar surveys can be organized periodically (every two to three years) for tracking progress under SE4All.
3. **Detailed country-level surveys.** At present, various international and national agencies conduct household energy surveys for their own project, program, or planning needs. This results in significant expense of time, effort, and resources for collecting overlapping data, even as data from different surveys are not comparable due to lack of standardization of questionnaires, sampling strategies, and coverage. SE4All offers a unique opportunity to integrate all such survey efforts into a standardized household energy survey (customized

to specific country needs) conducted every two to three years at the country level that could serve the needs of the multi-tier framework and the requirements of most stakeholders. Such surveys would use the comprehensive framework, encompassing all attributes across all locales, and can also provide an energy access diagnostic review for the country.

4. **Adoption of multi-tier measurement approach by programs and projects.** The multi-tier approach can be adopted by various agencies for programs and projects for supply-side and demand-side measurement. Many agencies were involved in the development of the multi-tier frameworks. As mentioned earlier, supply-side measurement can be based on the performance characteristics of solutions supplied, whereas demand-side measurement can be done through household surveys using the proposed survey instruments.

A combination of the four approaches just described can be used for regular tracking of progress on expansion of energy access. Periodic global and country-level surveys would form the backbone of such a tracking mechanism, and data and information from programs and projects could be used to track incremental progress in between two global surveys.

For the full report, please go to:
http://www.esmap.org/node/56715

SECTION I: BACKGROUND

CONCEPTUALIZING MULTI-TIER FRAMEWORKS FOR MEASURING ENERGY ACCESS

Access to energy is a key enabler of socioeconomic development.

Access to energy is crucial for addressing developmental challenges—poverty, gender inequality, poor health and education services, and absence of food security, among others—and is an important ingredient toward achieving Sustainable Development Goals (SDGs). Further, access to energy is an enabler for most amenities and comforts, which are increasingly seen as essential to meet basic needs and achieve an improved quality of life. “Universal access to modern energy by 2030” is one of the three key pillars of the Sustainable Energy for All (SE4All) program, an initiative co-chaired by the United Nations (UN) Secretary General and the World Bank President.

Achieving the goal of universal access to modern energy by 2030 will require a wide range of interventions by various agencies.

Achieving the goal of universal access to modern energy by 2030 will require a wide range of interventions by various agencies, including governments, energy utilities, private-sector corporations, funding agencies, and developmental organizations at national and international levels. These interventions will involve a multitude of technologies to meet the diverse energy needs and address a spectrum of socioeconomic ill-effects arising from energy poverty. Measuring cumulative progress across all such interventions entails assessing the number of those benefitted as well as the nature and magnitude of improvement in energy access. This requires a comprehensive framework for measuring access to energy.

Energy is needed for multifarious applications across households, productive enterprises, and community institutions.

Energy is required for multifarious activities at various locales: households, productive enterprises, and community institutions. Household applications that require energy include lighting, cooking, heating, cooling, communication, entertainment, and mechanical applications. Energy is needed for productive purposes across agriculture, mini and micro enterprises, commercial enterprises, and industry. Further, energy is also required for community purposes such as street lighting, water pumping, health facilities, education facilities, local government offices, and other shared infrastructure. The multifarious applications of energy can be fulfilled through various energy carriers, such as electricity, fossil fuels, biomass, charcoal, wood, and so forth.

Access to energy encompasses quantity as well as quality aspects.

Access to energy encompasses quantitative as well as qualitative aspects, including the amount of supply, time of supply, reliability, voltage, emissions, fuel collection time, and affordability, among others. Access to appropriate, adequate, and affordable energy is closely linked to achievement of several developmental objectives, including gender equality, education, health, food security, rural development, and poverty reduction. For example, access to clean cooking systems affects indoor pollution levels, and in turn respiratory health.[1] Similarly, street lights enable security at night, and electricity in schools and hospitals enables better education and health services. In the absence of a comprehensive and widely accepted approach to defining and measuring the different facets of energy access, most projects and programs treat energy access as a unidimensional and binary parameter that simply entails having or not having energy access.

The SE4All Global Tracking Framework (GTF) 2013 report (Banerjee et al. 2013) suggested the need to move beyond binary measurement of energy access, and introduced multi-tier frameworks for this purpose. The draft multi-tier frameworks suggested in the report were prepared in consultation with several international agencies, including the Energizing Development Program (EnDev), the Energy Sector Management Assistance Programme (ESMAP), the Global Alliance for Clean Cookstoves (the Alliance), the International Energy Agency (IEA), Practical Action Consulting (PAC), the UN Development Programme (UNDP), the UN Foundation, the UN Industrial Development Organization (UNIDO), The World Bank, and the World Health Organization (WHO).

GTF 2013 report introduces multi-tier frameworks for measuring energy access.

GTF 2013 identified the methodological challenges in measuring energy access, and suggested specific tasks for addressing them. It envisaged the use of binary metrics over the immediate term in view of paucity of data for multi-tier metrics. Over the medium term, it proposed the development and piloting of multi-tier metrics for household electricity, cooking, and heating, as well as for productive and community uses, considering a series of methodological challenges (Figure 1.1). Going forward, GTF 2013 proposed the use of the full multi-tier metrics for country-level surveys and a simplified version for global measurement through existing household surveys such as the Demographic and Health Survey (DHS) of the U.S. Agency for International Development (USAID) and Living Standards Measurement Survey (LSMS) of the World Bank.

GTF 2013 identifies tasks for improved measurement of energy access over the medium term.

FIGURE 1.1

Addressing Methodological Challenges to Measuring Energy Access over the Medium Term

METHODOLOGICAL CHALLENGE	PROPOSED APPROACH IN GTF 2013
Off-grid, mini-grid, and grid solutions	Technology-neutral multi-tier measurement based on attributes of supply, and covering grid and off-grid solutions.
Quality of supply	Quality of supply aspects are reflected through detailed household surveys using the multi-tier framework.
Access to electricity supply versus electricity services	Both electricity supply and electricity services are measured through separate multi-tier frameworks.
Productive and community services	New methodologies to be developed.
Heating	New methodology to be developed.
Improved solid-fuel cookstoves	Technology-neutral multi-tier framework reflects the wide range of technical performance of non-BLEENS cookstoves, along with the associated convenience-conformity-adequacy attributes.
Stacking of stoves and fuels	Multi-tier framework reflects fuel stacking through the adequacy attribute.
Convenience and conformity	Multi-tier framework reflects all actual use attributes.

Note | BLEENS = Biogas, liquefied petroleum gas (LPG), ethanol, electricity, natural gas, and solar.

This report is a culmination of the multi-agency effort on developing multi-tier frameworks to fulfill the mandate suggested by the GTF 2013.

This report is a culmination of the multi-agency effort on developing multi-tier frameworks for measuring energy access to fulfil the mandate suggested by the GTF 2013. It addresses the approach proposed in GTF 2013, and goes beyond to develop additional frameworks for measuring household lighting as well. It proposes a tool kit for multi-tier measurement through household energy surveys and suggests the methodology for aggregated and disaggregated analysis of data. The approach may be adopted by global agencies, countries, programs, and projects for establishing a baseline, setting targets, monitoring progress, and also for conducting an energy access diagnostic review.

SE4All offers a unique opportunity to invest in strengthening data-collection and progress-monitoring systems.

The SE4All initiative offers a unique opportunity to invest in strengthening data-collection and progress-monitoring systems in developing countries, not only for tracking the universal energy access goal but also for improved sector planning, investment prioritization, market research, customer satisfaction, impact analysis, accountability for service delivery, and academic research.

The report is organized in 13 chapters within three sections.

This report is organized into three sections: (i) Background, (ii) Measurement Framework, and (iii) Approach for Implementation, with each section comprising multiple chapters.

The first section provides the context of this work (Chapter 1), reviews the literature for existing approaches for defining and measuring energy access (Chapter 2), lays out a conceptual background to enunciate some basic concepts underlying this work (Chapter 3), and explains the idea of an "energy results chain" that brings out the causal linkages between investments in energy projects and the socioeconomic and development effects of use of energy (Chapter 4).

The second section develops a comprehensive approach for defining and measuring energy access at various locales, starting with enunciation of an overarching framework (Chapter 5). It examines in detail access to energy across each locale, encompassing households (electricity in Chapter 6, modern lighting in Chapter 7, and cooking and heating solutions in Chapter 8), productive purposes across all sectors and enterprise sizes (Chapter 9), and community applications, including street lighting, schools, health facilities, and community/government buildings (Chapter 10). This section ends with a review of the strengths of the suggested multi-tier approach as well as its shortfalls (Chapter 11).

The third section of this report examines the approaches for applying the multi-tier framework in project situations, especially the upstream interventions such as generation and transmission of electricity (Chapter 12). The section ends with conclusions and a discussion of next steps (Chapter 13).

Annexes to the report present some additional work conducted in the course of developing the multi-tier frameworks that may be of interest to readers but does not merit inclusion in the main report. Tools for implementation of the proposed multi-tier framework, such as survey questionnaires, will be available on the ESMAP website.

ENDNOTE

[1] Women and girls are particularly affected, as they are generally responsible for collecting firewood and cooking, impacting their health and restricting their time for potential productive activities.

2

REVIEW OF EXISTING APPROACHES FOR DEFINING AND MEASURING ENERGY ACCESS

Measuring energy access is challenging because (i) energy may be provided through multiple sources, delivered by different technologies; (ii) energy has multiple uses enabled through a wide range of application; and (iii) energy supply is characterized by multiple attributes.

There are two initial challenges in measuring access to energy: the absence of a universal definition of access and the difficulty of measuring against any definition in a precise manner. Such difficulty results from the multifaceted nature of the issue. Multiple sources of energy, delivered by a range of diverse technologies, need to be captured. Additionally, energy is used for a wide spectrum of applications. Such applications are enabled when and if the supply of energy is adequate. The issue of stacking (the use of multiple energy solutions to meet a single energy need) is particularly challenging to capture, and data on the simultaneous use of multiple energy sources are scarce.

The lack of a universal definition of access to energy has led to the emergence of several approaches attempting to measure access to energy using a variety of indicators—single indicators, dashboards of indicators, composite indices, and multi-tier frameworks. This chapter analyzes the different types of energy access metrics and presents a number of recent approaches attempting to measure energy access.

TYPES OF ENERGY ACCESS METRICS

Single Indicators and Binary Variables

Single indicators are easy to interpret but cannot capture the multidimensional aspect of the issue.

Single indicators often rely on binary variables, which entail a single minimum threshold of energy supply, services, consumption, or fuel and equipment use.

Single indicators focus on one specific dimension and, therefore, are easy to collect data for and interpret. However, they describe a narrow picture and tend to ignore the multiple dimensions of energy access. They are often binary measures (having access versus not having access), relying on a single threshold to determine access. Such thresholds may be defined based on the availability of electricity connection, the use of electric lighting, the use of nonsolid fuels as a primary cooking solution, or the minimum levels of services or energy consumption, which may be combined with maximum levels of pollution. Minimum levels of access are set subjectively and are defined as necessary for adequate access. Binary measurements classify a continuous phenomenon into a discrete variable, failing to capture the gradual improvement of energy access. Energy consumption has often been used for measuring energy access; however, consumption levels depend on several external factors, such as household income and size, spending priorities, and others, and reward higher consumption, clashing with energy efficiency goals.

Dashboard of Indicators

Energy access is a multifaceted and multidimensional issue, and needs to be measured across a range of indicators capturing various elements. A number of initiatives compiled a dashboard of individual indicators to depict a more comprehensive picture of the energy access issue. Such a dashboard has also been used to measure the Millennium Development Goals (MDGs), with over 60 indicators. However, evaluating changes in a large number of indicators is challenging, and deriving meaningful conclusions is difficult. Some sort of aggregation model becomes indispensable.

Dashboards of indicators capture the multiple elements of the issue but prove to be impractical for evaluating changes.

Composite Indices

Composite indices are one way for combining multidimensionality with simplicity. They overcome the shortfalls of both single indicators and dashboards by compiling several variables into a single metric that is easy to interpret. The set of subindicators may or may not have a common unit of measurement, but comparability is maintained. Composite indices satisfy the need for aggregating information to a level that makes analysis convenient and meaningful and allow for easy comparison across countries. Aggregation inevitably implies some sort of simplification and may prove misleading unless interpreted correctly. Aggregation models and the weighting methods of such indices have often been criticized. It is always important to analyze the subindicators along with the overall index to ensure sound conclusions.

Composite indices combine simplicity and multidimensionality by aggregating a set of subindicators into a single metric.

Multi-tier Indices

Enhancing energy access involves a continuum of improvements, and its measurement needs to move away from binary indicators and adopt multi-tier measurement to fully define intermediate stages between no access and full access, delivered by a range of technologies (e.g., solar lanterns, solar home systems, diesel generators, mini-grids and grids, solid fuels, liquid fuels, gaseous fuels). Multi-tier indices are premised on improved usability of energy enabled through the enhancement of a range of characteristics.

Multi-tier indices determine intermediary stages of energy access, capturing the continuum of improvement that various technologies provide.

Because the challenge of delivering improved energy access varies between and within countries, setting minimum standards that apply uniformly to every country would not be meaningful in a context of significantly different energy access situations. Multi-tier metrics allow for a flexible definition of energy access as well as for country-specific and province-specific targets to be set and progress measured.

Multi-tier indices require a large amount of data to be collected and a robust methodology for determining multiple thresholds.

REVIEW OF EXISTING APPROACHES

Wide-ranging approaches spanning the previously described four types of metrics have been developed by various researchers and practitioners to measure different aspects of energy access. A review of some of these approaches is presented next.

Binary Metrics

Binary measures entail a single minimum threshold of energy supply, services, consumption, or fuel and equipment use.

Binary measures rely on a single minimum threshold of energy supply or services to determine the number of households that can be considered as having access. The threshold can be defined in multiple ways, based on connection, minimum services, minimum energy consumption, or use of certain fuels. Such approaches are used in most existing household surveys, such as the DHS and LSMS. Binary definitions have proven insufficient because they are limited to only one aspect of energy needs (e.g., electricity or cooking). Further, they attempt to classify a continuous phenomenon into two discrete sets. Many binary measures subjectively impose a minimum set of energy services that must be used for the household to be considered as having adequate access. Similarly, some binary measures require a certain minimum amount of energy consumption, which is again prescriptive and ignores lower consumption due to improvements in energy efficiency. Also, binary definitions typically do not shed much light on what aspects of energy access are deficient and how those can be improved going forward. Binary measures often tend to be technology specific (such as having an electricity connection) and ignore the quality of energy accessed and different aspects of energy use.

UNDP/WHO Dashboard of Indicators

A dashboard of binary indicators has been used by the UNDP and WHO to measure energy access across countries.

A 2009 collaborative study by UNDP and WHO aimed to understand the energy access situation in developing countries by gathering and compiling existing country-level energy access data available across various sources (international databases,[2] national statistical surveys,[3] government websites, and policy documents) and make them accessible in a single publication to provide a global picture (UNDP/WHO 2009).

Beyond its focus on energy access metrics, the report also measures the health impacts attributable to household air pollution from household use of solid fuels for cooking and heating. Additionally, it draws attention to national targets for modern energy access by counting how many countries have targets. Finally, it develops scenarios to estimate access in 2015 under different assumptions about progress in achieving national targets or in reaching the MDGs (UNDP/WHO 2009).

The report uses binary indicators to measure access to modern energy (Table 2.1).

TABLE 2.1

Indicators Used to Measure Energy Access

MODERN FORM OF ENERGY	INDICATOR
Access to Electricity	Percentage of people with a household electricity connection
Access to Modern Fuels[a]	Percentage of people who use electricity/liquid fuels/gaseous fuels as their primary fuel to satisfy their cooking needs[b]
Access to Cooking Fuels	Percentage of people who use different types of cooking fuels as their primary cooking fuel, including both modern and solid forms of energy[c]
Access to Improved Cooking Stoves[d]	Percentage of people relying on solid fuels (traditional biomass and coal) who use improved stoves for their cooking needs[e]
Access to Mechanical Power[f]	Percentage of people who use mechanical power for productive, nonindustrial applications, such as water pumping, agricultural mechanization, and small-scale agro-processing (e.g., grinding, milling)[g]

[a] Modern fuels include LPG, natural gas, kerosene (including paraffin), ethanol, and biofuels. Modern fuels exclude all traditional biomass (e.g., firewood, charcoal, dung, crop residues) and coal (coal dust and lignite).

[b] The study assumes that fuels used for cooking are also used for heating. Available data mainly refer to fuels used for cooking.

[c] The types of cooking fuels for which data are available and were collected are: (i) electricity, (ii) gas (including LPG, natural gas, and biogas), (iii) kerosene, (iv) charcoal (including char-briquettes), (v) coal (including coal dust and lignite), (vi) wood (including wood chips, straw, shrub, grass, and crop and agricultural residues), (vii) dung.

[d] This category includes closed stoves with chimney, as well as open stoves or fires with chimney or hood, but excludes open stoves or fires with no chimney or hood. Stoves that use electricity, liquid fuels, or gaseous fuels are not included.

[e] REN21, in its report Renewable 2007 Global Status Report (Renewables 2007 Global Status Report), estimated the number of improved cooking stoves disseminated.

[f] Mechanical power is defined in UNDP/WHO 2009 as the transmission of energy through a solid structure to impart motion, such as for pumping, pushing, and other similar needs, and it is obtained from energy carriers (e.g., electricity, modern fuels, traditional biomass) or energy sources transmitted directly (e.g., wind, hydroelectric power).

[g] Only three countries (Benin, Central African Republic, and Mali) provide estimates of access to mechanical power, and these are for rural areas only.

Source | UNDP/WHO 2009.

The UNDP/WHO approach does not utilize a composite index system, but presents data as a series of percentages of population with access to specific energy supplies and equipment. The study identifies paucity of data in some areas. Although acknowledging the importance of mechanical power, it is only able to provide data on access to mechanical power for three countries.

The report recognizes that "understanding what type of energy carriers and energy services are available, who uses them, how much they cost, and the benefits they provide to users, are factors to consider when assessing energy access" (UNDP/WHO, 2009, p. 7).

The energy poverty line determines the minimum level of energy consumption, below which the energy consumption becomes insensitive to changes in household income.

Energy Poverty Line

As mentioned earlier, binary metrics of energy access usually involve subjective thresholds of energy supply, services, or consumption. They entail defining a minimum level of energy required to satisfy basic human needs. However, the actual minimum energy need itself varies depending on climatic conditions, cultural preferences, economic conditions, level of development, and access to coping solutions, among other factors.

Based on the well-established concept of an economic poverty line, a demand-based approach to defining the energy poverty line has been developed by Barnes, Khandker, and Samad (2011). The energy poverty line is defined as the threshold point at which energy consumption begins to rise with increasing household income. In other words, the energy poverty line is the minimum level of energy consumption necessary for human sustenance in any country, below which energy consumption becomes insensitive to changes in household income. Above this point, energy contributes to greater welfare and increasingly higher levels of economic well-being. Below this point people are not using enough energy to sustain normal lives (Barnes et al. 2011). Energy-poor households (i.e., below the energy poverty line) are not necessarily income poor (i.e., below the poverty line).[4]

Although this approach circumvents the subjectivity in determination of the binary threshold, like other binary measures, it does not shed much light on deficiencies in energy access and how those may be rectified going forward.

Incremental Levels of Access to Energy Services

As an input to the UN Secretary General's SE4All initiative, the AGECC prepared a report on approaches for measuring access to energy services that suggested, inter alia, the need to move toward a multi-tier framework.

The UN Secretary General's Advisory Group on Energy and Climate Change (AGECC) recognizes the importance of energy for development, and argues that "a well-performing energy system that improves efficient access to modern forms of energy[5] would strengthen the opportunities for the poorest few billion people on the planet to escape the worst effects of poverty" (AGECC 2010, p. 7).

Ensuring universal access to modern energy services by 2030 means providing "access for the 2–3 billion people excluded from modern energy services, to a basic minimum threshold of modern energy services for both consumption and productive uses." Moreover, the group adds that "access to these modern energy services must be reliable and affordable,[6] sustainable and where feasible, from low-GHG [greenhouse gas] emitting energy sources" (AGECC 2010, p. 9).

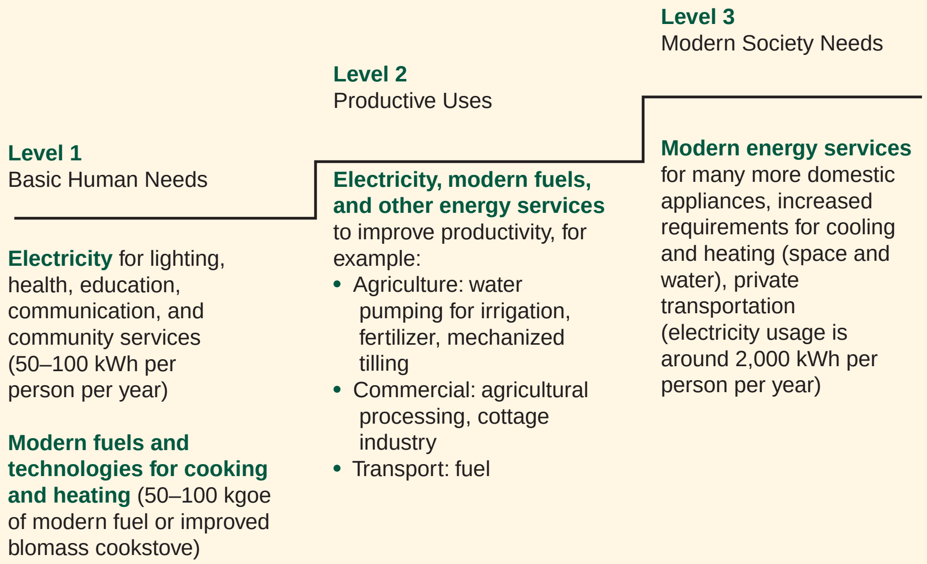
Acknowledging the lack of consensus and clarity around the term "energy access," the AGECC suggests a measurement based on three incremental levels of access to energy services and the benefits they can provide (Figure 2.1).

The report defines access as "access to clean, reliable and affordable energy services for cooking and heating, lighting, community and productive uses" (AGECC 2010, p. 13), which corresponds to the first two levels of access. The group decided to set the minimum threshold at Level 2 to emphasize the importance of productive uses in improving livelihoods and driving economic development, as well as increasing users' ability to pay for energy services.

The main indicator is energy usage measured in kilowatt hours (kWh) for electricity and kilograms of oil equivalent (kgoe) for modern fuels. Basic needs at Level 1 require 50–100 kWh/person/year of electricity to be reached, whereas modern-society needs at Level 3 require 2,000 kWh/person/year

FIGURE 2.1

Incremental Levels of Access to Energy Services



Level 1
Basic Human Needs

Electricity for lighting, health, education, communication, and community services (50–100 kWh per person per year)

Modern fuels and technologies for cooking and heating (50–100 kgoe of modern fuel or improved blomass cookstove)

Level 2
Productive Uses

Electricity, modern fuels, and other energy services to improve productivity, for example:

- Agriculture: water pumping for irrigation, fertilizer, mechanized tilling
- Commercial: agricultural processing, cottage industry
- Transport: fuel

Level 3
Modern Society Needs

Modern energy services for many more domestic appliances, increased requirements for cooling and heating (space and water), private transportation (electricity usage is around 2,000 kWh per person per year)

Source | AGECC 2010, p. 13.

to be satisfied. The energy usage required at Level 2 is set at 500–1,000 kWh. The definition does not clearly separate energy needs across households, businesses, and the public institutions, and combines all energy needs into a kWh/person/year metric.

The cleanliness of energy access is a requirement to be met across all levels, through the use of electricity for most energy services, and the use of modern fuels and improved cookstoves for cooking and heating. There is no indicator for reliability of energy access. Affordability is defined as a cost to end users that is compatible with their income and does not exceed the cost of traditional fuels. If this cost is equal to or higher than 10 to 20 percent of their income, temporary subsidies should be considered.

Minimum Service Levels and Multi-tier Framework

EnDev (2011) has developed a framework to define household energy poverty. Minimum standards for access to modern energy services have been established in order to allow energy-poor households to achieve a significant improvement in living conditions (HEDON 2011; Table 2.2).

EnDev has developed a set of minimum standards for access to energy services, as well as multi-tier frameworks for defining and measuring access to electricity and cooking solutions.

TABLE 2.2

Minimum Levels for Three Key Energy Services

CATEGORY	INDICATOR	ENERGY TECHNOLOGY
Light	300 lumens at household level for at least 4 hours a day	Kerosene pressure lamp, gas lamp, 9 W CFL, LED lamps of sufficient brightness
	Low fire hazard through light equipment	Safety tested kerosene and gas lamps, electric lamps
	Low level of particulate matter emitted by light device	Kerosene pressure lamps, gas lamps, electric lamps
Cooking	10,000 kJ fuel per person per day (assuming that about 5,000 kJ is sufficient to prepare a hot meal per person)	1 kg firewood per person per day, or 0.3 kg charcoal or 0.04 kg LPG or 0.2 liters of kerosene or ethanol per person per day
	Annual mean concentrations of particulate matter (PM2.5) < 10 μg/m^3 in households caused by stove	Smokeless cookstoves, cookstoves with chimney, gas cookers, electric cookers
	Low fire hazard of cooking equipment	Insulated cookstoves, safety-tested cookstoves
Information & Communication	Access to fixed line or mobile phone and use of a radio for at least 4 hours or a small TV for at least 1.5 hours a day	10 kWh per year and household (7 W × 4 hours × 365 days or 20 W × 1.5 × 333 days)
Accessibility & Affordability	Expenditures for energy do not exceed 10% of the household income or do not require more than 10% of the working hours of a household member	Low-cost fuels and energy technologies and/or highly energy-efficient energy technologies

Source | *HEDON 2011.*

The proposed requirements focus on quality, efficiency, safety, duration, and other factors, but ignore the aspect of cultural appropriateness (particularly important for cooking solutions).The affordability issue is treated separately, by assuming that the maximum acceptable level of energy spending is 10 percent of the household's income. The framework does not cover energy services such as space heating or cooling. Maximum and minimum indoor air temperatures have to be defined as a standard for acceptable living conditions, which may be achieved if needed through fans, ventilators, or space heating. Community institutions and enterprises, which have specific energy needs, are also excluded from this framework.

In addition, EnDev proposes a multi-tier framework for electricity services and consumption (Table 2.3) and for cooking solutions (EnDev 2011; Table 2.4).

The EnDev framework is a significant step toward the evolution of multi-tier frameworks. However, the frameworks remain technology specific. For example, a biomass cookstove could perform as well as an electricity- or gas-based cookstove, but would still be classified as a basic solution. Similarly, a deficient supply of electricity—in terms of duration or reliability, for example—would still be classified as full access. Therefore, the service package does not reflect the availability of these services as and when needed. Nonetheless, the EnDev framework provides the conceptual underpinnings of a sound multi-tier approach.

TABLE 2.3

Different Access Levels for Electricity

TERMINOLOGY	SERVICE PACKAGE	kWh PER PERSON PER ANNUM (PPPA)	TYPICAL SYSTEM	COST PER PERSON
Full	All you want	2,200	Grid	€500
Advanced	Basic + TV, fan, video, productive uses	220	Mini-grid	€250
Basic	Light, telephone, radio, small TV	22	Solar Home System (SHS)	€75
Partial	Less or only light, radio, TV, phone	2	Rechargeable battery	€20
Minimum	Even less light	1	Lantern	€3

Source | *EnDev 2011.*

TABLE 2.4

Different Access Levels for Fuel and Cooking/Heating Technology

TERMINOLOGY	OPTION 1: SERVICE PACKAGE	OPTION 2: TYPE OF FUEL
Full	All you want	Connected to the electricity or gas grid
Advanced	Hot food, boiled water, hot shower, and hot water for washing, with clean, safe, efficient technologies	LPG, kerosene, ethanol in limited amounts
Basic	Two hot meals and boiled water with clean, safe, efficient technology according to international standards	Biomass in combination with clean, safe, efficient technology according to international standards
Partial	Part of the hot food prepared with clean, safe, efficient technology according to international standards	Biomass used in clean, safe, efficient stoves according to international standards as well as in traditional low-quality stoves
Minimum	Part of the hot food prepared with improved cookstoves, which, however, do not meet all international standards	Biomass used in stoves that are cleaner and more efficient than three-stone fires but do not meet international standards

Source | *EnDev 2011.*

Total Energy Access and Energy Supply Index

The Total Energy Access (TEA) concept has been developed by PAC (2010, 2012) and presented in the Poor People's Energy Outlook (PPEO) reports in 2010 and 2012. It comprises the TEA minimum standards and the Energy Supply Index (ESI).

TEA minimum standards define what level of energy services a household should be receiving in order to escape energy poverty (Table 2.5). When assessing a household with the TEA standards, a 14-stage yes/no questionnaire is conducted with a household member. This questionnaire allows the

PAC has developed the Total Energy Access model, which comprises nine parameters that define minimum standards for energy access.

TABLE 2.5

Total Energy Access Minimum Standards

ENERGY SERVICE		MINIMUM STANDARD
1. Lighting	1.1	300 lumens for 4 hours per night minimum, at household level
2. Cooking & Water Heating	2.1	1 kg wood fuel, 0.3 kg charcoal, 0.04 kg LPG, or 0.2 L of kerosene or biofuel per person per day, taking < 30 minutes per household per day to obtain
	2.2	Improved solid fuel stoves to be minimum of 40% more efficient than three-stone fires
	2.3	Annual mean concentration of particulate matter ($PM_{2.5}$) is less than 10 $\mu g/m^3$, with interim goals of 15 $\mu g/m^3$, 25 $\mu g/m^3$, and 35 $\mu g/m^3$
3. Space Heating	3.1	Minimum daytime indoor air temperature of 18˚C
4. Cooling	4.1	Households able to extend life of perishable products by minimum of 50% over ambient storage conditions
	4.2	Maximum apparent indoor air temperature of 30˚C
5. Information & Communication	5.1	People are able to communicate electronic information from their households
	5.2	People are able to access electronic media relevant to their lives and livelihoods in their household

Source | *PAC 2012.*

interviewer to establish if each of the minimum standards is reached. A household that completes the TEA survey is scored on a 9-point system, with 1 point awarded for each standard reached; only a score of 9/9 achieves “total energy access.”

The Energy Supply Index complements the TEA by providing a multi-tier framework of energy access across three dimensions: household fuels, electricity, and mechanical power.

The TEA survey can also help in the establishing of an ESI score. The ESI identifies three principal dimensions of energy access: household fuels, electricity, and mechanical power. The supply of energy in these three categories is graded into six discrete levels, allowing for an accurate understanding of a household’s quality of energy supply (Table 2.6).

By considering the TEA and the ESI in tandem, it is possible to gauge both a qualitative and quantitative understanding of energy access, and how supply of energy and the services it facilitates are interlinked. Most important, the methodology considers the relationships between household electricity or cooking/heating requirements and the applications of the various energy supplies.

The TEA minimum standards are a set of individual indicators (or dashboard) to measure energy access quantitatively. The score of households against the TEA standards can also be analyzed as a composite index over a population. Although the average scores for a country can be a useful overall indicator, to understand the reasons behind a lack of energy access it is necessary to consider individual supply performance and deprivation of energy services. In this respect, the ESI is essential to achieving this greater understanding; where a standard is not met, the identification of service gaps can be linked to improvements in energy supply.

TABLE 2.6

Energy Supply Index Quality Levels

ENERGY SUPPLY	LEVEL	QUALITY OF SUPPLY
Household Fuels	0	Using nonstandard solid fuels such as plastics
	1	Using solid fuel in an open/three-stone fire
	2	Using solid fuel in an improved stove
	3	Using solid fuel in an improved stove with smoke extraction/chimney
	4	Mainly using a liquid or gas fuel, or electricity, and associated stove
	5	Using only liquid or gas fuel, or electricity, and associated stove
Electricity	0	No access to electricity
	1	Access to third-party battery charging only
	2	Access to standalone electrical appliance (e.g., solar lantern)
	3	Own limited power access for multiple home applications (e.g., SHS or power-limited off-grid)
	4	Poor-quality and/or intermittent home alternating current (AC) connection
	5	Reliable home AC connection available for all uses
Mechanical Power	0	No household access to tools or mechanical advantages
	1	Hand tools available for household tasks
	2	Mechanical advantage devices available to magnify human/animal effort for most household tasks
	3	Powered mechanical devices available for some household tasks
	4	Powered mechanical devices available for most household tasks
	5	Mainly purchasing mechanically processed goods and services

Source | *PAC 2012.*

The ESI focuses specifically on the household level of energy access, and also considers the importance of mechanical power in improving the efficiency and effectiveness of productive activities, and in providing physical processes essential to human needs, such as water pumping. The ESI recognizes that energy access is not simply a case of having modern fuels or not, and staggers access into a series of intermediate stages.

The TEA/ESI methodology is suited to localized analysis, but requires a large amount of data to be collected and has not yet been operationalized on an international scale. However, there is scope to develop greater linkages between aggregated indicators and more comprehensive local measurements.

Multi-tier Technical Metrics for Cookstoves

The Alliance, WHO, the PCIA, and the ISO secured an International Workshop Agreement (IWA) in February 2012 on an interim multi-tier rating system for technical evaluation of cookstoves.

As part of their commitment to developing globally recognized standards for clean and efficient cookstoves, the Alliance in collaboration with the Partnership for Clean Indoor Air (PCIA) and the International Organization for Standardization (ISO) organized an International Workshop Agreement (IWA) in February 2012, where 91 participants from 23 countries reached an agreement to establish an interim rating system for the evaluation of cookstove models that reflects different tiers of performance in four areas: (i) fuel use/efficiency, (ii) emissions, (iii) indoor emissions, and (iv) safety (PCIA 2012a).

Although the standards are yet to be finalized, indicators have been selected for each area and are compiled into a five-tiered (or zero-to-five tier) framework. Tier 0 represents the lowest performance, defined by a three-stone fire, whereas the other end of the spectrum is an aspirational goal specific to each indicator. The number of tiers reflects a balance between measurement uncertainty and the ability to provide meaningful differentiation between stove performance (PCIA 2012b). The proposed multi-tier framework is depicted in Figure 2.2 (Johnson 2012).

FIGURE 2.2

Proposed Emissions Tiers for Cookstoves

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4

PERFORMANCE INDICATOR	THREE-STONE FIRE	ASPIRATIONAL GOAL
Fuel Use	Low-power specific energy consumption: 0.050 MJ/(min x L) High-power thermal efficiency: 15%	Low-power specific energy consumption: 0.01 MJ/(min x L) High-power thermal efficiency: 45%
Emissions	Low-power CO: 0.20 g/(min x L) High-power CO: 16 g/MJ delivered Low-power $PM_{2.5}$: 8 mg/(min x L) High-power $PM_{2.5}$: 979 mg/MJ delivered	Low-power CO: 0.09 g/(min x L) High-power CO: 8 g/MJ delivered Low-power $PM_{2.5}$: 1 g/(min x L) High-power $PM_{2.5}$: 41 mg/MJ delivered
Indoor Emissions	CO: 0.97 g/min $PM_{2.5}$: 40 mg/min	CO: 0.42 g/min $PM_{2.5}$: 2 mg/min
Safety	Iowa State University Rating System: 45	Iowa State University Rating System: 95

Note | *CO = carbon monoxide; PM = particulate matter.*

Source | *Johnson 2012.*

The IWA multi-tier framework will enable stove testers to utilize the most appropriate laboratory protocols for the stove and the performance indicator that is being tested, instead of being limited to a single laboratory protocol. The agreement document also specifies the minimum equipment and methodology required for certified testing of emissions, performance, and indoor emissions (PCIA 2012b).

PCIA and the Alliance are working with more than 570 partners in 117 countries to achieve the adoption of clean and efficient stoves and fuels in 100 million homes by 2020 (PCIA 2012c). However, this framework only focuses on some of the technical specifications of cookstoves (i.e., efficiency, emissions, household air pollution, and safety), as its main concern is the health impact and safety of end users. It does not address other important adoption factors such as affordability, convenience, and cultural compatibility, which are crucial for assuring the success for a cookstove project (Dehejia 2012).

Multidimensional Energy Poverty Index

The Multidimensional Energy Poverty Index (MEPI) developed by UNIDO is a novel composite index aiming to measure energy poverty and report progress of energy access policies. It recognizes "the multidimensional nature of energy poverty and the need to capture a range of various elements to adequately reflect the complexity of the nexus between access to modern energy services and human development" (Nussbaumer et al. 2012, p. 233).

The MEPI is a composite index measuring deprivation of energy services through ownership of appliances. It is based on existing household survey data.

The index focuses on demand-side variables at the household level, aiming to measure deprivation of access to a range of modern energy services affecting individuals. It considers household energy requirements and basic needs, as opposed to a purely supply-based approach, by using the lack of ownership of modern appliance as a proxy to energy deprivations.

It is composed of five dimensions representing basic energy services and uses household survey data[7] on six indicators, highlighting the multidimensional nature of energy poverty (Table 2.7). In order to capture the effects of cooking applications on health and convenience, two types of indicators are considered: modern cooking fuel and indoor air pollution.

The MEPI measures both the average intensity of deprivation and the share of energy poor individuals (Nussbaumer et al. 2012). A MEPI score is compiled for each household by aggregating the weighted deprivations.[8] A household is considered energy poor if the sum of its deprivations exceeds a total cut-off value, set up at 0.3. The overall MEPI index of a country is then calculated by the equation MEPI = H*A, where H represents the incidence of energy poverty (number of people who exceed cut-off score/total population), and A is the average weighted deprivation across the energy-poor population (above cut-off).

The MEPI is based on existing household survey data and is constrained by the availability of data in terms of frequency and content. The number of surveys and the frequency of update over the last three decades vary across countries, although a five-year cycle appears to be the desired objective.

TABLE 2.7

Multidimensional Energy Poverty Index Indicators

DIMENSION	INDICATOR (WEIGHT)	VARIABLE	DEPRIVATION CUT-OFF (DEPRIVED IF)
Cooking	Modern cooking fuel (0.2)	Type of cooking fuel	Use any fuel besides electricity, LPG, kerosene, natural gas, or biogas
	Indoor air pollution (0.2)	Food cooked on stove or open fire (no hood/chimney) if using any fuel besides electricity, LPG, natural gas, or biogas	True
Lighting	Electricity access (0.2)	Has access to electricity	False
Services Provided by Household Appliances	Household appliance ownership (0.13)	Has a refrigerator	False
Entertainment/Education	Entertainment/education appliance ownership (0.13)	Has a TV and/or radio	False
Communication	Telecommunication means (0.13)	Has a landline and/or mobile phone	False

Source | *Nussbaumer et al. 2012.*

The methodology assumes that if a household owns a particular appliance, it has adequate access to the respective energy carrier required and is able to use and pay for the energy service.

Energy Development Index

The EDI is a composite index aiming to track progress in a country's transition to the use of modern fuels. It is based on four supply-side measurements (two binary metrics and two consumption indicators). It distinguishes residential and commercial energy, and it is based on national-level data.

Devised by IEA in 2004, the Energy Development Index (EDI) aims to track progress in a country's transition to the use of modern fuels (IEA 2010). The composite index includes four indicators with equal weights (Table 2.8).

Each indicator has a separate index, which has been normalized based on the actual maximum and minimum values for the countries covered. Performance is expressed as a value between 0 and 1 calculated using the following formula:

Dimension Index = (Actual Value – Minimum Value)/(Maximum Value – Minimum Value)

The arithmetic average of the four values gives the EDI for each country.

The EDI is compiled annually and included 64 countries[9] in the 2010 version (IEA 2010), using country data from 2009. The database has undergone major data revisions, resulting from better data and more recent census and rural surveys. In 2012, IEA introduced the new EDI that includes indicators for community level access, encompassing both public services and productive uses (IEA 2012).

TABLE 2.8

Energy Development Index Composition

INDICATOR	UNIT	WEIGHT	DATA SOURCE
Commercial energy consumption/capita	toe	0.25	IEA Statistics
Electricity consumption in the residential sector/capita	toe	0.25	IEA Statistics
Share of modern fuels in total residential sector energy use	%	0.25	IEA Statistics
Share of population with access to electricity	%	0.25	IEA Electricity Access Database

Source | *IEA 2010.*

The EDI uses aggregate data for a country as a whole and does not provide disaggregated information about the degree of energy access, deficiencies that impede access, and who is affected by such deficiencies.

Energy Indicators for Sustainable Development

An interagency effort headed by the International Atomic Energy Agency (IAEA)[10] developed the Energy Indicators for Sustainable Development (EISD) in 2005, representing a quantitative tool for monitoring progress and for defining strategies toward a more sustainable energy future. The EISD aims to provide policymakers and practitioners with a method "for measuring and assessing the current and future effects of energy use on human health, human society, air, soil and water" and help them determine "whether current energy use is sustainable and if not how to change it" (IAEA 2005, p. 2).

The approach involves indicators that are divided into three dimensions, further classified into 7 themes and 19 subthemes. These encompass the social dimension, across the themes of equity (accessibility, affordability, and disparities) and health (safety); the economic dimension, across the themes of use/production patterns (energy use, energy productivity, supply efficiency, production, end use, diversification, and prices) and security (imports, strategic stocks); and the environmental dimension, across the themes of atmosphere (air quality, climate change), water (water quality), and land (soil quality, forestation, and solid waste).

The EISD categorization is a theme and subtheme framework aiming to emphasize policy issues and discern correlations among themes, defining sustainable development goals and basic societal needs. It does not use any model of cause and effect in order to avoid unwieldiness and definitional difficulties and promote a framework that is easy to understand and implement at the country level. Therefore, care must be taken when interpreting indicators, particularly in terms of causality.

The Energy Indicators for Sustainable Development (EISD) is a dashboard of indicators encompassing the social, economic, and environmental dimensions. The EISD aims to emphasize policy issues and discern correlation, without using any model of cause and effect for simplicity purposes.

NEED FOR A COMPREHENSIVE APPROACH

The ideal energy access index should measure to what extent energy access is a constraint in people's everyday lives.

There is growing consensus that energy access should be geared toward adequately reflecting the needs of the end users as well as facilitating socioeconomic development. The energy access index should measure to what extent energy access is a constraint in people's everyday lives and provide insight on how such access may be improved. Such a metric would be useful for both project design ex-ante and project monitoring and evaluation ex-post, as well as for setting national targets and, thereby, driving resource allocation to energy access.

Multi-tier methodologies become increasingly popular, measuring energy access as a continuum of improvement, resulting from a variety of different technologies.

Multi-tier methodologies have become increasingly popular, as there is a growing recognition that energy access should be measured not as a binary metric, but as a continuum of improvement. Binary definitions typically do not shed light on what aspects of energy access are deficient and how those can be improved. Binary measures often tend to be technology specific (such as having a grid connection) and ignore the quality of energy accessed and different aspects of energy use. A multi-tier approach would embrace all technologies to adequately track progress toward universal energy access across countries. It would emerge from the combination of several indicators structured along multiple thresholds and would form an overall composite index. Such an index could cover multiple locales beyond the household, such as productive and community applications of energy.

The majority of the existing approaches are constrained by the limited availability of data.

The majority of the existing approaches are constrained by the limited availability of energy data, as they rely on available databases derived from existing household surveys, electricity connection data obtained from utilities, or energy consumption data at the country level. Energy-focused household surveys are required in order to obtain relevant data that will allow the multifaceted nature of energy access to be captured.

ENDNOTES

[2] International databases include World Health Surveys (WHO), Demographic and Health Surveys (USAID), Multiple Indicators Cluster Surveys (UNICEF), and World Energy Outlook (IEA).

[3] Statistical surveys include living condition surveys, household income and expenditure surveys, social and living standards measurement surveys, and censuses.

[4] In a slightly different approach, Foster et al. (2000) define the energy poverty line as the level of energy consumed by households at the known income poverty line.

[5] Modern sources of energy include fuels such as natural gas, LPG, diesel, and biofuels such as biodiesel and bioethanol. Technology, such as improved cookstoves, can also enable cleaner and more efficient delivery of traditional fuels.

[6] Affordable in this context means that the cost to end users is compatible with their income levels and no higher than the cost of traditional fuels, in other words, what they would be able and willing to pay for the increased quality of energy supply in the long run, although it may be necessary to provide temporary subsidies to reach affordability in the shorter run before economic development accrues.

[7] The MEPI's data comes from the MEASURE-DHS program funded by USAID.

[8] A deprivation will score at the weight provided, whereas no deprivation will score 0.

[9] Broader coverage is constrained by data availability; countries with missing data are not included.

[10] Other agencies involved are the United Nations Department of Economic and Social Affairs (UNDESA), IEA, the European Environmental Agency (EEA), and Eurostat.

3

CONCEPTUAL BACKGROUND

It is not easy to define the concept of access to energy.

The concept of access to energy does not lend itself to an easy definition. In the past, access to energy has usually been considered synonymous with household access to electricity. It has been defined variously as a household electricity connection, an electricity distribution pole in the village, or an electric light bulb in the house.

A definition of energy access based on household electricity connection is inadequate in many respects.

However, these definitions do not take into account the quantity and quality of electricity provided. There are many instances where connected households receive electricity at low voltage, for limited hours, during odd hours of the day (or night), and with poor reliability. Further, this approach does not address the question of affordability of energy and sustainability of supply. A related issue is whether increased availability and reliability of electricity, enabled by upstream interventions such as generation and transmission expansion, are regarded as improving access. Off-grid electricity solutions render the definition of energy access even more difficult. For example, when measuring energy access, standalone systems such as solar lanterns, solar home systems, and limited-power mini-grids have to be either ignored or considered on par with full-service grid connections, despite obvious differences in the energy services that these technologies can support.

A definition of energy access based on household electricity connection ignores energy for cooking and heating needs, as well as for productive and community applications.

A definition of energy access based on household electricity connection ignores the energy needs for household cooking and heating applications. Cooking needs are essential to human living, and even those who have minimal access to modern energy find some energy resources for cooking purposes. The challenge, then, is to include cooking needs when defining household energy access, and reflect the efficiency, health impact, convenience, and safety aspects of energy for cooking. Further, energy services are required to meet the needs of not only households, but also productive enterprises and community institutions. Indeed, access to energy contributes to socioeconomic development largely through productive enterprises and community institutions.

Ambiguity regarding access to energy supply and access to energy services remains.

Energy is used for many services, such as lighting, cooking, air circulation, communication, entertainment, computation, mechanical aids, and space heating and cooling, among others. Each of these services requires an energy supply as well as an end-use appliance. A key difficulty in defining access to energy is whether to measure access to energy supplies (without the end-use appliance), access to energy services (including the end-use appliance), or the actual use of energy for these applications (consumption). This is further complicated by technologies such as solar lanterns in which the means of supply and the appliance are inextricably combined.

Addressing these difficulties in defining energy access requires developing detailed conceptual frameworks, making simplifying assumptions, making subjective judgements, and developing standards. This chapter attempts to clarify some of the underlying concepts that can help formulate a comprehensive definition of energy access.

PRIMARY GOAL OF EXPANDING ACCESS TO ENERGY

Socioeconomic development of the users is the primary goal of expanding energy access.

Expanding access to energy should facilitate increased and improved use of energy for various services by those people who currently exhibit low levels of energy use or consume mainly solid fuels in an inefficient and unhealthy manner. Expanding energy access is not an end in itself but it is an important means to multiple ends. The services that energy provides are critical ingredients for socioeconomic development, including the achievement of MDGs and SDGs (PAC 2010, 2012; UN 2010). With socioeconomic development as the ultimate objective of all energy access initiatives, access should be defined and measured based on the causal chain leading to such development (see Chapter 4 for the energy results chain).

Access to energy is usually necessary but not sufficient for socioeconomic development.

However, although energy access is necessary for socioeconomic development (AGECC 2010), it is usually not sufficient, as development may be affected by other external factors (such as household income and size, spending priorities, etc.). Nonetheless, it is important to ensure that achievement of socioeconomic development goals is not constrained by inadequate access to energy, even as other factors may yet constrain it.

USE OF ENERGY SERVICES ACROSS MULTIPLE LOCALES

Socioeconomic development requires increased use of energy services across multiple locales.

Achieving socioeconomic goals requires sufficient use of various energy services, such as lighting, cooking, space heating and cooling, air circulation, refrigeration, entertainment, communication, mechanical loads (such as motors, pumps, and engines), among others. These services or applications may be needed by households, productive enterprises, and community institutions.[11] Therefore, a comprehensive definition of energy access needs to take into account all of these locales of energy use.

At the household level, access to energy encompasses electricity as well as cooking and heating solutions.

In the household, electricity can deliver several energy services, such as lighting, air circulation, entertainment, communication, and powering household appliances. Some of these services (particularly modern lighting and communication) can only be powered by electricity; however, cooking and heating applications are unlikely to be met by electricity in most parts of the developing world, due to the high cost of such energy intense applications. They are expected to continue to largely depend on solid biomass, and, to a lesser extent, liquid and gaseous fuels. For the poorest households, cooking represents the largest share of energy use and often involves time-consuming and exhausting fuel collection, particularly for women and children. In addition, the health impact of household air pollution due to the use of traditional fuels and basic cookstoves is now recognized as an important issue. WHO has introduced guidelines for indoor air quality in the context of cooking solutions. Therefore, definition and measurement of energy access at the household level should encompass access to electricity[12] as well as access to energy for cooking and heating,[13] in line with the SE4All initiative.

Access to energy for productive uses increases income, productivity, and employment, while delivering higher-quality and lower-price goods.

Energy is also crucial for productive uses because it can dramatically increase productivity and drive enhanced economic and social development by increasing income and employment, reducing manual workload and freeing up time for other activities, and facilitating the availability of higher quality and lower priced products allowed by local production (EUEI 2011).[14] Productive uses of energy are defined as those that increase income or productivity and refer to the activities that add value that could be taxable if part of the formal economy (EUEI 2011). An additional advantage of providing energy access to businesses is that it secures higher economic sustainability of electrification projects. Productive activities often translate into higher energy demand density and more reliable capacity to pay (EUEI 2011). Higher revenues for the utility and better management of the electricity supply systems usually lead to better chances to finance maintenance and repairs, and to improve sustainably of the overall system.

Productive uses entail a wide array of services that may be obtained through a range of energy carriers.

The energy services required by productive uses are wide ranging and can be met by electricity; liquid, solid, and gaseous fuels; or mechanical power. For example, mechanical power can provide energy services over a wide array of applications in the water supply, agriculture, agro-processing, natural resource extraction, and small-scale manufacturing sectors.

Access to energy for community services can lead to substantial improvement of human capital and improved governance.

Energy for community services (such as health, education, etc.) is fundamental for socioeconomic development because it can lead to substantial improvement of human capital. Healthier, more educated people with access to basic community infrastructure (such as clean water, street lighting, information and communication technology [ICT] network, etc.) have better chances of escaping the poverty trap (Cabraal et al. 2005). Improved energy access to community services also relates directly to the achievement of the MDGs (UN 2010).

THE USER'S EXPERIENCE OF ENERGY ACCESS

The user's experience of energy encompasses access to energy supplies as well as energy services.

Definition and measurement of access to energy must be based on the user's experience of such energy access, rather than the perspective of the energy provider. The user's experience of energy access stems from the available energy supply as well as the energy services used. Deficiencies in energy supply compromise the benefit of the desired energy services. For example, a person may have an electricity connection and also own a television. However, his experience of the television service is compromised when erratic supply or poor voltage interferes with proper functioning of the television. Deficiencies in energy supply may also cause people to forego certain energy services. For example, in areas where the supply of electricity is erratic, people may choose not to purchase refrigerators (even if they can afford to) because a refrigerator would not function properly with deficient electricity supply. Similarly, a family may not opt for a liquefied petroleum gas (LPG) cookstove due to erratic supply of LPG cylinders in the area.

Conversely, availability of adequate energy supply does not automatically imply that users will start utilizing various energy services. For example, a household that receives adequate electricity supply from the grid may choose not to buy an air conditioner because it prioritizes saving over physical comforts. Another household may have an adequate electricity supply but choose not to buy a television because there is no broadcast (through airwaves or cable).

Therefore, both the use of energy services and the usability of the energy supply should be measured to provide an indication of the level of energy access.

USABILITY OF ENERGY SUPPLY

The usability of energy refers to the potential to use the available energy supply when required for the applications that a user needs or wants. The energy provided should have all the necessary attributes for use in these applications. For example, for use of lighting services, electricity supply should be available after dark. Similarly, an electricity connection in a local health clinic in a remote village using low-voltage (LV) lines may not be able to provide adequate quality of supply for running x-ray machines. In both cases the energy provided is not usable for the required application.

Usability of energy refers to the potential to use available energy for desired applications.

The usability of energy is inferred from the attributes of the energy supply as seen by the user and the requirements of various applications. Inability to provide energy with suitable attributes would prevent applications from being used effectively and efficiently, and in some cases these applications may not be used at all.

ACCESS TO ENERGY SERVICES VS. ACCESS TO ENERGY SUPPLY

What is access to energy services?

Access to energy services refers to the actual use an individual may have from energy, when converted into light, sound, heat, cold, motion, and so forth. In addition to the usability of the energy supply, this requires ownership of devices such as lights, mobile phones, radios, fans, cookstoves, and machines to convert the energy into services.

What is access to energy supply?

Access to energy supply refers to the potential to use energy (or usability) should the user desire to do so. This usability of energy improves with increasing levels of energy attributes, such as quantity, quality, reliability, and affordability, among others, which enable certain applications to be run.

The actual use of energy may be constrained by external factors[15] despite an adequate level of access to energy supplies. Further, even when adequate access to an energy supply is achieved, the actual use of energy generally evolves over a period of time. Therefore, although access to energy supply is a precondition for actual use of energy, its measurement does not take into account the actual energy used or the ownership of end-use appliances. The energy provider (e.g., the electricity utility) cannot be held responsible for the users not consuming enough energy or not owning certain appliances. However, it can be held responsible for not providing adequate access to electricity in terms of quantity, quality, and reliability of supply.

Actual use of energy (energy services) lags behind energy supplies. In general, the energy provider can be held responsible only for energy supply and not for energy services.

ATTRIBUTES OF ENERGY SUPPLY

The attributes of energy supply are the characteristics that impact the ability of users to convert energy into the desired services. The attributes of energy include capacity, availability, reliability, affordability, quality, health impact, safety, legality, and convenience. The definition of energy access should take these various attributes of energy into account.

The attributes of energy impact the usability. They include, inter alia, adequacy, availability, affordability, quality, reliability, health impact, safety, and convenience.

The capacity of the energy supply captures the quantity of energy available compared with service requirements, whereas its availability takes into account the timing and duration of that energy supply, reliability considers the frequency and length of interruptions to supply, and quality relates to voltage and frequency fluctuations in the case of electricity and calorific value and combustibility in the case of fuels.

The health impact characteristics of energy supply relate to the level of household air pollution, and the safety characteristics account for other hazards, such as fire and electrocution risks.

If an energy supply is not legal the user's ability to access the supply would be insecure. The legality of the energy supply is also likely to have an impact on safety because it is unlikely to be regulated if illegal.

The affordability of energy access has two underlying factors: the price of the energy solution (including one-time equipment and connection costs, periodic maintenance costs, and running costs), which is a characteristic of the energy supply solution, and the income level of the user. Affordability could be measured as a ratio of the price characteristic of the energy solution and the income level of the user.[16] Such an affordability measure gives an objective indication of the general level of affordability but it does not mean that every user in that area perceives the energy supply as affordable.

The convenience of an energy supply relates to the time required from the user to maintain the supply (including collecting fuel, maintaining equipment, etc.). Reductions in time spent (hence, increases in convenience), represent one of the key benefits of modern over traditional energy.

STACKING OF ENERGY SOLUTIONS

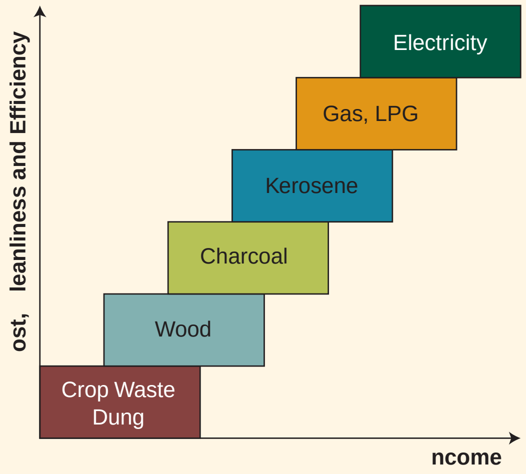
The energy ladder considers that household energy choices change with income, following a linear movement toward higher forms of energy.

The dynamics of household energy use across income levels was explained in the 1980s through the concept of the energy ladder (Baldwin 1986; Hosier and Dowd 1988; Leach and Mearns 1988; Smith 1987). This concept postulates that household energy use often shows a transition from lower to higher forms of energy in a successive manner. Households move from traditional biomass fuels (wood, dung, crop residues) through liquid and solid fossil fuels (coal and kerosene) to modern energy forms (natural gas, LPG, and electricity; Barnes and Floor 1996). The fuels on the energy ladder are ordered according to physical characteristics such as cleanliness, efficiency, and ease of use; and the process of climbing the ladder is described as a linear movement, implying that households move to higher forms of energy as their income increases and their socioeconomic status improves (Figure 3.1). Fuel switching is central in the energy transition process—a move up to a new fuel is simultaneously a move away from the fuel used before.

The concept of an energy ladder has since been extended to apply to electricity technologies, such as a movement from solar lanterns to solar home systems and then to a grid connection. The analogy of an energy ladder has also been used to suggest that securing a relatively low level of energy access enables improvement in economic livelihoods, which in turn supports higher levels of energy access.

FIGURE 3.1

The Energy Ladder



Source | Duflo et al. 2008.

However, reality appears to be more complex than the linear transition of the energy ladder concept. Energy transition does not occur as a series of simple, discrete steps; instead multiple-fuel use, or fuel stacking, is more common (Arnold et al. 2006; Brouwer and Falcao 2004; Campbell et al. 2003; Davis 1998; Heltberg 2005; Leach 1992). With increasing income, households adopt new fuels and technologies that serve as partial rather than perfect substitutes for more traditional ones (Elias and Victor 2005). Multiple-fuel models have been developed, where instead of switching fuels, households choose to consume simultaneously different energy options at various points on the energy ladder (Figure 3.2). Similarly, on the electricity side, households that lack a stable electricity grid connection often use a combination of solar lanterns, solar home systems, generators, and inverters as coping mechanisms or as backup electricity supply sources. Also, renewable energy sources such as roof-top solar panels are being increasingly used by grid-connected households to reduce draws from the electricity grid on a net metering basis.

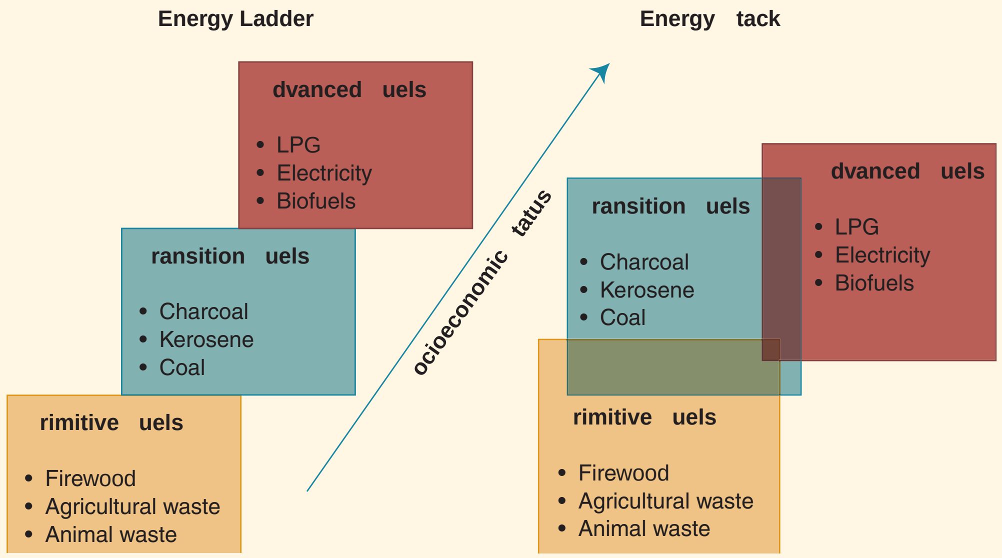
Fuel stacking, or the use of multiple fuels, is a common household behavior, complementing the fuel ladder theory.

Several reasons have been introduced to explain fuel stacking behavior by households. First, fuel supply problems lead to the accumulation of one or two fuel options that can be used as backups in case the primary fuel is temporarily unavailable (ESMAP 1999; Hosier and Kipondya 1993; Masera et al. 2000; Soussan, O'Keefe, and Munslow 1990). Second, fluctuations in energy prices may make the primary fuel temporarily unaffordable (Hosier and Kipondya 1993). Additionally, irregular and variable income flows in poor households prohibit the regular consumption of modern energy forms, leading to fuel stacking to increase energy security (Davis 1998). Finally, culinary traditions inhibit the

Fuel stacking is often a consequence of fuel availability issues, fuel affordability constraints, and traditional cooking methods.

FIGURE 3.2

The Energy Transition Process



Source | van der Kroon, Brouwer, and van Beukering 2013.

complete transition to modern fuels, as certain traditional cooking methods (such as bread making) are only possible with biomass (Masera et al. 2000; Murphy 2001).

STANDALONE ENERGY SOLUTIONS

The attributes of standalone energy solutions pertain to both the energy supply and the conversion device.

Some standalone energy solutions such as solar lanterns and household cooking solutions provide a package of the energy supply and conversion device. In such systems, the attributes of the system pertain to the combined attributes of the energy supply and the conversion device. For example, in the case of solar lanterns, the solar panel (the energy supply) and the bulb (appliance) are integrated into a single device. Therefore, the attributes of the energy solution are the characteristics of the solar lantern as a whole and not that of the solar panel separately. Similarly, in the case of cooking solutions, the fuel and cookstove together form the complete energy solution. Thus, the attributes of a cooking solution pertain to both the fuel and cookstove system.

On one hand, projects targeting improved cooking that include the promotion of improved cookstoves[17] provide a package of improved energy supplies and improved appliances. Thus, a complete energy service (or energy application) is provided. On the other hand, electrification projects primarily address access to energy supplies to which the user must add the required appliances in order to have access to energy services.

ACCESS TO ENERGY IS A CONTINUOUS RATHER THAN A BINARY PARAMETER

The definition and measurement of access to energy should focus not only on the number of users benefitting from improved energy access, but also on the nature and magnitude of that improvement. The degree of improvement encompasses various attributes of the energy supplied. Therefore, improvement in energy access is not a single-step transition but a continuum of increasing levels of energy attributes across different technologies and service quality levels. For electricity services, the range starts from no electricity access and extends up to an affordable, reliable, uninterrupted, unlimited electricity supply. The energy applications that become accessed along this continuum are not all comparable. For example, a low-wattage solar lantern does not provide energy access (or service) comparable to that of a reliable and uninterrupted supply of grid electricity.

The definition and measurement of access to energy should focus not only on the number of users benefitting from improved energy access, but also the nature and magnitude degree of that improvement.

It is not possible to capture all of these aspects in a binary (single-threshold) definition, which usually focuses on minimum standards and ignores the fact that aspirations and needs of people often extend beyond the minimum standards. For instance, a minimum standard set too low (such as access to lighting products) only addresses one aspect of energy access and is also less relevant for many countries where modern energy systems are developing rapidly, and adequate supply performance should be the next goal. A minimum standard set too high, such as access to grid-based electricity with uninterrupted supply, could be unachievable for many and would fail to recognize important improvements achieved below this threshold. Therefore, it is proposed to develop multi-tier approaches for measuring access to energy supplies, with successive tiers capturing improved levels of quantity, quality, reliability, and affordability of energy supply. The energy supply levels within each tier may equate to possible energy service levels. The aim is that the multi-tiers capture the continuum of improvement in energy options. It is recognized that by defining a number of tiers or steps, a number of levels are still excluded, but that five steps is a better representation of that continuum than two steps.

ANY PROJECT THAT IMPROVES THE ATTRIBUTES OF ENERGY SUPPLY HELPS EXPAND ACCESS

Interventions in the energy sector contribute to improved access by moving beneficiary users to higher levels of access. Such interventions not only include new household electricity connections and dissemination of clean cookstoves, but also other projects such as power generation, transmission, gas pipelines, LPG bottling and delivery projects, mini-grid systems, solar home systems, biogas projects, fuel-wood plantations, and briquette manufacture. In addition, other elements of the energy system, such as policy formulation, credit mechanisms, market structuring, regulatory reforms, institutional capacity development, consumer services enhancement, loss reduction measures, and efficiency improvement, also contribute to enhanced access to energy. All such interventions lead to improved attributes of energy supply for a set of targeted users. For example, in a country with

Projects that improve the attributes of energy supply make energy more useable and therefore lead to expansion of energy access.

massive power shortages and grid supply of only four to six hours per day, access can be enhanced by improving availability of energy by setting up generation power plants.

In order to claim contribution to enhanced energy access, any project should assess a baseline distribution of the target population across different tiers of access. The project should assess the attribute deficiencies that are holding the users to lower levels of access. For example, in the case just discussed, the shortfall in electricity availability means that users have a lower tier of access despite being connected to the grid. Energy projects should then be aimed at improving the deficient attributes by strengthening elements of the energy system, such as installed generation capacity or transmission system for import of electricity.

ENDNOTES

[11] Transport is another important application of energy. Poor people typically use public transportation services (which may be run by private operators in some cases) and often do not interface directly with energy for transportation. The fuel needed to run transportation equipment is usually supplied along the routes in almost all cases, but the cost of fuels is a function of macroeconomic factors such as prevailing international crude oil and gas prices, government subsidy (or cross-subsidy), and tax regime. As a result, public transport is typically not affected by initiatives to expand access to energy. Therefore, transportation has not been included in this report as a locale of energy access. However, going forward, with the greater penetration of solar-powered and electric private vehicles, transportation could also emerge as an application directly affected by efforts to improve energy access.

[12] While this document considers only electricity as an energy carrier for all household applications other than cooking/heating, some of these applications are also met through liquid and gaseous fuels (notably gas and kerosene lamps). These nonelectric energy sources would be treated as coping mechanisms in the absence of adequate access to electricity and would be reflected at the lower tiers in a multi-tier framework.

[13] This distinction means that the two sub-locales of household energy—electricity and cooking/heating solutions—will be treated separately. However, the cooking/heating framework considers electricity as a top-tier energy source.

[14] It is understood that energy access is a necessary but rarely sufficient condition for driving economic growth. Access to finance, markets, raw materials, technology, and a qualified workforce are also determinant factors.

[15] External factors inhibiting actual use of energy may include spending priorities, affordability of end-use appliances, consumer awareness, cultural preferences, and education, among others.

[16] A suggested approach for estimating affordability would be to calculate an indicative energy expense of the household for a given energy solution (by multiplying the energy unit price by the energy quantity required to run a standard set of applications). Note that such indicative expense is a characteristic of the energy solution and not the actual energy consumption incurred by the household. To be considered affordable, this household energy expense should not exceed a fixed percentage of the household income.

[17] There are many fuels and advanced stoves that—at least in controlled settings—represent “improved cooking.” These solutions might be thought of as moving along a spectrum, often referred to as the energy ladder. At one end of the spectrum is the use of raw, unprocessed solid fuels (e.g., dung, crop residues, humid wood) in open fires or rudimentary stoves, and at the other end of the spectrum are ultra-clean fuels (e.g., natural gas, electricity, solar) or modern cooking devices such as propane stoves. In the middle are a wide range of technologies and fuels of dramatically varying efficiency, emissions, durability, and safety.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4

THE ENERGY RESULTS CHAIN

ENERGY FOR SOCIOECONOMIC DEVELOPMENT

Socioeconomic development is enabled by greater use of energy for enhanced human capital, improved productivity, higher economic output, reduced drudgery, increased comfort, provision of basic amenities, and increased awareness and knowledge.

Achievement of socioeconomic development goals is enabled by greater use of energy services across households, health and education facilities, street lighting, public institutions, agricultural farms, manufacturing units, and commercial enterprises. Greater use of energy delivers benefit to people through improved productivity, higher economic output, reduced drudgery, increased comfort, provision of basic amenities, enhanced human capital, and increased awareness and knowledge. Wide-ranging energy services are involved in the process, including lighting, communication, air circulation, computing, entertainment, heating, cooking, pumping, mechanical loads, refrigeration, climate control, health equipment, and so forth. Various appliances (such as light bulbs, fans, televisions, cookstoves, refrigerators, machines and computers, etc.) are required to deliver energy services using available energy supplies.

Adequate delivery of energy services requires a supply of energy with attributes consistent with user requirements as well as appliance specifications.

Adequate delivery of energy services requires energy supplies to have certain minimum characteristics (attributes), which should be commensurate with user requirements as well as appliance specifications. These characteristics include capacity, availability, quality, reliability, convenience, safety, and affordability, among others, and are typically determined by the type of energy supply technology and the capabilities of the energy delivery system. For example, a solar home system typically does not provide adequate energy to power an air conditioner, but can be reliable for powering light bulbs for a few hours a day. A grid connection may enable unlimited electricity consumption but may experience intermittent power outages.

Improvements to energy attributes require investments in energy projects to strengthen the energy delivery ecosystem.

Improvements to energy supply attributes are achieved through investments in energy projects to strengthen the energy delivery ecosystem, which encompasses physical assets and institutional capabilities, as well as legal, policy, and regulatory regimes. Improved energy supply attributes can in turn enable:

- Increased energy use—enjoying the energy services in greater quantity (e.g., more light bulbs) or to a greater extent (e.g., more hours a day)
- Improved energy use—allowing new energy services (e.g., space heating) or improved quality of energy services (e.g., upgrading from an electric fan to air conditioning)

Improvements in energy supply attributes do not automatically result in increased consumption of energy services.

However, improvements in energy supply attributes do not automatically result in increased consumption of energy services. A wide range of context-specific factors influence whether a user will choose to obtain and use the energy appliances for availing a particular service. For example, use of refrigeration services by households requires a stable and reliable electricity supply as well as ownership of a refrigerator. However, despite provision of a stable and reliable electric supply, families may choose to forego air-conditioning services because they prefer to save money for medical needs.

Similarly, it is important to note that although energy services are important enablers of socioeconomic development, improvements do not inevitably follow; various other factors play an important role. For example, effective delivery of health services requires access to reliable electricity and diagnostic equipment in health facilities. However, provision of the reliable electricity and diagnostic equipment may not by itself lead to improved health outcomes, which may be still constrained by inadequate training of staff and availability of medicines.

Energy services are necessary but may not be sufficient for socioeconomic development.

THE ENERGY RESULTS CHAIN

Investments in the energy sector are usually aimed at strengthening various elements of the energy ecosystem. The energy ecosystem includes physical elements such as generation plants, transmission lines, distribution infrastructure, and standalone energy delivery systems, as well as soft elements such as the legal framework, policies, programs, regulations, technology availability, market structure, and institutional capacity of key stakeholders. Improvements in elements of the energy ecosystem enable enhancements in attributes of energy supply to consumers, making it more usable for the desired energy services. Greater use of energy for the desired energy services by consumers leads to their socioeconomic development.

The ERC captures causal links from energy investments to achievement of socioeconomic developmental goals.

One way of visualizing the linkages from energy investments to socioeconomic development is through the energy results chain (ERC), as presented in Figure 4.1. The ERC explains the causal relationship between energy investments, energy projects, elements of the energy ecosystem, attributes of the energy supply, usability of energy, actual use of energy services, and progress toward socioeconomic development goals.

The ERC starts with inputs in terms of project finance or development finance, which create intermediate outputs within projects (such as construction milestones, policy/regulation documents, training sessions, creation of equipment manufacturing capacity, etc.). These intermediate outputs ultimately translate into outputs, which are elements of an energy ecosystem (including physical energy assets—whether centralized or decentralized—laws, policy frameworks, market structures, regulations, and institutional systems in utilities.). When used effectively, these outputs lead to the intermediate outcome in terms of improvements in attributes of the energy supply (such as capacity, availability, affordability, reliability, convenience, safety, etc.).

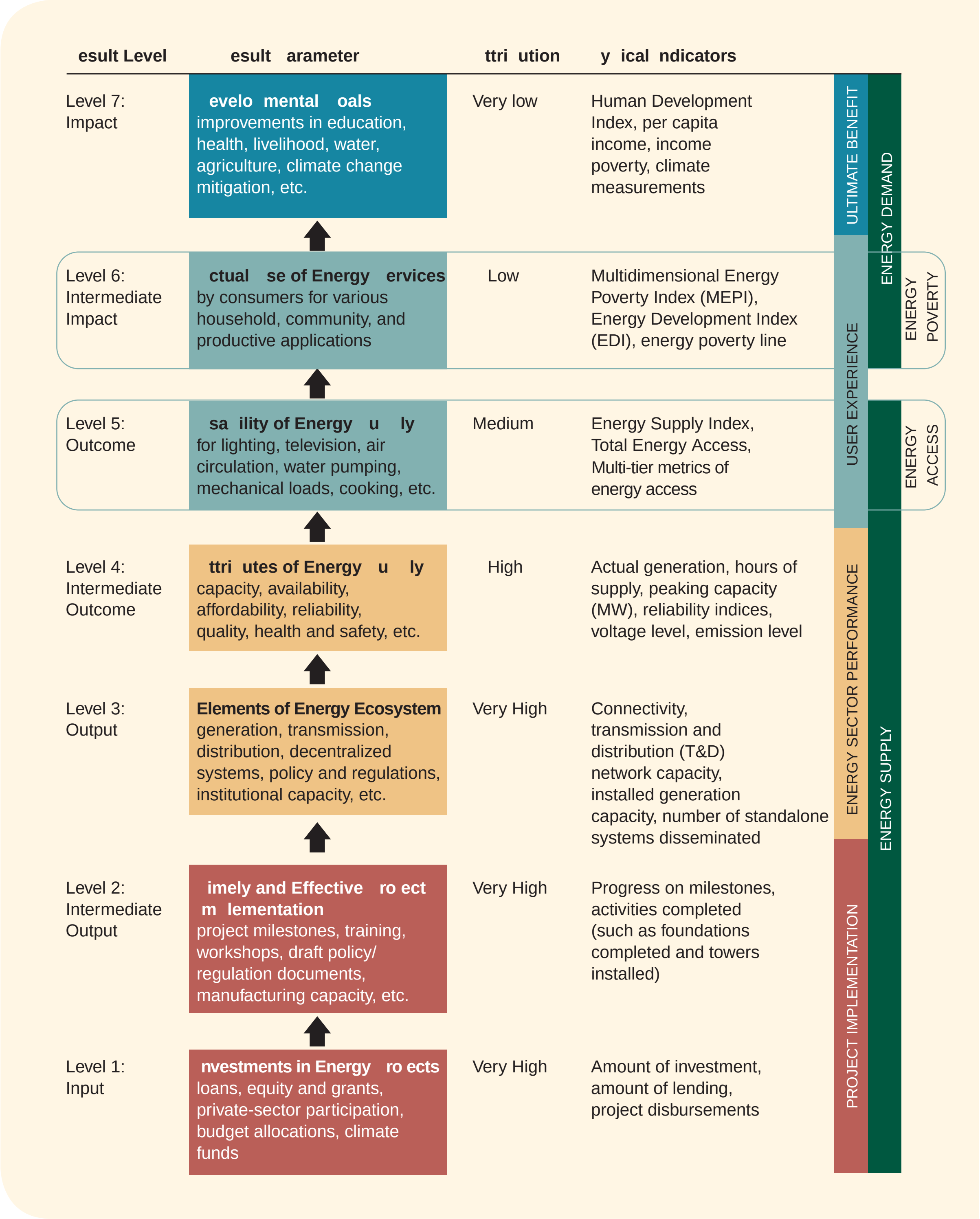
The ERC encompasses inputs, intermediate outputs, outputs, intermediate outcomes, outcomes, and impacts.

The user's experience of the energy supply depends on whether it is conducive for the desired energy applications. Each energy application (including household, productive, and community applications) requires a combination of different energy attributes to effectively deliver the energy service. For example, a refrigerator requires a continuous supply of electricity with a minimum voltage and supply interruptions of no more than a couple of hours, so that the stored food does not deteriorate due to undercooling. Thus, various intermediate outcomes (attributes) together lead to the outcome of improved usability of the energy supply (from centralized or decentralized sources) for various applications.

The user's experience of energy supply is reflected in its usability for the desired energy services.

FIGURE 4.1

Energy Results Chain



Result Level	Result Parameter	Attribution	Typical Indicators
Level 7: Impact	**Development Goals** improvements in education, health, livelihood, water, agriculture, climate change mitigation, etc.	Very low	Human Development Index, per capita income, income poverty, climate measurements
Level 6: Intermediate Impact	**Actual Use of Energy Services** by consumers for various household, community, and productive applications	Low	Multidimensional Energy Poverty Index (MEPI), Energy Development Index (EDI), energy poverty line
Level 5: Outcome	**Usability of Energy Supply** for lighting, television, air circulation, water pumping, mechanical loads, cooking, etc.	Medium	Energy Supply Index, Total Energy Access, Multi-tier metrics of energy access
Level 4: Intermediate Outcome	**Attributes of Energy Supply** capacity, availability, affordability, reliability, quality, health and safety, etc.	High	Actual generation, hours of supply, peaking capacity (MW), reliability indices, voltage level, emission level
Level 3: Output	**Elements of Energy Ecosystem** generation, transmission, distribution, decentralized systems, policy and regulations, institutional capacity, etc.	Very High	Connectivity, transmission and distribution (T&D) network capacity, installed generation capacity, number of standalone systems disseminated
Level 2: Intermediate Output	**Timely and Effective Project Implementation** project milestones, training, workshops, draft policy/regulation documents, manufacturing capacity, etc.	Very High	Progress on milestones, activities completed (such as foundations completed and towers installed)
Level 1: Input	**Investments in Energy Projects** loans, equity and grants, private-sector participation, budget allocations, climate funds	Very High	Amount of investment, amount of lending, project disbursements

Improved usability of the energy supply in turn enables the intermediate impact of greater use of energy services by consumers. This intermediate impact in terms of energy services used enables the impacts of human development, poverty alleviation, and climate change mitigation through improvements in health, education, livelihood, water, sanitation, and other such initiatives, provided that other non-energy determinants of these services are also in place.

Greater use of energy for desired energy services (intermediate impact) leads to socioeconomic development (impact).

PROJECT, SECTOR, USER EXPERIENCE, AND ULTIMATE BENEFIT

The ERC can also be interpreted in terms of project, sector, user experience, and ultimate benefit aspects, as in Table 4.1:

ERC can also be interpreted in terms of project, sector, user experience, and ultimate benefit aspects.

TABLE 4.1

Simplified Energy Results Change

Project Implementation Aspects	Project investments	Level 1
	Project implementation	Level 2
Sector Performance Aspects	Energy ecosystem	Level 3
	Attributes of energy supply	Level 4
User Experience Aspects	Usability of energy	Level 5
	Actual use of energy	Level 6
Ultimate Benefit Aspects	Socioeconomic development	Level 7

SUPPLY AND DEMAND SIDES OF ENERGY RESULTS CHAIN

Levels 1 to 5 of the ERC represent the supply side, as illustrated on the right-hand side of Figure 4.1. Starting with financial investments, the supply side goes through project interventions and elements of energy ecosystems, leading to supply of energy with enhanced attributes, culminating in the user experience of what applications such energy supply can potentially enable. For example, investments in grid extension and densification would increase connectivity, but in the absence of adequate availability and reliability of power, the user would experience poor electricity access due to frequent and prolonged blackouts. As another example, in a generation-constrained country, user experience of access to electricity can be enhanced by adding generation capacity, thus, increasing availability and reducing power outages, making the energy more usable. It may be pointed out that the responsibility for ensuring usability of energy (Level 5) lies with the supply-side agencies.

The supply side of the ERC encompasses investments, activities, the energy ecosystem, attributes of energy, and the usability of energy.

The demand side is represented by Levels 6 and 7 of the ERC, where energy is actually used by the user in pursuit of greater socioeconomic development. At Level 6, the users translate their Level 5 experience of usability of energy into actual consumption of energy with end-use equipment used for various applications. Apart from poor usability of the energy supply, the actual use of energy may be hindered by several external factors, including nonavailability of energy appliances, lack of awareness

The demand side of the ERC comprises actual use of energy and its developmental impact.

about applications, cultural barriers, lack of physical space, spending priorities, absence of financing instruments, and appliance affordability constraints. Although these factors are generally considered beyond the responsibility of the energy-supplying utility, these form part of the energy ecosystem and may be considered to fall within the responsibility of governments and, perhaps, the international donor community.

Actual use of energy typically lags behind improvements in usability of the energy supply.

It is also important to note that there is usually a significant time delay between improved usability of energy (Level 5) and increase in actual utilization of energy services (Level 6). Further, greater use of energy at Level 6 may not translate into socioeconomic benefits at Level 7 due to external factors from non-energy sectors such as livelihood, health, education, capital, and so forth.

TRACKING ACCESS TO ENERGY

Energy access is placed at the outcome level of the ERC, whereas deficiency in actual use of energy (energy poverty) is placed at the intermediate impact level.

In the past, number of connections provided and number of energy systems installed have often been used as measures of energy access. However, these parameters pertain to sector performance rather than the user experience of energy access. Energy access appears at the outcome level of the ERC (Level 5), referring to the usability of the available energy supply. Deficiency in actual use of desired energy services—usually termed as energy poverty—is captured at the intermediate impact level.

Supply-side agencies such as the electricity utility cannot be held responsible for access to energy services because consumer discretion also has a role to play in purchase of appliances and energy expenditure. Supply-side agencies are certainly responsible for ensuring access to energy supplies that should be usable for various applications. Thus, supply-side agencies are responsible for ensuring the usability of the energy supply (energy access), whereas deficiency in energy use (energy poverty) is a consequence of supply-side as well as demand-side factors.

5

SECTION II: MEASUREMENT FRAMEWORK

OVERARCHING FRAMEWORK

Energy is needed inside and outside the household.

This chapter proposes the broad contours of an overarching framework for measurement of energy access. People need adequate access to energy for various purposes both inside and outside the household. Inside the household, energy is needed in the form of electricity for lighting, air circulation, entertainment, communication, and a whole range of mechanical and thermal uses, such as fans, cloth irons, microwaves, washing machines, air conditioners, and so forth. In the absence of electricity, people often use candles, kerosene, or other fossil fuels to meet their needs. Energy is also needed for cooking food and (in cold climates) for heating. These needs are met mainly through the use of electricity or fuels.

Outside the household, energy is needed for productive activities and community infrastructure.[18] Productive activities include agriculture and allied activities, as well as micro or mini, small, medium, and large enterprises across services and manufacturing sectors. Community infrastructure includes education and health facilities, street lighting, and government and community buildings.

The broad areas of energy use may be termed the locales of energy access.

The broad areas of energy use—(i) households, (ii) productive activities, and (iii) community institutions—may be termed the locales of energy access. Any approach for a comprehensive measurement of access to energy must encompass all of these locales.

Energy access at each locale is examined across several components.

For the household locale, the proposed multi-tier framework examines (i) access to electricity, (ii) access to energy for cooking, and (iii) access to energy for heating as three separate components.

For the productive use locale, the framework examines the range of energy applications needed for any productive activity that a person may be engaged in, with the overall level of energy access being a composite of the levels of energy access for the individual applications.

For the community infrastructure locale, access to energy in each of several types of institution is examined separately, including: (i) education facilities, (ii) health facilities, (iii) street lights, (iv) local government offices, and (v) community buildings (such as places of worship and community halls). Each of these institutions is treated as a component of the overall access to energy at the community infrastructure locale.

This chapter proposes indices for measuring access to energy at various locales. A review of the mathematical treatment of the methodology behind these indices is presented in Annex 1. The annex brings out the shortfalls of such indices and examines various alternate methodologies that may be explored in the future.

HOUSEHOLD ELECTRICITY ACCESS

Households need electricity for a wide gamut of applications, and the proposed framework should reflect their ability to use energy to utilize all such applications. As explained in detail in Chapter 6, improved access to the electricity supply can be defined in terms of enhanced attributes of electricity that make it more usable for the desired applications. The increasing levels of electricity attributes can be captured across a multi-tiered framework comprising thresholds that define the minimum standards for each of the attributes. Thus, any given household can be placed on a tier of electricity access commensurate with the attributes of electricity received.

The household electricity dimension can be measured based on improving attributes of the electricity supply.

An index of household access to electricity supply for any given geographical area can be calculated as the average tier level across all the households in that area, which can be estimated through sample surveys of households.

Index of access to household electricity supply.

> *The index of access to household electricity supply is the average of electricity supply tier ratings of households in the relevant geographical area scaled to 100.*

The conceptual underpinnings behind the multi-tier framework for measuring electricity supply and calculating the index of access to household electricity are discussed in detail in Chapter 6.

Access to Lighting and Mobile Phone Charging Solutions

Access to modern (usually electric) lighting and mobile phone charging in the household is an important first step toward household access to electricity in general. It is important enough in many developing countries—especially in Sub-Saharan Africa, South Asia, and several island countries—to merit separate attention. In the multi-tier framework for household access to electricity, Tier 1 represents the thresholds of attributes for having adequate energy for basic lighting and mobile phone charging. Therefore, apart from minimum electricity supply attributes, Tier 1 has also been defined in terms of standards for minimum lighting and mobile phone charging that need to be satisfied for a household. Many households may be using modern lighting in a quantity that is lower than the minimum standard required at Tier 1. It is important to measure this fractional progress toward the Tier 1 threshold and an approach for more nuanced measurement of access that involves continuous fractional measurement between Tier 0 and Tier 1 is presented in Chapter 7.

An approach for more nuanced measurement of access to modern lighting and mobile phone charging, which involves continuous fractional measurement between Tier 0 and Tier 1 of household electricity access, has been developed.

HOUSEHOLD ACCESS TO ENERGY FOR COOKING

Cooking is a basic requirement in all households, while heating is necessary in cold climates and during winters. Lack of access to clean, convenient, affordable, and safe cooking (and heating) solutions imposes significant coping costs in terms of time, effort, and money spent on cooking, but also has significant health consequences due to household air pollution.

Access to household cooking solutions can be measured based on technical attributes and use attributes.

As explained in detail in Chapter 8, access to energy for cooking can be measured through a set of attributes, such that in a multi-tier framework, increasing levels relate to simultaneous improvements in these attributes.

It should be pointed out that the multi-tier framework proposed here for defining and measuring access to household access to energy for cooking is different from the multi-tier framework for measuring cookstove performance proposed under the International Workshop Agreement (IWA) of the International Organization for Standardization (ISO). To avoid any confusion with the IWA "tiers" for cookstoves, the proposed multi-tier framework uses the term "levels" for improving rungs of attributes of energy accessed.

The levels of access to energy for cooking reflect simultaneous increases in attributes related to indoor air quality (for health), safety, convenience, quality, efficiency, affordability, and availability.

The approach is consistent with the World Health Organization (WHO) guidelines for household air pollution as well as the IWA tiers for measuring cookstove performance. Because measurement of indoor air quality requires extensive instrumentation that cannot be installed across thousands of households in repeat household energy surveys, indoor air quality may be assessed using mathematical models with some simplifying assumptions. The multi-tier framework for measuring indoor air quality allows continued refinement of models and assumptions by various technical experts, which is expected in the ensuing years.

Index of access to household cooking solutions.

An index of household access to cooking solutions for any given geographical area can be calculated as the average tier level across all the households in that area, which can be estimated through sample surveys of households.

> *The index of access to household cooking solutions is the average of cooking solutions level ratings of households in the relevant geographical area scaled to 100.*

The conceptual underpinnings behind the multi-tier framework for measuring energy access for cooking and calculating the index of access to energy for household cooking are provided in Chapter 8.

HOUSEHOLD ACCESS TO ENERGY FOR SPACE HEATING

Access to household space heating solutions can be measured based on technical attributes and use attributes.

Access to energy for space heating is a survival need in many cold climates and in many warmer climates during winters. There are mechanisms by which the need for space heating can be partially alleviated, such as warm clothing, building design to prevent heat loss, and consumption of hot beverages. However, although partially mitigating the need for space heating, in most cases these mechanisms cannot annul it completely.

A range of energy solutions are used for space heating, from solid biomass (including wood) to charcoal, and from electricity and solar heating to natural gas and liquid fuels. Some of these solutions may be standalone household-level solutions (such as a wood-based fireplace, a gas-based heater, or an electric heater), whereas others may be delivered centrally (such as a municipal heating system). Even within the household, some solutions may cover heating needs for one room (or part of a room) only, whereas others may cover the whole house. The multi-tier framework for household access to energy for space heating starts by examining whether local climate requires space heating. If needed, the primary and secondary space-heating solutions should be identified, and assessed for various attributes on a multi-tier scale for each attribute.

Index of household access to energy for space heating.

An index of household access to energy for space heating for any given geographical area can be calculated as the average tier-level across all the households in that area, which can be estimated through sample surveys of households.

> *The index of household access to energy for space heating is the average of tier ratings of households for space heating in the relevant geographical area scaled to 100. It is calculated only for areas with a climate that necessitates space heating during winters or throughout the year.*

The conceptual underpinnings behind the multi-tier framework for measuring access to energy for space heating and calculating the index of access to household space heating are provided in Chapter 8.

ACCESS TO ENERGY FOR PRODUCTIVE USES

Measuring the energy needs of productive enterprises is a complex challenge.

Measuring the energy needs of productive uses is a complex challenge. On the one hand, there are multiple types of productive enterprises, encompassing different scales of operation, varying degrees of mechanization, a multitude of energy applications (across motive, thermal, lighting, and electronic applications), and use of a multitude of energy solutions (energy stacking). Further, it is not possible to set norms of energy needs for different enterprises or applications, against which deficit in energy access can be measured. Also, lack of adequate access to energy may not be the only (or even primary) constraint faced by the productive enterprise, which also requires raw materials, capital, land, skilled workforce, markets, transportation, government licenses, and so forth.

For example, a tailoring enterprise may require energy for lighting, sewing, ironing, water heating, computers, and televisions. The enterprise can sew using hand needles, hand- or foot-operated sewing machines, or electrically driven sewing machines. The choice of sewing technology is dependent upon a variety of economic factors, going far beyond access to energy. Further, this tailoring enterprise may comprise a single tailor or hundreds of tailors, depending on the scale of operations. Thus, measuring access to energy for productive uses is a complex challenge.

Alternate approaches for acquiring data to measure access to energy: survey of productive enterprises versus survey of households.

There are two alternate approaches for acquiring data for measuring access to energy for productive uses: enterprise level and individual level. In the first approach, the measurement is done at the enterprise level, based on the energy needs of the enterprise and the extent to which these are being satisfactorily met. This approach poses two difficulties. First, it is difficult to collect relevant data for most small holders and mini or micro enterprises such as shops and household-based manufacturing and service units. Most enterprise surveys tend to focus on large, medium, and small enterprises only, leaving out the mini and micro enterprises that often employ a majority of the poor population in most developing countries. A second difficulty arises in aggregation of measured energy access across enterprises in a given geography. Productive enterprises vary in scale of operations, number of employees, and financial turnover. Aggregation of measured energy access without reflecting the relative scale of operations of different enterprises is likely to present a distorted figure. For example, a tailoring shop with a single tailor should not carry the same weight in calculating an aggregate index as a tailoring factory that employs 500 tailors.

A second approach entails household-level measurement of access to energy for productive purposes by assessing the extent to which the energy needs of different members of the household are met in their respective occupations. This approach resolves both of the previously mentioned difficulties. It addresses the difficulty in tracking mini and micro enterprises by reaching out to households, which are the loci of such enterprises in many cases. Further, under this approach, measured energy access for productive uses is aggregated across respondents, eliminating the need for reflecting the relative scale of operations of different enterprises. However, this approach may suffer from less-accurate reporting about energy needs of enterprises, as some respondents may be employees and may not fully appreciate the energy equation faced by the enterprise. Despite this shortcoming, a household survey-based approach would be better suited for capturing energy access in countries where an overwhelmingly high proportion of people work in the informal sector or micro- and small-scale enterprises.

Index of access to energy for productive uses.

An index of access to energy for productive uses for any given geographical area can be calculated as the average tier level across all respondents in that area, which can be estimated through sample surveys of households.

> *The index of access to energy for productive uses is the average of productive use tier ratings of respondents in the relevant geographical area scaled to 100.*

Separate indices can be calculated for various productive activities.

In addition, indices of access to energy for productive uses can also be calculated for various productive activities by collating the data accordingly. For example, an index of access to energy in small shops can be calculated by aggregating the data for all respondents who work in small shops.

Index of Access to Energy for Agriculture

$I_{\text{Agriculture}}$ = Average of tier ratings across all respondents engaged in agriculture scaled to 100

Index of Access to Energy for Small Shops

$I_{\text{Small Shops}}$ = Average of tier ratings across all respondents working in small shops scaled to 100

The conceptual underpinnings behind the multi-tier framework for measuring access to energy for productive uses and calculating the corresponding index are provided in Chapter 9.

COMMUNITY INFRASTRUCTURE

Energy is used for various community services across a range of institutions and infrastructure. There are five sub-locales of energy use for community infrastructure:

Access to energy for community infrastructure.

- Health facilities
- Education facilities
- Street lighting
- Government buildings (e.g., post office, local administration, etc.)
- Public buildings (e.g., places of worship, community halls, etc.)

Access to energy for community infrastructure relates directly to human development aspects such as education and health. It also relates to mobility in the night and security. Access to modern energy is necessary for delivery of public services, including e-governance in post offices and local government offices. It is also necessary for proper conduct of public buildings such as places of worship and community halls. All of these benefits directly relate to social development of the people.

Access to energy for each of the sub-locales can be determined based on surveys of either the users of the facility or the providers of the facility. The former requires a survey of households, whereas the latter requires a survey of the concerned community institutions. However, household surveys can only obtain limited information about energy access in community institutions, whereas surveys of institutions can obtain more detailed information. In any given multi-tier analysis, only one type of survey (household or institution based) needs to be applied toward calculation of the index of access to energy for community infrastructure.

An index of access to energy for community infrastructure for any given geographical area can be calculated as the average tier level for that infrastructure across all respondents in that area.

> *The index of access to energy for any community infrastructure is the average tier rating of respondents for the relevant infrastructure in the relevant geographical area scaled to 100.*

Indices for various community sub-locales are calculated by taking the average tier rating for that sub-locale across various respondents in a geographical area. These respondents could be either household members (as users of the facilities) or the community institutions themselves (as providers of the facilities), depending on the survey approach.

Separate indices can be calculated for each of the five community sub-locales.

Index of Access to Energy for Community Sub-locales

Community Sub-locale = Average of tier ratings for sub-locale across all respondents scaled to 100

Using this approach, the following indices can be calculated:

- Index of Access to Energy in Health Facilities ($I_{\text{Health Facilities}}$)
- Index of Access to Energy in Educational Facilities ($I_{\text{Education Facilities}}$)

- Index of Access to Energy for Street Lighting ($I_{\text{Street Lighting}}$)
- Index of Access to Energy in Government Buildings ($I_{\text{Government Buildings}}$)
- Index of Access to Energy in Public Buildings ($I_{\text{Public Buildings}}$)

The overall index of access to energy for community infrastructure for any given geographical area can be calculated as the average of all relevant community sub-locale indices.

> *The overall index of access to energy for community infrastructure is the average of indices for all relevant sub-locales in the relevant geographical area scaled to 100.*

The conceptual underpinnings behind the multi-tier framework for measuring access to energy for community infrastructure and calculating the corresponding index are provided in Chapter 10.

TRANSPORTATION

Transportation is not included as a locale of energy use.

"Transport" is another important aspect of energy use. However, poor people typically use public transportation services (which may be run by private operators in some cases), bicycles, animal-drawn vehicles, or walk on foot. As a result, in most cases they do not directly procure or use energy for transportation. Transport services depend on the availability of vehicles, as well as roads, railway lines, and other infrastructure, and fuel needed to energize these is sold (or supplied) along these routes in almost all cases. Further, the cost of liquid and gaseous fossil fuels used for transportation is a function of macroeconomic factors such as prevailing international crude oil and gas prices, government subsidy (or cross-subsidy), and the tax regime. As a result, public transport is typically not affected by initiatives to expand access to energy. Therefore, under the proposed methodology, transportation is not being included as a dimension of energy use.

AGGREGATION OF DIFFERENT INDICES

Equal weights are assigned to the three locales of energy use.

A key issue in designing a comprehensive framework for measurement of access to energy is the relative weights that should be accorded to each of the energy use locales. In the past, measurement of energy access was often focused on the household electricity dimension. However, achievement of socioeconomic development goals would require adequate access to energy across all of the three locales. The proposed methodology accords equal weight to each of these three locales, as they together influence socioeconomic development and the comfort of the people.

Equal weights are also assigned to each sub-locale within each locale.

The index of household access to energy can be calculated by combining the access levels for household electricity, energy for cooking, and energy for space heating. The aggregation is done by according equal weight to each of these three sub-locales. However, space heating is not taken into account in areas where climate does not necessitate heating.

Index of Household Access to Energy

$I_{\text{Household}}$ = Average of ($I_{\text{Electricity}}$, I_{Cooking}, and $I_{\text{Space Heating}}$)

The index of access to energy for productive uses is calculated as an average of the tier ratings across all survey respondents.

The index of access to energy for productive uses is calculated as an average across all survey respondents.

Index of Access to Energy for Productive Uses

$I_{\text{Productive Uses}}$ = Average of tier ratings across all survey respondents

The index of access to energy for community infrastructure is calculated as an average of indices across different sub-locales (street lighting, health facilities, education facilities, community buildings, and public buildings).

The index of access to energy for community infrastructure is calculated as an average of indices across sub-locales.

Index of Access to Energy for Community Infrastructure

$I_{\text{Community Uses}}$ = Average of $I_{\text{Health Facilities}}$, $I_{\text{Education Facilities}}$, $I_{\text{Street Lighting}}$, $I_{\text{Govt. Buildings}}$, and $I_{\text{Public Buildings}}$

Taking all the locales of energy into account and giving them equal weight, the overall index of access to energy is calculated as follows:

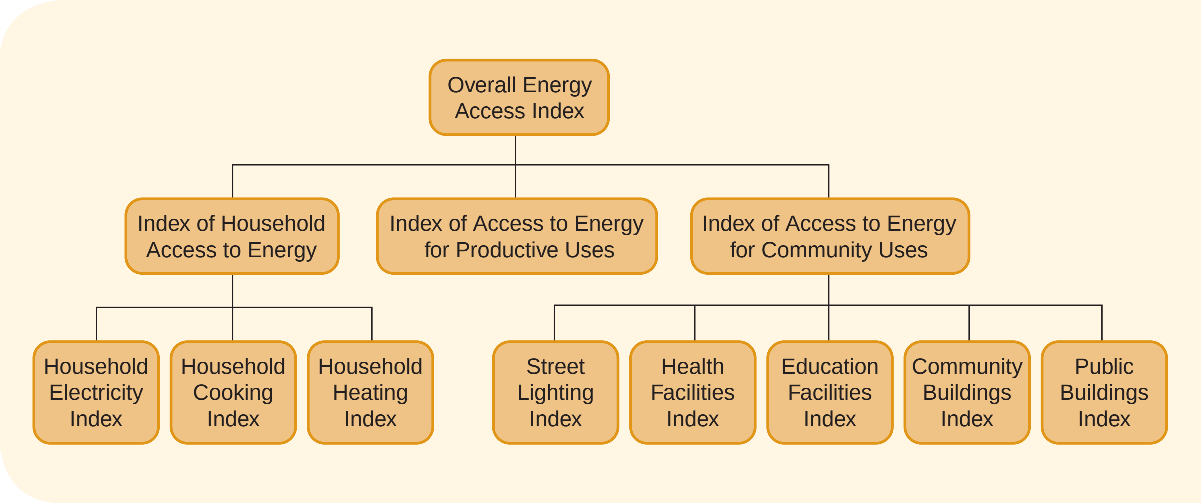
Overall index of access to energy = Average of the indices of access to energy for households, productive uses, and community infrastructure

A summary diagram of these indices is presented in Figure 5.1.

Diagram of the overall index of access to energy and the indices for each locale and sub-locale.

FIGURE 5.1

Diagram of Energy Access Indices



Subsequent chapters detail the measurement of energy access for each of the locales.

ENDNOTE

[18] In some cases, productive activities may be physically located inside the house premises.

6

HOUSEHOLD ACCESS TO ELECTRICITY

A comprehensive approach for defining and measuring household access to electricity as a continuum of improvement is presented in this chapter.

It is now generally accepted that without electricity it is challenging, if not impossible, to alleviate poverty and boost prosperity. Although not sufficient, access to electricity is a necessary condition for development. Devoid of electricity, people either use less energy or deploy other forms of energy, which are much more polluting or much less convenient, and sometimes more expensive, to obtain lighting, heating, motive power, and other needs. This chapter provides a comprehensive approach for defining and measuring household access to electricity as a continuum of improvement, considering multiple attributes that determine the performance of the electricity supply and reflect the user's experience.

Electricity connection, supply, service, and consumption are different terms used in the context of defining electricity access.

Various terms are used in the context of household access to electricity, and it is important to differentiate each. Grid connectivity refers to the physical connection to the distribution network by a wire, but does not imply that electrons are actually flowing through. In conventional parlance, grid connectivity is often confused with electricity access, although the two are indeed different. Electricity supply refers to the actual power being available to the consumer. A host of electricity sources and technologies may be used for electricity supply, including grids, mini-grids, diesel generators, solar home systems, solar lanterns, and rechargeable batteries, among others. Electricity services are the functions that can be availed using electricity, such as lighting, ventilation, motive power, heating, refrigeration, and so forth. Appliances are the electricity-operated devices used for availing the electricity services, such as a light bulb, a television, or a fan. Finally, electricity use implies the actual consumption of electricity.

This chapter presents the multi-tier approach for measuring access to household electricity and explains its uses.

This chapter starts by explaining the impacts of access to cooking on socioeconomic development and presents an overview of the current state of access to household electricity, followed by a review of the challenges in measuring access to household electricity. Then, it elaborates on the multi-tier approach for measuring access to household electricity. Finally, it shows how to use the results of such measurement for policy formulation and investment planning, as well as the monitoring and evaluation of projects and programs.

IMPACTS OF ACCESS TO HOUSEHOLD ELECTRICITY ON SOCIOECONOMIC DEVELOPMENT

Access to household electricity, one of the objectives of SE4All, is essential for achieving the MDGs. The use of electric appliances leads to improved quality of life.

Universal access to household electricity is one of the energy access objectives of the SE4All initiative, along with universal access to modern cooking solutions (AGECC 2010; SE4All 2012). Access to electricity is essential for achieving the MDGs, such as reducing poverty, improving women's and children's health, and broadening the reach of education. There is strong evidence that electricity facilitates social and economic development, offering an opportunity for improved lives and economic progress (Modi 2005; UNDP 2005; UNDP and WHO 2009; WHO 2004). Through the use of a variety of electric appliances, households can raise their standards of living. Electric lights, phone chargers, televisions, and space coolers (such as fans) are typically among the first devices utilized in a newly electrified household, thus, improving comfort levels (Khandker et al. 2009).

Electricity extends the length of the day, frees up time for additional activities or repose, and leads to better education.

Electrification extends the length of the active day, with people staying up later at night, undertaking various activities such as reading, watching television, and socializing (ESMAP 2002; Wamukonya and Davis 2001; WB 2008). Labor-saving household electric appliances free up time, particularly for women, allowing them to participate in income-generating activities (Dinkelman 2011; ESMAP 2002; Grogan and Sadanand 2012). Women in electrified households may also spend more hours in reading (WB 2002). The relationship between electrification and education has been discussed in multiple studies (Barnes 1988; Lipscomb et al. 2013). There is growing evidence that electric lighting increases studying time in the evening, leading to increased school enrollment and grade completion (Banerjee et al. 2011; Khandker et al. 2012a, 2012b, 2012c; Kumar and Rauniyar 2011; Samad et al. 2013).

Health benefits of electrification are driven by cleaner lighting, refrigeration, and reduced fuel-related accidents.

The introduction of refrigeration has a positive impact on health through improved food conservation and enhanced nutrition (Toman and Jemelkova 2002; WHO 2004; WB 2008). Health benefits also occur when electric lighting replaces kerosene lamps, which reduces the likelihood of respiratory illnesses (Samad et al. 2013). In principle, electric cooking generates similar health benefits. However, electricity is rarely used for cooking in most developing countries. Electrification may also lead to reduction in fire-related accidents from candles or fuel-based lamps (FRES 2013).

Electricity access improves household welfare.

Electrification may also lead to higher household incomes. Studying the welfare impacts of grid connectivity in rural areas, Khandker et al. (2009) suggest that household income can increase between 9 and 30 percent. An impact evaluation study analyzing the benefits from solar home systems concludes that household expenditure rises, driven by savings coming from lower energy costs as well as increased time availability for income-generating activities (Samad et al. 2013).

CURRENT STATE OF ACCESS TO HOUSEHOLD ELECTRICITY

In 2010, an estimated 1.2 billion people lived without electricity.

In 2010, approximately 1.2 billion people, or 17 percent of the world's population, lived without electricity. About 85 percent of that population lived in rural areas, and 87 percent was geographically concentrated in Sub-Saharan Africa, Southern Asia, and South-Eastern Asia (Banerjee et al. 2013). This estimation assumes that having a grid connection or a source of electrical lighting indicates access to electricity.

The number of people living without electricity in absolute terms decreased by 128 million since 1990, driven by strong expansion in Asia.

The share of the global population living with electricity increased from 76 percent in 1990 to 83 percent in 2010, driven largely by expansion of the network in the rural areas. Globally, access to electricity outpaced population growth by about 128 million people over the period. However, Sub-Saharan Africa was the only region where the growth in the electrified population fell behind the growth in total population. The electrification rate in urban areas also failed to keep up with population growth, driven by rapid urbanization rates, whereas an increase in rural electrification rates was facilitated by the relatively modest population growth. Of the 20 countries that have electrified the largest number of people over the last two decades, 12 are in Asia. The strongest expansion occurred in China, India, Indonesia, Pakistan, and Bangladesh. In particular, India electrified 474 million people over two decades, equivalent to an annual growth of 1.9 percent. It is worth noting that almost no country has improved electricity access at an annual rate greater than 3.5 percent of the population[19] (Banerjee et al., 2013).

Under business as usual, 12 percent of the world's population will lack access to electricity in 2030.

According to IEA projections, 12 percent of the world's population will still lack access to electricity in 2030 under the "business-as-usual" scenario (New Policies Scenario in IEA's World Energy Outlook). In developing Asia, the number of people without electricity access is projected to be halved to 335 million under the same scenario, whereas in Sub-Saharan Africa is it expected to rise by 11 percent, reaching 655 million by 2030. However, the share of electrified people in Sub-Saharan Africa will increase by less than one-half to around two-thirds (Banerjee et al. 2013).

Universal access to household electricity by 2030 would require investment of about $890 billion.

It is estimated that universal access to household electricity by 2030 would require an investment of about $890 billion over the period (in 2010 dollars), of which around $288 billion is projected to be forthcoming under the business-as-usual scenario, meaning that an additional $602 billion ($30 billion per year between 2011 and 2030) would be required to provide universal access to household electricity by 2030 (Banerjee et al. 2013). Furthermore, the IEA estimates that by 2030, 70 percent of rural areas will be connected either to mini-grid (65 percent) or stand-alone off-grid solutions (35 percent; IEA 2012).

These estimates adopt a very limiting definition of energy access.

However, all of these estimates assume that having a grid connection or a source of electrical lighting indicates access to electricity. Such an estimation based on binary definitions of electricity access may not adequately capture the extent of usability of available electricity for various desired applications.

CHALLENGES IN MEASURING ACCESS TO HOUSEHOLD ELECTRICITY

Binary measurement for tracking access to household electricity fails to capture the multifaceted nature of access to electricity.

Access to household electricity is often equated with the availability of an electricity connection in the household or the use of electricity for lighting (Banerjee et al. 2013). However, these binary metrics fail to capture the multifaceted nature of the underlying phenomenon, and, therefore, do not adequately inform energy policy, planning, project implementation, and progress monitoring. Such metrics do not provide any insight on the amount of electricity available or its duration. Further, issues regarding the quality and reliability of the electricity supply are overlooked. Affordability and legality are additional aspects of access that should be included in the measurement. Different solutions, including grid, mini-grid, and off-grid, can deliver different levels of access, and their contribution toward improving access should be evaluated according to the characteristics of the electricity supply that determine its performance and, thus, the users' experience.

Reflecting Multiple Electricity Supply Issues

Poor performance of the electricity supply limits its usefulness and results in low adoption rate.

In many developing countries, grid electricity suffers from irregular supply, frequent breakdowns, and quality problems such as low or fluctuating voltage. Duration of supply may be limited or provided at odd hours (such as midnight or midday) when the need for electricity is minimal. Inadequate quantity and quality of supply significantly lower the usefulness of electricity access provided. Poor performance of electricity supply, inhibiting households from benefiting from electricity services, often explains low adoption rate in areas where power lines and transformers are available (Kemmler 2007; Modi 2005; WB 2002).

Affordability issues constrain the use of electricity.

Affordability is another aspect that constrains the use of electricity (Afrane-Okese 2001; Banerjee et al. 2008; Winkler et al. 2011). Households may be forced to remain without electricity due to high connection fees and electricity tariffs. Affordability, thus, is a key aspect of the electricity supply, as even a highly rated supply becomes meaningless if the user cannot afford to consume electricity and, therefore, cannot benefit from the electricity services.

Electricity theft causes significant financial losses and may lead to accidents.

Illegal usage of electricity is a common practice in many countries across the world, and may occur through several strategies, such as hook-ups (illegal connections), meter tampering (fraud), billing irregularities (bribery), and unpaid bills (Smith 2004). Electricity theft may result in significant financial losses for the utility and cause overloading of the supply infrastructure. Thus, the viability of services is compromised, leading to deterioration in reliability and quality of supply. Legal consumers end up subsidizing illegal users as electricity charges increase to compensate for the losses (Jamil 2013; WB 2009), while those accessing electricity illegally do not have any ongoing security of supply. Illegal and secondary connections[20] also pose a significant safety hazard due to poor wiring and absence of safety devices (Patinkin 2013).

Lack of safety measures may lead to electrocution.

Safety effects of use of electricity can be a concern, especially when design and use standards are compromised. The spectrum of electrical injuries is broad, ranging from minor burns to severe shocks and death.[21] Several studies have analyzed electrocution-related morbidity and mortality, and highlight the lack of elementary knowledge of the risks of electrocution, particularly in rural areas (Blumenthal 2009; Gupta et al. 2012; Kumar et al. 2014; Mashreky et al. 2010). Accidents are usually preventable with simple safety measures. Poor households with sketchy wiring infrastructure run higher risks of electrocution.

Household electricity connection rate as a sole measure of electricity access ignores the issues of the quantity, quality, reliability, duration, affordability, legality, and safety of the electricity supply.

Accounting for Different Types of Electricity Access Solutions

Electricity access through off-grid standalone and mini-grid solutions needs to be tracked in addition to grid connections.

Off-grid standalone solutions and mini-grid systems are being deployed in many countries as stepping stones to grid-based electricity access, and even as long-term solutions in some areas. Therefore, electricity access through off-grid standalone and mini-grid solutions needs to be tracked alongside grid connections. However, simple numerical aggregation of households using grid, mini-grid, and off-grid solutions puts these on an equal footing, without recognizing the significant difference in the amount and duration of electricity supply from different solutions. Depending on their size and capacity, standalone systems present differences in the amount and duration of electricity they can provide (WB 2008). Similarly, mini-grids often have power load constrains and may be unreliable (Shyu 2013). Power limitations constrain the use of energy-intensive appliances, such as those used for cooking or heating (Murphy 2001), and limit the time of use (Wamukonya and Davis 2001). Standalone solutions, however, may provide more reliable[22] electricity supply than the grid.

Distinguishing between Access to Electricity Supply and Electricity Services

Electricity is only useful if it allows the desired electricity services to be run adequately.

Electricity is only useful if it allows the desired energy services to be run adequately. Different energy services (such as lighting, television, air circulation, refrigeration, space heating, etc.) require different levels of electricity supply in terms of quantity, time of day, supply duration, quality, and affordability. Expanding access to electricity supply, by considering aspects of supply, lies within the responsibility of the power utility and other supply-side actors, as they can be incentivized to undertake actions to improve the usability of supply.

However, apart from an adequate energy supply, appliances are also needed to use electricity services such as lighting, air circulation, television, refrigeration, and so forth. The purchase of appliances and the consumption of electricity depend on multiple factors, including household income, spending preferences, and level of education, among others. Experience has also shown that usually there is a time lag between grid connection, appliance diversification, and consumption uptake (Khandker et al. 2009)

MEASURING ACCESS TO HOUSEHOLD ELECTRICITY USING A MULTI-TIER APPROACH

The framework captures the multiple attributes that influence the user's experience of access to household electricity.

The multi-tier approach aims to measure access to household electricity as a continuum of improvement (as opposed to a binary metric) by reflecting all attributes of electricity supply that affect the user's experience, while being technology and fuel neutral. The approach attempts to provide insight into the types of policy reforms and project interventions that would drive higher levels of energy access to household electricity, along with facilitating monitoring and evaluation.

Electricity Services at the Core of the Approach

Electricity services, classified into seven categories, are at the center of the multi-tier approach.

Electricity services are at the center of the multi-tier approach because they respond to various household needs and directly affect socioeconomic development. Electricity services frequently encountered in the household can be broadly classified into seven categories (Table 6.1). These services play a key role in enhancing quality of life and comfort, reducing human effort, providing knowledge and awareness, and improving productivity.

Electricity services can also be classified based on the amount of power they draw from the electricity system (Table 6.2). Therefore, the capacity of the system needs to be sufficient to enable operation of the relevant appliances. Due to the nature of the services they deliver, certain appliances need to run on a continuous basis (e.g., refrigerators, space heaters, and air conditioners). Some other services are needed at a specific time of the day (e.g., cooking applications), and their operation cannot easily be rescheduled without disrupting household activities.

Electricity services can also be classified based on the power load required.

TABLE 6.1

Household Electricity Services

1. Lighting
2. Entertainment & Communication
3. Space Cooling & Heating
4. Refrigeration
5. Mechanical Loads
6. Product Heating
7. Cooking

In the face of inadequate access to electricity, people may either forego the services just described or may obtain them through coping solutions. This usually involves significant coping costs in terms of health impacts, safety implications, social and gender aspects, and economic costs.

Inadequate access to electricity involves significant coping costs.

TABLE 6.2

Typical Household Electric Appliances by Power Load

	VERY LOW-POWER APPLIANCES	LOW-POWER APPLIANCES	MEDIUM-POWER APPLIANCES	HIGH-POWER APPLIANCES	VERY HIGH-POWER APPLIANCES
Lighting	Task lighting	Multipoint general lighting			
Entertainment & Communication	Phone charging, radio	Television, computer, printer			
Space Cooling & Heating		Fan	Air cooler		Air conditioner,[a] space heater[a]
Refrigeration			Refrigerator,[a] freezer[a]		
Mechanical Loads			Food processor, water pump	Washing machine	Vacuum cleaner
Product Heating				Iron, hair dryer	Water heater
Cooking			Rice cooker	Toaster, microwave	Electric cooker

[a] *Continuous load*

Attributes of Electricity Supply

The framework is built on seven attributes, which determine the usefulness of the supply.

The framework is built on seven attributes of energy, which determine the usefulness of the electricity supply and influence the extent to which electricity services are used, thus, determining the user's experience. Some attributes, such as quality of supply, legality of connection, and affordability, are essential for using almost any energy service. Others, such as quantity, duration of supply, and evening supply, vary with the type of energy service. Minimum requirements for ensuring adequacy of the attributes may be set.

Capacity

The capacity of the electricity supply refers to the ability of the system to deliver a quantity of electricity.

The capacity of the electricity supply (or peak capacity) is defined as the ability of the system to provide a certain amount of electricity in order to operate different appliances (peak capacity), ranging from a few watts for light-emitting diode (LED) lights and mobile phone chargers to several thousand watts for space heaters or air conditioners. Similarly, different technologies supply different quantities of electricity, ranging from small amounts delivered by a solar lantern to nearly unlimited quantities from the centralized grid.

Capacity is measured in watts for grids, mini-grids, and fossil-fuel-based generators, and in watt-hours for rechargeable batteries, solar lanterns, and solar home systems. The measurement of capacity can be done across multiple tiers in which an increasing number of higher power-demanding appliances can be run (Table 6.3).

TABLE 6.3

Tiers of Capacity of Electricity Supply

CAPACITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Power Capacity Ratings (minimum in W or daily Wh)		3 W	50 W	200 W	800 W	2,000 W
		12 Wh	200 Wh	1.0 kWh	3.4 kWh	8.2 kWh
Supported Appliances		Very low-power appliances	Low-power appliances	Medium-power appliances	High-power appliances	Very high-power appliances
Typical Supply Technologies		Solar lantern	Rechargeable battery, SHS	Medium SHS, fossil fuel-based generator, mini-grid	Large SHS, fossil fuel-based generator, mini-grid, central grid	Large fossil fuel-based generator, central grid

It may be difficult to assess the capacity by simple observation. Standalone solutions, such as solar lanterns or solar home systems may (or may not) have a name plate indicating the capacity of the system. For other technologies such as mini-grids, there is usually no written information within the household premises. A rough estimation of available capacity may be done based on the source of supply, appliances used, and occurrence of overload-tripping (Annex 3).

Capacity may be approximated by considering the types of appliances used in the household.

Availability (Duration)

Availability (duration) of supply refers to the amount of time during which electricity is available. It is particularly important for lighting, entertainment, and climate control (fan, air conditioner, or space heater), and it is crucial for refrigeration, as food spoils when electricity supply is disrupted for several hours. Some other services require short use of electricity, such as mechanical loads and cooking (washing machine, water heating, etc.), which may be shifted to whenever the supply is available. However, longer duration of supply enables improved electricity service by allowing the user to choose the time of usage. Many electricity applications are used in the evening, lighting in particular. It is, therefore, important to ensure that electricity supply is available during the evening and that households are not subject to recurrent load-shedding due to the incapacity of the grid to cope with peak demand in the evening.

The availability (duration) of the electricity supply refers to the time during which electricity is available.

Availability, therefore, is measured through two indicators: (i) the total number of hours per day (24-hour period) during which electricity is available, and (ii) the number of evening hours (the 4 hours after sunset) during which electricity is available (Table 6.4).

Availability is measured by two indicators.

Reliability (Unscheduled Outages)

When electricity supply goes off unexpectedly it presents a significant nuisance to consumers, and blackouts often make it into the news (Badkar 2012; Mkinga 2014; Patinkin 2013). A common phenomenon emerging in places where the grid is highly unreliable is the proliferation of costly backup generators as a coping mechanism (Ilskog 2011; Karekezi and Kimani 2002). The impact on the use of electricity services depends on the frequency of the power cuts and their duration. Although duration and reliability may be seen as the same issue, it is important to differentiate them as different actions, and interventions may be required to address them separately. Also, unscheduled versus scheduled

The reliability of the electricity supply is defined in terms of frequency and duration of unscheduled outages.

TABLE 6.4

Tiers of Availability (Duration) of Electricity Supply

AVAILABILITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Hours per day (minimum)		4	4	8	16	23
Hours per evening (minimum)		1	2	3	4	4

TABLE 6.5

Tiers of Reliability of Electricity Supply

RELIABILITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Number of Disruptions					Max 14 disruptions per week	Max 3 disruptions per week with aggregate disruption duration of <2 hours per week
Annual System Average Interruption Frequency Index (SAIFI) and Annual System Average Interruption Duration Index (SAIDI)[a]					<730	<156
						<6,240 mins

[a] Includes effects of low duration of supply.

interruptions are perceived differently by consumers (Sagebiel and Rommel 2014). The cost of the interruption can be estimated based on the reduced consumption and thus loss of consumer surplus (Santosh, Granger, and Eswaran 2014).

A reliable supply should not have interruptions exceeding 120 minutes per week.

The reliability of electricity supply is a combination of two factors: frequency of disruption and duration of disruption. Poor supply reliability is a problem co-terminus with inadequate duration of supply. Supply disruptions may arise either due to curtailment to cope with generation constraints or due to breakdown of supply systems. Accordingly, reliability requirements are not specified for lower tiers, where duration of supply is less than 16 hours. Further, only the frequency of disruptions is specified for Tier 4; households at this tier still have significant inadequacies in duration of supply in any case. Only at the highest tier are both frequency and duration of disruptions specified (Table 6.5).

Quality (Voltage)

The quality of the electricity supply refers to the level and stability of the voltage.

The quality of the electricity supply is defined in terms of voltage (Table 6.6). Most electricity applications cannot be operated properly below a minimum level of supply voltage.[23] For example,

TABLE 6.6

Tiers of Quality of Electricity Supply

QUALITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Voltage					Voltage problems do not prevent the use of desired appliances (voltage is within the parameters specified by the prevalent grid code)	

compact fluorescent lamps (CFLs) do not light up if the voltage is too low, and fans do not deliver enough air circulation. Further, transformers draw a higher current at low voltage, subjecting the system to greater thermal losses as well as the risk of burn-out and fire. Low voltage usually results from overload in any electricity system—standalone home system, mini-grid or grid—or from long-distance low-tension cables connecting far-flung households to the grid. Voltage stability is also important, as fluctuations in voltage can damage equipment and cause electrical fires.

Affordability of Use

Affordability refers to whether households are able to pay for the electricity they need to use. Affordability entails a complex interaction between (i) the quantity of electricity consumed, (ii) the price of electricity, and (iii) the ability of the consumer to pay for the electricity consumed.[24] The ability to pay is a function of the income level as well as the expenditure priorities of the household.

Affordability refers to whether households are able to pay for the electricity.

Measuring affordability offers significant challenges. A common approach for estimating affordability in the energy sector is to use household expenditure on energy as a proportion of total household disposable income. However, this ratio does not facilitate easy interpretation of affordability. For example, it is not clear whether a 5 percent expenditure of household income on energy indicates better or worse affordability than a 7 percent expenditure on energy. Expenditure on electricity itself depends on the size of household, spending preferences, energy efficiency of appliances, and levels of electricity tariffs (Foster and Tre 2000).

Measuring affordability offers significant challenges.

To overcome these difficulties, affordability may be tested with reference to a defined standard consumption package, regardless of the actual consumption by the household. This standard consumption package could be set at 365 kWh, or 1 kWh per day, to represent minimum levels of use of electricity services to satisfy basic electricity needs, excluding cooking and heating needs.[25] Such an approach also bypasses the cumbersome task of measuring actual energy consumption through a household survey, which may be challenging in cases where an electricity bill is not available. An important challenge is to set a benchmark for an affordable share of electricity expenditure. Multiple studies have indicated that households spend about 10 percent of their income on energy, including electricity, as well as fuels (Fankhauser and Tepic 2005; IPA Energy 2003). The framework considers that a standard consumption package of 365 kWh per year should cost the household less than 5 percent of its income (Table 6.7).

To be affordable, a stipulated consumption of 365 kWh per year should cost less than 5 percent of the household income.

TABLE 6.7

Tiers of Affordability of Electricity Supply

AFFORDABILITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Cost of a standard consumption package of 365 kWh/year				< 5% of household income		

TABLE 6.8

Tiers of Legality of Electricity Supply

LEGALITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Bill payment					Bill is paid to the utility, prepaid card seller, or authorized representative	

Legality of Connection

Legality of connection is inferred by bill payment.

Legality of connection[26] to the grid needs to be monitored, as illegal connections pose a significant safety risk and also affect the financial sustainability of the utility (Kakkar and Mustafa 2013; Patinkin 2013; Smith 2004). Although the user may utilize various electricity services from an illegal connection, the risk of disconnection always lingers. Reporting on the legality of connection is challenging. The utility may not be able to accurately estimate the number of illegal connections, and households may be sensitive about disclosing such information in a survey. Legality may be inferred from indirect survey questions that respondents may be more willing to answer, as well as bill payment (Table 6.8).

Health and Safety

The evaluation of the risk of electrocution is a proxy for the safety of the electricity system.

Electricity access is safe when the wiring installation in the household is done according to national standards set by regulation, ensuring that people are protected from hazards that can arise from the operation of electricity under both normal and fault conditions. The household should also be aware of basic safety measures. In a household survey, safety may be measured through the evaluation of electrocution risk (Table 6.9). Household, therefore, are asked to report any past accident or perceived high risk of future accidents.

Multi-tier Matrix for Measuring Access to Household Electricity Supply

Electricity access is assessed based on the combination of seven attributes across six tiers.

The methodology is designed to be technology and fuel neutral when evaluating the performance of the electricity supply. Electricity access is measured based on the combination of seven attributes of

TABLE 6.9

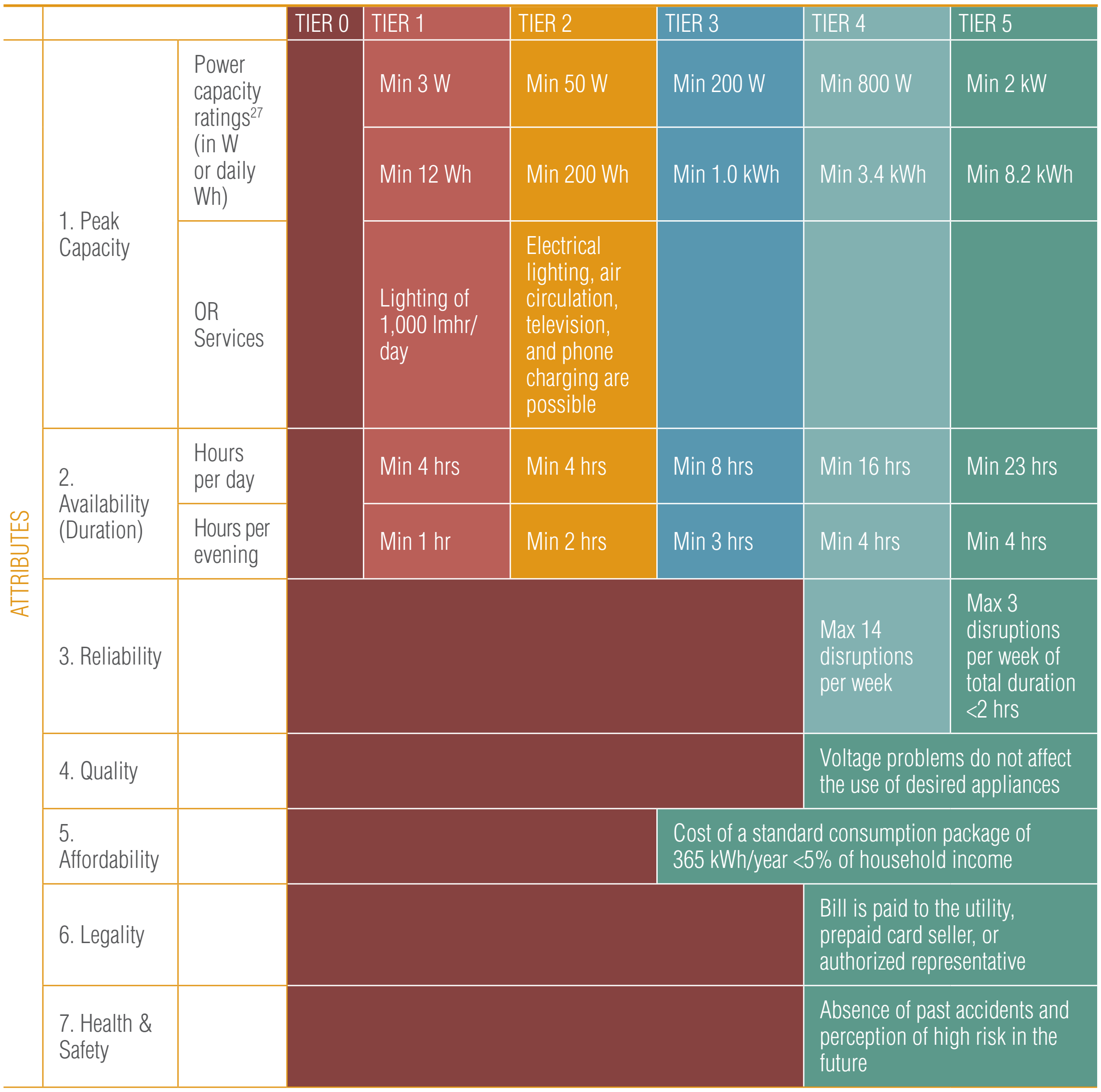
Tiers of Health and Safety of Electricity Supply

HEALTH & SAFETY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Wiring installation as per national standards					Absence of past accidents and perception of high electrocution risk	

energy across six tiers of electricity supply, starting with limited access to small quantities of electricity for a few hours per day and increasing gradually to unlimited supply (Table 6.10). Each attribute is assessed separately, and the overall tier for the household's access to electricity is calculated by applying the lowest tier obtained in any of the attributes.

TABLE 6.10

Multi-tier Matrix for Measuring Access to Household Electricity Supply



			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	1. Peak Capacity	Power capacity ratings[27] (in W or daily Wh)		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
				Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
		OR Services		Lighting of 1,000 lmhr/ day	Electrical lighting, air circulation, television, and phone charging are possible			
	2. Availability (Duration)	Hours per day		Min 4 hrs	Min 4 hrs	Min 8 hrs	Min 16 hrs	Min 23 hrs
		Hours per evening		Min 1 hr	Min 2 hrs	Min 3 hrs	Min 4 hrs	Min 4 hrs
	3. Reliability						Max 14 disruptions per week	Max 3 disruptions per week of total duration <2 hrs
	4. Quality						Voltage problems do not affect the use of desired appliances	
	5. Affordability					Cost of a standard consumption package of 365 kWh/year <5% of household income		
	6. Legality						Bill is paid to the utility, prepaid card seller, or authorized representative	
	7. Health & Safety						Absence of past accidents and perception of high risk in the future	

TABLE 6.11

Multi-tier Matrix for Measuring Access to Household Electricity Services

	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Tier criteria		Task lighting AND Phone charging	General lighting AND Phone Charging AND Television AND Fan (if needed)	Tier 2 AND Any medium-power appliances	Tier 3 AND Any high-power appliances	Tier 2 AND Any very high-power appliances

Multi-tier Matrix for Measuring Access to Household Electricity Services

Multi-tier access to electricity services measures the actual use of energy services.

A gradually improving electricity supply implies enhanced feasibility of electricity services. Additional electricity applications become possible as tiers increase along with the performance of supply. Therefore, a second matrix measuring access to household electricity services mirrors the supply matrix, based on the type of appliances used in the household (Table 6.11).

A given household can be on different tiers of electricity supply and electricity services.

The two multi-tier matrices measure different aspects of the electricity access: usability of supply and actual use of services. Therefore, it is possible for a household to obtain different tier ratings across the two matrices. A high tier of electricity supply does not automatically result in high use of electricity services. Use of electricity services usually lags behind improvements in electricity supply, as consumers gradually purchase electrical appliances. Use of electricity is also constrained by limited household income and costlier electricity at higher consumption levels due to telescopic tariffs prevalent in most countries. On the other hand, some households may be reporting high levels of electricity services despite poor electricity supply, because they can afford backup standalone solutions such as diesel generators and invertors. Thus, gaps between access to electricity supply and access to electricity services are only to be expected, revealing important indications for the kind of access enhancement interventions needed.

Multi-tier Matrix for Measuring Household Electricity Consumption

Access tiers may also be approximated by electricity consumption.

Access tiers may also be defined through electricity consumption levels, which are aligned with tiers of electricity services (Table 6.12). An estimated annual consumption level for each tier has been obtained by multiplying an indicative number of hours of use for a range of appliances by their power load in watts (Table 6.13). It is important to mention that an indicator based on kilowatt hours consumed cannot accurately reflect the diversity of appliances used or appropriately account for

TABLE 6.12

Multi-tier Matrix for Measuring Household Electricity Consumption

	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Annual consumption levels, in kWhs		≥4.5	≥73	≥365	≥1,250	≥3,000
Daily consumption levels, in Whs		≥12	≥200	≥1,000	≥3,425	≥8,219

TABLE 6.13

Indicative Calculation of Electricity Consumption, by Tier

APPLIANCES	WATT EQUIVALENT PER UNIT	HOURS PER DAY	MINIMUM ANNUAL CONSUMPTION, IN kWh				
			TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Task lighting	1/2	4/8	1.5	2.9	2.9	5.8	5.8
Phone charging	2	2/4	1.5	2.9	2.9	2.9	2.9
Radio	2/4	2/4	1.5	5.8	5.8	5.8	5.8
General lighting	12	4/8/12		17.5	17.5	35.0	52.5
Air circulation	20/40	4/6/12/18		29.2	87.6	175.2	262.8
Television	20/40	2		14.6	29.2	29.2	29.2
Food processing	200	0.5			36.5	36.5	36.5
Washing machine	500	1			182.5	182.5	182.5
Refrigerator	300	6				657.0	657.0
Iron	1,100	0.3				120.5	120.5
Air conditioner	1,500	3					1,642.5
Total			4.5	73	365	1,250	3,000

energy efficiency. Also, tiers of consumption are distinct from tiers of access to energy services, which in turn are different from tiers of access to energy supply.

OBTAINING DATA FOR MEASURING ACCESS TO HOUSEHOLD ELECTRICITY

A comprehensive measurement of household access to electricity in any geographic area requires data and information about several aspects, including:

A comprehensive measurement requires extensive collection of data and information.

- Primary source of electricity
- Capacity of primary source in watts and watt hours
- Secondary (backup) sources of electricity
- All electrical appliances in use
- Duration of supply during the day and during evening hours
- Reliability of supply with regard to average frequency and duration of interruptions
- Quality of supply with regard to level and stability of voltage

- Affordability in terms of cost of a standard package for the technology in use, with reference to the household income
- Legality of connection to grid based on whether bill is being paid to the authorized agencies
- Health and safety with regard to fumes from batteries, emissions from generation, and unsafe electrical fittings that can harm the users
- Consumption of electricity by the household based on actual measurement or electricity bill

Information about these aspects can be obtained either from the demand side (household energy surveys and sensor-based instrumentation) or the supply side (utility and project/program data). Each of these two approaches for data gathering has certain advantages and disadvantages, as explained next.

Demand-Side Measurement

Demand-side measurement involves collection of data from electricity users through household energy surveys and the use of sensor-based instrumentation.

Demand-side measurement involves collection of data from electricity users through household energy surveys and the use of sensor-based instrumentation. Household energy surveys can provide information about all of the required aspects based on the respondent's awareness, perception, and willingness to report. Although such surveys can provide an insight into the user's experience, they may suffer from inaccuracies and subjectivity. Some of the technical parameters can be better obtained by deploying sensor-based instrumentation that can capture information about duration of supply, consumption, voltage levels, and disruptions. However, other information, such as off-grid solutions, use of backup secondary solutions, affordability (based on household income), legality, and health and safety aspects, can only be obtained through household energy surveys. A combination of household energy surveys with sensor-based instrumentation provides the ideal approach for data collection on household electricity access.

Supply-Side Measurement

Supply-side measurement can be done using utility and project or program data.

Supply-side measurement can be done using utility and project or program data. However, in the developing country context, utility data may suffer from several deficiencies. Typically, utilities do not have data about off-grid installations and secondary or backup solutions. Also, they may not objectively record and share information about duration and reliability of supply. Many utilities do not have robust systems for recording instances of supply disruptions and time to restoration. Data on low and unstable voltage is also not gathered by most utilities. Utilities do not have information about household income levels for determining affordability. Finally, utilities in many developing countries do not have information about the safety aspects of electrical installations in households.

Despite several limitations to supply-side utility data, utilities can undertake a basic estimation of the access to electricity being provided by them. This can be based on information about connectivity, duration of supply, and reliability, while ignoring the other attributes. The result would reflect an upper bound of the actual tier rating rather than the actual tier rating itself.

ANALYSIS OF RESULTS

The multi-tier framework yields a wide range of results that can be compiled and analyzed to produce an energy access diagnostic for a geographic area. Such a diagnostic includes in-depth disaggregated data analysis, as well as aggregated analysis in the form of an index of access, aiming to facilitate planning and strategy, project design, monitoring of progress, impact evaluation, and comparison across geographic areas and over time.

Results can be compiled and analyzed to produce an energy access diagnostic.

Disaggregated Analysis: Cross-Cutting Analysis of Access to Household Electricity

Data can be sliced variously to analyze different attributes of electricity supply and bring out the magnitude and locus of various deficiencies. Among the various indicators that can be calculated are: (i) proportion of households using various electricity sources (grid, mini-grid, diesel generator, solar home system, rechargeable batteries, solar lanterns, etc.); (ii) proportion of legal connections to the grid; (iii) average hours of electricity supply; (iv) proportion of households receiving different durations of electricity supply during the day; (v) proportion of households receiving different durations of electricity supply during the evening; (vi) proportion of households reporting unreliable supply; (vii) average frequency of unscheduled interruptions (system average interruption frequency index [SAIFI]); (viii) average duration of unscheduled interruptions (system average interruption duration index [SAIDI]); (ix) proportion of households reporting voltage problems; (x) proportion of households that cannot afford a basic electricity consumption package; (xi) proportion of households with risk of electrocution; (xii) proportion of households using each electricity service; and (xiii) average consumption of electricity across households.

Data can be variously to analyze different attributes of electricity supply for a disaggregate analysis.

Data can also be based on the technology deployed to obtain insights into how various attributes vary for the users of specific technologies. Such sliced analysis can also be performed on the basis of other factors, such as household income, location (urban, peri-urban, rural), household size, female- versus male-headed household, and so forth.

Aggregated Analysis: Index of Access to Household Electricity

To compile the information captured by the multi-tier matrix into a single number representing the level of access to household electricity in a selected geographic area, a simple index can be calculated by weighting the tiers and arriving at a weighted average. The following formula is applied:

A single number representing the level of access to household electricity may be compiled based on the multi-tier matrix.

$$\sum_{k=0}^{5}(20 * P_k * k)$$

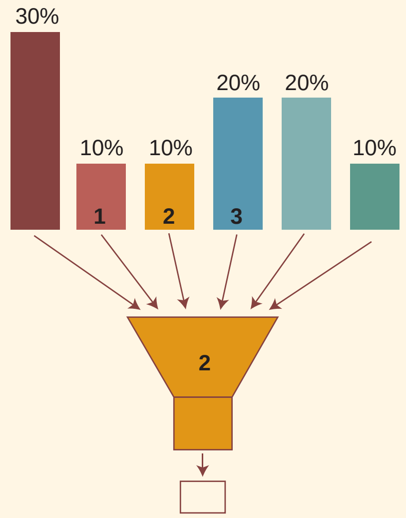
k: tier number

P_k: proportion of households at the kth tier

The index evaluates both the extent of access (how many households have access) and the intensity of that access (the level of access that households have)[28] (Figure 6.1).

FIGURE 6.1

Example of Index Calculation



Comparison across Geographic Areas and over Time

The index, as well as disaggregated data, may be compared across countries or any geographic area, including subnational, regional, and worldwide.

Both disaggregated and aggregated data may be compared across geographic areas and over time. The index can be calculated for any geographic area, such as a country, a province, a district, a town, or a village, but also a continent and the world as a whole. For example, developed countries are likely to have an index value close to 100, whereas in many countries in Sub-Saharan Africa, the index value may only reach 20 or less. The index for a larger geographic area can be obtained by calculating the population-weighted average of indices across the smaller geographic areas within the total area. For example, the index at the state level can be obtained by calculating the weighted average of the district-level indices. Similarly, state-level indices can be aggregated into a national-level index, which would in turn be used to calculate regional and global indices.

The index, as well as disaggregated data, may be compared over time to track progress in access.

Progress in improving access to household electricity can be tracked by comparing indices over time. Further, a comparison of disaggregated data over time would detect areas where efforts have been successful, as well as bottlenecks inhibiting higher index values.

CONCLUSION

The multi-tier framework provides a comprehensive tool to capture information about household access to electricity encompassing various attributes. It allows disaggregate as well as aggregate analysis to yield detailed information about various parameters as well as indices that facilitate comparison over time and across geographic areas.

ENDNOTES

[19] Two exceptions are the United Arab Emirates (UAE) (3.66%) and Qatar (3.53%).

[20] Illegal connections include secondary connections (connection through a neighbor) and direct theft.

[21] The extent of the injury depends on multiple factors, including voltage, current strength and type (alternative current [AC] or direct current [DC]), resistance to flow, duration of contact with the electricity source, etc.

[22] Households in Bangladesh have kept their standalone home systems even when the grid arrived in their area, despite the option they had to sell it back to the provider (Sadeque et al. 2014).

[23] Frequency has reliability consequences for the grid, but does not directly affect usability of applications.

[24] Affordability of upfront costs, such as connection to the grid or purchase of a standalone system, are not included here, unless they are being paid off at the time of the survey through an installment scheme. If not, such costs are considered affordable given that they have already been paid for.

[25] Cooking and heating needs are excluded from the standard electricity package, for two main reasons: (i) other fuels are often used for cooking (as well as heating), and (ii) heating needs vary with climate and location.

[26] Illegal connections include secondary connections (connection through a neighbor) and direct theft. Other illegal practices such as meter tampering, billing irregularities, and unpaid bills have been excluded because they are much more difficult to detect.

[27] The minimum power ratings in watts are indicative, particularly for Tier 1 and Tier 2, as the efficiency of end-user appliances is key for determining the real level of capacity, and the type of electricity services that can be performed.

[28] This aggregation method is used by the Multi-Dimensional Energy Poverty Index (Nussbaumer et al. 2012).

7

HOUSEHOLD ACCESS TO LIGHTING AND PHONE CHARGING

This chapter discusses the measurement of the transition from status quo approaches to Tier 1 access to modern lighting and mobile phone charging.

The first tier of the multi-tier framework for measuring access to household electricity services is based on two services critical for human development: lighting and charging capabilities for mobile communication (mobile phone charging). Each of these services shares the unique feature of being valued enough by households to cobble together energy access with a range of alternatives when electricity is not available, both for off-grid households in permanent deprivation and grid-connected household during blackouts. Without access to good-quality grid supply or off-grid power systems, people turn to fuel-based lighting, disposable flashlights, and fee-based mobile phone charging to fill the gaps. Tier 1 energy supply is characterized by replacing these status quo coping mechanisms with access to modern off-grid power. This chapter discusses the measurement of the transition from status quo approaches to Tier 1 access to modern lighting and mobile phone charging.

Lighting

Electricity offers lighting service that is many times more affordable than fuel-based lighting, but still fails to reach over a billion people.

Lighting is inextricably linked with household energy and (along with cooking) is arguably one of the original "household energy demands." Starting with firelight from hearths and stoves that lit up the night, lighting evolved into better-performing fuel-based solutions like candles and kerosene lamps, which remained pervasive across the world until the advent of electricity (Figure 7.1). Electricity offers hundreds to thousands of times more affordable lighting service than fuel-based lighting and has spread rapidly over the last 100 years, but still fails to reach over a billion people (Alstone et al. 2014a). Tier 1 energy access involves making the transition to electricity for lighting with an individual or household-level energy system.

LED or "solid-state" lighting represents a quantum step up in lighting efficiency.

Similar to the large difference between fuel-based and electric light with arcs and incandescent sources, light-emitting diode (LED) or "solid-state" lighting represents a quantum step up in efficiency for converting electricity to light. The efficacy (lumens per watt) of LEDs recently surpassed that of fluorescent lighting and is projected to continue to rapidly rise in the coming decades (Azevedo et al. 2009; Tsao and Waide 2010; USDOE 2013). Figure 7.2 shows a stylized summary of the efficacy trends for electric lighting.

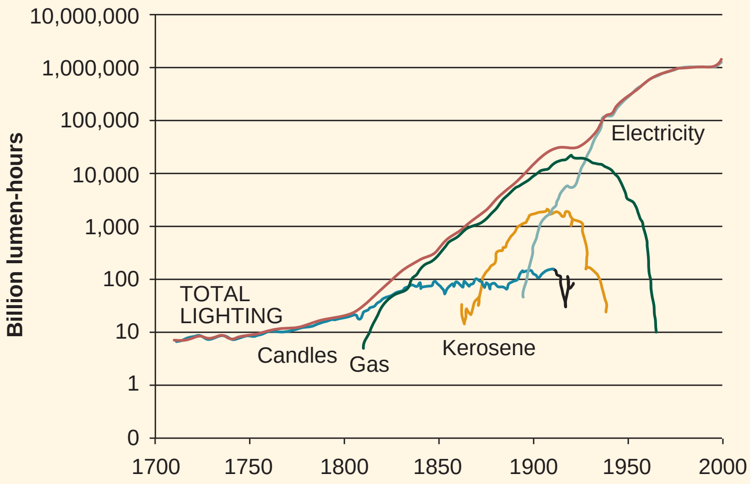
Off-Grid Energy Systems

Different types of solar systems can be classified according to portability and functionality.

Off-grid lighting is powered by an emerging continuum of off-grid individual and household-level energy systems that contribute to Tier 1 access. Many of these rely on solar power, which has become more affordable in the past decades (Dalberg 2013). The wide capacity range of the solar home

FIGURE 7.1

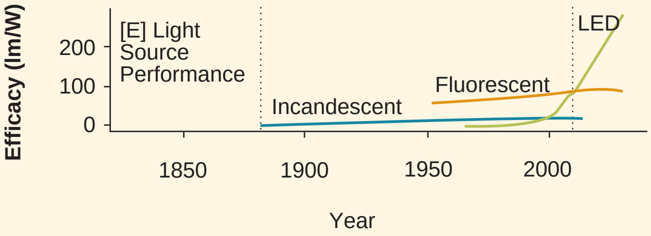
Consumption of Lighting by Candles, Gas, Paraffin (Kerosene and Town Gas), and Electricity in the United Kingdom, 1700–2000



Source | *Adapted from Fouquet and Pearson 2009.*

FIGURE 7.2

Efficacy Trends for Electric Lighting



Source | *Adapted from Azevedo et al. 2009.*

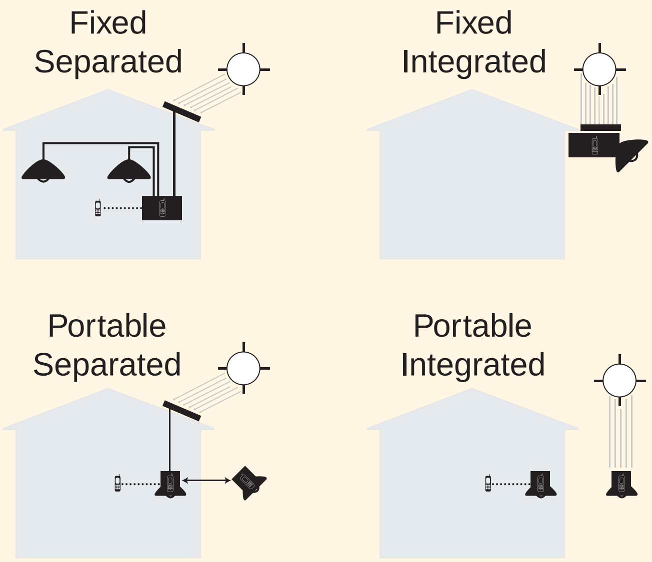
system is enabled by the scalability of solar cells (from sub-watt cells integrated into some of the smallest-scale lighting devices to gigawatt-level grid-connected power plants). Different types of solar systems can be classified according to portability and functionality, as summarized in Figure 7.3. The classification is based on the portability of the lamp (portable or fixed), and the arrangement of the solar module (integrated into the battery pack or separated with a cord). Fixed separated systems often have a classic "solar home system" arrangement, while fixed integrated systems refer to applications such as outdoor lighting. In addition to being useful for product identification, the classification also provides a general sense of the scale of the system—typically portable integrated products have the lowest cost and performance, followed by separated lamps, and finally, fixed products.

The wide range of solar technologies allows them to be more affordable for the poor.

The wide range of solar technologies allows individual and household-level systems to be more affordable for the poor. Cash constraints, including limited access to consumer finance, is a key barrier to accessing modern lighting (Niethammer and Alstone 2012). Rural poor pay a lot for traditional lighting, often 2 to 5 percent of their income or more (Alstone et al. 2014a; Bacon et al. 2010; REMMP 2014). They have limited ability to save for investing in a modern alternative. Figures 7.4 and 7.5 show that lowering the upfront cost of modern lighting solutions can dramatically increase their reach to a much larger fraction of the off-grid population.

FIGURE 7.3

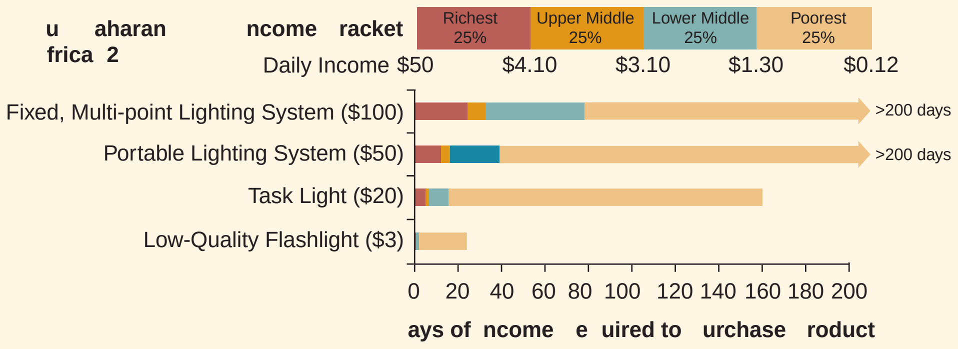
Classification of Individual and Household-Level Energy Systems



Source | Adapted from IEC 2013..

FIGURE 7.4

Days of Income Required to Purchase Solar Systems in Five Sub-Saharan African Countries

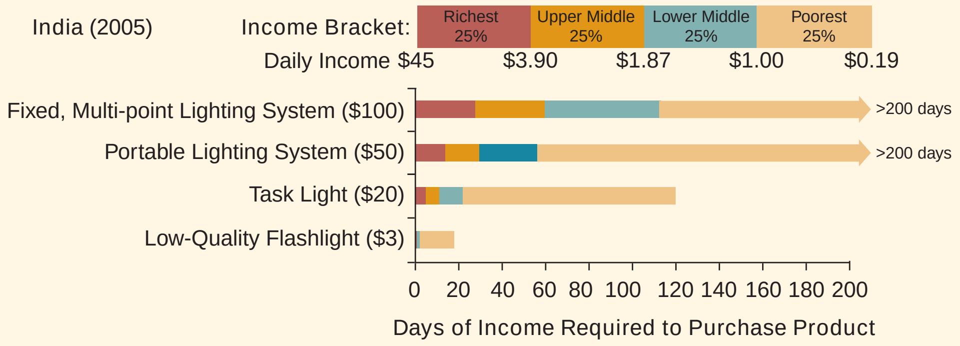


Note | *Income data are self-reported in the context of a 2008 market assessment survey conducted by Lighting Africa in five countries: Kenya, Ghana, Tanzania, Ethiopia, and Zambia (Baker and Alstone 2011). n = 1,000 for each country for a total of 5,000.*

Source | *Adapted from Alstone et al. 2011.*

FIGURE 7.5

Days of Income Required to Purchase Solar Systems in India



Note | *Data come from the India Human Development Survey (2005). The survey includes 45,000 households, among which about two-thirds are electrified. Only 15% of 'on-grid' households reported access to 24 hours/day electricity supply.*

Source | *Desai et al. 2008.*

Mobile Communication

Mobile telephony has witnessed a much faster adoption than electricity, and has emerged as a driver for adoption of electricity solutions.

Although it has taken over 100 years to reach about 80 percent of the world with electric light, the mobile phone has seen an extraordinary trajectory of adoption, from roughly zero in the 1990s to nearly ubiquitous access today (WB 2012). Globally there are more active mobile phone accounts than people, and in the developing world there are currently 90 accounts for every 100 people (International Telecommunications Union 2014), meaning that in many countries the rate of household access to mobile phones is much higher than the rate of access to electricity. Inexpensive handsets and scratch cards for airtime were key innovations, along with the clear value of easy access to information and communication technology (ICT).

ICT has long been a key appliance driving demand for electricity, from radio to television and mobile connectivity today. Energy for powering television, phone charging, and other ICT is highly valued by off-grid people and often drives adoption of off-grid electricity (Jacobson 2007). There are important parallels today with developing ICT and off-grid energy systems, as they mutually support each other (Nique and Arab 2013).

Over 500 million people who regularly use mobile phones lack access to household electricity (Roach and Ward 2011), and rely on expensive fee-based charging services (GSMA 2011; Collings 2011). Others have some level of access to electricity outside the household, where they charge their mobile phone. People with access to electricity for charging have been shown to make more use of mobile services, as they are able to leave their devices turned on for a longer period of time. Additionally, they have reduced charging costs, some of which can be diverted to airtime (GSMA 2011).

BENEFITS OF LIGHTING AND COMMUNICATION ACCESS FOR SOCIOECONOMIC DEVELOPMENT

Lighting

Electric lighting contributes to socioeconomic development by improving health and safety, reducing the burden of fuel expenditure, and improving the quality of light.

Replacing fuel-based and status quo lighting with good-quality electric lighting has a range of important human development benefits:

Improving public health and safety: Fuel-based lighting induces exposure to particulate matter and other indoor air pollutants that cause chronic disease (Apple et al. 2010; Lam et al. 2012). In addition, there are important and acute health and safety risks that are often much more salient for users: accidental fires accelerated by spilled fuel that lead to burns and deaths, broken glass from lamps, explosions of adulterated fuel, and accidental ingestion of kerosene by children (often stored in bottles in the kitchen) can all be tragic outcomes of fuel-based lighting and are not uncommon (Mills 2012).

Lifting the economic burden of paying for fuel-based lighting: Incumbent systems typically consume 2 to 5 percent of income (Bacon et al. 2010) but provide paltry service in return (Mills 2003; Mink et al. 2010). Furthermore, the price of kerosene is linked with global oil prices, which can fluctuate wildly, and markets for kerosene in rural areas can be subject to mark-up from transport costs and scarcity. This directly exposes the rural poor to seemingly random changes in the price of fuel (Tracy and Jacobson 2012).

High-quality light: The light produced by flames is usually (but not always) of poor quality compared to electric light (Alstone et al. 2010). The flame itself causes glare, reducing the ability of one's eyes to make best use of the available light. Flickering can cause eye strain, and dimness leads to difficulty with task-oriented applications, like reading, writing, and cooking (Jacobson et al. 2013). Thus, people report strong preferences for LED and other electric lighting (Alstone et al. 2014b).

Climate: Although fuel-based lighting is carbon dioxide (CO_2) intensive compared to electric lighting (in terms of CO_2 emissions per unit of lighting service), the levels of consumption are so low that it is not a critical source of greenhouse gases. However, the black carbon associated with some wick-based lamps is a potent greenhouse gas and leads to localized effects (Lam et al. 2012). The scale of the black carbon effect from fuel-based lighting appears to be just as large as or many times larger than open-wick lamps. Regional forcing creates added incentives for this climate mitigation opportunity (Jacobson et al. 2013).

Mobile Communication

Access to communication services also provides a range of benefits to human development. Unlike gains from access to light that arise from displacing incumbent fuel-based (dangerous and expensive) technology, the gains from access to communication stem from augmenting communication and information opportunities. Where lighting is a service in itself, access to ICT is a platform on which the following valuable services are delivered:

Mobile communication improves social connectivity, enhances financial inclusion and economic activity, facilitates emergency assistance, and supports broader development by providing a platform for m-governance.

Social connectivity: The first, obvious role of mobile phones is directly connecting people with their families and broader social networks through voice and text messaging. The ability to quickly and easily communicate is highly valued, both for interpersonal and professional connections (Burrell and Matovu 2008). Maintaining and strengthening family and personal relationships both within communities and among the diaspora are highly valued (Donner 2006).

Financial inclusion: Rapidly expanding mobile money services enable people to save and transfer electronic cash, which has wide-ranging implications for the structure and operation of economies (both local and national) in the developing world as the services move from an emerging technology to being widely integrated (Donner and Tellez 2008; Hughes and Lonie 2007; Kendall et al. 2011). Access to mobile money is particularly important for remittances, which can reduce risks from rural income shocks through better responsiveness from urban and expatriate support (Jack and Suri 2014).

Participation in the economy: People have used ICT to access and amplify their ability to engage with a range of markets, where cheap and fast communication can lead to economic gains (Aker and Mbiti 2010). Studies focusing on labor and commodity markets have found a range of gains from ICT. In a seminal paper on fishers and mobile phone adoption in Kerala, India, Jensen (2007) documented a dramatic improvement in the efficiency of the auction-based wholesale markets at shore landings, as communications between boats at sea and people on shore was enabled by mobile phones. Others showed that such improvement stem from a complex combination of previously existing institutions and relationships in the context of which mobile phones amplified the ability of some market actors to improve outcomes, with spillover effects for the broader market (Abraham 2007; Srinivasan and Burrell 2013).

Emergencies: Access to mobile phones can be critically important for getting help in medical emergencies (Burrell and Matovu 2008; Srinivasan and Burrell 2013) and coordinating responses by governments and citizens in times of disaster and unrest (Goldstein and Rotich 2008). At critical moments for individuals and communities, widespread access to communication is vital for coordination and has high value.

Supporting broader development: It is not possible to give full treatment in this chapter to the range of approaches that use ICT to rethink the way basic public goods such as governance, health, education, water, and energy are delivered. The critical element is that mobile phones are a platform on which people and organizations are building myriads of ICT applications that can enable individuals to amplify and shape their livelihoods and relationships. Inclusion in this digital revolution requires relatively small amounts of electricity as a basic input for participation, with large gains for those with access.

BASIC PRINCIPLES

Tier 1 electricity access involves two services: lighting and phone charging.

Tier 1 electricity access can be defined in terms of lighting and communication services: Tier 1 electricity access is defined in the previous chapter as a minimum of 3 watts of electricity supply for at least 4 hours each day. This tier is a unique case because the systems involved are often portable and relatively small, lending themselves to individually controlled rather than broad household-level use. Further, it typically involves only two services, compared to the expanding and more diverse set in higher tiers. Therefore, it is possible to define Tier 1 in terms of lighting and phone charging characteristics.

Access to lighting in off-grid situations is an individual rather than household-level service.

Basic lighting is an individual rather than household-level service: Small amounts of light from off-grid solutions are often difficult to share physically among multiple members of a household. Also, the number of light sources is typically limited. As a result, access to light in off-grid situations is often an individual rather than household-level service. Therefore, access to lighting should be measured based on the characteristics of every standalone lighting device in the household and the number of people it is capable of serving (as opposed to purely counting on a household level). In economics parlance, lighting is treated as an excludable good.

Access to phone charging can be treated as a common good within the household.

Basic phone charging is a household rather than an individual-level service: Phone charging is treated as a common good within the household. This distinction from lighting is particularly important because although simultaneous use of ICT is difficult on a physical basis, the assumption is that it is easier and more common to share the utility benefits of phone-charging access within the household. ICT has a diverse set of often difficult-to-measure benefits, some that are a common good and others an individually valuable good.

Technology-neutral approach with emphasis on elimination of harms: Although most off-grid lighting solutions tend to be solar energy based, the proposed measuring framework should adequately classify other solutions such as biogas-based lighting. Therefore, the approach should define lighting solutions as sustainable, the one that yields substantial human development benefits. Use of systems that do not dramatically eliminate the harms and hardships of the traditional lighting solutions should not be counted toward access.

All sustainable lighting solutions that eliminate the harms and hardship of traditional lighting should be counted toward access to lighting.

Tier scores should have a simple relationship with service levels: Despite a simple relationship with the level of service, the tier score should still reasonably describe the complex dynamics of Tier 1 energy access in ways that are understandable and implementable by a broad set of stakeholders. The framework should use easy-to-discuss benchmarks as anchor points.

The tier score should reasonably capture the complex dynamics of Tier 1 energy access.

Tier targets should be aspirational but realistically affordable in the context of the purchasing power of the off-grid poor who pay for and use Tier 1 systems: The intent of Tier 1 access is to capture the first rung of the energy ladder where significant (but not complete) human development benefits accrue from electrification.

Tier targets should be aspirational but realistically affordable in the context of the purchasing power of the off-grid poor.

Account for multiple devices in a household that incrementally fulfil service needs: The approach should account for the combined benefits of access for users that utilize several devices and systems to achieve access—a common practice. It should measure the incremental progress from even relatively small levels of service and consider individuals' ability to access energy outside of household premises.

The approach should measure the use of multiple devices in the household.

Avoid perverse incentives in system design: Delivery of lighting solutions may be sensitive to the thresholds defined by the definition of energy access, as donor programs are likely to recognize results on this basis. Therefore, the approach should define continuous relationships between lighting system performance and the expected impacts, without break-points or cut-offs that could reduce the dynamism in device design.

The approach should avoid any perverse incentives that may promote inferior products.

MINIMUM PERFORMANCE THRESHOLDS FOR BASIC ACCESS

There are few studies focusing on performance standards for off-grid lighting applications (Alstone et al. 2014c). This section summarizes data that help inform the benchmark levels for Tier 1 access to lighting and communication. The relevant parameter for lighting is lumen-hours of lighting service, the combination of the number of hours or service with the brightness or light output during that operation. For phone charging, the unit of service is watt hours of charging, which depends on the devices used.

The relevant parameter for lighting is lumen-hours per day, whereas for communication it is watt hours of phone charging.

Lighting benchmark: Tier 1 access to electricity supply is defined in terms of power capacity and duration. Equally, the Tier 1 benchmark for access to lighting can be defined in terms of power (brightness) and duration (run-time).

Over 90 percent of groups across Africa and India are satisfied with levels around 25 lumens.

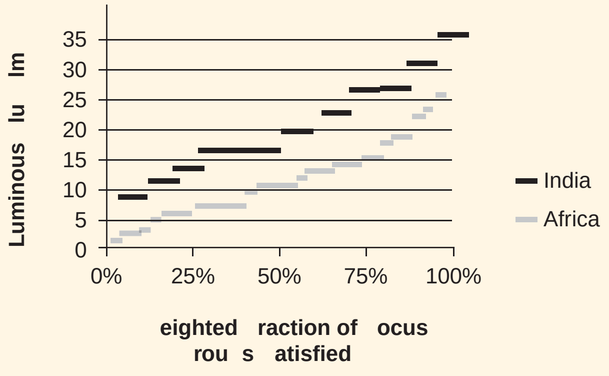
Minimum threshold for brightness: Focus group results collected by Lighting Global in 2011–2012 (summarized in Figure 7.6) show that people making the transition to electric lighting report being satisfied with notably lower levels of light compared with the levels that the grid provides. Over 90 percent of focus groups across Africa and India are satisfied with levels around 25 lumens. It is important to note that all lumens are not created the same (Figure 7.7). The light from LEDs is directional, or more concentrated in the direction the LEDs are aimed, compared to fuel-based lighting, which is omnidirectional. Therefore, the same luminous flux can result in substantially higher (~4×) brighter illumination on a surface, particularly in rooms with dark walls that absorb stray light. This general level for achieving basic access with roughly the same level of lighting as the incumbent has also been observed anecdotally and in other studies (Alstone et al. 2014b).

A rough global average of 4 hours of evening use of lighting solutions is observed.

Minimum threshold for duration of lighting: The run-time for lighting varies widely across households, but with a rough global average of 4 hours per day. The distribution in daily use of fuel-based lighting (self-reported in several countries of Sub-Saharan Africa and modeled based on kerosene consumption in India) is shown in Figures 7.8 and 7.9. It should be noted that the Sub-Saharan Africa distributions are only for night-time use, which ignores the common practice of early morning lighting. The India estimates are based on volumetric consumption results from a broad

FIGURE 7.6

Group Satisfaction with Levels of Luminous Flux, Africa and India



Note | *Weighted fraction of focus groups whose group expectation is exceeded for ambient lighting from a product that has passed a quality check, aggregated across all of the focus groups in 2011 for Africa (n = 34) and 2013 for India (n = 12) and weighted by the focus group size.*

FIGURE 7.7

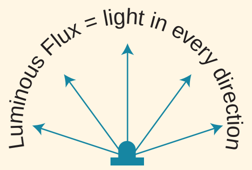
Basic Lighting Concepts

Brightness and Luminous Intensity

Intensity is often equated with how “bright” a light appears, and was originally described using light from a burning candle. Such ‘standard candles’ were used to define the candela, the basic unit of luminous intensity. A small spot of light like a candle (or an OLD) may appear bright, but not produce enough overall light to cover a larger surface or illuminate a room very well.

Luminous Flux and Illuminance

Luminous flux, measured in lumens (lm), is typically used to describe the total amount of light that a light source produces in all directions. A lumen represents a specific perceived amount of light, and takes into account the sensitivity of the human eye (the eye is more sensitive to green light and less sensitive to deep red and deep blue/purple).



Lumen Output Examples

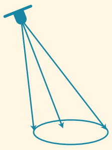
Standard candle = 12 lumens
Kerosene wick lantern = 8–40 lumens
Pressurized kerosene lamp = 330–1000 lumens
60 watt GLS incandescent = 900 lumens
23 watt compact fluorescent = 1000 lumens

Basic Photometric Units

Photometric Term	*SI Unit*	*Basic Units*
Luminous Flux	Lumen	lm = cd • sr*
Illuminance	Lux	$lx = lm/m^2$
Luminous Intensity	Candela	Cd = lm/sr

**sr = steradian = solid angle. A solid angle is a two-dimensional angular span in three-dimensional space, like a cone intersecting a sphere.*

Illuminance is the amount of light incident on a surface, measured in lumens per meter^2 (lm/m^2). The unit of illuminance is lux; 1 lux = 1 lm/m^2. A typical handheld illuminance meter measures lux (or foot-candles in English units).



Illuminance = Lux = Light incident on a surface. This is what you measure with an illuminance meter; this is NOT luminous flux!

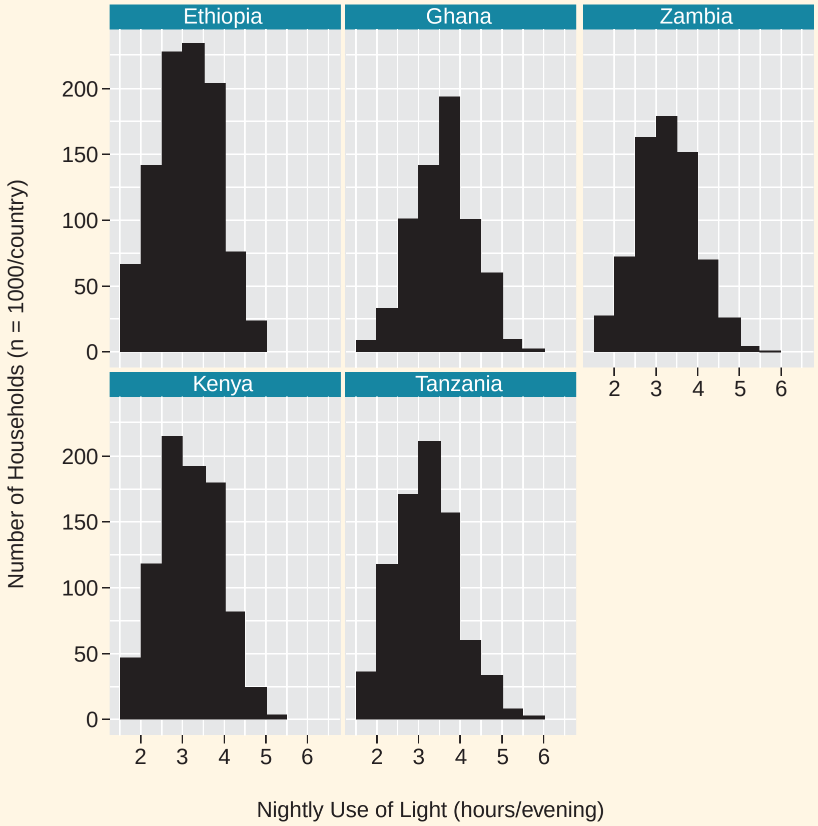
Flux vs. Illuminance

The difference between lumens and lux is important. A focused LED can concentrate light onto a small area, and the illuminance at this point can be very high. But the total lumen output (luminous flux) for the device can still be very low because the light is only emitted in a narrow angle.

Source | *This is an excerpt from a Lighting Global Technical Briefing Note. It is part of a series available here at http://lightingglobal.org/resources/briefing-notes.*

FIGURE 7.8

Histograms of Self-Reported Nightly Use of Fuel-Based Lighting in Five Sub-Saharan Countries



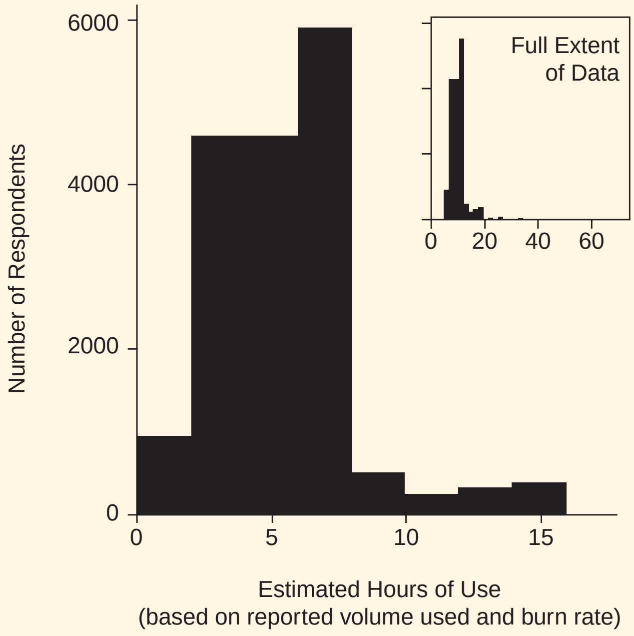
Note | *The histograms show the distribution in responses for people who could recall the typical time they begin and end the use of artificial light in the evening (this does not include any use in the mornings). The household survey sample size was 1,000 in each country.*

Source | *Lighting Africa 2008.*

household survey. Additionally, many people who use fuel-based lighting are income constrained and may use more lighting if it is available and affordable. A notable difference in the distributions for hourly use between Sub-Saharan Africa and India is the relatively “fat” left side of the distribution in India, where there is higher mean and median use. This may be a result of using different methods for reaching the estimates, or could reflect the subsidized price for kerosene in India, where a rationed amount is subsidized for each household using a system of coupons and approved sellers, but there also exists a black market for the marginal additional kerosene that some households use.

FIGURE 7.9

Estimated Hours of Nightly Use of Kerosene, India



Note | Estimated hours of nightly use of kerosene by people who report using kerosene for "mostly lighting" in their household, a subset (n = 16,667) out of a full survey sample of ~41,000 in the 2004–2005 India Human Development Survey (IHDS). The estimate is derived from self-reported consumption of kerosene that results in an estimate of monthly volumetric use (liters/month). Using an estimated burn rate of 0.0215 liters/hour for fuel-based lamps (the mean of the measured samples in a technical assessment of fuel-based lighting (Mills 2003) and dividing by 30 days in a typical month leads to estimates for the implied hours of use. The mean of the data is 5.6 and the median is 4.6.

Knowing the number of watt hours available for phone charging is sufficient for estimating access to electricity for phone charging. Although there is a relatively large difference in battery sizes of phones (a factor of roughly 5 from basic phones to smartphones), this variability is far less than that of efficacy derived from lighting. Setting targets for lighting starts with defining a metric for service performance based on a brightness target (lumens) and operational time target (hours/day) to achieve a lighting service metric of lumen-hours/day (Alstone et al. 2014c).

Measuring light output directly is costly and difficult, so a proxy measure is required for field observations, which involves either identifying a product with known characteristics or estimating the energy available and efficacy of the light source based on observations.

A proxy measure for light output is required.

DEFINING TIER 1 ACCESS

A score for access to lighting is defined in terms of number of persons whose basic lighting needs are met.

In the proposed framework, devices are rated for the level of access to lighting on a continuous basis, with a non-linear function that links a set of performance benchmarks. A score for access to lighting is defined in terms of number of persons whose basic needs are met depending on the typical lumen-hour capabilities of the system. The score is additive based on all light sources available (each source meets a number of individuals' needs and the total is the sum across persons, up to the full household).

Energy for communication is defined after electricity for lighting is counted.

Access to electricity for phone charging is defined in terms of watt hours expected to be available after the lighting score is counted. Full credit for charging capabilities is given if systems can charge one phone every day, whereas partial (two-thirds) credit is given if one phone can be charged every three days. If the phone charging service is available at a short distance from the household, but remains accessible and feasible (e.g., a fee-based charging shop or neighboring household), one-third credit is given. The credit for mobile charging is scaled so it provides 30 percent of the Tier 1 score.

Further details with specific mathematical relationships and benchmarks are explained in the following section.

Lighting Access

Lighting access provided by each device is measured on the basis of the number of people that the device is able to serve.

Lighting access provided by each device is measured on the basis of the number of people that the device is able to serve. Such measurement of number of people served includes a fractional measurement where the device may be seen as being capable of serving only a fraction of a person's daily lighting needs. The relationship between lumen-hour service and access is defined based on a set of benchmarks for service that are joined by non-linear functions reflecting the utility of light. This non-linear relationship is reflective of the background market and research data (presented earlier) and practical insights from organizations and individuals who are active in supporting and distributing off-grid lighting systems. For each lighting device, and on a household level, the number of people with service from a particular unit or system is capped at the household size.

Measurement of access to lighting is designed around three benchmark levels.

The three core benchmarks of lighting service are 0, 100, and 1,000 lumen-hours per day. The relationship for estimating the access level based on brightness begins at the "zero" point: access for 0 persons at 0 lumen-hours. Even very small amounts of modern light are counted. From 0 to 100 lumen-hours, there are increasing levels of access for additional light, reflecting increased utility as the quantity approaches levels that are typically available from fuel-based lighting (roughly 25 lumens for 4 hours a day or 100 lumen-hours). Based on user self-reported expectations for brightness and run-time discussed earlier, combined with the fact that low-level lighting is an individual service, a second benchmark is placed at 100 lumen-hours for meeting the needs of one person. Multiple people using the same light source simultaneously can often reduce the utility of lighting because it can be difficult optically to spatially distribute light where it is needed for meeting joint needs. Thus, there are declining access returns on additional light as more people are served, up to a full (typical/average size) household of five being served by 1,000 lumen-hours. This represents the third benchmark for lighting.

Two different mathematical functions are used to link the benchmarks.

Two different mathematical functions are used to link the benchmarks (Figure 7.10). The first, from 0 to 100 lumen-hours per day, has increasing returns on additional light and takes a logistic form. The logistic function is defined so it passes through the benchmarks and a "tuning" benchmark of 1/100th of a person at a light level equivalent to half the service from a candle (20 lumen-hours per day). Above 100 lumen-hours per day, a logarithm (base 10) that reflects the declining returns to lighting, is used. It passes through the benchmarks at 100 and 1,000 lumen-hours per day. At levels above 1,000 lumen-hours per day from a particular source, additional persons can be served following the logarithmic function. The number of persons who are served with Tier 1 access by a set of lighting systems is the sum of the number of persons whose needs are served by each independent light source, subject to a maximum of the household size itself.

An additional set of sustainability criteria is also applied.

In addition, the lighting system must meet a set of sustainability criteria (detailed in Box 7.1) to be counted as contributing to access. This approach allows nonelectric solutions to be counted as well.

BOX 7.1
Defining Sustainable Lighting Systems

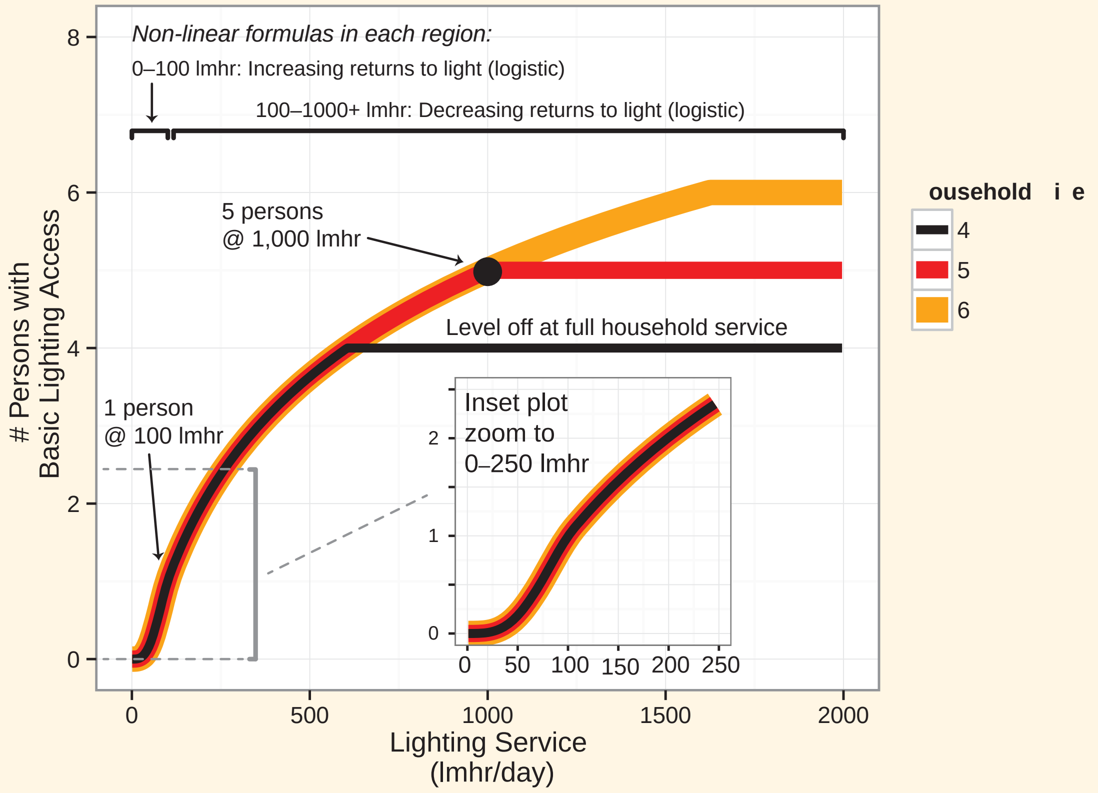
Only lighting systems that meet the following basic sustainability criteria are counted toward Tier 1 access:

Eliminate household pollution: Lighting systems that result in direct emissions inside households will not be counted toward sustainable energy access. This excludes kerosene-burning appliances, candles, and most other flame-based lighting from the framework. However, an exemption is provided for biogas-powered mantle-type lamps that are associated with on-site biogas digesters. In addition to electric lighting, good-quality biogas lighting systems (i.e., those that are safely installed and provide reliable service) may qualify for Tier 1 lighting needs.

Good quality: Only lighting systems that are expected to last at least 6 months will be counted toward providing sustainable energy access. This excludes low-quality lighting systems from the framework.

FIGURE 7.10

Implications of the Tier 1 Framework for a Household of Five Using a Single Light Source with a Range of Performance Characteristics and Different Levels of Access to Mobile Charging



For devices from 0–100 lmhr/day	For devices from 100–1,000 lmhr/day	Total number of persons served in the household
A logistic function	*A logarithmic function*	*A summation function*
$P_l = d\left(1 - \frac{1}{1+(\frac{L}{e})^f}\right)$ where: P_l = number of persons served with lighting service by the device L = quantity of available light (lmhr/day) $d = 2$ $e = 100$ $f = 3.3$	$P_l = 0 < h_{base} \times \log10\left(\frac{L}{a} + b\right) - c < h$ where: P_l = number of persons served with lighting service by the device L = quantity of available light (lmhr/day) $a = 95$ $b = 0.732$ $c = 0.0515$ $h_{base} = 5$ h = household size	Sum for all the light sources in a household: $P_{tot} = \max\left(\sum_{i}^{All} P_{l,i},\ h\right)$ $T_l = \frac{P_{tot}}{h}$ where: P_{tot} = number of persons served with lighting service in total h = household size T_l = effective tier for lighting

Communication Access

Access to communication refers to people's ability to charge and operate mobile phones, using the minimum necessary amount of electricity. There is a wide variation in the energy requirement, from roughly 3.5 to 4 Wh for a basic feature phone to 10+ Wh for a smartphone (based on typical battery capacity). There is also variation in the usage profiles and energy efficiency of charging and operation (Heikkinen et al. 2012). Some low-cost basic handsets optimized for off-grid charging can run for five days on a single charge with limited use (in the beginning of the battery lifespan), whereas others must be charged every day. Thus, daily electricity requirements for charging range from approximately 1 to 10 Wh per day. Radios are another valued ICT load and consume energy levels similar to mobile phones.

Daily electricity requirements for charging range from approximately 1 to 10 Wh per day.

Phone charging can be accessed either through household-level energy systems or through neighborhood access. Household access is defined as energy systems with charging ports inside the household, whereas neighborhood access implies that users must leave their phones (or spare batteries) at a nearby shop or other place with electricity access.

Phone charging can be accessed either through household energy systems or through neighborhood access.

In the case of neighborhood access to phone charging, one-third of credit access is given. This is granted for households where users do not need to personally travel more than 1 km to access the services and where the services are available and accessed on a regular basis, for example, at a charging shop or at a neighbor's house.

One-third of access credit is given for neighborhood access to phone charging.

In the case of household access, two situations are distinguished. The framework considers that having access to sufficient power to keep at least one basic-feature phone (that is relatively energy efficient) charged and in standby mode should count for partial access. This is due to the high network-effect value derived from having continuous access to a mobile phone in the 'on' state. Such service requires at least 1 Wh per day for a household of five people. Above five people, a proportional increase in service is required (e.g., 1.2 Wh for six people) but for less than five people, 1 Wh still applies (as it is not possible to have fewer than one operational mobile phone and still have access to service). Therefore, only two-thirds of access credit is given when 1 Wh per day is available for phone charging.

Two-thirds of access credit is given when 1 Wh per day is available for phone charging.

In addition, the framework considers a second situation where having access to sufficient power to use at least one basic-feature phone (that is relatively energy efficient) for calls and texts as required by the user, should count for full access. Such service requires at least 3 Wh per day for a household of five people, and may be available every three days. For households larger than five, a linearly proportional increase in the threshold is required (e.g., 4.2 Wh for seven people). Therefore, full access credit is given when 3 Wh per day is available for phone charging.

Full access credit is given when 3 Wh per day are available for phone charging.

For all charging systems available to the household:

$$T_{c_{pub}} = if\,[neighborhood\ access] \rightarrow 0.33,\ else\ 0$$

$$T_{c_{hh}} = if\,[household\ access > 1\ Wh/day] \rightarrow 0.66$$

$$T_{c_{hh}} = if\,[household\ access > 3\ Wh/day] \rightarrow 1$$

$$T_c = \max(T_{c_{pub}}, T_{c_{hh}})$$

where:

$T_{c_{pub}}$ = Communication tier score through neighborhood access

$T_{c_{hh}}$ = Communication tier score through household-system-level access

T_c = Communication tier score

Combined Tier 1 Access Score

Access to light and communication are combined to estimate a combined access score, with 70 percent weightage to lighting and 30 percent to phone charging.

Access to light and communication are combined to estimate a total access score, with 70 percent weight given to lighting and 30 percent to phone charging. The split in weights is based on the direct and substantial health, safety, and quality benefits that result from improved lighting compared to less direct (and well-understood) benefits resulting from access to mobile phones.

The combined tier score across lighting and phone charging is computed considering the full set of devices and systems available to the household, such that the limitations of competing use of total energy available across the two services is properly reflected. Standalone household-level devices that provide lighting and phone charging often have limited energy storage capacity. As a result, lighting and phone charging are competing services for the same stored energy. Table 7.1 describes the implications of this combined framework for meeting the needs of a household of five people.

$$T = 0.7T_l + 0.3T_c$$

and

$$P = T \times H$$

where:

T = Household tier

T_l = Household tier for lighting

T_c = Household tier for phone charging

P = Number of persons served with Tier 1 service

H = Household size

TABLE 7.1

Number of People with Tier 1 Access Using a Single Device in a Household of Five

	ADDITIONAL MOBILE CHARGING (Wh/DAY)			
LIGHTING SERVICE FROM SINGLE SOURCE (LMHR/DAY)	0–0.99 PEOPLE (NO NEIGHBORHOOD CHARGING)	0–0.99 PEOPLE (USE OF NEIGHBORHOOD CHARGING)	1–2.99 PEOPLE (DAILY CHARGING FOR BASIC PHONES)	3+ PEOPLE (EVERY THIRD DAY CHARGING FOR BASIC PHONES)
10	~ 0	0.5	1.0	1.5
20	~ 0	0.5	1.0	1.5
50	0.1	0.6	1.1	1.6
100	0.7	1.2	1.7	2.2
200	1.4	1.9	2.4	2.9
500	2.5	3.0	3.5	4.0
750	3.1	3.6	4.1	4.6
1,000+	3.5	4.0	4.5	5.0

DATA REQUIRED FOR MEASURING ACCESS TO LIGHTING AND PHONE CHARGING

Based on the type of data available (demand-side or supply-side data), the framework for measuring access to lighting and phone charging is applied differently. Supply-side data, based on supplier/program data, provide the exact number of solutions distributed and good knowledge of their technical performance characteristics, but often little is known about the household characteristics, unless information from national or regional survey statistics is used. Demand-side data (such as household surveys) offer a good understanding of the household context and patterns of use, but the exact identification of the lighting solution and its technical performance characteristics are more challenging to obtain.

The framework for measuring access to lighting and phone charging is applied differently for demand-side and supply-side assessment.

Supply-Side Measurement

The basic supply-side measurement approach is to estimate access resulting from each model of the lighting solution and add up the number of people provided with Tier 1 access using this solution.

Supply-side measurement involves knowledge of performance characteristics of each model, calculation of the number of people benefitting from each unit sold, and the total sales of the model.

Aggregating across units: For each model supplied, the program would know the expected performance characteristics. These are used to estimate the number of people whose Tier 1 needs are met per unit of this model supplied. By knowing the average household size in the region, the fraction of the household that has received Tier 1 access can be estimated. Thus, the total number of people or households with Tier 1 access can be estimated by taking a sum-product of the number of various models supplied and the number of people benefitting from each of the models. This is then rounded down to the nearest person.

Measurement of technical performance: The expected technical performance should be measured, ideally, through third-party testing that verifies the quality and performance. For example, the Lighting Global program runs a quality assurance (QA) program for the pico-solar market with publicly available, verified, and standardized specifications sheets (Lighting Global 2015). There are current efforts to expand the scope of QA to include larger household-level systems.

Assumptions required to apply the framework with supply-side data:

Number of people in a typical household: Five people is a standard global assumption; more accurate regional estimates may be used if available.

System life: System life determines the period of access that counts for a given sale. System life is highly variable and should be estimated based on past and current field experience along with laboratory testing.

Use of service across people within a household: The use of service across household members reflects the degree to which each individual's needs are met. Although this is difficult to determine through household surveys, it is nearly impossible without such surveys. The implicit assumption is that the service is shared equally among each household member.

Demand-Side Measurement

Demand-side measurement gathers data on the characteristics of the energy system combined with key questions to the household member(s) about their utility and use.

The basic demand-side measurement approach is to estimate access for a particular household by gathering information about the devices available and their use.

Survey design: The number of questions must be kept low to maintain affordability of implementation and avoid survey fatigue on behalf of the participants. Training on assessing the technical performance of the energy system should be provided to household survey enumerators.

Approach from two angles: There is a dual approach taken for measurement in the household—characteristics of the energy system combined with key questions to household member(s) about their utility and use. By including both, consistency checks can be applied during data processing.

A detailed methodology for estimating the capacity of the solar lighting solution is presented in Annex 3.

CONCLUSION

Access to lighting and communication is a foundational element of electricity access. The framework presented in this chapter facilitates monitoring of the diverse and fast-changing markets for decentralized electricity systems and appliances. Today's technology landscape is shifting based on superefficient end uses, inexpensive solar cells, and near-ubiquitous access to mobile phones. As users move into and beyond Tier 1, there is an opportunity to learn more about the transition with coordinated effort on surveys and data sharing, strengthening the ability of organizations and institutions to engage in this important energy transition and simultaneously adding self-supported rigor to the global tracking framework.

This framework facilitates monitoring of the diverse and fast-changing markets of off-grid systems.

8

HOUSEHOLD ACCESS TO COOKING SOLUTIONS

A comprehensive approach for defining and measuring household access to cooking is presented in this chapter.

Following consideration of household access to electricity, a separate focus on household access to cooking is required, as evidence shows that even when electricity is available, the poor rarely use it to meet their cooking needs (Bacon, Bhattacharya, and Kojima 2010; Davis 1998; WB 2011a). This chapter provides a comprehensive approach for defining and measuring household access to energy for cooking as a continuum of improvement in multiple energy attributes that affect the user's choice of cooking solutions and reflect the user's energy experience.

It is challenging to categorize the wide range of cooking solutions (defined as the combination of a cooking fuel and a cookstove), as performance varies widely.

A wide variety of cooking fuels—across solid,[29] liquid,[30] and gaseous[31] fuels—and a range of cookstove types are available to households for meeting their cooking needs. This chapter defines a cooking solution as the combination of a cookstove and a cooking fuel taken together. As explained in this chapter, the performance of cooking solutions varies widely based on several parameters, making the categorization of such solutions challenging. Typically, the terms "modern" and "clean" cooking fuels refer to fuels with very low levels of polluting emissions, such as biogas, LPG, electricity, ethanol, natural gas, and solar (BLEENS). BLEENS fuels often provide high technical performance based on parameters such as emissions and efficiency, which is largely "stove independent."[32] The term "improved" cookstoves is typically applied by practitioners to cookstoves that use solid (or sometimes liquid) fuel delivering higher efficiency compared to traditional stoves (which are usually made of mud or metal at the local level). "Advanced" cookstoves usually refer to solid- or liquid fuel-based cookstoves that deliver low levels of polluting emissions as compared to traditional stoves (Ekouevi et al. 2014). However, most of these terms fail to clearly and comprehensively reflect the performance of the cooking solution and the level of household access to energy for cooking.

This chapter presents the multi-tier approach for measuring household access to cooking.

This chapter starts by explaining the impacts of access to cooking on socioeconomic development and presents an overview of the current state of household access to cooking, followed by a review of the challenges in measuring access to cooking solutions. It then elaborates on the multi-tier approach for measuring household access to cooking and, finally, shows how to use the results of such measurement for policy formulation and investment planning, as well as for monitoring and evaluation of projects and programs.

IMPACTS OF HOUSEHOLD ACCESS TO COOKING SOLUTIONS ON SOCIOECONOMIC DEVELOPMENT

Inefficient use of solid fuels impacts health, development, gender inequality, education, and climate.

Despite well-documented benefits of access to clean cookstoves, a large proportion of the world's population still uses polluting, inefficient cooking solutions that emit toxic smoke. The inefficient use of solid fuels has significant impacts on health, socioeconomic development, gender equality, education, and climate (Ekouevi and Tuntivate 2012; UNDP and WHO 2009; WB 2011b).

Household air pollution has been associated with a wide range of adverse health impacts, such as increasing risk of acute lower respiratory infections among children under 5 years old, and chronic obstructive pulmonary disease and lung cancer (in relation to coal use) among adults above 30 years old. An association between household air pollution and adverse pregnancy outcomes (i.e., low birth weight), ischemic heart disease, interstitial lung disease, and nasopharyngeal and laryngeal cancers, may also be tentatively drawn based on limited studies (Dherani et al. 2008; Rehfuess, Mehta, and Pruss-Ustun 2006; Smith, Mehta, and Maeusezahl-Feuz 2004).

Household air pollution has been associated with a wide range of adverse health impacts.

Several studies agree that exposure to air pollutants emitted from inefficient combustion of cooking fuels is one of the biggest health challenges in low-income countries (Bruce, Perez-Padilla, and Albalak 2000; Lim et al. 2012). WHO estimates that over 4 million people die prematurely each year from illness attributable to household air pollution. Over 50 percent of deaths among children under 5 years old are due to pneumonia caused by particulate matter (PM) inhaled from household air pollution. Also, 3.8 million premature deaths per annum from noncommunicable diseases (including stroke, ischemic heart disease, chronic obstructive pulmonary disease, and lung cancer) are attributed to exposure to household air pollution (WHO 2014a).

Household air pollution causes over 4 million premature deaths per year.

The consequences of inefficient energy use for cooking extend beyond direct health impacts, inhibiting socioeconomic development. The burden of lengthy fuel collection and cooking tasks is often carried by women and girls. Collection time depends on the local availability of fuel and may reach up to several hours per day (ESMAP 2004; Gwavuya et al. 2012; Parikh 2011; Wang et al. 2013). Time spent in fuel collection often translates into lost opportunities for gaining education, and increasing income (Blackden and Wodon 2006; Clancy, Skutch, and Batchelor 2003). In addition, associated drudgery increases the risk for injury and attack (Rehfuess et al. 2006).

The burden of lengthy fuel collection and cooking tasks deprives women and girls from education and income-generating activities.

Pollution from inefficient cooking solutions also affects local and global environments. Incomplete combustion of biomass and fossil fuels for household use is one of the largest contributors to black carbon[33] levels and other short-lived pollutants globally, leading to changes in precipitation cycles, which can cause drought and increase risk of vector-borne diseases such as malaria (Bond 2009; Gustafsson et al. 2009; Kopacz et al. 2011; Menon et al. 2002; UNEP and WMO 2011; Ramanathan and Carmichael 2008; Venkataraman et al. 2005). Unsustainable extraction of biomass, such as wood fuel and charcoal, contributes to deforestation and land-use problems, such as erosion and desertification (Arnold et al. 2003; Chidumayo and Gumbo 2013; Cordoba-Aguilar 1992; Ektvedt 2011; McGranahan 1991; Mwampamba 2007; Reijnders 2006), and has adverse effects on climate through greenhouse gas emissions (Edwards et al. 2004; Smith et al. 2000).

Inefficient combustion of cooking fuels contributes to emissions of short- and long-lived pollutants, the unsustainable harvesting of these fuels may lead to deforestation.

CURRENT STATE OF HOUSEHOLD ACCESS TO COOKING SOLUTIONS

Universal access to modern cooking services is one of the energy access objectives of the SE4All initiative, along with universal access to electricity (SE4All 2012). Access to modern cooking solutions

Access to modern cooking solutions, one of the objectives of SE4All, is essential for achieving the MDGs.

is essential for achieving the MDGs, such as reducing poverty, improving women's and children's health, and broadening the reach of education. Energy facilitates social and economic development, offering an opportunity for improved lives and economic progress (Modi et al. 2005; UNDP 2005; UNDP and WHO 2009; WHO 2006). In 2012, approximately 41 percent of the world's population, or 2.8 billion people, relied primarily on solid fuels[34] (i.e., wood, charcoal, or animal waste) to cook their food, typically over open fires or rudimentary stoves. About 78 percent of that population lived in rural areas, and 96 percent was geographically concentrated in Sub-Saharan Africa, Eastern Asia, Southern Asia, and South-eastern Asia (Banerjee et al. 2013).

The number of people relying on solid fuels for cooking in absolute terms has remained constant since 1990, as increase in use of non-solid fuels has been offset by population growth.

Although the share of the global population relying primarily on solid fuels for cooking decreased from 53 percent in 1990 to 41 percent in 2010, the number of people in absolute terms remained nearly constant, as increase in use of nonsolid fuels almost kept pace with population growth (Banerjee et al. 2013). Nearly 1.2 billion people obtained access to nonsolid fuels for cooking in 1990–2010, but this figure was 200 million behind the overall population increase. Most of the top 20 countries where the largest numbers of people transitioned to use of nonsolid fuels are in Asia. The greatest growth occurred in India, China, and Brazil, where a total of 783 million people secured access to nonsolid fuel as their primary[35] cooking fuel during this period. India charted a remarkable trajectory, providing access to nonsolid fuels to 402 million over the two decades (Banerjee et al. 2013). It is worth noting that over the last 20 years, almost no country has improved access to nonsolid fuel at an annual rate greater than 3.5 percent of the population.[36]

Under a business-as-usual scenario, 2.6 billion people will still depend on solid fuels for cooking in 2030.

According to IEA's projections, 30 percent of the world's population, or 2.6 billion people, will still depend on solid fuels in 2030 under the "business-as-usual" scenario (New Policies Scenario in IEA's World Energy Outlook). Asia will show an improvement, driven by China, whereas the situation in Sub-Saharan Africa will worsen as the number of people securing access to nonsolid fuels will not keep pace with the population growth expected over the period (Banerjee et al. 2013). It is estimated that universal access to modern cooking solutions by 2030 would require an investment of about $89 billion over the period (in 2010 dollars), of which about $13 billion is projected to be forthcoming under the business-as-usual scenario, meaning that an additional $76 billion ($3.8 billion per year between 2011 and 2030) would be required to provide universal access to modern cooking solutions by 2030 (Banerjee et al. 2013).

CHALLENGES IN MEASURING ACCESS TO COOKING SOLUTIONS

Binary measurement, tracking use of non-solid fuels, fails to capture the multifaceted nature of access to cooking solutions.

Access to energy for cooking is often equated with the use of nonsolid fuels[37] as the primary cooking energy source (Banerjee et al. 2013). However, this binary metric fails to capture the multifaceted nature of the underlying phenomenon, and does not adequately inform energy policy, planning, project implementation, and progress monitoring. This fuel-type binary metric omits the role of the cookstove and presumes that all nonsolid fuels are clean and efficient, and that all solid fuels are harmful. Such an approach also does not adequately reflect the underlying scientific evidence regarding interlinkages between health risks and indoor air quality. In addition, convenience aspects such as the time and effort involved in collecting or preparing the fuel are ignored. Other attributes of household access to cooking solutions such as availability and affordability of fuel, and safety, are also not reflected. An important challenge in measuring access to cooking solutions is the phenomenon of "stacking," which involves the parallel use of multiple cooking solutions in the same household. Also, access to cooking solutions is affected among factors such as variations in type and quality of fuel used, different cooking practices, proper use of equipment, and the size of the kitchen and the degree of ventilation. The key challenges in measuring access to cooking solutions are further elaborated in the following sections. In essence, access to energy for cooking refers to the usability of the cooking solutions in the context of the various attributes mentioned above, and not just the availability of a clean cooking solution.

Measuring the Health Impacts of Indoor Air Quality

An important aspect of access to energy for cooking is the health risk from poor indoor air quality (IAQ) due to cookstove emissions. Understanding and measuring the health risk faced by a household due to deficiencies in access to cooking solutions is a complex task. It requires the ability to understand, measure, and predict the interlinkages between health risks, indoor air quality, cookstove emissions, cookstove performance characteristics, kitchen characteristics, use patterns, and other related factors. This complex interlinkage is depicted in Figure 8.1.

Measuring the health risks resulting from deficiencies in access to cooking solutions is a complex task.

Indoor air quality depends on emissions from all indoor fuel combustion, ambient air pollution in the area, as well as kitchen volume and air exchange, and can be measured directly or simulated using mathematical models. Indoor emissions depend on the emission characteristics of each cooking solution (to account for stacking), along with its use, duration, and pattern. Emissions also depend on fuel quality, device maintenance, and user adherence to specifications. Cookstove performance can be measured against performance standards (i.e., IWA standards) under actual conditions (through a field-based emissions test such as a kitchen-based test) reflecting the culture-specific culinary practices. It can also be measured under standard conditions in the laboratory (e.g., through a water-boiling test), ignoring the cultural context.

The indoor air quality is a function of cookstove emissions, kitchen volume, air exchange rate, and ambient pollution in the area. Emissions are a function of the device's characteristics, its use duration and pattern, user adherence to use specifications, maintenance, and fuel quality.

A number of researchers and health agencies, including WHO, have undertaken studies to establish and quantify the health risks from poor indoor air quality. The Guidelines Development Group (GDG), organized by WHO for this purpose, examined available evidence. Using integrated exposure-response (IER) functions,[38] it identified important links between indoor air quality and several diseases, including child acute lower respiratory infections (ALRIs), chronic obstructive pulmonary disease (COPD), lung cancer (with coal and biomass exposure), cardiovascular disease, and stroke (Figure 8.2).

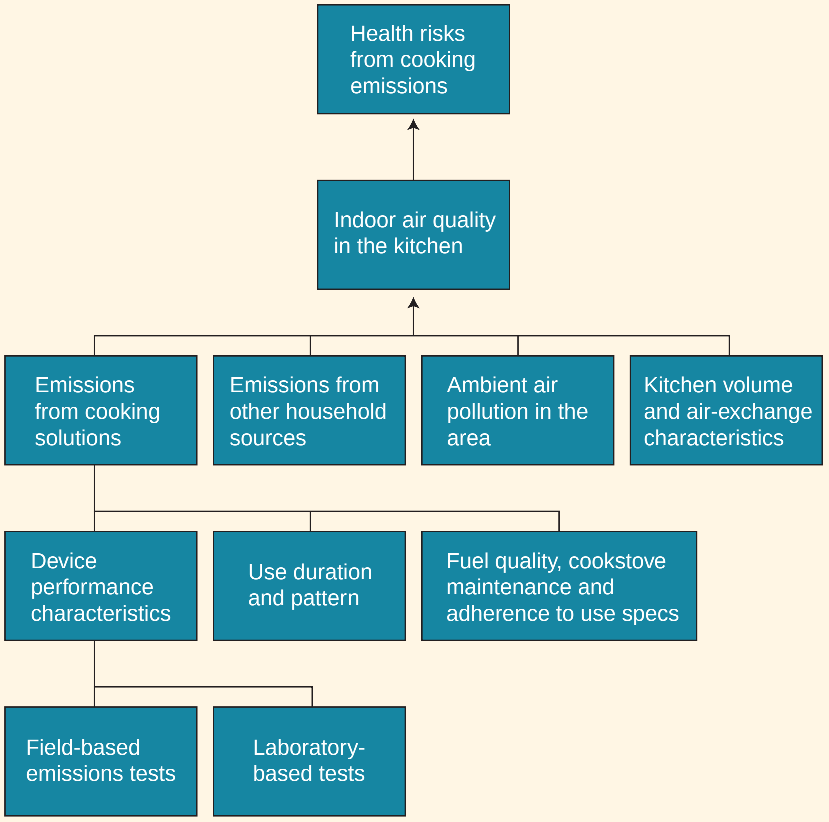
WHO has identified important linkages between IAQ and diseases such as child ALRI, COPD, lung cancer, and cardiovascular disease.

Based on available evidence, WHO has developed guidelines for indoor air quality, including standards for particulate matter with an aerodynamic diameter of 10 microns or less (PM_{10}), particulate matter with an aerodynamic diameter of 2.5 microns or less ($PM_{2.5}$), carbon monoxide

WHO has developed IAQ guidelines, where where $PM_{2.5}$ and CO are the most relevant pollutants for cooking energy.

FIGURE 8.1

Interlinkages between Health Risks, Cookstove Emissions, and Other Factors



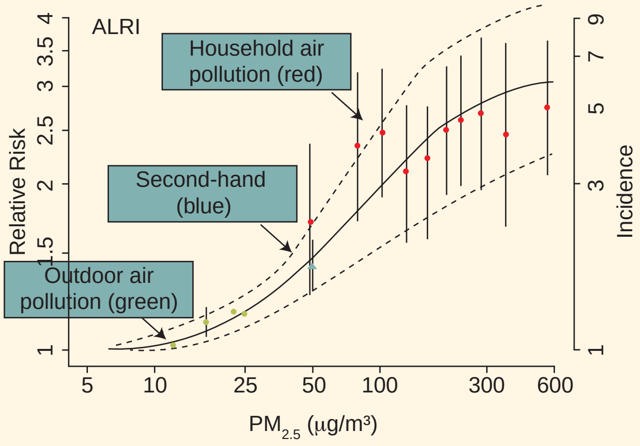
Source | *Authors.*

(CO), dampness and mold, nitrogen dioxide, sulphur dioxide, ozone, and other pollutants. In the context of use of energy for household cooking, the most relevant guidelines are for $PM_{2.5}$ and CO, and are summarized as shown in Table 8.1.

The WHO $PM_{2.5}$ guideline corresponds to the level above which total cardiopulmonary and lung cancer mortality have been shown to increase with more than 95 percent confidence in response to long-term exposure to $PM_{2.5}$. The interim target 1 (IT-1) level is associated with 15 percent higher long-term mortality risk compared to the guideline level. The IT-2 level lowers the risk of premature mortality by approximately 6 percent (2–11 percent) compared to the IT-1 level, whereas the IT-3 level lowers the risk of premature mortality by approximately 6 percent (2–11 percent) relative to the IT-2 level.

FIGURE 8.2

Relationship between Level of $PM_{2.5}$ Exposure (µg/m³) and Relative Risk (95% Confidence Interval) of Child ALRI, Based on IER Function



Source | *EHP 2014.*

TABLE 8.1

WHO Guidelines for Indoor Air Pollution ($P_{2.5}$ and CO)

POLLUTANT	GUIDELINE/TARGET	EXPOSURE PERIOD	LEVEL (µg/m³)
$PM_{2.5}$	Guideline	Annual Average	10
	IT-3		15
	IT-2		25
	IT-1		35
POLLUTANT	GUIDELINE/TARGET	EXPOSURE PERIOD	LEVEL (mg/m³)
CO	Guideline	8 hours	10
	Guideline	24 hours	7

IT = Interim Target

Source | *WHO 2005; 2010; 2014b.*

The IER functions can also be used to assess the relative risk of child ALRI, COPD, lung cancer, stroke, and cardiovascular disease at higher levels of annual exposure to $PM_{2.5}$ and CO. Such an assessment would be useful in determining the likely health benefits of reduction in $PM_{2.5}$ and CO to levels higher than IT-1, through incremental improvements in cookstove performance and other parameters. However, the current research literature does not provide specific information in

The relative risk of child ALRI, COPD, lung cancer, and cardiovascular disease at higher levels of annual exposure to $PM_{2.5}$ and CO needs to be estimated.

this regard, even though such information can be easily obtained from the already available IER functions. The absence of specific information about health impacts of indoor air quality at $PM_{2.5}$ and CO levels higher than the IT-1 level, with accreditation by a reputed health-sector agency such as WHO, poses a difficulty in measuring the health risk emanating from cooking solutions that do not meet the WHO guideline or the interim targets, but are an improvement over the traditional cookstoves and are currently in use in developing countries.

Measuring Indoor Air Quality in Households

Measurement of household IAQ requires elaborate instrumentation and careful engagement, making it difficult and costly to conduct it on a large scale.

Measurement of household indoor air quality requires elaborate instrumentation and careful engagement over an extended period of time. Although such measurement can be done for the purposes of obtaining reliable data for scientific research, it is difficult and costly to conduct it on a large scale in the course of household surveys across countries.

There are three possible approaches for measuring IAQ: (i) direct measurement, (ii) mathematical modelling, and (iii) broad categorization of cookstoves based on conservative estimation in absence of verifiable evidence.

There are three possible approaches to measuring indoor air quality in households:

i. Through direct measurement in kitchens using appropriate instrumentation. This approach is most accurate, but remains difficult and costly for large-scale implementation.

ii. Through mathematical modeling using evidence from research and relevant surveys with information about household characteristics, type of cookstove, and cooking practices. Although less accurate, this approach would allow a reasonable estimate, while being more feasible and cost-efficient to implement.

iii. Through broad categorization of cookstove types and generalized assumptions about cooking practices. This approach would be the least accurate, and should be applied by making conservative estimation in the absence of verifiable evidence. On the positive side, this approach can be implemented using existing survey data on the type of primary cookstove.

While the first approach involves direct measurements in the kitchen, the second and third approaches require secondary scientific evidence of cookstove performance under actual use conditions reflective of the culinary practices in the local culture. Such performance evidence is needed for all cookstoves used by the household to capture the effect of stacking. The second approach requires detailed information about the type of fuel (including quality of fuel), duration of use, regular maintenance of cookstove equipment, as well as user adherence to use specifications for each cooking solution. It also requires information about kitchen volume and air exchange rate.

Evaluating the Technical Performance of Cooking Solutions

A consistent approach for performance evaluation of a wide range of cooking solutions is required.

A wide range of cooking solutions are being used around the world, from three-stone fires using solid fuels to BLEENS-based solutions, including various types of traditional, improved, or advanced cookstoves. The technical performance of a cooking solution varies widely in terms of pollution, efficiency, and safety and depends on the combination of cookstove and fuel used. A consistent approach for performance evaluation that can cover the wide range of cookstoves and cooking fuels is needed.

Although emission levels corresponding to the WHO guidelines and IT-1 can be typically obtained through the use of BLEENS fuels, improved emission performance can be achieved even with solid fuels. This is important, as it is projected that a large part of the developing world will continue to rely on solid fuels (biomass and coal) for cooking despite increasing use of nonsolid fuels (IEA 2012). It is usually not possible to evaluate the technical performance of solid fuel-based cookstoves without testing under controlled conditions, which may be simulated either in a laboratory or in the field itself. This requires standard testing protocols, testing equipment, and trained personnel.

Assessing the technical performance of the cookstove requires testing under controlled conditions.

Typically, laboratory-based tests under standard conditions (e.g., the water-boiling test) are relatively easier, quicker, and less expensive than field-based tests under actual use conditions (e.g., the kitchen-based test). However, results from the former would require adjustments to reflect local factors such as the actual cooking cycle, flame intensity, and the effect of using different cooking vessels. Box 8.1 provides more information on cookstove testing.

Segregating the Emission Contribution of Cooking Solutions

Indoor air quality is affected by emissions from cooking solutions, emissions from other sources of fuel combustion in the household (such as for heating or lighting), and the ambient air quality in the local area. An important challenge in assessing the health impact of cooking solutions is to segregate the emission contribution of the cooking solutions from that of other sources of emissions and ambient air quality.

Standards for Cookstove Performance: Emission Rate Targets Proposed by WHO

Emission Rate Targets: The WHO uses a mathematical model for calculating the cookstove emission rate targets (ERTs) to meet its guidelines and IT-1 (WHO 2014b). The methodology uses a single-zone model[39] under the assumptions of constant emission rate and instantaneous and perfect mixing to estimate the indoor air quality across a population of kitchens that uses a given cooking solution (Johnson et al. 2014). The basic mathematical equation that applies to the single-zone model is as follows:

A single-zone model with Monte Carlo simulation is used to determine the cookstove emission rates for which a given fraction of households would meet the WHO Guidelines (or IT-1).

$$C_t = \frac{Gf}{\alpha V}(1 - e^{-\alpha t}) + Co(e^{-\alpha t})$$

where,

C_t = Concentration of pollutant at time t (mg/m^3)

G = Emission rate (mg/min)

α = First-order loss rate (nominal air exchange rate) (min^{-1})

V = Kitchen volume (m^3)

t = time (min)

C_o = Concentration from preceding time unit (mg/m^3)

f = Fraction of emissions that enters the kitchen environment

BOX 8.1

Protocols for Biomass Cookstove Testing

Over the last 30 years, several protocols have been developed for comparing different types of cookstoves and understanding the different design parameters, as well as the processes of combustion, fluid mechanics, and heat transfer inside the stove. The main tested characteristics are combustion quality and emissions, thermal efficiency and heat transfer, power range, and safety, among others.

Laboratory tests intend to provide repeatable results in measuring performance characteristics (such as combustion quality and emissions, thermal efficiency and heat transfer, power range, etc.) in order to identify areas of poor performance and determine the effect of a design alteration on the performance. The main laboratory tests are the water-boiling test (WBT) and the controlled cooking test (CCT). Under controlled conditions, the WBT measures the differences in performance from the cold to the hot start under high-power and low-power settings. It is mainly suitable for wood stoves but can also be adapted for charcoal stoves. Despite several shortcomings, the WBT is the most widely used test due to its simple and quick procedures. The CCT evaluates stove performance, under controlled settings, to ensure that the stove is used to its best potential, using locally available fuels and pots and prevailing cooking practices. It measures the quantity of fuel used while the real cook prepares a simple meal.

However, the performance of a stove under controlled conditions is different from the one achieved in real household conditions. Thus field tests are essential for verifying results. The main field tests are the kitchen performance test (KPT) and the stove-use monitors (SUMs). The KPT is carried out in a real kitchen and assesses the actual fuel use along with qualitative aspects of performance, as the user cooks on the stove as usual. The SUMs are electronic temperature data loggers installed inside the cookstove aiming to monitor stove use. Emission sensors are increasingly used. SUMs can record temperature and emissions concentration changes over a period of time. They are relatively cheap, reliable, accurate, safe, and easy to install and maintain.

Source: Kshirsagar and Kalamkar 2014.

ERTs are based on a Monte Carlo simulation on a single-zone model using kitchen data for India.

A Monte Carlo simulation is used with the single-zone model to account for the variations in air exchange rate, kitchen volume, and device burn time across kitchens. Using data on air exchange rate, kitchen volume, and device burn time from a survey in India (Table 8.2), the methodology is used to determine the cookstove emission rates for which a given fraction of households would meet the WHO guidelines or IT-1 (Table 8.3). The proposed WHO emission rate target (ERT) for $PM_{2.5}$ of 0.23 mg/min corresponds to 90 percent of kitchens meeting the indoor air quality guideline (10µg/m^3). Similarly, the proposed intermediate ERTs for $PM_{2.5}$ of 1.75 mg/min corresponds to 60 percent of kitchens meeting the IT-1 (35 µg/m^3). Similarly, WHO provides ERTs and intermediate ERTs for CO, as shown in Table 8.4.

WHO proposes to develop an online tool that would calculate ERT values using country-specific values of input parameters.

The ERTs provide a useful benchmark for cookstove performance. However, the underlying assumptions about the mean and variations in air exchange rate, kitchen volume, and device burn time vary across different communities. To improve accuracy, WHO proposes to develop an interactive web-based tool that would calculate ERT and intermediate ERT values for a given country by using context-specific values for these parameters.

TABLE 8.2

Input Distributions for Monte Carlo Simulation to Calculate Emission Rate Targets

PARAMETER	UNIT	GEOMETRIC MEAN	RANGE		STANDARD DEVIATION
			MINIMUM	MAXIMUM	
Air Exchange Rate	per hour	15	5	45	7.5
Kitchen Volume	m^3	30	5	100	15
Device Burn Rate	hours per day	4	0.75	8	2

Source | *WHO 2014b.*

TABLE 8.3

Emission Rate Targets for Meeting WHO Indoor Air Quality Guidelines for $PM_{2.5}$

EMISSION RATE TARGET		EMISSION RATE (MG/MIN)	PERCENTAGE OF KITCHENS MEETING IAQ GUIDELINES	PERCENTAGE OF KITCHENS MEETING IAQ IT-1
Unvented	Intermediate ERT	1.75	6	60
	ERT	0.23	90	100
Vented	Intermediate ERT	7.15	9	60
	ERT	0.80	90	100

Source | *WHO 2014b.*

TABLE 8.4

Emission Rate Targets for Meeting WHO Indoor Air Quality Guidelines for CO

EMISSION RATE TARGET		EMISSION RATE (G/MIN)	PERCENTAGE OF KITCHENS MEETING IAQ GUIDELINES
Unvented	Intermediate ERT	0.35	60
	ERT	0.16	90
Vented	Intermediate ERT	1.45	90
	ERT	0.59	90

Source | *WHO 2014b.*

The technical performance of a cooking solution can be evaluated using (provisional) IWA standards.

International Workshop Agreement Multi-tier Guidelines: The technical performance of the primary cooking solution can be evaluated based on multi-tier guidelines that were introduced in February 2012 by the International Workshop Agreement (IWA) led by the Alliance in collaboration with WHO and the International Organization for Standardization (ISO). IWA provided the basis for measurement of cookstove performance on four technical attributes: efficiency, indoor pollution, overall pollution, and safety (Table 8.5).

IWA standards cannot be aggregated into an overall cookstove rating, including all attributes.

It should be noted that these guidelines have been developed separately for each technical attribute and are not designed to be aggregated to obtain an overall rating for the cookstove. The different technical attributes have been kept separate in the IWA to allow programs, donors, investors, and consumers the ability to distinguish and prioritize among different attributes. Also, protocols are under development for additional types of cookstoves, beyond wood (e.g., plancha and charcoal), and multiple end-use stoves and will be incorporated into the IWA framework.

There is consistency across Tier 4 of indoor pollution for IWA, ERTs, and IT-4.

Establishing Correspondence between IWA Indoor Air Pollution Tiers and Indoor Air Quality: Tier 4 values of the indoor air pollution attribute in the IWA guidelines roughly correspond to the Tier 4 values of the intermediate ERT of WHO, which in turn corresponds to the IT-1 of indoor air quality under specific kitchen conditions. There is consistency across all of these standards of cookstove performance. However, available literature does not indicate how the other IWA tiers of indoor air pollution correspond to the level of indoor air quality. Such correspondence can be established based on the single-zone mathematical model using specific kitchen conditions.

TABLE 8.5

International Workshop Agreement Technical Guidelines

TECHNICAL ATTRIBUTES		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4
Efficiency	HPTE (%)	< 15	≥ 15	≥ 25	≥ 35	≥ 45
	LPSC (MJ/min/L)	> 0.050	≤ 0.050	≤ 0.039	≤ 0.028	≤ 0.017
Indoor Pollution	CO (g/min)	> 0.97	≤ 0.97	≤ 0.62	≤ 0.49	≤ 0.42
	PM (mg/min)	> 40	≤ 40	≤ 17	≤ 8	≤ 2
Overall Pollution	HPCO (g/MJ_d)*	> 16	≤ 16	≤ 11	≤ 9	≤ 8
	LPCO (g/min/L)	> 0.20	≤ 0.20	≤ 0.13	≤ 0.10	≤ 0.09
	HPPM (mg/MJ_d)**	> 979	≤ 979	≤ 386	≤ 168	≤ 41
	LPPM (mg/min/L)	> 8	≤ 8	≤ 4	≤ 2	≤ 1
Safety	Iowa protocol	< 45	≥ 45	≥ 75	≥ 88	≥ 95

** g/MJ_d is grams per megajoule delivered to the pot*

*** mg/MJ_d is milligrams per megajoule delivered to the pot*

HPCO = high-power CO; HPPM = high-power PM; HPTE = high-power thermal efficiency; LPCO = low-power CO; LPPM = low-power PM; LPSC = low-power specific consumption

Source | Adapted from PCIA 2012.

The IWA tiers for indoor pollution can be thought of as a specific case (where mean kitchen size, ventilation rates, and duration of emissions are specified in the Monte Carlo model) of a more generalized set of thresholds that are based on indoor air quality thresholds in any kitchen. The generalized standards for emissions from cookstoves would correspond to thresholds of indoor air quality for any kitchen. The generalized thresholds can be used to derive specific thresholds in any local context by using the appropriate values of mean and standard deviation for kitchen volume, air exchange rate, and cooking duration. Thus, the generalized form of the tier thresholds can help reflect country-specific (or subcountry-specific) conditions that would allow the same threshold of indoor air quality to be achieved across all country contexts. The generalized form of multi-tier indoor emission standards can be formulated based on the indoor air quality levels (discussed later in this chapter) as shown in Table 8.6.

The IWA tiers for indoor pollution are a specific case of a more generalized set of standards based on IAQ standards in any kitchen.

TABLE 8.6

Multi-tier Emissions Standards

INDOOR AIR QUALITY	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Health risks		Tentatively proposed at 15% higher long-term mortality than at Level 2	Tentatively proposed at 15% higher long-term mortality than at Level 3	Tentatively proposed at 15% higher long-term mortality than at Level 4	15% higher long-term mortality than at Level 5	Lowest level above which total cardiopulmonary and lung cancer mortality increases in response to $PM_{2.5}$
Relation to WHO guidelines and IAQ threshold values		[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	WHO IT-1 $PM_{2.5}$: $<35\ \mu g/m^3$ CO: $<7\ mg/m^3$	WHO guideline $PM_{2.5}$: $<10\ \mu g/m^3$ CO: $<7\ mg/m^3$
COOKSTOVE POLLUTION	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Cookstove indoor pollution performance assuming no stacking and Level 5 ambient air quality		Emission rate required to achieve Level 1 IAQ for 60% of households based on statistical distribution of kitchen volume, air exchange rate, and duration of use	Emission rate required to achieve Level 2 IAQ for 60% of households based on statistical distribution of kitchen volume, air exchange rate, and duration of use	Emission rate required to achieve Level 3 IAQ for 60% of households based on statistical distribution of kitchen volume, air exchange rate, and duration of use	Emission rate required to achieve Level 4 IAQ for 60% of households based on statistical distribution of kitchen volume, air exchange rate, and duration of use	Emission rate required to achieve Level 5 IAQ for 90% of households based on statistical distribution of kitchen volume, air exchange rate, and duration of use

Source | *Authors.*

A system of labeling and certification (or branding) needs to be devised and adopted.

Ideally, systems for certification and labeling for cooking solutions should emerge, based on cookstove emission thresholds, to facilitate the identification of the technical performance of the cooking solution, assist prospective buyers in their purchase decision, and regulate the industry. Certified cookstoves may carry a stamp or label for easy identification by all stakeholders, promoting product differentiation in the market.

Incorporating Convenience Aspects of Cooking Solutions

Time and effort involved in fuel collection and stove preparation may impact health, income-generating activities, and gender equality.

Time and effort required in collecting fuel, preparing and cleaning the cookstove, as well as cooking itself may be termed convenience. These are important factors impacting health, income-generating opportunities, education, and time dedicated to other tasks, leisure, and repose—especially for women (Clancy et al. 2003). For the poorest households, cooking often involves lengthy and exhausting fuel collection, particularly for women. Gender roles and inequalities impose differential burdens on family members with regard to cooking energy systems. Women and children often bear the main negative impacts of lengthy and unsafe fuel collection and cooking. Therefore, it is important to measure the convenience aspects along with the technical performance of a cooking solution to obtain a comprehensive measure of access.

Considering Stacking and Multiple End Uses

The parallel use of multiple cooking solutions (stacking) often reduces the health benefits of a clean primary cooking solution.

Any measure of access solely based on the primary cooking solution fails to capture the complex phenomenon of stacking, which refers to the parallel use of multiple fuels and cookstoves. Stacking is a common practice throughout the developing world. Households in both urban and rural areas routinely use two or more cookstoves and/or fuels for a variety of reasons. The transition to more modern energy solutions is a dynamic process, and many factors contribute to the choice of fuels and cookstoves. Even households that have adopted a clean fuel or an advanced cookstove may continue regular, parallel use of other cooking solutions that deliver lower technical performance, and thus impede in achieving complete access. Studies in Latin America found that households that have switched to LPG as a primary cooking fuel continue to rely on simpler, less-efficient cookstoves or open fires to prepare some types of foods, such as tortillas—a daily staple (Masera et al. 2000; Masera, Diaz, and Berrueta 2005). Similar patterns of multiple-fuel use have been documented in Ghana, India, Nepal, South Africa, and Vietnam (Heltberg 2004; Joon, Chandra, and Bhattacharya 2009). The parallel use of multiple cookstoves may also address households' need for space, water heating, and lighting.

Stacking occurs for a variety of reasons, including multiple end uses, cooking practices, fuel availability, and fuel affordability.

The causes underlying the practice of stacking need to be identified to inform policy and project design. Fuel and cookstove stacking have been attributed to a combination of factors, including household income, multiple end uses (cooking, reheating, boiling, food drying, space heating, etc.), cooking practices (types of food prepared, cooking time, taste, etc.), fuel availability and affordability issues, and available infrastructure (electricity grid and gas pipelines) (Davis 1998; Heltberg 2005; Link, Axinn, and Ghimire 2012).

A comprehensive approach for measuring access to cooking solutions aiming to address the wide range of challenges should account for the multiple parameters that determine indoor air quality levels and the use aspects of the cooking process. Building upon the growing consensus that access to energy should be measured not by binary metrics, but along a continuum of improvement, a comprehensive multi-tier framework for measuring access to cooking solutions is presented in the next section.

To address the wide range of challenges, the multiple aspects of the performance and use of cooking solutions should be accounted for.

MULTI-TIER MEASUREMENT OF HOUSEHOLD ACCESS TO COOKING SOLUTIONS

The multi-tier approach is designed to be technology and fuel neutral, and capture all underlying factors that impact the user's experience, while measuring household access to cooking as a continuum of improvement (as opposed to a binary metric). The approach aims to provide insight into the types of policy reforms and project interventions that would drive higher levels of access to energy for cooking, along with facilitating monitoring and evaluation.

The multi-tier framework captures multiple attributes underlying access in order to inform policy and investment and facilitate monitoring.

Attributes of Energy for Cooking

The framework includes seven attributes of energy, which determine the usefulness of the cooking solutions, influence the choice of the cooking solutions, and assess the ability of the user to utilize the benefits of access to cooking, thus enhancing living standards.[40]

The framework is built on seven attributes.

Health

Health is the most important attribute of energy for cooking because it reflects the strong correlation between household air pollution from cooking activities and adverse impacts on women's and children's health, especially with regard to ALRIs in children below five years of age; and COPD, lung cancer, cardiovascular disease, and stroke among all adults. The health aspect of energy for cooking is related directly to the indoor air quality of the kitchen.

The health aspect of energy for cooking is related directly to the IAQ in the kitchen.

Indoor air quality inside a kitchen depends upon a range of factors, including the emission rate of the cookstove, cookstove usage pattern, air exchange rate, and kitchen volume. The emission rate of the cookstove, in turn, depends on the cookstove characteristics, fuel quality, and heat rate. Air exchange rate depends on the ventilation area as well as the wind flow (natural or mechanically induced). Finally, the health impact from indoor air quality depends not only on the indoor air quality but also on the exposure of the person. However, for the sake of simplicity, indoor air quality—regardless of the amount of exposure—can be used as the key factor underlying the health impact of cooking.

A multi-tier framework for measurement of indoor air quality consistent with the WHO recommendations is shown in Table 8.7.

TABLE 8.7

Multi-tier Framework for Measurement of Indoor Air Quality

INDOOR AIR QUALITY	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Health risks		Tentatively proposed at 15% higher long-term mortality than at Level 2	Tentatively proposed at 15% higher long-term mortality than at Level 3	Tentatively proposed at 15% higher long-term mortality than at Level 4	15% higher long-term mortality than at Level 5	Lowest level above which total cardiopulmonary and lung cancer mortality increases in response to $PM_{2.5}$
Indoor air quality threshold values		[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	WHO IT-1 $PM_{2.5}$: <35 μg/m^3 CO: <7 mg/m^3	WHO guideline $PM_{2.5}$: <10 μg/m^3 CO: <7 mg/m^3

There are three ways of determining indoor air quality for any household:

- Direct measurement based on a defined protocol
- Estimation based on mathematical simulation using a combination of measured parameters and some simplifying assumptions
- Rough but conservative estimation based on broad categorization of primary cookstoves and the extent of usage of inferior secondary solutions

Direct measurement of indoor air quality is an elaborate exercise that may not be feasible on a large scale and across repeated household energy surveys. In many situations, indoor air quality may have to be estimated using mathematical models based on survey responses and some basic measurements. A single-zone model, reflecting combined pollution from all cooking solutions (as well as other emission sources and ambient pollution), that also takes into account the kitchen size, air exchange rate, and various aspects of cooking practice may be applied.

Because direct measurement and mathematical modeling may be difficult in many contexts, a rough and conservative approach based on the type of cooking solution and extent of usage of lower performing secondary solutions may be adopted. The multi-tier framework for indoor air quality measurement using this rough and conservative approach is shown in Table 8.8.

Measurement of cookstove emission performance under standard conditions requires a global network of cookstove testing laboratories.

Measurement of indoor air quality performance using mathematical simulation or rough and conservative estimation requires laboratory/field testing of cooking solutions. However, few cookstove testing laboratories are available across the world at present. The Alliance and various other agencies are establishing regional cookstove testing laboratories to support manufacturers in developing appropriate products. It is expected that testing results will increasingly become

TABLE 8.8

Multi-tier Framework for Indoor Air Quality Measurement (Rough and Conservative Approach)

HEALTH	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Primary cookstove Should have been formally tested and found to meet the required cookstove performance on indoor pollution AND Can be visually identified for performance using stove type, brand, or labeling	Untested three-stone fire, home-made stove, mud/earthen ring	Primary solution has met Tier 1 of generalized form of multi-tier indoor emission standards OR Potentially improved cookstoves but either untested or cannot be visually identified	Primary solution has met Tier 2 of generalized form of multi-tier indoor emission standards	Primary solution has met Tier 3 of generalized form of multi-tier indoor emission standards	Primary solution has met Tier 4 of generalized form of multi-tier indoor emission standards OR Cookstove using biogas, LPG, ethanol, or natural gas	Primary solution has met Tier 5 of generalized form of multi-tier indoor emission standards OR Electric or solar-based cookstove
Secondary cookstove		Any inferior secondary solutions are used for <20% of the cooking time, else shift one level below				Only BLEENS are used

Note | *BLEENS = Biogas, LPG, ethanol, electricity, natural gas, and solar.*

available for a wide range of cooking solutions, and eventually a certification mechanism may also be established. Results from third-party laboratory testing of cookstoves are already reported for a number of cookstoves through the Clean Cooking Catalog, a public platform maintained by the Alliance (The Alliance 2013).

In the absence of laboratory/field testing, visually observable characteristics may be used as a rough and conservative proxy for the likely HAP performance.

Before testing, certification, and labeling efforts become widespread, and cookstoves are tested (and certified and labeled) on a systematic basis, an assessment based on visually observable characteristics, such as shape and design type, may be used as a rough and conservative proxy for the likely indoor air quality performance of a wide range of cooking solutions. Although such a proxy is no substitute for actual testing (either in the laboratory or field), but provides a less data-intensive method for measuring household access to cooking solutions. The approach distinguishes between the use of BLEENS and non-BLEENS fuels, as well as the use of mass-manufactured and self-made (artisanal) cookstoves.

Convenience

Convenience of the cooking solution refers to the overall time and effort involved.

Convenience of the cooking solution refers to the overall time and effort involved in the process of securing and processing energy for cooking, including the time and effort involved in obtaining the fuel, and preparing the fuel and stove. Information about convenience is collected based on the recall of the respondents during a household energy survey (Table 8.9).

Safety

Safety of the cooking solution refers to possible injury during use and is determined based on the IWA methodology.

Safety of the cooking solution refers to possible injury during use and is determined based on an evaluation of the cookstove design with regard to equipment stability, sharp edges, exposed hot surfaces, fuel containment, and similar factors. The IWA has proposed a four-tier methodology for assessment of cookstove safety (PCIA 2012).

In a cooking solution stacking scenario, where multiple cooking solutions are used, it is difficult to assess the safety attributes of all cooking solutions and aggregate them into a cooking safety rating for the household as a whole. As a simplification measure, the multi-tier framework limits the assessment of safety attribute to the primary cooking solution (Table 8.10).

Safety may be estimated based on past accidents and risk perception.

Also, assessment of safety attributes of the cooking solutions using the IWA methodology cannot be done in the course of a household energy survey. Such an assessment is usually done for each

TABLE 8.9

Tiers of Convenience for Cooking Solutions

CONVENIENCE	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Fuel collection time (hrs/week)			< 7	< 3	< 1.5	< 0.5
Stove preparation time (min/meal)			< 15	< 10	< 5	< 2

TABLE 8.10

Tiers of Safety for Cooking Solutions

SAFETY	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
IWA safety tiers		Primary solution meets (provisional) IWA Tier 1 for Safety	Primary solution meets (provisional) IWA Tier 2 for Safety	Primary solution meets (provisional) IWA Tier 3 for Safety	Primary solution meets (provisional) IWA Tier 4 for safety	
OR, Past accidents (burns and unintended fires)					No accidents over the last 1 year that required professional medical assistance	

cookstove type in laboratory settings, and the results are applied to similar cookstoves during field surveys. In the absence of clear information about laboratory evaluation results, the safety attribute of the primary cookstove in a household is assessed based on past experience of accidents and risk perception going forward.

Affordability

In general, affordability of energy supply refers to the complex interaction between the quantity of energy consumed, its price per unit, and the ability of the user to pay. The quantity of energy consumed depends on the frequency, type, and volume of food cooked, as well as the efficiency of the stove. The price of energy depends on the type of fuel and transportation and distribution costs. Finally, the ability to pay is a function of the income level and spending preferences of the household.

Affordability refers to the complex interaction between the quantity of energy consumed, its price per unit, and the ability of the user to pay.

Unlike other discretionary energy needs, cooking is an indispensable activity for human survival. As a result, every household identifies cooking solutions that they can afford, often compromising other attributes such as health, safety, convenience, quality, and capacity. On the other hand, expenditure on energy for cooking may crowd out other expenditures that are relatively more discretionary. In face of high cost of energy for cooking, households either resort to a complete shift to a lower performing but affordable cooking solution, making it their primary cooking solution, or use it as a secondary solution to balance the high cost of the primary cooking solution. The multi-tier framework considers cooking affordable if the levelized cost of a cooking solution over a period of time is lower than 5 percent of the household income (Table 8.11).

Efficiency

The efficiency of the cookstove is assessed based on laboratory measurement under standard conditions or field testing under actual conditions. The (provisional) IWA tiers are used as the metric for measurement (Table 8.12). The cookstove efficiency includes the effect of combustion efficiency and heat-transfer efficiency. The heat-transfer efficiency is not relevant for cases where the cooking solution is also used for space heating, because heat lost is largely transferred to the surrounding room space. The effect of combustion efficiency is partially captured in the measurement of pollution ($PM_{2.5}$ and CO) levels. In cases where the cooking solution also serves toward space heating, the efficiency parameter is ignored.

Efficiency is assessed based on the laboratory measurement of cookstove performance under standard conditions or field testing under actual conditions.

TABLE 8.11

Tiers of Affordability for Cooking Solutions

AFFORDABILITY	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Levelized cost of cooking solution (including fuel and cookstove)					<5% of household income	

TABLE 8.12

Tiers of Efficiency for Cooking Solutions (Rough and Conservative Approach)

EFFICIENCY	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Primary cookstove Should have been formally tested and found to meet the required cookstove performance on efficiency AND Can be visually identified for performance using stove type, brand or labeling	Untested three-stone fire, home-made stove, mud/earthen ring	Primary solution has met IWA Tier 1 on efficiency parameters OR Potentially improved cookstoves but either untested or cannot be visually identified	Primary solution has met IWA Tier 2 on efficiency parameters	Primary solution has met IWA Tier 3 on efficiency parameters	Primary solution has met IWA Tier 4 on efficiency parameters OR BLEENS-based cookstove	

Because direct measurement and mathematical modeling of cookstove efficiency may be difficult in many contexts, a rough and conservative approach based on cooking solution type may be adopted, as shown in Table 8.12.

Quality

Quality refers to caloric value, moisture, and combustion characteristics, or voltage (for electricity), which, if inadequate, may impact the performance of the cooking solution.

Quality of the cooking fuel refers to its caloric value, moisture, and combustion characteristics, or voltage for electricity-based solutions, which, if inadequate, may impact the performance of the cooking solution (Berkley Air Monitoring Group 2012; Table 8.13).

Quality of the primary fuel can be measured based on user recall of whether variations in fuel quality affect heat rate during cooking in a manner that presents difficulties or delays in cooking. For example, fuel adulteration may induce weak flame, and wet biomass often causes unusual black smoke.

Availability

Availability of cooking fuel may be an issue regardless of the technology, and often requires the use of a secondary fuel.

Availability of the cooking fuel may be an issue for a variety of reasons, depending on the type of fuel. Availability of solid fuels, such as wood or agricultural residues, may vary with seasonality. Shortages of LPG cylinders may be observed due to difficulty in supply logistics, particularly in the rural areas, or limited subsidy support. Biogas is subject to feedstock flow issues, and natural gas and electricity are subject to network outages.

TABLE 8.13

Tiers of Quality for Cooking Fuels

QUALITY	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Variations in heat rate due to fuel quality affecting cooking					No major effect	

TABLE 8.14

Tiers of Availability for Cooking Fuels

AVAILABILITY	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
Availability of primary fuel					Primary fuel is readily available for at least 80% of the year	Primary fuel is readily available throughout the year

In order to assess whether the availability of the primary cooking solution is adequate, the regular use of a secondary[41] cooking solution is analyzed (Table 8.14). If the household uses a secondary solution mainly because the primary cooking fuel is not always available, it is concluded that the availability of the primary cooking fuel is inadequate.

It is also possible that the household uses an “aspirational” secondary solution, usually of higher emissions performance as compared with the primary. Usually in such a case, the aspirational secondary solution is the household’s preferred solution but cannot be used as a primary due to affordability or availability issues.

Aggregating Attributes into a Household Cooking Access Tier Rating

The methodology for aggregating attributes into an overall tier rating is designed to be technology and fuel neutral, while reflecting the wide range of cooking solutions. Cooking solutions in the household are evaluated based on the combination of seven attributes of energy across six tiers (Tiers 0 to 5), starting with access to rudimentary solutions and increasing gradually to modern cooking solutions that deliver the highest results for all attributes (Table 8.15). Each attribute is assessed separately and the overall tier for the household’s access to cooking solutions is obtained by applying the lowest tier among all the attributes.

Cooking solutions are evaluated based on the combination of seven attributes.

Health, convenience, safety, and efficiency are the main concern at the lower tiers (Tier 1 to 3), as households tend to experience high pollution rates and suffer from unsafe solutions. Indeed the choice of inferior solutions on these attributes is usually a consequence of difficulty with affordability or

At the lowest tiers, health and safety are the main concern.

TABLE 8.15

Multi-tier Matrix for Measuring Access to Cooking Solutions

ATTRIBUTES		LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
1. Indoor Air Quality	$PM_{2.5}$ (μg/m^3)		[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	< 35 (WHO IT-1)	< 10 (WHO guideline)
	CO (mg/m^3)					< 7 (WHO guideline)	
2. Cookstove Efficiency (not to be applied if cooking solution is also used for space heating)			Primary solution meets Tier 1 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	Primary solution meets Tier 2 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	Primary solution meets Tier 3 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	Primary solution meets Tier 4 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	
3. Convenience:	Fuel acquisition and preparation time (hrs/week)			< 7	< 3	< 1.5	< 0.5
	Stove preparation time (min/meal)			< 15	< 10	< 5	< 2
4. Safety of Primary Cookstove	IWA safety tiers		Primary solution meets (provisional) IWA Tier 1 for Safety	Primary solution meets (provisional) IWA Tier 2	Primary solution meets (provisional) IWA Tier 3	Primary solution meets (provisional) IWA Tier 4	
	OR Past accidents (burns and unintended fires)					No accidents over the past year that required professional medical attention	
5. Affordability						Levelized cost of cooking solution (inc. cookstove and fuel) < 5% of household income	
6. Quality of Primary Fuel: variations in heat rate due to fuel quality that affects ease of cooking						No major effect	
7. Availability of Primary Fuel						Primary fuel is readily available for at least 80% of the year	Primary fuel is readily available throughout the year

availability attributes. At higher tiers (Tier 4 and 5), affordability, availability, and quality requirements are also imposed to deliver a comprehensive cooking experience.

Access to cooking solutions is evaluated by considering all relevant energy attributes influencing users' experience. Mainly focused on the health and safety attributes, the approach gradually factors in the rest of the attributes as access improves, to ensure that health impacts are observed and users benefit from enhanced cooking activities. The final multi-tier metric represents access at the household level, considering not only the primary cooking solution but also secondary ones.

An integral measurement of access to cooking solutions captures all relevant attributes.

Household Access to Energy for Space Heating

Households in countries that experience cold weather during the whole or part of the year need access to energy for space heating. In many such households, cooking solutions also serve to meet heating needs. These households use cookstoves for cooking, and the waste heat serves to warm the surroundings. In most modern houses, however, heating solutions tend to be separate from the cooking solutions. Energy for space heating can be accessed through a range of solutions, including electric heating, fuel-based centralized district heating, fuel-based standalone heating, and direct solar heating.

The need for energy for space heating is influenced by several factors, including the local climate, season, time of day, size and orientation of the house building, heat insulation characteristics of the building, and floor carpeting, among others. In addition, the need for heating can be met with increased clothing (pullovers, blankets, etc.) as well as consumption of warm beverages. Thus, the need for energy varies significantly, and it is difficult to arrive at any standard norms of energy availability. Unlike cooking, which is a basic requirement for survival and cannot be avoided despite poor access to energy, space-heating needs can be curtailed through adoption of other coping mechanisms, albeit with discomfort and harmful in extreme cases.

Household access to heating (where needed) is measured using a separate multi-tier framework, and a separate index of access to energy for space heating is calculated. The multi-tier matrix for this framework is presented in Table 8.16.

OBTAINING DATA FOR MEASURING HOUSEHOLD ACCESS TO COOKING SOLUTIONS

A comprehensive measurement of household access to energy for cooking in any geographic area requires data and information about several aspects, including:

A comprehensive measurement of household access to energy for cooking in any geographic area requires data and information about several aspects.

1. Indoor air quality in the household (usually difficult to obtain)
2. Emission performance of the primary and secondary cooking solutions
3. Size of the cooking area
4. Ventilation in the cooking area, including through natural and forced draft

TABLE 8.16

Multi-tier Matrix for Access to Space Heating

			LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
ATTRIBUTES	1. Capacity			Personal space around individuals is heated	At least one room has heating		All rooms in the household have heating	
	2. Duration					At least half the time when needed (> 50% of the time)	Most hours when needed (> 75% of the time)	Almost all hours when needed (> 95% of the time)
	3. Quality					Comfortable temperature at least 50% of the time	Comfortable temperature at least 75% of the time	Comfortable temperature all the time
	4. Convenience (fuel collection time in hrs/week)				<7	<3	<1.5	<0.5
	5. Affordability					Cost ≤ 2 times the grid tariff		Cost ≤ the grid tariff
	6. Reliability (number of disruptions/day)					<7	<3	<3 (total duration < 2 hours)
	7. Indoor Air Quality	PM$_{2.5}$ (μg/m^3)		[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	< 35 (WHO IT-1)	< 10 (WHO guideline)
		CO (mg/m^3)					< 7 (WHO guideline)	
	8. Safety						No accidents (burns or unintended fires) over the past year that required professional medical attention	

5. Conformity to use specifications, including the use of chimneys, hoods, or skirts as per cookstove design; use of appropriate fuel; and regular maintenance and cleaning of the cookstove
6. Quality of fuel used
7. Safety design of the cookstove
8. Convenience of use with regard to time and effort in fuel collection, fuel preparation, cookstove preparation, and cooking itself
9. Capacity of the primary cooking solution with regard to number of burners, cultural elements of cooking needs, and size of the flame
10. Availability of the fuel for primary cooking solution on a reliable basis
11. Affordability of the fuel for primary cooking solution

Items 2 through 6 in the list directly affect the indoor air quality in the cooking area, which impacts the health of the cook as well as other household members. Data and information on indoor air quality performance and the safety design of the cookstoves can only be gathered through expert assessment under controlled conditions in a laboratory or a suitable setup in the field. All other aspects can only be observed through field surveys. As a result, a comprehensive assessment of household access to energy for cooking requires a mix of expert assessment of the cooking solutions in laboratories (or in the field) along with a field survey to collect information about other aspects of cooking.

Data and information about household access to energy for cooking can be gathered through demand-side or supply-side measurements, as explained next.

Demand-Side Measurement

Demand-side measurement involves collecting data from the users through household energy surveys. The indoor air quality and safety characteristics of the cookstoves can be inferred during the survey by one of the following ways, listed in the order of reducing accuracy:

Demand-side measurement involves collecting data from the users through household energy surveys.

1. Actual measurements of indoor air quality through relevant instrumentation in the surveyed households
2. Inferring the cookstove performance by leveraging a system of testing, certification, and labeling
3. Rough and conservative proxy of the likely cookstove performance based on visible characteristics such as basic design and comparing with known minimum performance of similar solutions

Data and information about other attributes can be obtained through direct questions to the households. Demand-side measurement can be a useful approach for periodic reporting of household access to energy for cooking in any geographic area. It can be used to establish the baseline for program evaluation, as well as for periodic tracking of progress.

Supply-Side Measurement

Supply-side measurement involves upfront laboratory (or field) testing of the cookstove to establish IAQ performance under controlled conditions.

Supply-side measurement involves upfront laboratory (or field) testing of the cookstoves covered under the program to establish the indoor air quality performance under controlled conditions. Information about other attributes can be gathered or inferred through one of the following ways, listed in the order of reducing accuracy:

1. Regular and comprehensive household energy surveys in the target area
2. Limited surveys to gather data about use aspects that can be extrapolated to the entire population
3. Conservative assumptions about use attributes that may not have been fully validated through actual surveys but are expected to hold true

Supply-side measurement can be used by various projects and programs to estimate and report the likely energy access impact of improved cookstoves by applying actual laboratory test results and field survey data (when available), or using suitable assumptions backed by sample surveys or reasonable justifications.

ANALYSIS OF RESULTS

Results can be compiled and analyzed to produce an energy access diagnostic.

The multi-tier framework yields a wide range of results that can be compiled and analyzed to produce an energy access diagnostic for a given area. Such diagnostic includes in-depth disaggregated data analysis, as well as aggregated analysis, in the form of an index of access, aiming to facilitate planning and strategy of the cooking sector, project design, progress monitoring, impact evaluation, and comparison across geographic areas and over time.

Disaggregated Analysis: Cross-Cutting Analysis of Household Access to Cooking

Data can be analyzed under different lenses and analyzed in multiple ways, leading to a wide range of indicators.

Data can be used to analyze different attributes of energy and various underlying factors that affect these attributes. Data can be viewed in various ways to gain perspective on the levels of energy access available to different segments of the population, as well as insights into the various phenomena affecting energy access. Among the various indicators that can be calculated are: (i) the proportion of households using different types of fuel; (ii) the penetration of tested cookstoves; (iii) the proportion of households by level of health and safety; (iv) the proportion of households with poor, normal, or good ventilation in the cooking area; (v) the proportion of households using their cooking solution in conformity with technical requirements; (vi) the proportion of households suffering from low fuel quality; (vii) the proportion of households spending over 7 hours for fuel collection; (viii) the average time needed to obtain fuel by type of fuel; (ix) the proportion of households spending over 15 minutes for fuel and stove preparation by type of cooking solution; (x) the proportion of households dissatisfied by the ease of cooking by type of cooking solution; (xi) the proportion of households using a secondary cooking solution of higher technical performance (compared with the primary one); (xii) the proportion of households using a secondary cooking solution of lower technical performance (compared with the primary one); (xiii) the proportion of households facing issues with inadequate flame size by type of cooking solution; (xiv) the proportion of households facing issues with inadequate number of burners by type of cooking solution; (xv) the proportion of households that cannot cook traditional food with their primary cooking solution by type of cooking solution; (xvi) the proportion of households facing fuel availability issues by type of primary fuel; and (xvii) the proportion of households facing fuel affordability issues by type of primary fuel.

Such analysis can be done across different population groups segmented on the basis of income, location (urban, peri-urban, rural), household size, female- versus male-headed households, and other dimensions. For example, affordability could be analyzed by looking at the distribution of households using a secondary cooking solution of lower technical performance due to nonaffordable primary cooking fuel across quintiles. Such analysis may be particularly of interest for households using a BLEENS-based cooking solution as a primary one and a (non-BLEENS) solid- or liquid-based solution as a secondary one, thus informing policy regarding energy price reforms.

Aggregated Analysis: Index of Access to Household Cooking

To compile the information captured by the multi-tier matrix into a single number representing the level of access to cooking in a selected geographical area, a simple index can be calculated by weighting the tiers and arriving at a weighted average. The following formula is applied:

A single number representing the level of access to cooking may be compiled based on the multi-tier matrix.

$$\sum_{k=0}^{5}(20 * P_k * k)$$

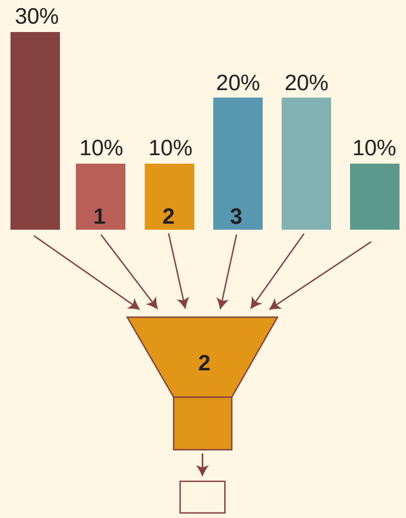
k: tier number

P_k: proportion of households at the kth tier

The index evaluates both the extent of access (how many households have access) and the intensity of that access (the level of access that households have)[42] (Figure 8.3).

FIGURE 8.3

Example of Index Calculation



Comparison across Geographic Areas and over Time

The index, as well as disaggregated data, may be compared across countries or any geographic area, including sub-national, regional, and worldwide.

Both disaggregated and aggregated data may be compared across geographic areas and over time. The index can be calculated for any geographic area, such as a country, a province, a district, a town, or a village, but also a continent and the world as a whole. For example, developed countries are expected to have an index value of 100, whereas in many countries in Sub-Saharan Africa, the index value may only reach 20 or less, due to a large population cooking with homemade stoves. The index for a larger geographical area can be obtained by calculating the population-weighted average of indices across the smaller areas that constitute the larger area. For example, the index at the state level can be obtained by calculating the weighted average of the district-level indices. Similarly, state-level indices can be aggregated into a national-level index, which would in turn be used to calculate regional and global indices.

The index, as well as disaggregated data, may be compared over time to track progress in access.

Progress in improving household access to cooking solutions can be tracked by comparing indices over time. Further, the comparison of disaggregated data over time would detect areas where efforts have been successful, as well as bottlenecks inhibiting higher index values.

CONCLUSION

The multi-tier framework provides a comprehensive tool to capture information about access to energy for cooking, encompassing various cooking solutions, user behavior, cooking conditions, and use of multiple cooking solutions, as well as convenience and safety aspects. It allows disaggregate as well as aggregate analysis to yield detailed information about various parameters as well as indices that facilitate comparison over time and across geographic areas.

ENDNOTES

[29] Solid fuels typically include: (i) traditional biomass (e.g., wood, charcoal, agricultural residues, and dung); (ii) processed biomass (i.e., pellets and briquettes); and (iii) other solid fuels (i.e., coal and lignite).

[30] Liquid fuels typically include kerosene, ethanol, and other biofuels.

[31] Gaseous fuels typically include LPG, natural gas, and biogas.

[32] Usually, the technical performance of BLEENS fuel-based cookstoves does not significantly vary with the cookstove design, but is inherent to the characteristics of the fuel itself.

[33] Black carbon is a component of particular matter formed by the incomplete combustion of fossil fuels, biofuels, and biomass. It is a climate-forcing agent with a short atmospheric lifetime (days to weeks).

[34] Solid fuels include: (i) traditional biomass (e.g., wood, charcoal, agricultural residues, and dung); (ii) processed biomass (such as pellets and briquettes); and (iii) other solid fuels (such as coal and lignite).

[35] The primary cooking solution refers to the one used most of the time for cooking meals in the household.

[36] Two exceptions are the United Arab Emirates (3.97%) and Qatar (3.76%).

[37] Nonsolid fuels include: include: (i) liquid fuels such as kerosene, ethanol, or other biofuels; (ii) gaseous fuels (e.g., natural gas, LPG, and biogas); and (iii) electricity.

[38] Integrated exposure-response function is a model that combines exposure and risk data for four sources of combustion-related pollution: outdoor air, second-hand smoke, household air pollution, and active smoking.

[39] Other models, such as the three-zone model and the computational fluid dynamics model, can yield more accurate results but are significantly more complex to apply.

[40] Of the eight attributes of energy access, reliability and legality are not included in the multi-tier framework for access to cooking. Reliability of fuel supply is covered in the availability attribute, whereas legality has not been included because it is difficult to determine whether fuel sourcing and free collection of fuel is legal or illegal.

[41] The secondary cooking solution is a solution used most frequently in parallel with the primary solution.

[42] This aggregation method is used by the Multi-Dimensional Energy Poverty Index (Nussbaumer et al. 2012).

9

ACCESS TO ENERGY FOR PRODUCTIVE ENGAGEMENTS

It is important to measure access to productive uses of energy, as they affect income-generating opportunities and improve the economic sustainability of energy projects.

Productive use of energy is a significant driver of socioeconomic growth. The use of modern forms of energy can (i) underpin the creation and upgrading of value chains; (ii) facilitate the diversification of economic structures and livelihoods; and (iii) reduce vulnerability to multiple stresses and external shocks (EUEI 2011). Energy is one of the key inputs of the production process for most, if not all, enterprises. It is understood that energy, although a necessary factor, is rarely sufficient for driving economic growth. Access to finance, markets, raw materials, technology, and a qualified workforce is also necessary. However, energy is crucial for enterprises, as it fosters economic and social development by (i) increasing productivity, income, and employment; (ii) reducing workloads and freeing up time for other activities; and (iii) facilitating the availability of higher quality or lower priced products through local production. To be successful, energy projects should aim to directly impact livelihoods and revenue generation, beyond the provision of connections and kilowatt hours (ESMAP 2008). In addition, providing energy to businesses improves the financial sustainability of electrification projects. Productive activities help increase the load factor by spreading demand evenly throughout the day. This often translates into more reliable capacity to pay (EUEI 2011; Schnitzer et al. 2014) and higher revenues for the utility or better management of the electricity supply systems, which leads to better chances to finance maintenance and repair and improve the system's sustainability. This chapter provides a comprehensive approach for defining and measuring access to productive uses of energy as a continuum of improvement, considering multiple energy attributes that determine users' choices and reflect their experience.

Productive uses of energy are defined as those that increase income or productivity and refer to value-adding activities.

Productive uses of energy are defined as those that increase income or productivity and refer to the activities that add value, which could be taxable if a part of the formal economy (EUEI 2011). In addition, productive uses include activities that contribute to economic livelihoods, such as subsistence farming. Productive applications of energy refer to the services needed to support the productive activities that energy makes possible, such as lighting, information and communication technology (ICT), motive power, heating, and so forth. Appliances are the energy-operated devices used for utilizing various services, and include light bulbs, computers, refrigerators, mills, water pumps, heaters, and so on. Engines and stoves are the typical equipment used for obtaining energy from direct combustion of fuels.

The chapter presents the multi-tier approach for measuring access to productive uses of energy.

The chapter starts by presenting the impacts of access to energy for productive engagements on socioeconomic development, and reviews the challenges in measuring access to energy for productive engagements. It then elaborates on the multi-tier approach used to measure access to energy for productive engagements, and, finally, shows how to use the results of such measurement for policy formulation and investment planning, as well as monitoring and evaluation.

IMPACTS OF ACCESS TO ENERGY FOR PRODUCTIVE ENGAGEMENTS ON SOCIOECONOMIC DEVELOPMENT

Energy has both direct and indirect effects on production.

The linkages between energy and economic development are often explained using the production function. Straub (2008) modeled the impact of electricity through direct and indirect channels: electricity services may enter production directly as an additional input and indirectly by increasing productivity through cost reductions and more efficient use of other inputs. Indirect impacts include: (i) reduction of operating costs or extension of capital life span driven by high-quality electricity (e.g., stable voltage for connected equipment), (ii) reduction of capital adjustment costs driven by reliable electricity (e.g., investment in backup generators), and (iii) increase of labor productivity, raising effectiveness of human capital (e.g., due to improved ICT).

Most studies find a positive causal relationship between energy consumption and growth.

Despite conflicting results in the literature, most studies examining the causal relationship between energy consumption and economic growth conclude that the causality runs from electricity consumption to economic growth. Shocks to the energy supply are likely to have negative impacts (Ozturk 2010). There is wide evidence on the positive effects of electricity on gross domestic product (Estache, Speciale, and Veredas 2005; Foster and Briceno-Garmendia 2010; Khanna and Rao 2009; Payne 2010), as well as on other development measures such as employment, particularly of women (Dinkelman 2011; Goedhuys and Sleuwaegen 2010; Grogan 2008), and the Human Development Index (Lipscomb, Mobarak, and Barnam 2011). Calderon (2009) finds that the amount and service quality of electricity affect both long-run growth and income equality, whereas other studies report negative correlation between electrification and equality (ADB 2005).

Evidence suggests that rural electrification has a positive impact on home businesses. The number of home businesses is significantly higher in electrified communities, and the presence of electricity extends work hours and improves net income (WB 2008). Gibson and Olivia (2010) and Kumar and Rauniyar (2011) find that the incidence and average income of non-farm enterprises is positively related to improved access to electricity. Research in Sri Lanka shows that poor electricity supply performance inhibits productivity, proliferation of non-farm activities, and investment expansion (Deininger and Jin 2007).

CHALLENGES IN MEASUREMENT

Data paucity on access to energy for productive uses could affect energy policy, planning, project implementation, and progress monitoring.

At present, there is little or no systematic and comprehensive monitoring of access to energy for productive engagements, especially for micro and mini enterprises in the informal sector. Enterprise surveys often collect information on electricity supply to large enterprises, whereas other types of energy are often ignored. However, direct combustion of fuels is widely used for motive power and heating, and renewable motive and thermal energy (such as traditional water mills or solar thermal systems) are also employed by some users. Details about the attributes of energy supply are rarely captured, and issues regarding the quality, reliability, and affordability of the supply are overlooked. Nonetheless, a strong understanding of the multifaceted nature of energy access for productive uses is required to adequately inform energy policy, planning, project implementation, and progress monitoring.

Enterprises Vary in Scale and Scope

The wide diversity of productive activities and enterprises makes it difficult to devise a one-size-fits-all metric for energy access.

Productive enterprises span thousands of income-generating (and subsistence) activities across various sectors, encompassing agriculture, trading, manufacture, services, and handicrafts, among others. Any measurement of energy access must cover the energy needs of all such activities. For example, the energy needs of a tailoring enterprise may be very different from that of a restaurant. Further, within a sector, the scale of the activity varies widely across enterprises, in terms of number of employees, turnover amount, number of establishments, and so on. For example, a small tailoring shop may employ just two persons, whereas a large garment factory may employ thousands of workers. The degree of mechanization varies depending, inter alia, on the relative economics of the different enterprises. Whereas some enterprises may fall in the formal sector, others may belong to the informal sector, which has a particularly large presence among developing countries. Most poor people in developing countries participate in occupations such as small shops, small eateries, artisanal works, and agricultural labor—all of which fall in the informal sector of the economy. Such diversity leads to very different energy requirements and a varying degree of mechanization. Depending on their characteristics, the energy needs of enterprises are affected differently by deficient energy supply. Therefore, it is challenging to devise a measuring methodology based on a one-size-fits-all scale.

Enterprises Require a Wide Range of Energy Applications

Productive enterprises engage a wide range of energy applications, all of which need to be addressed during the access to energy assessment.

Productive enterprises require a wide range of energy services in their operations. Lighting is a key requirement that allows extension of the working day and increased production (or service delivery), leading to higher income (ESMAP 2002). Applications for the improvement of working processes facilitate reduction of heavy physical tasks for laborers (e.g., purchase of electric wood-saws or oil-presses instead of manual sawing and pressing of oil). ICTs, including mobile telephony and internet-based technologies, as well as more traditional forms of communication such as radio and television, allow entrepreneurs to be up-to-date on market conditions. Along with increased availability of information, benefits from ICTs include lower barriers to entry, reduced communication and transaction costs, new sources of revenue, and affordable global reach (Tanburn and Singh 2001). Motive power is used in many productive activities, helping reduce drudgery and increase productivity. The applications of motive power are endless. In agriculture, water pumping for irrigation and the introduction of machinery for tillage, ploughing, harvesting, and so forth, dramatically improved productivity and farmers' livelihood. Agro-processing has greatly benefitted from mechanization of milling, pressing, cutting, decorticating, spinning, and so on (PAC 2009). Similarly, artisanal activities and to a greater extent manufacturing have been transformed by motive applications in wood and metal working, carpentry, textile making, pottery, brick making, and paper making, among others. Refrigeration improves food preservation and drives sales in the retail sector (ESMAP 2011). Space cooling and space heating increase comfort for customers and workers. Heating applications are multiple when it comes to product heating needs. Food processing activities require applications such as cooking, baking, drying, smoking, pasteurizing, and so forth, and industrial processes include firing, smelting, soldering, incubating, sterilizing, and so on. Finally, water heating is an important energy application in the agricultural, industrial, and service sectors for hygienic and cleaning purposes. Any assessment of energy access must look at all energy applications that may be used by the enterprise.

Enterprises Deploy Multiple Sources of Energy

Productive activities use electricity as well as other energy sources.

Enterprises often deploy multiple sources of energy, either because of the nature of their energy needs or because of poor quality of access that necessitates diversification of energy sources. Electricity is perhaps the only energy carrier that can be used to run all energy applications. As a result, most studies on energy access for enterprises focus only on electricity access. Similarly to households, enterprises may receive electricity from multiple solutions, including grid, mini-grid, and off-grid standalone systems, which present significant differences in the quantity and quality of electricity delivered. All solutions need be monitored and evaluated according to the performance of the electricity supply that they provide, as the impact on productive activities will vary (Valer et al. 2014).

Beyond electricity, other sources of energy are often used by productive enterprises, including direct combustion of solid, liquid, and gaseous fuels for motive and heating applications. Some enterprises also use direct renewable energy for motive and heating applications, including wind- and water-powered mills, as well as solar energy. Human or animal power may also be used for certain motive applications, particularly in the agricultural sector. Any framework for access to energy for productive enterprises must address the multiplicity of energy sources.

Enterprises May Be Affected by Multiple Energy Supply Issues

Poor performance of the energy supply leads to financial losses and slows down economic growth.

It has been widely documented that deficient energy supply dampens economic growth (Eberhard et al. 2008; IMF 2008; Jones 2011). As explained in earlier chapters, energy supply may be deficient in multiple ways. The capacity of the energy supply may not be sufficient for supporting the required applications for operating the activities. For instance, off-grid electricity systems may only support lighting and ICT applications but fail to deliver energy-intensive motive power. Similarly, water mills may not be large enough to cover all productive needs.

Deficiencies in duration of supply and regular availability of fuel can drive enterprises toward higher-cost solutions.

Enterprises may also suffer from fuel availability issues or inadequate duration of electricity supply. Higher energy prices are likely to be accepted by several enterprises in exchange for improved availability and reliability of supply (Wijayatunga and Jayalath 2008). Reliable energy supply that is available for an appropriate duration can significantly strengthen economic growth. For example, Rao (2013) estimates that if every existing home-based non-farm enterprise in Indian households received 16 hours per day of electricity, additional annual income would account for at least 0.1 percent of India’s GDP. Chakravorty, Pelli, and Marchand (2014) find that whereas having a grid connection can increase nonagricultural income by 9 percent, income growth can reach 29 percent in cases of improved duration.

The World Bank 2014 Enterprise survey indicates that over a third of the enterprises in developing countries identify electricity as a major constraint to their operations.

The reliability of the energy supply significantly influences energy access for productive uses. The impacts of electricity supply interruptions are quantified based on production losses (Foster and Briceno-Garmendia 2010; IEA 2010). According to the World Bank,[43] the average number of power outages across countries during a typical month is 5.5, and the average duration of an outage is 4.5 hours (Enterprise Surveys 2014). Over one-third of the enterprises identify unreliable electricity as a major constraint for their operations, and about one-third of the enterprises own or share a generator. As a result, the average losses due to power outages have been estimated at 4.5 percent of annual sales. The IEA (2010) estimates that in developing countries power interruptions account for a month of lost services per year on average. Andersen and Dalgaard (2013) suggest that power outages significantly affect Africa's growth, and estimate that the average annual rate of real GDP per capita growth in Africa would have been 2 percentage points higher if all African countries had experienced South Africa's electricity supply performance. Wijayatunga and Jayalath (2008) find that the economic impact of electricity supply interruptions in the industrial sector in Bangladesh is over two times higher when outages are unplanned compared to the impact of planned outages.

Inadequate quality of the energy supply can affect production and damage equipment.

Inadequate quality of the energy supply may have major implications for productive uses. For example, voltage fluctuations may not only stop production, but also damage equipment. Fluctuating temperature may lower the quality of dried products, and certain heating applications, such as baking, require high temperature levels (EUEI 2014).

Unaffordability of energy can affect its use in productive enterprise. Illegal use of energy is observed in the form of hook-ups and meter tampering in small enterprises, whereas bribery and collusion occurs in large enterprises.

Affordability issues constrain the use of energy for productive uses (ESMAP 2011), or lead to the use of inconvenient or polluting energy solutions. As with households, illegal usage of electricity may occur in the commercial sector (Bhatia and Gulati 2004). Electricity theft strategies include hook-ups (illegal connections), meter tampering (fraud), billing irregularities (bribery), and unpaid bills (Smith 2004). Hook-ups and meter tampering may be more frequent in micro and small enterprises, whereas bribery and collusion occur between large commercial consumers and utility employees (WB 2009). Electricity theft results in significant financial losses for the utility and causes overloading of the supply infrastructure. Thus, the viability of services is compromised, leading to deterioration in the reliability and quality of the energy supply (ESMAP 2011). Legal consumers end up subsidizing illegal users as electricity charges increase to compensate for the losses (Jamil 2013; WB 2009).

Time and effort spent in sourcing energy and maintaining supply can affect productivity. Poorly installed and poorly maintained energy systems can cause accidents and damage.

Time and effort spent in sourcing energy and maintaining supply equipment may cause significant inconvenience to enterprises, affecting revenues or productivity. Poor levels of health and safety in the energy system may cause accidents or physical harm. For electricity systems, electrocution is the major risk, whereas pollution and burns may occur from direct combustion of fuels (ESMAP 2011).

Any measurement of energy access across productive engagements must suitably capture all of these attributes of the energy supply that may be deficient.

Survey-Related Limitations

Apart from the previously mentioned challenges in measuring access to energy for productive enterprises, devising surveys for gathering data offers additional difficulties, including the following:

Measurement is also constrained by survey limitations, including the need to address the informal sector. In any household multiple people may engage in multiple productive activities. Finally, the respondent may not be fully aware of the energy constraints.

- **Enterprise-level surveys often do not address the informal sector:** Enterprise surveys often focus on large enterprises in the formal sector. They often overlook the energy needs of the micro and mini enterprises, small-holder farmers, artisans, wage employees, and other laborers, which constitute the bulk of the population in developing countries. Therefore, there is a need to measure access to energy for all individuals in their respective productive activities rather than for enterprises in the formal sector. Because many small-scale productive activities take place either inside or near the household, this information can be captured through household energy surveys.
- **Multiple working members in the household:** During household energy surveys it is likely that many households would have multiple working members, with many of them engaged in marginal productive activities or even disguised unemployment. An important challenge is how to segregate the most important productive activities for an efficient data-collection effort.
- **Multiple occupations of a person:** Poor people often engage in multiple productive occupations, across seasons or even during the day, to earn more income. It is important to segregate the most important occupations from the less important ones.
- **Employees may not be fully informed:** If a respondent of the household energy survey does not own or manage the enterprise, but is only an employee, he or she may not have the full information about the state of energy access in the enterprise, especially in the case of large enterprises. In such a situation, it is important to limit the scope of the information gathering to the activity in which the respondent is directly engaged.

MULTI-TIER MEASUREMENT FRAMEWORK

The multi-tier approach aims to measure access to energy for productive purposes as a continuum of improvement (as opposed to a binary metric) by reflecting all attributes of the energy supply across all applications for various productive activities, while being technology and fuel neutral. The approach attempts to provide insight into the types of policy reforms and project interventions that would drive higher levels of energy access for productive enterprises, along with facilitating monitoring and evaluation.

The multi-tier framework captures the multiple attributes that influence access to energy or productive uses, in order to inform policy and investment.

The proposed approach is based on the energy access experienced by individuals rather than enterprises. This allows data on access to energy for productive uses to be gathered through household surveys, rather than requiring a separate enterprise survey process. It also ensures that

The proposed multi-tier framework is based on the energy access experienced by the individual rather than the enterprise.

the level of access measured relates to the experience of most people and avoids some of the issues related to differences in scale of various enterprises.

A multi-step process is applied by first determining the most important productive activities and the productive applications required by these activities, and then identifying the primary energy source used for each application. The performance of the energy supply is measured for each combination across eight attributes of energy, and, finally, a multi-tier measurement of access to energy for various applications is compiled to obtain the multi-tier energy access rating for the productive activity as a whole.

Step 1: Identify the Most Relevant Productive Activities

The most relevant productive activities are identified by first identifying the members of the household who contribute to the household's livelihood and their most important occupations.

Members of any household are likely to be involved in multiple productive activities. The most relevant productive activities can be identified during the household energy survey as follows:

- First, identify household members who regularly undertake productive activities. (Because the survey is aimed at gathering information about energy access in the local area, only members who work in the area should be considered.)
- Next, if any of these persons is engaged in multiple occupations, then identify the most important occupation for that person (i.e., the productive activity that contributes most to the person's livelihood).
- Further analysis is conducted for each working household member and the related main productive activity.

Step 2: Identify the Relevant Energy Applications

Productive enterprises typically require five types of energy applications: lighting, ICT, motive power, space heating, and product heating.

Energy applications are at the core of the multi-tier approach. Regardless of their size and sector, productive enterprises typically require the following five types of energy applications (Annex 2 provides a list of related sub-applications):

1. Lighting refers to the use of energy to light working spaces to enable workers to undertake tasks and for the comfort of customers (particularly in retail and hospitality).
2. ICTs refer to the use of energy for computing, electronics, and other communication and audiovisual purposes.
3. Motive power refers to mechanical uses of energy in which motion (either linear or rotational) is imparted to machinery. It is acknowledged that absorption cooling does not involve motive power. However, cooling as a whole is analyzed as a motive power application for simplicity reasons.
4. Space heating refers to uses of energy to heat interior working spaces for the welfare and comfort of workers and customers.

5. Product heating refers to uses of energy for heating as a direct part of the production process, including water heating as a means of achieving product heating.

This step aims to identify relevant energy applications for the productive activity. For an application to be relevant, it must be necessary for performing the productive activity and must significantly impact productivity, sales, costs, or the quality of the product or service provided. Energy access is measured only for relevant applications. In the case of respondents working in multi-person enterprises, the relevance of the energy applications refers to the respondent's individual productive use rather than the enterprise as a whole.

Identify relevant energy applications based on significant impact on productivity, sales, cost, or quality.

Step 3: Identify the Primary Energy Source for Each Application

The primary energy source used to run each relevant productive application refers to the source used most of the time. Secondary sources or backup solutions are not taken into account, as they are either considered as coping solutions to overcome poor performance of the primary source or used in emergency situations. Relevant applications can be run using a variety of energy sources (Table 9.1). Four categories have been identified:

Energy sources, categorized into four types, are matched to each productive application.

1. Electricity supplied through a wide range of technologies (such as solar lantern, rechargeable battery, solar home system (SHS), fossil fuel generator, biomass, biofuel or biogas generator, hydro or wind generator, mini-grid and grid) may power all types of applications.

TABLE 9.1

Productive Application and Energy Source Matrix

		PRODUCTIVE APPLICATION				
		Lighting[a]	ICT & Entertainment	Motive Power	Space Heating	Product Heating
Energy Source	Electricity	✓	✓	✓	✓	✓
	Fuel			✓	✓	✓
	Renewable Mechanical Energy (RME)			✓		
	Renewable Thermal Energy (RTE)			✓	✓	✓
	Animal Power (AP)			✓		
	Human Power (HP)			✓		

[a] Only electrical lighting is considered here—candles, kerosene lamps, and other solid- or liquid-based lighting fuels are considered as no access.

2. Fuels, such as biomass, biogas, biofuels, natural gas, kerosene, LPG, and other petroleum products may be directly burned in stoves or engines for motive power and heating applications. (Electricity generation from fuel combustion is excluded, being included under "electricity" in the first category).
3. Renewable motive energy (RME) includes direct use of wind and water for motive power, such as wind and water mills,[44] whereas renewable thermal energy (RTE) refers to the direct use of solar power for heating applications using solar thermal collectors, but also motive power (such as water pumps[45]).
4. Animal and human power may be used for motive applications.

Step 4: Measuring Attributes of the Energy Supply

The level of energy access provided by the primary energy source used for each productive application is assessed against eight attributes, which determine the usefulness of the energy supply and influence the user's experience. If the same primary energy source is used for multiple applications, energy access is assessed for those applications taken together rather than separately.

Capacity

The capacity of the electricity supply refers to the ability of the system to deliver a certain quantity of energy.

The capacity of the energy supply is defined as the ability of the energy system to provide a certain amount of energy per day in order to operate productive applications. For electricity, capacity is measured in watts if the technology used is grid, mini-grid, or a fossil fuel-based generator, and in daily watt hours for rechargeable battery, solar lantern, and solar home systems. The measurement of capacity is done across multiple tiers in which an increasing number of growing power-intensity appliances can be run. If capacity is unknown (in terms of watts or watt hours),[46] the power rating of the appliances deployed may be used as a proxy (see Annex 4).

For nonelectric energy sources, including direct combustion of fuels, RME, RTE, and animal and human power, measurement units differ by technology, and capacity depends on multiple factors and may not be easily observable. For simplicity, capacity is evaluated based on the requirements met using the subjective judgement of the respondent (Table 9.2). An additional indicator is included for all energy sources, in order to identify cases where users do not invest in required applications because of capacity constraints. Adequate capacity is reached when relevant applications are not missing solely due to capacity constraints.

Availability (Duration)

Availability or duration of energy supply refers to the amount of time for which the energy is available.

The availability or duration of the energy supply refers to the amount of time for which the energy is available, compared to the amount of time that the energy is required (Table 9.3). For electricity, RME, RTE, and animal and human power, duration is measured by dividing the number of hours per day

TABLE 9.2

Tiers of Capacity of Energy Supply for Productive Applications

CAPACITY		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Electricity	Power		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
	Daily Supply Capacity		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
	Typical Technology		Solar lanterns	Standalone solar systems	Generator or mini-grid	Generator or grid	Grid
Nonelectric (fuel, RME, RTE, AP, HP)					Available nonelectric energy at least partially meets requirements	Available nonelectric energy largely meets requirements	Available nonelectric energy fully meets requirements
Both					No relevant application is missing solely due to capacity constraints		

TABLE 9.3

Tiers of Availability (Duration) of Energy Supply for Productive Applications

AVAILABILITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Electricity		Min 2 hrs	Min 4 hrs	Half of the work hours (min 50%)	Most of the working hours (min 75%)	Almost all working hours (min 95%)
Nonelectric (fuel, RME, RTE, AP, HP)				Available nonelectric energy partially (50%) meets requirements	Available nonelectric energy largely (75%) meets requirements	Available nonelectric energy fully (95%) meets requirements
Both				Longer working hours are not prevented solely by lack of adequate availability (duration) of supply		

during which the energy supply is available by the number of hours during which it is required. For fuels, availability is measured by dividing the quantity available per day by the quantity required per day. An additional indicator is included for all energy sources in order to identify cases where users restrict their operations because of availability (duration) constraints. Adequate availability (duration) is reached when working hours are not limited solely due to supply availability (duration) constraints.

Reliability (Unscheduled Outages)

The reliability of the electricity supply is defined in terms of frequency and duration of unscheduled outages.

Reliability is defined in terms of unscheduled interruptions of supply, due to grid outages or breakdowns of the equipment delivering energy (such as a generator, a water mill, or an animal). Depending on the source of energy, reliability may be driven by different causes, requiring different solutions. Unexpected blackouts may significantly disrupt productive activities, and are often translated into financial losses, the extent of which depends on the frequency and duration of the interruption. Different types and size of productive activities would be impacted differently. The use of costly backup generators as a coping mechanism is even more common for businesses than for households.

The reliability indicator combines reliability issues and level of impact on the productive activity.

The electricity supply is considered to be reliable when unscheduled interruptions do not occur more often than three times per week on average, and their cumulative duration does not exceed 2 hours per week (Table 9.4). To account for the different impacts that reliability may have on a productive activity depending on its type and size, a three-level indicator combining reliability issues with the level of impact on the productive activity is applied: (i) reliability issues with severe impact, (ii) reliability issues with moderate impact, (iii) no reliability issues or issues with little or no impact. The impact of reliability on the productive activity may be defined in terms of financial losses or productivity reductions, but is assessed based on the subjective judgment of the respondent.

Quality

The quality indicator combines quality issues and level of impact on the productive activity.

The quality of the energy supply refers to different characteristics based on the energy source. For electricity, quality is defined in terms of voltage. Most electricity applications cannot be operated properly below a minimum level of supply voltage. For example, CFLs do not light up if the voltage

TABLE 9.4

Tiers of Reliability of Energy Supply for Productive Applications

RELIABILITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
All Energy Sources					Reliability issues have moderate impact	No reliability issues or little (or no) impact

is too low, and motors do not rotate properly. Further, transformers draw a higher current at low voltage, subjecting the system to greater thermal losses and increasing the risk of burn-out and fire. Low voltage usually results from overload in electricity mini-grids or grids—or from long-distance, low-voltage cables connecting far-flung households to the grid. Voltage stability is also important, as voltage fluctuations can damage equipment, and cause electrical fires.

For fuel- or renewable energy-based heating systems, quality is defined in terms of the fuel's ability to deliver the desired temperature level with stability. Similarly, for renewable energy-based motive systems, quality is defined in terms of its ability to deliver the required revolutions per minute (RPM) level with stability.

To account for the different impacts that quality may have on a productive activity depending on the nature and scale of operations, a three-level indicator combining quality issues with the level of impact on the productive activity is applied: (i) quality issues with severe impact, (ii) quality issues with moderate impact, (iii) no quality issues or issues with little or no impact (Table 9.5). The impact of quality on the productive activity may be defined in terms of financial losses or productivity reduction. As for reliability, the impact of energy quality on the productive activity is assessed based on the subjective judgment of the respondent.

Affordability of Use

Affordability[47] refers to the ability of the enterprise to pay for the energy required to run productive applications without unduly sacrificing market competitiveness. Affordability of energy use, thus, relates to a complex interaction between (i) the quantity of energy consumed, which depends on the type of equipment used and usage patterns; (ii) the unit price of energy, which is technology and location specific; (iii) the energy costs faced by other competing enterprises producing similar products; and (iv) the priority placed by customers on the enterprise's product versus their other competing expenditure priorities.

Affordability of energy affects the competitiveness of the enterprise.

Measuring affordability is challenging, particularly when multiple energy sources need to be considered. It is also difficult to set a threshold, such as a proportion of the expenditure or revenues devoted to energy costs, as every productive activity requires a different level of energy intensity.

The benchmark for affordability of energy use is the grid tariff per kWh.

TABLE 9.5

Tiers of Quality of Energy Supply for Productive Applications

QUALITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
All Energy Sources					Quality issues have moderate impact	No quality issues or little (or no) impact

TABLE 9.6

Tiers of Affordability of Energy Supply for Productive Applications

AFFORDABILITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
All Energy Sources					Variable energy cost ≤ 2 times the grid tariff	Variable energy cost ≤ the grid tariff

Certain activities by their nature may spend a higher share of their revenues on energy or may not have other high costs involved. The grid tariff per kilowatt hour (or kWh equivalent) may be taken as a benchmark for affordability. Therefore, energy is considered to be unaffordable if the unit cost is higher than two times the grid tariff (Tier 0 to Tier 2), somewhat affordable if the unit cost is up to two times higher than the grid tariff (Tier 3 and Tier 4), and quite affordable if the unit cost is equal or less than the grid tariff (Tier 5; Table 9.6).

Legality

Legality of connection is inferred by bill payment.

The legality of connection[48] to the grid needs to be monitored, as illegal connections pose a significant safety risk, while also affecting the financial sustainability of the power utility (Kakkar and Mustafa 2013; Smith 2004). Although the user may benefit from electricity services from an illegal connection, the risk of disconnection always lingers. Similar issues arise in relation to illegal access to mini-grid electricity supply.[49] Obtaining information about the legality of connection is challenging. The utility may not be able to accurately estimate the number of illegal connections, and users may be sensitive about disclosing such information in a survey. Alternative questions may be formulated to approximate legality, such as to whom the bill is paid (Table 9.7; see Annex 3 for further discussion).

Convenience

Energy supply is considered convenient when time and effort spent do not impact productivity.

Convenience refers to the time and effort spent in sourcing energy and maintaining the supply equipment, effectively acting as an additional cost to the enterprise. Energy supply is considered convenient when this time and effort do not cause significant impact on the productive activity

TABLE 9.7

Tiers of Legality of Energy Supply for Productive Applications

LEGALITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Grid and Mini-grid Electricity					Energy bill is paid to the utility, prepaid card seller, authorized representative, or legal market operator	

TABLE 9.8

Tiers of Convenience of Energy Supply for Productive Applications

CONVENIENCE	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
All Energy Sources					Time and effort in securing and preparing energy cause moderate impact	Little (or no) time and effort spent in securing and preparing energy and/or little (or no) impact

(Table 9.8). Similar to the case of reliability and quality, the impact of energy quality on the productive activity is also assessed based on the subjective judgment of the respondent.

Health

Health is a function of the indoor air quality resulting from the use of fuels. As explained in Chapter 8: Access to Household Cooking Solutions, the health risks of fuel combustion may be estimated by assessing emissions resulting from the energy solution. Based on WHO guidelines, tiers for $PM_{2.5}$ and CO can be established (Table 9.9). In cases where the performance of the energy solution in terms of emissions is not known, a less accurate approach based on a broad categorization of fuels may be used. The lowest level (Tier 0 and Tier 1) refers to non-BLEENS fuels used indoors without smoke extraction, while Tier 2 and Tier 3 refer to non-BLEENS fuels used outdoors or with smoke extraction. Finally, the highest level (Tier 4 and Tier 5) refers to the use of BLEENS fuels (or equivalent).

Tiers for health are established based on WHO guidelines on $PM_{2.5}$ and CO, or a less accurate fuel categorization.

TABLE 9.9

Tiers of Health Risks of Energy Supply for Productive Applications

HEALTH		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Fuels	$PM_{2.5}$ (μg/m^3)		[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	< 35 (WHO IT-1)	< 10 (WHO guideline)
	CO (mg/m^3)					< 7 (WHO guideline)	
	OR Use of Fuels (BLEENS)			Use of non-BLEENS solutions (if any) outdoors or with smoke extraction		Use of BLEENS or equivalent solutions only (if any)	

TABLE 9.10

Tiers of Safety of Energy Supply for Productive Applications

SAFETY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
All Energy Sources					Energy supply solutions caused accidents that did not require professional medical assistance	Energy supply solutions did not cause any accidents

Safety

The safety of the energy system is defined in terms of risk of accident or damage related to the energy system.

The safety of the energy system refers to the risk of accident or damage. For electricity, this risk refers primarily to electrocution,[50] whereas fire, burns, and explosion risks are the major concerns in the case of direct combustion of fuels. Inadequately guarded renewable energy equipment can present a risk of injury, and physical harm may also occur when using animal or human energy. The safety attribute is measured by monitoring whether accidents or damage have occurred over the last 12 months. Three levels of safety may be identified (Table 9.10). The lowest level (Tier 0 to Tier 3) refers to energy solutions that caused accidents that required professional medical assistance. Tier 4 refers to energy solutions that caused accidents that did not require professional medical assistance. Finally, the highest level (Tier 5) refers to energy solutions that did not cause any accidents.

Step 5: Determining the Tier of Access for the Productive Application

The framework is built on eight attributes, which determine the usefulness of the supply for each application needed for the productive activity. Access to energy is first assessed for each application separately.

Assessing the level of energy access for each relevant application: The level of access is first assessed for each relevant application separately (or group of applications taken together, if the same source of energy is used for all of them). The performance (or usability) of the primary energy source for each application is evaluated through the combination of the eight attributes of energy across six tiers of access (Table 9.11), thus, quantifying the usefulness of the energy supply, which influence the extent to which applications are used and determine the user's experience. Each attribute is assessed separately and the overall tier of energy access for the application is calculated by applying the lowest tier obtained in any of the attributes. For relevant productive applications that are required but are not used due solely to energy-related issues (such as availability or affordability issues of the energy supply), the access tier is Tier 0.

The energy access level for the respondent is the lowest tier among all applications.

Assessing the level of energy access of the respondent: Once the access tier for each relevant application has been assessed, the overall access tier at the respondent level is obtained by applying the lowest tier among the relevant applications. A conservative aggregating approach aims to reflect energy access bottlenecks faced by the productive use.

TABLE 9.11

Multi-tier Matrix for Measuring Access to Productive Applications of Energy

				TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	1. Capacity	Electricity	Power		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
			Daily Supply Capacity		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
			Typical Technology		Solar lanterns	Standalone solar systems	Generator or mini-grid	Generator or grid	Grid
		Nonelectric (fuels, RME, RTE, AP, HP)					Available nonelectric energy partially meets requirements	Available nonelectric energy largely meets requirements	Available nonelectric energy fully meets requirements
		Both					No relevant application is missing solely due to capacity constraints		
	2. Availability (Duration) of Daily Supply	Electricity			Min 2 hrs	Min 4 hrs	Half of the working hours (min 50%)	Most of working hours (min 75%)	Almost all working hours (min 95%)
		Nonelectric (fuels, RME, RTE, AP, HP)					Available nonelectric energy partially meets requirements	Available nonelectric energy largely meets requirements	Available nonelectric energy fully meets requirements
		Both					Longer working hours are not prevented solely by lack of adequate availability (duration) of supply		
	3. Reliability							Reliability issues with moderate impact	No reliability issues or little (or no) impact
	4. Quality							Quality issues with moderate impact	No quality issues or little (or no) impact
	5. Affordability							Variable energy cost ≤ 2 times the grid tariff	Variable energy cost ≤ the grid tariff

TABLE 9.11 continued

			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	6. Legality						Energy bill is paid to the utility, pre-paid card seller, authorized representative, or legal market operator	
	7. Convenience						Convenience issues cause moderate impact	Little (or no) convenience issues or little (or no) impact
	8. Health (IAQ from use of fuels)	$PM_{2.5}$ (μg/m^3)		[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	< 35 (WHO IT-1)	< 10 (WHO guideline)
		CO (mg/m^3)					< 7 (WHO guideline)	
		OR Use of fuels (BLEENS)			Use of non-BLEENS solutions (if any) outdoors or with smoke extraction		Use of BLEENS or equivalent solutions only (if any)	
	9. Safety						Energy solutions caused accidents that did not require professional medical assistance	Energy solutions did not cause any accidents

OBTAINING DATA FOR MEASURING ACCESS

Data for energy access for productive uses can be obtained through household energy surveys.

Data for assessing energy access for productive uses can be obtained through household energy surveys, where respondents would provide information about their respective productive activities. Such activities would typically encompass agriculture, micro enterprises, and artisanal jobs, as well as laborers in the informal sector and formal-sector employment (although the latter tends to be a smaller component of productive employment in developing countries).

ANALYSIS OF RESULTS

Results can be compiled and analyzed to produce an energy access diagnostic.

The multi-tier framework yields a wide range of results that can be compiled and analyzed to produce an energy access diagnostic for a selected area. Such a diagnostic includes in-depth disaggregated data analysis, as well as aggregated analysis, in the form of an index of access, aiming to facilitate planning and strategy, project design, progress monitoring, impact evaluation, and comparison across geographic areas and over time.

Disaggregated Analysis: Cross-Cutting Analysis of Access to Productive Uses of Energy

Data can be used to analyze access under different lenses and in mulitple ways. Analyzing data for productive uses can be based on: (i) attributes, (ii) geographic areas, (iii) occupations, (iv) applications, and (v) supply sources. For example, data on farming can be analyzed by selecting only respondents who reported farming as their primary occupation. Within farming, data for irrigation can be analyzed, and further data for irrigation using electric pumps can be analyzed separately from data for irrigation using diesel pumps. Data can also be analyzed separately for various scales of operations, or key characteristics of the enterprise. Thus, each of the attributes can be analyzed for each of the supply sources and each of the applications across various occupations.

Data can be analyzed under different lenses and sliced in multiple ways, leading to a wide range of indicators.

Aggregated Analysis: Index of Access to Productive Uses of Energy

To compile the information captured by the multi-tier matrix into a single number representing the level of access to produce uses of energy in a selected geographic area, a simple index can be calculated as the average tier rating across respondents. The following formula is applied:

A single number representing the level of access to productive uses of energy may be compiled based on the multi-tier matrix.

$$\sum_{k=0}^{5}(P_k * k)$$

k: tier number

P_k: proportion of respondents at the kth tier

The index evaluates both the extent of access (how many respondents have access) and the intensity of that access (the level of access that respondents have)[51] (Figure 9.1).

Additional indices may be compiled, such as the index of access by (i) type of industrial enterprise (agriculture, small shops, artisans, etc.), (ii) productive application (lighting, motive power, product heating, etc.), and (iii) energy source (grid, mini-grid, fuels, etc.). Thus, lighting may be rated at 3.5 in an area but motive power at 2.2. Similarly, indices may be obtained by energy source (such as electricity, fuels, RME and RTE, etc.)

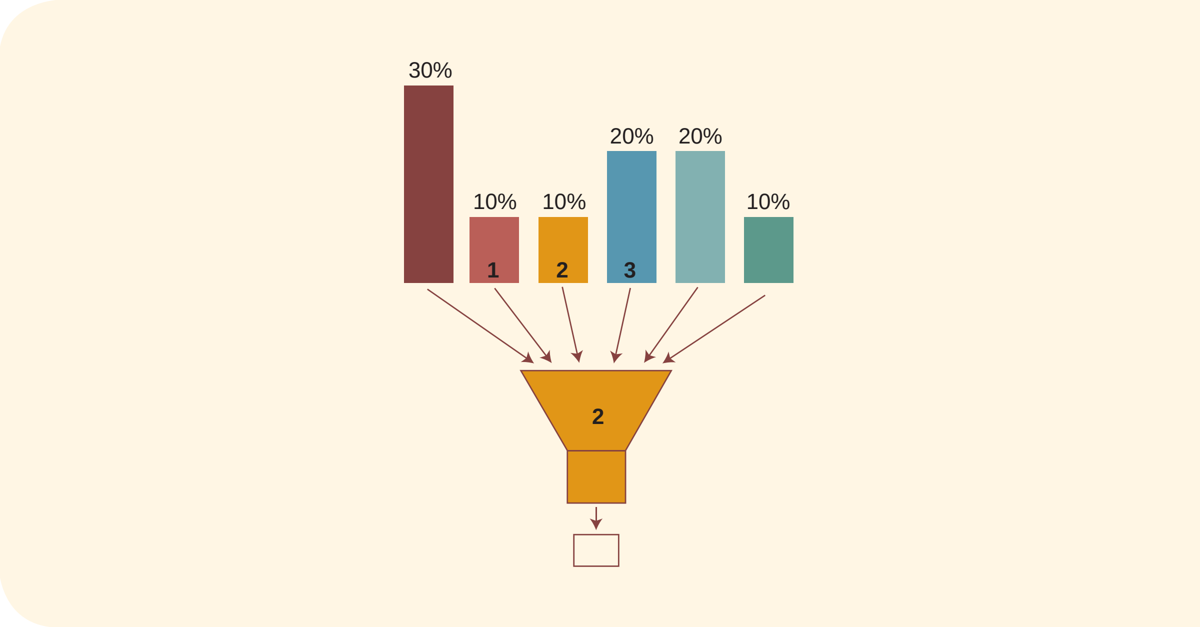
Comparison across Geographic Areas and over Time

Both disaggregated and aggregated data may be compared across geographic areas and over time. The index may be compared across countries or any geographic area, such as a country, a province, a district, a town, or a village, but also a continent and the world as a whole. For example, developed countries are expected to have an index value close to 100, whereas in many countries in Sub-Saharan Africa, the index value may only reach 20, due to a large number of productive activities running on grid delivering few hours of supply per day, or suffering from diesel fuel availability issues.

The index, as well as disaggregated data, may be compared across countries or any geographic area (including sub-national regional, and worldwide), as well as over time.

FIGURE 9.1

Example of Index Calculation



The index for a larger geographical area can be obtained by calculating the population weighted average of indices across the smaller areas that constitute the larger area. For example, the index at the state level can be obtained by calculating the weighted average of the district-level indices. Similarly, state-level indices can be aggregated into a national-level index, which would in turn be used to calculate regional and global indices.

The index, as well as disaggregated data, may be compared over time to track progress in access.

Progress in improving access to productive uses of energy can be tracked by comparing indices over time. Further, the comparison of disaggregated data over time would detect areas where efforts have been successful, as well as bottlenecks inhibiting higher index values.

The impacts of specific projects and programs can be assessed by undertaking a baseline survey in the project or program area (and ideally in a similar area unaffected by the project or program) and then repeating the survey after the project or program has been implemented to establish how the productive energy access of those benefiting from the project or program has improved.

CONCLUSION

The multi-tier approach provides a comprehensive tool for assessing access to energy across various productive uses.

The multi-tier approach provides a comprehensive tool for assessing access to energy across various productive uses, while addressing the key challenges to measurement. It allows disaggregate and aggregate analysis to yield detailed information about various parameters, and indices that facilitate comparison over time, across geographic areas, and across different occupations. The methodology reveals the various bottlenecks to effective energy access, thus enabling remedies leading to enhanced energy access, higher productivity, and greater socioeconomic activity.

ENDNOTES

[43] Data based on enterprise surveys done in 140 countries during the period of 2006 to 2014.

[44] Electricity generation is excluded.

[45] An example of a solar water pump may be found at: http://www.bsrsolar.com/sv/produkte2_e.html.

[46] It may be difficult to assess the capacity by simple observation. Standalone solutions, such as solar lanterns or SHSs, may not have a name plate indicating the capacity of the system, while for other technologies such as mini-grids, there is usually no written information within the premises.

[47] Affordability of upfront costs, such as connection to the grid or purchase of a standalone system, are not included here, unless there are being paid off at the time of the survey through an installment scheme. If not, such costs are considered affordable given that they have already been paid for.

[48] Illegal connections include secondary connections (connection through a neighbor) and direct theft. Other illegal practices, such as meter tampering, billing irregularities, and unpaid bills, have been excluded as they are more difficult to detect.

[49] Other forms of energy may also be obtained illegally. Wood fuel may be taken without the landowner's permission, or from an unlicensed source, often meaning that the supply is likely to be environmentally unsustainable. Similarly, direct renewable energy installations may be built without the landowner's permission or without obtaining necessary licenses and consents. However, the end user may be unaware of the legality of such energy sources and/or of any licensing and similar requirements. Legality, therefore, is only assessed for grid- and mini-grid-supplied electricity.

[50] Poorly installed electricity systems also create a significant fire risk, and poorly designed or poorly installed generating equipment can also present risks of physical injury.

[51] This aggregation method is used by the Multi-Dimensional Energy Poverty Index (Nussbaumer et al. 2012).

10

ACCESS TO ENERGY FOR COMMUNITY INFRASTRUCTURE

Energy for community services is fundamental for socioeconomic development, as it drives improvements in human capital.

Energy for community services, such as health and education, is fundamental for socioeconomic development, as it drives improvements in human capital. Healthier and better educated people with access to basic community infrastructure (such as clean water and sanitation, street lighting, and so on) have better chances of escaping the poverty trap (Cabraal, Barnes, and Agarwal 2005; White 2002). Many public institutions contribute to the functioning and well-being of a community, including administrative offices, religious buildings, police stations, and public libraries, among others. This chapter provides a comprehensive approach for defining and measuring access to energy for community infrastructure as a continuum of improvement, considering multiple energy attributes that determine the user's experience. The key community infrastructure elements examined here are: (i) street lighting, (ii) health facilities, (iii) education facilities, (iv) government buildings, and (v) public buildings.

Community uses of energy refer to services that indirectly affect socioeconomic development.

Community uses of energy refer to services that *indirectly* impact socioeconomic development and the production of income or value, as opposed to productive uses of energy (presented in Chapter 9), which *directly* impact socioeconomic development and economic growth. Street lighting refers to lampposts on the edge of a road or walkway that provide light at nighttime. Most systems are grid connected, although photovoltaic (PV)-powered LED lamps are gaining ground. Community infrastructure includes health facilities and education facilities, as well as government and public buildings. Government buildings include local government offices, police stations, and post offices, whereas public buildings include places of worship, orphanages, public libraries, and sport facilities.

This chapter presents a multi-tier approach for measuring access to energy for community infrastructure.

This chapter starts by explaining the impacts of access to energy for community services on socioeconomic development and presenting an overview of the current state of access to energy for community infrastructure, followed by a review of the challenges in measuring access to energy for community infrastructure. Then, it elaborates on the multi-tier approach for measuring access to energy for community infrastructure, and, finally, shows how to use the results of such measurement for policy formulation and investment planning, as well as monitoring and evaluation on projects and programs.

IMPACT OF ENERGY ACCESS FOR COMMUNITY INFRASTRUCTURE ON SOCIOECONOMIC DEVELOPMENT

Street lighting can improve mobility and security and encourage economic and social activity.

Street lighting can improve road safety, promote security and mobility, particularly for women, and encourage economic and social activity. Poor roads, poor lighting, and low adherence to road regulations make traveling at night a dangerous, yet unavoidable activity for many people. Street lighting assists drivers, cyclists, and pedestrians in finding their way in the dark, and is a relatively low-cost intervention that may prevent accidents (Beyer and Ker 2009). It improves security, yet many rural areas do not have access to street lighting. Mobility at night is often avoided, particularly by women, for fear of robbery or attack, or due to threat of dangerous or poisonous animals (DFID 2011). Street lighting also facilitates responses to emergency situations, including midwives reaching mothers more quickly and safely. It can also increase school attendance, as girls feel safer walking to school in the early morning (Cecelski 2004). Public lighting also creates a safer environment for nighttime commercial activities, and improves social life. Where there is light, businesses stay open longer because customers are available after dark (UNEP 2012). Children can play outdoors more safely, and social events and festivals are facilitated, creating opportunities to socialize (DFID 2011). Lack of street lighting leads to restricted mobility and use of inefficient, costly, and polluting coping solutions, such as handheld lights, kerosene lamps, or dry cell-powered torches (PAC 2013).

Energy access in health facilities is a critical enabler of access to health services.

Access to adequate, reliable, and sustainable energy in health facilities is a critical enabler for delivery of health services. Without energy, many life-saving interventions cannot be performed, thus inhibiting universal health coverage and the achievement of health-related MDGs. About 800 women die every day due to preventable complications related to pregnancy and childbirth, of which 99 percent are in developing countries (WHO 2012a). Health facilities without energy access are unable to deliver adequate health care, due to poor lighting, refrigeration, and sterilization services and the inability to attract trained staff, especially in remote areas. Infections from unsterilized equipment affect 1 in 5 postoperative patients in the developing world (WHO 2012b).

Although multiple components, such as buildings, equipment, medicines, and medical staff, are necessary for adequate delivery of health services, energy plays a critical role in strengthening health systems and improving health outcomes (WHO 2007a). Access to energy in health facilities improves lighting conditions, enabling the provision of medical services after sunset. Medical equipment may be operated for diagnosis, treatment, and surgery; illnesses and injuries are better managed; and surgical and obstetric emergencies can be better handled. Refrigerated storage for vaccines and medicines, as well as adequate sterilization conditions, further support disease prevention and treatment and reduce wastage. Poor temperature-controlled shipping and storage services are responsible for massive vaccine wastage, with WHO (2003) reporting over 50 percent vaccine wastage around the world. Communication between peripheral and central health units facilitates medical information and support, transport for patients and specialized staff, and timely supply of medicines (Musoke 2002). General cleanliness improves, while patients and staff feel more comfortable with lighting, water heating, and space heating or cooling (EC 2006).

Access to energy in education facilities increases the time students spend at school and improves children's and teachers' experience.

It is well established that education has a positive impact on income levels, and educational enrollment ratios are positively correlated with access to energy (UNDP and WHO 2009). Access to energy in schools increases the time students spend at school and improves children's and teachers' experience. As in the health sector, retaining qualified teachers in rural areas is a challenge that is made easier if access to modern energy is available. The UNESCO Education for All (EFA) initiative identifies five enabling inputs supporting quality education (UNESCO 2005): (i) teaching and learning (learning time, teaching methods, assessment/feedback/incentives, class size); (ii) teaching and learning materials; (iii) physical infrastructure and facilities; (iv) human resources (teachers, principals, administrators, etc.); and (v) school governance. Energy provision contributes to strengthening all enabling components. Lighting allows schools to run in the evening to accommodate more and better-sized classes. Students without adequate lighting at home may also stay at school to complete homework. Lighting also facilitates lesson preparation and administrative task for teachers. ICTs enable more interesting and engaging lessons through audiovisual teaching aids, and students can also learn computer skills. Distance learning and staff training also become possible, and teachers have timely access to the latest information. In addition, improved access to cooking solutions may increase time available for teaching and learning in schools where students and teachers are responsible for fuel collection (PAC 2013). Use of computers in schools for administrative and pedagogical purposes is also dependent on the availability of electricity. Table 10.1 provides a summary of percentages of schools with electricity and computer access for various countries, and Table 10.2 summarizes the role of energy in the delivery of education services.

It is difficult to measure the impact of community institutions on socioeconomic development.

Government buildings are aimed at delivering a wide range of public services, including postal, police, and administrative services, among others. Similarly, community buildings such as places of worship, marriage halls, clubs, and other facilities provide space for religious, social, and cultural activities. It is difficult to determine and more so to measure the socioeconomic development effects of government and community institutions. The role of such institutions has often been undervalued, and their access

TABLE 10.1

Percentage of Schools with Electricity and Computer Access

COUNTRY	SCHOOLS WITH ACCESS TO ELECTRICITY (%)	COMPUTERS FOR ADMINISTRATIVE USE (%)	COMPUTERS FOR STUDENTS TO USE WITH INTERNET ACCESS (%)
India	47.6	12.8	8.8
Peru	76.4	52.7	22.1
Sri Lanka	79.1	21.3	3.1
Philippines	89.0	47.8	5.8
Brazil	94.5	70.4	22.8
Paraguay	96.6	29.0	6.5
Tunisia	98.3	21.9	23.1
Malaysia	98.4	95.2	59.4
Argentina	98.7	75.3	22.9
Chile	99.4	93.4	90.2
Uruguay	100.0	93.4	36.8

Source | UNESCO 2008.

TABLE 10.2

Role of Energy in the Delivery of Education Services

ENERGY SERVICE	POTENTIAL ACTIVITY/OUTCOME
Teaching and Learning (learning time, teaching methods, assessment/feedback/incentives, class size)	
Lighting	Extend learning hours in the evening Extend working hours for preparing lessons and administrative duties Improve indoor light for reading, writing, and other tasks
ICTs (computers, mobile phones, music player, etc.)	Allow students to learn computer skills Enable more interesting and engaging lessons Enable staff training through distance learning Remove need for teachers to miss classes to travel for assessment, feedback, materials, and salary
Materials for Teaching and Learning	
Vocational tools & equipment ICTs	Enable training for vocational trades (e.g., carpentry, mechanics, electrics) and professional and technical skills (e.g., computer literacy) Teachers can access the latest information, and produce and prepare learning materials (printing, photocopying, etc.) Teachers can use effective audiovisual teaching aids Increased motivation of students to learn and teachers to teach
Physical Infrastructure and Facilities	
Cooking facilities Space heating & cooling Outdoor lighting Water pump Water purification ICTs	Provision of midday meals and boiling water for drinks Comfortable and healthy environments for students and staff Increased convenience, security, and safety outdoors in the evening Increased access to clean water and improved sanitation Access to clean water for drinking and cooking Communications with support services for facility management
Human Resources (teachers, principals, inspectors, supervisors, administrators)	
ICTs, lighting, heating, etc.	Enhance living conditions for teachers and ability for them to communicate with family and friends Facilitate training for staff Attract and retain qualified teachers
School Governance	
ICTs	Speed up communication with education authorities Facilitate management of student and staff records, school accounts, etc. Improve decision-making by school heads and staff

Source | *Practical Action 2013.*

to basic infrastructure has been overlooked. However, organizations formed by the poor (e.g., the landless, slum dwellers) often emerge to compensate for ineffective local government (Bigg and Satterthwaite 2005). Electricity in government buildings is a critical enabler of better administration through e-governance.

CURRENT STATE OF ACCESS TO ENERGY FOR COMMUNITY INFRASTRUCTURE

Energy access for community uses is not consistently tracked, and only sparse data are available across countries.

The number of communities without street lighting is unknown.

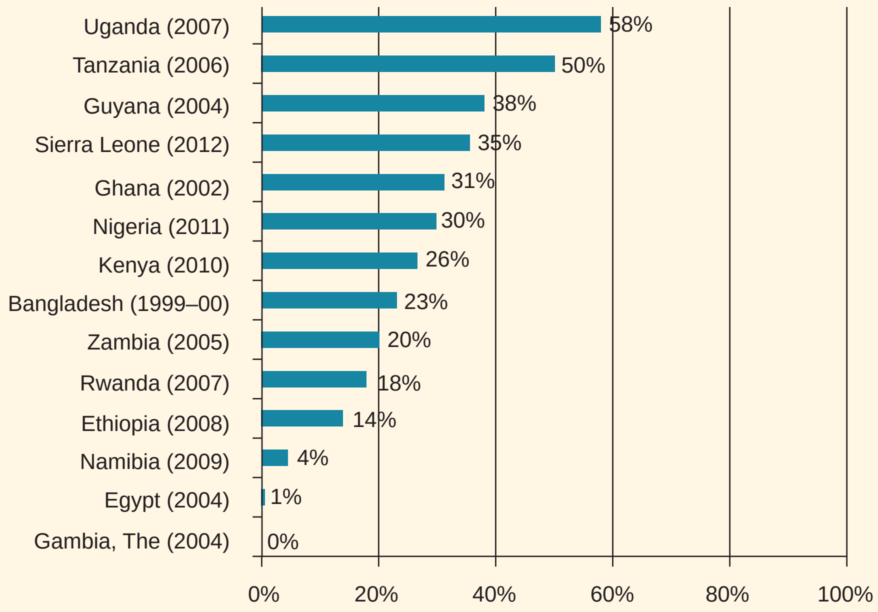
Street lighting: The United Nations Statistic Database (UNDATA) tracks electricity consumption by public lighting since 1990, and provides estimates for about 100 countries (UNDATA 2014). However, consumption data does not reflect access in terms of coverage and does not account for energy efficiency improvements. The number of communities without street lighting is therefore unknown. Although standalone street lights powered by solar PV are increasingly available, particularly in un-electrified areas, the majority of unconnected households are unlikely to have outdoor lighting around their homes. Street lighting may be provided along main roads while the rest of the community is left in the dark. The presence of poles is no guarantee that lighting is available, as the local authority or utility may be unable to afford to power them. Satellite imaging of outdoor lighting coupled with geographic information system (GIS) mapping of road locations provide an effective approach for measuring the availability of street lighting.

Nationally representative data on energy access in health facilities are available for only a few developing countries.

Health facilities: Reliable data on energy access among health facilities in developing countries are currently sparse. An initial review of available country data on health facility energy access by WHO found nationally representative data for only 14 developing countries globally, 11 of these were in Sub-Saharan Africa (Adair-Rohani et al. 2013; Figure 10.1). However, even this slim set of data yields striking findings regarding the widespread lack of electricity access. Among the 11 African countries assessed, an average of 26 percent of health facilities did not have any access to electricity at the time of the assessment. Only 34 percent of hospitals had reliable electricity (defined as no outages of more than 2 hours in the past week) across the 8 countries for which such data were available. Even when health facilities had an electricity connection, there may have been significant quality-of-supply issues for which data are not collected. The study shows that progress has been made on electrification of health facilities in some countries over the past decade. In Rwanda, the overall proportion of facilities with electricity access increased from 58 to 82 percent during 2001 to 2007, and in Kenya it increased from 65 percent to 74 percent during 2004 to 2010. Comprehensive health facility infrastructure surveys, such as the Service Availability and Readiness Assessment (SARA), developed jointly by WHO and the U.S. Agency for International Development (USAID), track the availability of infrastructure and equipment in health facilities in relation to provision of specific services. WHO, in partnership with the Energy Sector Management Assessment Programme (ESMAP) of the World Bank, has been improving the SARA questionnaire to include all relevant supply aspects of energy access (WHO and WB 2014).

FIGURE 10.1

Percentage of Health Facilities with No Access to Electricity



Source | *Adair-Rohani et al. 2013.*

Education facilities: Paucity of firsthand survey data is also observed for energy access in schools in many developing countries. Data on electricity connection and some related aspects are collected by the Ministries of Education of various countries and collated by UNESCO. According to UNESCO's data, only 35 percent of primary schools are electrified in Sub-Saharan Africa, compared to 48 percent in South Asia, and 93 percent in Latin America (UNESCO 2008, 2011; Figure 10.2). Some surveys also include data on availability of equipment, such as computers for administrative tasks or student use.

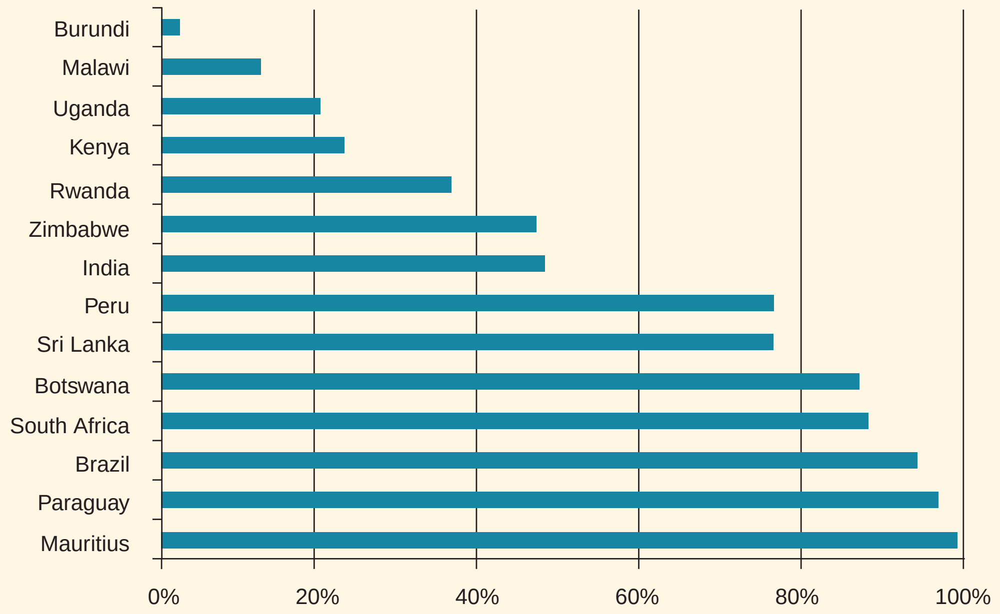
Data on electrification rates in schools are limited.

Government and community buildings: Little data exist on the number and coverage of government and community institutions, let alone on the level of access to energy in public and community buildings.

Data on energy access in public and government buildings does not exist.

FIGURE 10.2

Access to Electricity in Primary Schools in Selected Countries



Source | *UNESCO 2008, 2011.*

CHALLENGES IN MEASUREMENT

Data paucity on access to community uses of energy could inhibit energy policy, planning, project implementation, and progress monitoring.

Poor data availability does not allow for consistent binary measurement of energy access for community uses, nor provide insight on the amount of energy available or its duration. However, multiple aspects of the energy supply are critical for the functioning of community institutions and need to be monitored. A strong understanding of the multifaceted nature of energy access is required to adequately inform energy policy, planning, project implementation, and progress monitoring. To this end, several challenges need to be overcome, mainly because it is difficult to set common norms regarding energy needs and quantity of energy required across all community facilities. The comparison between a normative access level and the actual one cannot be done and the access gap cannot be accurately measured.

Measuring Coverage of Street Lighting

Measurement of street lighting has to encompass coverage as well as brightness.

Consumption data are not sufficient to evaluate the coverage of street lighting across a selected area. To fully reap the possible benefits resulting from street lighting, full coverage is important. The location of the street lights matters; they are not only required outside households and other facilities or along the main road, but should be available throughout the community to facilitate mobility and improve safety. Street lights should be on for the required hours, and brightness should be adequate to make people feel safe. However, even if a minimum standard for street lighting brightness in lux was adopted, it would be difficult to measure in the field.

Considering a Wide Diversity of Institutions

There is a wide diversity of community institutions. For instance, types and sizes of health facilities vary with countries' health systems, socioeconomic development orientation, and policies. They range from health posts to specialized hospitals, typically in large cities. Health facilities may be public, private, or operated by nongovernmental organizations (NGOs) or faith-based service providers (Schmid et al. 2008). Despite some efforts to define basic levels of health facilities, no universal consensus exists on a common typology used across countries. Energy needs vary with the type of health facility. Small facilities delivering basic health services may only need to operate low-power equipment during opening hours, whereas larger facilities typically require a high-power load with 24-hour supply (WHO and WB 2014).

Energy needs vary by the nature and size of the institution. The wide diversity of institutions makes it difficult to devise a one-fits-all measurement.

Similarly, the education sector includes a broad range of institutions serving people from early childhood to adult learning. Most education facilities are primary and secondary schools, followed by higher education and vocational centers. They may also be public, private, or run by NGOs or faith-based organizations, and each country has its own classification of education facilities. As with health facilities, energy needs vary with the size and type of educational facility.

Government and community buildings include several types of institutions, such as government administrative offices, police stations, prisons, faith-based and community centers, public libraries, sports facilities, and so on. They may be run by the public, private, or nonprofit sectors. Depending on their characteristics as well as size, their energy needs vary and they are affected differently by energy supply deficiencies. In the multi-tier framework, energy access in government buildings and community buildings are assessed separately.

Accounting for a Large Number of Energy Services

The energy services required by community institutions are multiple and variable. Health facilities require energy for a wide range of services. Infrastructure applications, such as lighting and communication (e.g., phones and computers), water heating and steam production, space temperature control, and waste management, are typically required by all facilities. Facilities should also be able to run available electric medical devices, such as microscopes, suction apparatuses, oxygen concentrators, incubators, ultrasound machines, HIV diagnosis equipment, X-ray machines, and support appliances such as vaccine refrigerators (WHO and WB 2014; PAC 2013).

Community institutions require a wide variety of energy services.

Education facilities mainly require lighting and ICT services, space heating or cooling (depending on the geographic area), and cooking (if applicable). Information and communication appliances include phone chargers, computers, radios, printers, photocopiers, and audiovisual equipment (such as projectors, DVD players). Space cooling may be important in certain locations because high-heat conditions affect concentration levels and may cause dehydration and discomfort. Ceiling fans, air coolers, or air conditioners may be required. Similarly, space heating for cold climates is equally important for concentration and comfort levels at school. In addition, cold and humid rooms may increase health issues. The recommended temperature in rooms used by children is 19° Celsius (WHO 2007b).

Government and community buildings need electricity for lighting and ICTs (including phone chargers, computers, audiovisual equipment, printers, and photocopiers). Institutions housing people, such as prisons, orphanages, nursing homes, and so on, also require space heating and cooling, water heating, and cooking applications.

Accounting for Multiple Sources of Energy

Community institutions may use electricity but also other energy sources.

As with productive activities, multiple sources of energy are available for community institutions. Most community facilities typically access electricity through the grid, often backed up by onsite fuel-based generators. In off-grid settings, fossil fuel generators have been the primary energy source. Large facilities may have a second fossil fuel generator for backup, whereas smaller ones rely on flashlights and kerosene lamps. Some community facilities also use standalone devices, such as “solar suitcases” and solar-powered refrigerators, as well as PV systems and combined heat and power (CHP) solutions in large facilities, such as hospitals (WHO and WB 2014). The performance of the energy supply varies with the type of solution. Standalone systems are typically constrained by their capacity to generate and store electricity, and small-scale systems may not be able to support all required applications. On the other hand, grid electricity can typically support any amount of power, but is often characterized by frequent outages. Facilities may also reach out to other energy sources to satisfy thermal needs, such as water and space heating, cooking, sterilization, and medical waste incineration. Such sources may include direct combustion of fuels (such as biomass, kerosene, LPG, diesel) or solar thermal panels (WHO and WB 2014).

Considering Multiple Issues in Electricity Supply

Poor performance of the energy supply leads to activity disruptions.

Deficient energy supply may disrupt activities in community institutions. Health facilities may access energy from a variety of sources, but effective use of electrical equipment depends upon the performance of the supply, which should be sufficient to run all required appliances and available during the facility’s working hours. Voltage should also be adequate and stable, as it can otherwise affect the delivery of health services and may damage vital medical equipment. Reliability of supply is critical, particularly for running essential laboratory and medical equipment, as well as operating surgery units. Outages also adversely affect support applications such as lighting, communications, and refrigeration, limiting nighttime services, and leading to wastage of refrigerated medicines and vaccines. To respond to such failures, and maintain essential services during power disruptions, most health facilities are equipped with backup generators. However, backup costs are not always affordable, and facilities may struggle to purchase fuel and/or maintain a generator

(Adair-Rohani et al. 2013; PAC 2013). Health and safety of the energy system is also important. Supply of energy should not lead to environmental damage in the health facility or the vicinity, such as air, water, and soil pollution, as well as noise pollution, which may damage the health of patients, medical staff, or residents in the vicinity. Basic electricity safety is an issue in many health facilities in low-income countries, as they struggle with inadequate wiring, insulation, and grounding (earthing), as well as inadequate transformers or connectivity to medical devices (WHO and WB 2014). Health facilities and other community institutions need to have sufficient funds to be able to operate and maintain energy systems in terms of timely payment of utility bills, purchase of fuel, and maintenance of the equipment delivering energy (Finucane and Purcell 2010; WHO and WB 2014).

Similarly, education facilities, as well as public and community institutions, may suffer from multiple supply issues, depending on their location and type of energy supply solution used. Grid-connected schools are subject to power outages. Off-grid solutions may not be sufficient to power all of the required appliances, depending on the capacity of the system and the size of the educational facility. Schools operating diesel generators may also face fuel shortages. Renewable and nonrenewable off-grid solutions may be affected by maintenance issues, limiting reliability of supply (Jimenez and Olson 1998). As in other institutions, voltage issues constrain the use of electric appliances and may damage equipment. Health and safety issues are particularly important in schools. For example, electrical outlets accessible to children should be covered with child-resistant covers (WHO 2007b).

MULTI-TIER MEASUREMENT FRAMEWORK

The multi-tier approach aims to be technology and fuel neutral and capture all factors that impact users' experience, while measuring access to community uses of energy as a continuum of improvement (as opposed to a binary metric). The objective is to provide insight into the types of policy reforms and project interventions that would drive higher levels of access to community uses of energy, along with facilitating monitoring and evaluation.

The framework captures multiple factors influencing access to energy for community uses.

Two different approaches are considered here:

1. Direct assessment through survey of community institutions
2. Indirect assessment through survey of users

The first approach can yield detailed information about energy access in various community institutions, but requires a separate effort to reach out to such organizations. Direct assessment of community institutions may be done through international agencies working in the relevant domain. For example, WHO periodically conducts the SARA survey of health facilities across various countries. The multi-tier framework for measurement of energy access in health facilities has been proposed for incorporation into the SARA survey instrument. The second approach can yield only limited information and is constrained by the subjective opinions of the users, but may be easier to administer as part of household energy surveys, and shall capture users' experience regarding community services. Each attribute is measured through distinct units and corresponding questions, based on the type of approach.

Two different approaches for collecting information are considered: direct assessment through surveys of community institutions, and indirect assessment through surveys of users.

Step 1: Identify the Most Relevant Community Services (Household Respondents)

Members of any household make use of a number of community services. The most relevant services and facilities through which these services are provided can be identified during the household energy survey as follows:

- First, the survey identifies whether there is a facility in each category (education, health, government/community) that household members regularly use.
- Next, if more than one facility within any single category (education, health, government/community) is used by household members, the most frequently used facility is identified.
- Then, the household member who most often uses the identified facility in each category is identified (or the adult best positioned to respond, if the user is a minor).
- Further analysis is conducted for each identified member in the household for the most frequently used facility for each relevant community service. (Street lighting is treated as relevant for all households.) Thus, a single survey response is secured from each household for each relevant community service.

Step 2: Identify the Relevant Energy Applications

Energy applications are at the core of the multi-tier approach. Community services typically require the following five types of energy applications, with the exception of street lighting (Annex 4 provides a list of related sub-applications):

1. Lighting refers to the use of energy to light facilities to enable workers to undertake tasks and for the comfort of users.
2. ICTs refer to the use of energy for computing, electronics, and other communication and audiovisual purposes.
3. Motive power refers to mechanical uses of energy in which motion (either linear or rotational) is imparted to machinery. In the context of community facilities, space cooling and refrigeration are among the most frequently required motive-power sub-applications. (It is acknowledged that absorption cooling does not involve motive power. However, cooling as a whole is analyzed as a motive-power application for simplicity reasons.)
4. Space heating refers to uses of energy to heat interior working spaces for the welfare and comfort of workers and facility users.
5. Product heating refers to uses of energy for heating as a direct part of the community service. Product heating includes water heating, which may also be used for incubation or sterilization, for example.

For an application to be relevant, it must satisfactorily deliver the community service. Energy access is measured only for relevant applications. Respondents, therefore, are asked which of these five applications they regard as necessary for each community service.

TABLE 10.3

Community Applications and Energy Source Matrix

ENERGY SOURCE	LIGHTING[a]	ICT & ENTERTAINMENT	MOTIVE POWER	SPACE HEATING	PRODUCT HEATING
Electricity	✓	✓	✓	✓	✓
Fuel			✓	✓	✓
Renewable mechanical energy (RME)			✓		
Renewable thermal energy (RTE)			✓	✓	✓

[a] *Only electrical lighting is considered here—candles, kerosene lamps, and other solid- or liquid-based lighting fuels are considered as no access.*

[b] *Human and animal (H&A) power are not considered as energy access for community services.*

Step 3: Identify the Primary Energy Source for Each Application

Energy sources, categorized in four types, are matched to each productive application.

The primary energy source used to run each relevant application refers to the source that is used most of the time. Secondary sources or backup solutions are not taken into account, as they are either considered as coping solutions to overcome poor performance of the primary source or are used in emergency situations. Relevant applications can be run using a variety of energy sources (Table 10.3). Four categories have been identified:

1. Electricity supplied through a wide range of technologies (such as solar lantern, rechargeable battery, solar home system, fossil fuel generator, biomass, biofuel or biogas generator, hydro or wind generator, mini-grid and grid) may power all types of applications.
2. Fuels, such as biomass, biogas, biofuels, natural gas, kerosene, LPG, and other petroleum products, may be directly burned in stoves or engines for motive-power and heating applications. (Electricity generation from fuel combustion is excluded, being included in "electricity" in the first category).
3. Renewable motive energy (RME) includes direct use of wind and water for motive power, such as wind and water mills.
4. Renewable thermal energy (RTE) refers to the direct use of solar power for heating applications using solar thermal collectors, but also motive power (such as water pumps).[54]

Step 4: Measuring Attributes of the Energy Supply

The multi-tier framework is built on eight attributes of energy, which determine the usefulness of the energy supply and affect user experience. The level of energy access provided by the primary energy source used for each application in relation to each community service is assessed against these eight attributes. If the same primary energy source is used for multiple applications, energy access is assessed for those applications taken together, rather than separately.

Capacity

The capacity of the electricity supply refers to the ability of the system to deliver a certain quantity of energy.

The capacity of the energy supply is defined as the ability of the energy system to provide a certain amount of energy per day in order to operate the applications needed in the community institutions. For street lighting, capacity is measured in terms of coverage ratio, which is defined as the percentage of neighboring area (0.5 km from the household) that has street lighting (Table 10.4). For electricity in institutions, capacity is measured in watts if the technology used is grid, mini-grid, or fossil fuel-based generators, and in daily watt hours for rechargeable battery, solar lantern, and standalone solar system. The measurement of capacity is done across multiple tiers in which an increasing number of growing power-intensity appliances can be run (Table 10.4). If capacity is unknown (in terms of watts or watt hours),[54] the type of technology may be used as a proxy.

For nonelectric energy sources (including direct combustion of fuels, RME and RTE), measurement units differ by technology, and capacity depends on multiple factors and may not be easily observable. For simplicity, capacity is evaluated based on the requirements met using the subjective judgment of the respondent (Table 10.4). An additional indicator is included for all energy sources, in order to identify cases where capacity constrains inhibit the use of relevant applications. Thus, adequate capacity is reached when relevant applications are not missing solely due to capacity constrains.

In the case of survey of users, simplified proxies are used to measure capacity. For electricity, capacity is estimated based on the type of technology used. Users are also asked to what extent the heating service is available in terms of duration and temperature (Table 10.4).

Availability (Duration)

The availability or duration of the energy supply refers to the amount of time for which the energy is available.

The availability or duration of the energy supply refers to the amount of time for which the energy is available, compared to the amount of time that the energy is required. For street lighting, duration is measured by the ratio between hours of available street lighting and total hours between sunset and sunrise (Table 10.5). For electricity in community institutions, duration is measured by the ratio between the number of hours of available electricity and the total number of hours of required electricity. For nonelectric sources, availability (duration) is measured by the extent that requirements are met—partially, largely, or fully. An additional indicator is included for all energy sources, in order to identify cases where availability (duration) constraints inhibit the use of relevant applications or limit operating hours. Adequate availability (duration) is reached when working hours and the use of relevant applications are not limited solely due to supply availability (duration) constraints. In the case of survey of users, respondents are asked if the facility operating hours and/or provision of services are (as far as user is aware) restricted solely by inadequate availability (duration) of supply.

Reliability (Unscheduled Outages)

Reliability is defined in terms of unscheduled interruptions of supply.

Reliability is defined in terms of unscheduled interruptions of supply, due to grid outages or breakdowns of the equipment delivering energy (such as a generator, or standalone solar system). Unexpected blackouts may significantly disrupt activities in community institutions, particularly in

TABLE 10.4

Tiers of Capacity of Energy Supply for Community Infrastructure

CAPACITY				TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
STREET LIGHTING		Electricity			At least one functional street lamp in the neighborhood	At least 25% of the neighborhood is covered by functional street lamps	At least 50% of the neighborhood is covered by functional street lamps	At least 75% of the neighborhood is covered by functional street lamps	At least 95% of the neighborhood is covered by functional street lamps
COMMUNITY INSTITUTIONS	SURVEY OF INSTITUTIONS	Electricity	Power Capacity		Min 3 W	Min 50 W	Min 200 W	Min 800 W[a] or Min 2kW[b]	Min 2 kW[a] or Min 10 KW[b]
			Daily Supply Capacity		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
			Typical Technology		Solar lanterns	Standalone solar systems	Generator or mini-grid	Generator or grid	Grid
		Nonelectric (fuel, RME, RTE)					Available nonelectric energy partially meets requirements	Available nonelectric energy largely meets requirements	Available nonelectric energy fully meets requirements
		Both					Relevant application not missing solely due to capacity constraints		
	SURVEY OF USERS	Electricity	Power Capacity		Min 3 W	Min 50 W	Min 200 W	Min 800 W[a] or Min 2kW[b]	Min 2 kW[a] or Min 10 KW[b]
			Daily Supply Capacity		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
			Typical Technology		Solar lanterns	Standalone solar systems	Generator or mini-grid	Generator or grid	Grid
		Heating					Heating (if required) is mostly available and delivers adequate temperature		Heating (if required) is always available and delivers adequate temperature

[a] *For small facilities (up to three rooms)*

[b] *For large facilities (over three rooms)*

TABLE 10.5

Tiers of Availability (Duration) of Energy Supply for Community Infrastructure

AVAILABILITY			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
STREET LIGHTING		Electricity		Street lighting functions for at least 2 night hours each day	Street lighting functions for at least 4 night hours each day	Street lighting functions for at least 50% of night hours each day	Street lighting functions for at least 75% of night hours each day	Street lighting functions for at least 95% of night hours each day
COMMUNITY INSTITUTIONS	SURVEY OF INSTITUTIONS	Electricity		Min 2 hrs	Min 4 hrs	Half of the working hours (min 50%)	Most of the working hours (min 75%)	Almost all working hours (min 95%)
		Nonelectric (fuel, RME, RTE)				Available nonelectric energy partially meets requirements	Available nonelectric energy largely meets requirements	Available nonelectric energy fully meets requirements
		Both				Operating hours and/or provision of services are not restricted solely by inadequate availability (duration) of supply		
	SURVEY OF USERS	Both				Facility operating hours and/or provision of services are not (as far as user is aware) restricted solely by inadequate availability (duration) of supply		

health facilities. The use of costly and often polluting backup generators as a coping mechanism is not always financially sustainable. The electricity supply is considered to be reliable when unscheduled interruptions occur rarely or do not cause significant disruption (Table 10.6).

Quality

The quality of the energy supply refers to the level and stability of voltage or temperature.

The quality of energy supply refers to different characteristics depending on the energy source. For electricity, quality refers to proper and stable voltage. Most electricity applications cannot be operated properly below a minimum level of supply voltage. For example, CFLs do not light up if the voltage is too low, and motors do not rotate. If heating applications are required, the quality of the heating supply is defined in terms of temperature level and stability. Quality is considered to be adequate when voltage/temperature delivered by the energy system is adequate. However, for the purpose of collecting information using surveys, quality has to be defined based on the user's experience. Thus, for street lighting it is defined as absence of any brightness issues as perceived by users. For community institutions, it is defined on the basis of whether any quality issues are observed and the magnitude of their impact on service delivery (Table 10.7).

Affordability of Use

Affordability of energy used for community institutions is defined as the ability to pay for energy use and refers to the availability of funds for operating and maintaining the electricity system (including

TABLE 10.6

Tiers of Reliability of Energy Supply for Community Infrastructure

RELIABILITY			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
	STREET LIGHTING	Electricity					No reliability issues perceived by users	
COMMUNITY INSTITUTIONS	SURVEY OF INSTITUTIONS	All Energy Sources					Reliability issues with moderate impact on service delivery	No reliability issues or little (or no) impact on service delivery
	SURVEY OF USERS	All Energy Sources					Interruptions have a moderate impact on service delivery, as observed by users	Rare or no interruptions observed by users

TABLE 10.7

Tiers of Quality of Energy Supply for Community Infrastructure

QUALITY			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
	STREET LIGHTING	Electricity					No brightness issues (dimming or flickering) perceived by users	
COMMUNITY INSTITUTIONS	SURVEY OF INSTITUTIONS	All Energy Sources					Quality issues have moderate impact on service delivery	No quality issues or little (or no) impact on service delivery
	SURVEY OF USERS	All Energy Sources					Quality issues have moderate impact on service delivery, as observed by users	Rare or no quality issues observed by users

the backup). Three types of expenses need to be covered in a sufficient and timely fashion through secure budget allocation in order to avoid disruptions in energy supply: (i) operating costs for electricity and heating fuels; (ii) maintenance expenses, including spare parts and technical support; and (iii) replacement expenses, such as batteries (Table 10.8). As mentioned, one of the main barriers for energy access expansion in community institutions is the increasing cost of fossil fuels

Affordability of energy refers to the availability of funds for operating and maintaining the electricity system.

TABLE 10.8

Tiers of Affordability of Energy Supply for Community Infrastructure

AFFORDABILITY			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
COMMUNITY INSTITUTIONS	SURVEY OF INSTITUTIONS	Variable Energy Cost (all energy sources)					Variable energy cost ≤ 2 times the grid tariff	Variable energy cost ≤ the grid tariff
		Financial Sustainability (all energy sources)					Energy access has not been interrupted due to unpaid utility bills, or lack of budget for fuel purchases, maintenance, spare parts, or batteries during the last 12 months	

and maintenance expenses for diesel as well as standalone solar systems. Affordability can only be measured by surveying the institution's manager, as users are usually not aware of the financial capacity of the institution.

Legality

Legality refers to whether the energy supply is drawn through legal means and does not involve theft or other illegal practices.

Legality refers to whether the energy supply is drawn through legal means and does not involve theft or other illegal practices. It can only be assessed by surveying the institution's manager, as users may not be aware of legality issues. Even the institution manager may be unaware of issues of legality, such as purchase of wood fuel that has been sourced without a proper license. Therefore, legality is only assessed for grid- and mini-grid-supplied electricity (Table 10.9).

Convenience

Convenience refers to the time and effort spent in sourcing energy and maintaining the supply equipment.

Convenience refers to time and effort spent in sourcing energy or maintaining supply equipment. Energy supply is considered convenient when this time and effort do not significantly impact on the delivery of the community service and does not impact users or staff (Table 10.10). As with affordability, convenience can only be measured by surveying the institution's manager, as users may not be aware of convenience issues.

TABLE 10.9

Tiers of Legality of Energy Supply for Community Infrastructure

LEGALITY			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
COMMUNITY INSTITUTIONS	SURVEY OF INSTITUTIONS	Grid or Mini-grid Electricity					Energy bill is paid to the utility, prepaid card seller, authorized representative, or legal market operator	

TABLE 10.10

Tiers of Convenience of Energy Supply for Community Infrastructure

CONVENIENCE			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
COMMUNITY INSTITUTIONS	SURVEY OF INSTITUTIONS	All Energy Sources					Time and effort in securing and preparing energy cause moderate impact on service delivery	Little (or no) time and effort spent in securing and preparing energy and/or little (or no) impact on service delivery

Health

Health is a function of the indoor air quality resulting from the use of fuels. As explained in Chapter 8: Household Access to Cooking Solutions, the health risks of fuel combustion may be estimated by assessing emissions resulting from the energy solution. Based on WHO guidelines, tiers for $PM_{2.5}$ and CO can be established (Table 10.11). In cases where the performance of the energy solution in terms of emissions is not known, a less accurate approach based on a broad categorization of fuels may be used. The lowest level (Tier 0 and Tier 1) refers to non-BLEENS fuels used indoors without smoke extraction, while Tier 2 and Tier 3 refer to non-BLEENS fuels used outdoors or with smoke extraction. Finally, the highest level (Tier 4 and Tier 5) refers to the use of BLEENS fuels (or equivalent).

Tiers for health are established based on WHO guidelines on $PM_{2.5}$ and CO, or a less accurate fuel categorization.

Safety

The safety of the energy system refers to the risk of accident or damage. For electricity, this risk refers primarily to electrocution,[55] whereas pollution, burns, and explosion risks are the major concerns in the case of direct combustion of fuels. Also, inadequately guarded renewable energy equipment can

The safety of the energy system is defined in terms of risk of accident or damage related to the energy system.

TABLE 10.11

Tiers of Health Risks of Energy Supply for Community Infrastructure

HEALTH			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
COMMUNITY INSTITUTIONS	SURVEY OF INSTITUTIONS	$PM_{2.5}$ (μg/m^3)		[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	< 35 (WHO IT-1)	< 10 (WHO guideline)
		CO (mg/m^3)					< 7 (WHO guideline)	
		OR Use of Fuels (BLEENS)			Use of non-BLEENS solutions (if any) outdoors or with smoke extraction		Use of BLEENS or equivalent solutions only (if any)	

TABLE 10.12

Tiers of Safety of Energy Supply for Community Infrastructure

SAFETY			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
	STREET LIGHTING	Electricity					No perceived risk of electrocution due to poor installation or maintenance	
COMMUNITY INSTITUTIONS	SURVEY OF INSTITUTIONS	All Energy Sources					Energy supply solutions caused accidents that did not require professional medical assistance	Energy supply solutions did not cause any accidents
	SURVEY OF USERS	All Energy Sources					No perceived risk of electrocution, fire, or injury due to poor installation or maintenance	

present injury risks. The safety attribute is measured by monitoring whether such accidents or damage have occurred in the past 12 months or whether they are likely to happen in the future, based on the user's knowledge and opinion (Table 10.12).

Step 5: Determining the Tier of Access for the Community Infrastructure

The framework is built on eight attributes, which determine the usefulness of the supply for each application needed for the community service. Access to energy is first assessed for each application separately.

Assessing the level of energy access for each relevant application in the five community sub-locales: The methodology for measuring energy access is designed to be technology and fuel neutral, while evaluating the performance of the energy supply for five community sub-locales: (i) street lighting, (ii) health facilities, (iii) education facilities, (iv) government buildings, and (v) public/community buildings (Tables 10.13, 10.14, and 10.15). The level of access is first assessed for each relevant application separately. The performance (or usability) of the primary energy source for each application is evaluated through the combination of the eight attributes of energy across six tiers of access, thus quantifying the usefulness of the energy supply, which influence the extent to which applications are used and determine the user's experience (Tables 10.13, 10.14, and 10.15). Each attribute is assessed separately and the overall tier of energy access for the application is calculated by applying the lowest tier obtained in any of the attributes. For relevant applications that are required but are not used, the access tier is Tier 0.

An assessment of the overall level of energy access for community uses for each household can be calculated by averaging the energy access tiers calculated for each community service used by the household.

TABLE 10.13

Multi-tier Matrix for Access to Street Lighting

STREET LIGHTING		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	1. Capacity		At least one functional street lamp in the neighborhood	At least 25% of the neighborhood is covered by functional street lamps	At least 50% of the neighborhood is covered by functional street lamps	At least 75% of the neighborhood is covered by functional street lamps	At least 95% of the neighborhood is covered by functional street lamps
	2. Availability (duration)		Street lighting functions for at least 2 night hours each day	Street lighting functions for at least 4 night hours each day	Street lighting functions for at least 50% of night hours each day	Street lighting functions for at least 75% of night hours each day	Street lighting functions for at least 95% of night hours each day
	3. Reliability					No reliability issues perceived by users	
	4. Quality					No brightness issues perceived by users	
	5. Safety					No perceived risk of electrocution due to poor installation or maintenance	

OBTAINING DATA FOR MEASUREMENT OF ACCESS

Data for assessing access to energy for community institutions and infrastructure can be obtained through a variety of channels:

Data on access to energy for community institutions can be collected through surveys, use of modern technology, as well as supplier information.

- Survey of users of these community services as a part of household energy surveys
- Survey of institutions conducted alongside the household energy surveys
- Survey of institutions conducted as part of information gathering by sector agencies (e.g., SARA survey by WHO)
- Collection of data by government agencies as a part of information gathering on sector performance (e.g., collection of data on schools by Ministry of Education)
- Use of modern technology such as remote satellite imaging for measuring street lighting
- Supply-side data from programs and projects or energy utilities on energy supply and equipment provided to community institutions

TABLE 10.14

Multi-tier Matrix for Measuring Access in Community Infrastructure (Survey of Institutions)

				TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	1. Capacity	Electricity	Power		Min 3 W	Min 50 W	Min 200 W	Min 800 W[a] or Min 2 KW[b]	Min 2kW[a] or Min 10kW[b]
			Daily Supply Capacity		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
			Typical Technology		Solar lanterns	Standalone solar systems	Generator or mini-grid	Generator or grid	Grid
		Nonelectric (fuels, RME, RTE)					Available nonelectric energy partially meets requirements	Available nonelectric energy largely meets requirements	Available nonelectric energy fully meets requirements
		Both					No relevant application is missing solely due to capacity		
	2. Availability (duration) of Daily Supply	Electricity			Min 2 hrs	Min 4 hrs	Half of the working hours (Min 50%)	Most of the working hours (Min 75%)	Almost all working hours (Min 95%)
		Nonelectric (fuels, RME, RTE)					Available nonelectric energy partially meets requirements	Available nonelectric energy largely meets requirements	Available nonelectric energy fully meets requirements
		Both					Operating hours and/or provision of services are not restricted solely by inadequate availability (duration) of supply		
	3. Reliability							Reliability issues have moderate impact	No reliability issues or little (or no) impact
	4. Quality							Quality issues have moderate impact	No quality issues or little (or no) impact
	5. Affordability	Variable Energy Cost						≤ 2 times the grid tariff	≤ the grid tariff
		Financial Sustainability						Energy access has not been interrupted due to unpaid utility bills, or lack of budget for fuel purchases, maintenance, spare parts, or batteries during the past 12 months	

TABLE 10.14 continued

Multi-tier Matrix for Measuring Access in Community Infrastructure (Survey of Institutions)

			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	6. Legality						Energy bill is paid to the utility, prepaid card seller, authorized representative, or legal market operator	
	7. Convenience						Time and effort in securing and preparing energy cause moderate inconvenience	Little (or no) time and effort spent in securing and preparing energy and/or little (or no) impact
	8. Health	$PM_{2.5}$ (µg/m^3)		[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	[To be specified by competent agency such as WHO]	< 35 (WHO IT-1)	< 10 (WHO guideline)
		CO (mg/m^3)					< 7 (WHO guideline)	
		OR Use of Fuels (BLEENS)			Use of non-BLEENS solutions (if any) outdoors or with smoke extraction		Use of BLEENS or equivalent solutions only (if any)	
	9. Safety						Energy supply solutions caused accidents that did not require professional medical assistance	Energy supply solutions did not cause any accidents

[a] *For small facilities (up to three rooms)*

[b] *For large facilities (over three rooms)*

TABLE 10.15

Multi-tier Matrix for Measuring Access in Community Infrastructure (Survey of Users)

ATTRIBUTES				TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
	1. Capacity	Electricity	Power		Min 3 W	Min 50 W	Min 200 W	Min 800 W[a] or Min 2kW[b]	Min 2kW[a] or Min 10kW[b]
			Daily Supply Capacity		Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
			Typical Technology		Solar lanterns	Standalone solar systems	Generator or mini-grid	Generator or grid	Grid
		Heating					Heating (if required) is mostly available and delivers adequate temperature		Heating (if required) is always available and delivers adequate temperature
	2. Availability (Duration) of Daily Supply						Facility operating hours and/or provision of services are not (as far as user is aware) restricted by inadequate availability (duration) of supply		
	3. Reliability							Interruptions have moderate impact on service delivery as observed by users	Rare, little, or no interruptions observed by users
	4. Quality							Quality issues have moderate impact on service delivery as observed by users	Rare or no quality issues, or little or no impact observed by users
	5. Safety							No perceived risk of electrocution due to poor installation or maintenance	

[a] *For small facilities (up to three rooms)*

[b] *For large facilities (over three rooms)*

ANALYSIS OF RESULTS

Results can be compiled and analyzed to produce an energy access diagnostic.

The multi-tier framework yields a wide range of results that can be compiled and analyzed to produce an energy access diagnostic for a selected area. Such diagnostic includes in-depth disaggregated data analysis, as well as aggregated analysis, in the form of an index of access, aiming to facilitate planning and strategy, project design, progress monitoring, impact evaluation, and comparison across geographic areas and over time.

Disaggregated Analysis: Cross-Cutting Analysis of Access to Community Uses of Energy

Data can be used to analyze access under different lenses and using multiple cuts. Among the various indicators that can be calculated are: (i) proportion of health facilities, education facilities, and public and community buildings connected to the grid or mini-grid; (ii) proportion of institutions using diesel generators as a primary source of electricity; (iii) proportion of institutions using standalone solar systems as a primary source of electricity; (iv) proportion of institutions receiving electricity for less than 25 percent of their operation hours; (v) average number of hours of daily electricity supply; (vi) proportion of institutions suffering from unreliable supply of electricity; (vii) proportion of institutions reporting voltage issues; (viii) proportion of institutions with affordability problems; (ix) proportion of institutions with unsafe electricity installation; (x) proportion of institutions covering less than half of their heating needs; (xi) proportion of the community covered by street lighting; (xii) average number of hours of street lighting supply; and (xiii) proportion of the community facing low street light brightness. In addition, indicators may be crossed with the technology of the primary electricity source, if known. For example, reliability or affordability may be compared across grid connections, diesel generators, and standalone solar systems.

Data can be analyzed under different lenses and multiple cuts, leading to a wide range of indicators.

Aggregated Analysis: Index of Access to Community Uses of Energy

To compile the information captured by the multi-tier matrix into a single number representing the level of access to each community use of energy in a selected geographic area, a simple index can be calculated as the average tier rating across respondents. The following formula is applied:

A single number representing the level of access to community uses of energy may be compiled based on the multi-tier matrix.

$$\sum_{k=0}^{5}(20 * P_k * k)$$

k: tier number

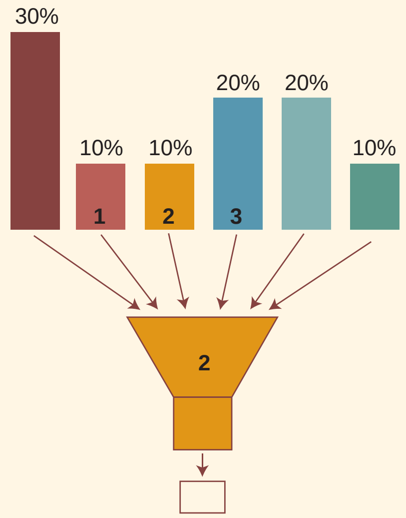
P_k: proportion of respondents at the kth tier
(only one type of respondent—household or institution)

The index evaluates both the extent of access (how many respondents have access) and the intensity of that access (the level of access that respondents have)[56] (Figure 10.3).

Multiple indices can be obtained, including: (i) index of access to street lighting, (ii) index of energy access in health facilities, (iii) index of energy access in education facilities, (iv) index of energy access in community buildings, and (v) index of energy access in public buildings. An overarching index of access to energy for all community uses for the area can be obtained by using the same formula to average the overall community uses energy access tiers calculated for each household.

FIGURE 10.3

Example of Tier Calculation



Comparison across Geographic Areas and over Time

The index, as well as disaggregated data, may be compared across countries or any geographic area (including sub-national, regional, and worldwide), as well as over time.

Both disaggregated and aggregated data may be compared across geographic areas and over time. The index may be compared across countries or any geographic area, such as a country, a province, a district, a town, or a village, but also a continent and the world as a whole. For example, developed countries are expected to have an index value close to 100, whereas in many countries in Sub-Saharan Africa, the index value may only reach 20 or less, due to a large number of community activities running on grid delivering few hours of supply per day, or suffering from diesel fuel availability issues.

The index for a larger geographical area can be obtained by calculating the population-weighted average of indices across the smaller areas that constitute the larger area. For example, the index at the state level can be obtained by calculating the weighted average of the district-level indices.

Progress in improving access to community uses of energy can be tracked by comparing indices over time. Further, the comparison of disaggregated data would detect areas where efforts have been successful, as well as bottlenecks inhibiting higher index values.

The impacts of specific projects and programs can be assessed by undertaking a baseline survey in the project or program area (and ideally in a similar area unaffected by the project or program) and repeating the survey after the project or program has been implemented to establish how energy access for community services has been improved.

CONCLUSION

The multi-tier approach provides a comprehensive tool for assessing access to energy across various community institutions. It allows disaggregate and aggregate analysis to yield detailed information about various parameters and indices that facilitate comparison over time and across geographic areas. Separate analysis can be done for various institutions, such as schools and health facilities. The methodology reveals the various bottlenecks to effective energy access, thus enabling remedies leading to enhanced energy access, higher levels of community services, and greater socioeconomic development.

The multi-tier approach provides a comprehensive tool for assessing access to energy across various community institutions.

ENDNOTES

[52] Electricity generation is excluded.

[53] An example of a solar water pump may be found at: http://www.bsrsolar.com/sv/produkte2_e.html.

[54] It may be difficult to assess the capacity by simple observation. Standalone solutions, such as solar lanterns or solar home systems, may not have a name plate indicating the capacity of the system, while for other technologies such as mini-grids, there is usually no written information within the premises.

[55] Poorly installed electricity systems also create a significant fire risk, and poorly designed or poorly installed generating equipment can also present risks of physical injury.

[56] This aggregation method is used by the Multi-Dimensional Energy Poverty Index (Nussbaumer et al. 2012).

11

STRENGTHS AND SHORTFALLS OF THE PROPOSED METHODOLOGY

This chapter discusses the strengths and shortfalls of the multi-tier methodology, and suggests approaches for addressing the identified shortfalls.

The previous chapters presented multi-tier frameworks for measuring energy access across households, productive engagements and community infrastructure, reflecting all of the key attributes of energy. The proposed methodology offers several strengths, but also has inherent shortfalls. The strengths of the methodology include: (i) comprehensive measurement, (ii) feasibility to conduct diagnostic analysis for strengthened energy access, (iii) attention to gender aspects, and (iv) foundation for multifarious analytics of energy access. On the other hand, this comprehensive measurement is complex and difficult to implement on a global scale. This key shortfall of the methodology can be addressed by devising simpler versions of the multi-tier frameworks that may not capture all the information relating to energy access, but may be easier to implement, especially in the context of global measurement. This chapter discusses the strengths and shortfalls of the multi-tier methodology, and also suggests approaches for addressing the identified shortfalls.

STRENGTHS OF THE PROPOSED METHODOLOGY

Comprehensive Measurement

The proposed multi-tier framework enables a comprehensive assessment of energy access, spanning across various locales and attributes.

The proposed multi-tier framework enables a comprehensive assessment of energy access, spanning across various locales and attributes, while remaining technology neutral. As a result, the proposed methodology captures the extent and intensity of energy access. The energy access indices provide an easy-to-understand tool for measuring energy access across geographic areas and over time, while the disaggregated analysis provide insights into the underlying causes of energy access deficiencies.

Measurement of Gender Aspects

The survey instrument gathers information on gender-related aspects.

The multi-tier framework and the related household questionnaires cover gender aspects of energy access in multiple ways. Specifically, the survey instrument gathers the following information on gender-related aspects:

- Ownership and regular use of various electrical appliances in the household, by gender of household members
- Use of various standalone lighting devices by gender of household members
- Gender of household members who frequently prepare meals and who obtain cooking fuel
- Gender of household members who use mobile phones
- Various aspects of cooking, including time spent in obtaining fuel, time spent in preparing both fuel and coockstove, and level of satisfaction with the cooking solution

- Indoor air quality that usually affects the health of women and children
- Availability of street lighting in the neighborhood area, facilitating mobility, especially for women
- Energy access for productive uses by gender of working household members
- Energy access for health facilities, facilitating child delivery

Additional survey questions may be included in specific surveys to elicit more information on gender aspects.

Diagnostic Review and Gap Analysis

The data on various attributes collected as part of the multi-tier analysis allows the calculation of various indices that summarize complex phenomena. These indices are comparable over time and across geographic areas. In addition, this extensive set of data and attribute-based analysis can be used to compile an energy access diagnostic review for the area. Such a review looks at the attribute deficiencies that restrict users to lower tier levels.The gap analysis provides insights into possible interventions that would enable users to move to higher tiers of energy supply and services. Thus, the measurement of energy access directly helps formulate approaches for improvement.

The aggregated and disaggregated analysis under the proposed approach enable an energy access diagnostic review that provides insights into possible interventions that would improve access.

Foundation for Multifarious Analytics

The multi-tier measurement of energy access forms the foundation for extensive analysis that can provide further insights into energy access-related aspects. Investments needed to improve energy access can be assessed based on scenarios that assume different movements across tiers. For example, the cost of a ‘Tier 0 to Tier 1’ movement would be different from the cost of a ‘Tier 1 to Tier 5’ movement and so on. Socioeconomic benefits of energy access can be estimated based on the energy access index. For example, socioeconomic benefits resulting from Tier 1 access would be different from benefits resulting from Tier 4 access. Thus, the multi-tier frameworks can provide an overarching paradigm for understanding energy access, based on which further theories and analytics can be developed.

The multi-tier treatment of energy access can form the foundation for extensive analysis that can provide further insights into energy access-related aspects.

Flexibility of Setting Target Tiers

The multi-tier measurement of energy access allows governments to set their own targets by choosing any tier above Tier 0. Such targets will depend on the situation in a country, its development status, the needs of its population, and the budget available. For example, countries in which a high proportion of the population lacks electricity in any meaningful form might set a target of moving people from Tier 0 to Tier 1 to ensure basic lighting services, whereas countries in which most people already have some form of access to electricity could focus on moving people into Tier 4 or 5. Similarly, countries with a low penetration of LPG or natural gas for cooking may decide to launch a program to introduce advanced biomass cookstoves that would move households into the middle tiers (2 or 3), while other countries may focus on higher tiers by increasing natural gas connections. Where funding is limited, governments will need to make trade-offs, for example between moving more people to Tier 1 or 2 or raising some percentage of the population to higher tiers.

SHORTFALLS OF THE PROPOSED METHODOLOGY

Complex and Elaborate Framework

The proposed methodology involves tier thresholds that may be considered subjective. Also, different attributes are independent of each other, and therefore cannot be assumed to improve simultaneously across tiers.

The proposed methodology is complex. It involves tier thresholds that may be considered subjective. These tier thresholds have been formulated based on a combination of technology break-points and the usability of energy supply required to deliver various services. Another criticism of the approach is that the different attributes are independent of each other, and therefore cannot be assumed to improve simultaneously across tiers. However, the requirement of simultaneous improvement of independent (or even negatively correlated) parameters is also observed in other standards. For example, vehicle emission standards require simultaneous reduction in various emission parameters such as carbon monoxide (CO), nitrogen oxides (NOx), and sulfur oxides (SOx), even as fuel efficiency is improved and power output is enhanced. Thus, simultaneous improvement of attributes that results in greater usability of energy supply is a logical approach.

The multi-tier framework requires extensive collection of data, which may not always be affordable.

The multi-tier framework requires extensive collection of data. The household survey costs involved may not always be affordable. Therefore, there is a need for simplification of the multi-tier framework, to facilitate data collection for the most critical attributes. Such simplification is discussed later in this chapter.

Scope for Adding More Modules to Survey Instrument

The proposed methodology does not cover all aspects that may be of interest to practitioners. These can be added into the standard survey instrument as additional modules.

Although the proposed methodology addresses various aspects of energy access, it does not cover all aspects that may be of interest to practitioners in specific situations. For example, several agencies could be interested in obtaining information about willingness to pay for different energy solutions. Also, programs and projects could be interested in undertaking an impact analysis and would like to know more details about various aspects of energy use. Although the survey instrument prepared for the multi-tier analysis does not cover many such aspects, it provides the opportunity to add more modules to collect additional information, as needed.

Mathematical Treatment of Indices of Energy Access

The methodology for calculating of indices of energy access is not mathematically robust. Further improvements may be explored as suggested in Annex 1.

The methodology underlying the indices of access to energy converts ordinal values of different tiers into cardinal values of energy access. This conversion may not be mathematically robust. An analysis of the shortfalls of the underlying methodology as well as alternatives for addressing these shortfalls is presented in Annex 1. The analysis points out that a linear conversion of ordinal tier values into cardinal values of energy access can be improved by varying the weightage given to different tiers such that it becomes reflective of the utility of availing energy access at different tiers as experienced by consumers. However, it is difficult to determine such weightage, which may also vary across countries. The annex concludes that the current formula for calculation of the energy access indices may be a step in the right direction but needs to be reviewed going forward in search for better methodologies. At a very minimum, the methodology needs to be strengthened by adopting a more credible set of weights for converting ordinal tier values into cardinal metrics of energy access.

SIMPLIFIED FRAMEWORKS FOR GLOBAL ASSESSMENT

To facilitate the implementation of the multi-tier framework on a global scale, simpler versions can be devised to capture varying amounts of information. Three different levels of the multi-tier framework can be envisaged: comprehensive, simplified, and minimalistic (Table 11.1).

To facilitate the implementation of the multi-tier framework on a global scale, three levels of the framework can be envisaged: (i) comprehensive framework, (ii) simplified framework, and (iii) minimalistic framework.

Comprehensive Framework

The framework presented in the preceding chapters examines energy access in a comprehensive manner across various locales and attributes. Although providing detailed information about all attributes, it remains difficult to implement at a global level under resource constraints.

Simplified Framework

A simplified framework focusing only on the most important attributes is suitable for data collection at a global level. Based on a reduced number of questions, this framework may be used for a centralized global survey (covering the key energy access deficit countries) for tracking progress under SE4All. It may also be used for country- or project-level surveys where resource constraints do not allow the use of the comprehensive framework.

Minimalistic Framework

Household surveys such as the DHS and LSMS are conducted periodically (every three to five years) by most countries and could be a convenient and efficient vehicle for collecting energy access-related data. However, these surveys typically would only allow for a few questions on energy to be added in the questionnaires. Therefore, a minimalistic framework that is highly selective in adding questions, and focuses only on household access to electricity and cooking, may be considered.

A comparison of data requirements of the three frameworks in terms of attributes across various locales is presented in Table 11.1.

TABLE 11.1

Comparison of Frameworks for Global Assessment

	COMPREHENSIVE FRAMEWORK	SIMPLIFIED FRAMEWORK	MINIMALISTIC FRAMEWORK
Key Purpose	Detailed survey questionnaire for country-level assessment that can be used for diagnostic review	Reduced number of questions that may be used for global assessment of energy access under SE4All	Minimum number of questions that may be incorporated in existing household surveys (e.g., DHS and LSMS)
Household Characteristics	Covered in detail, including, inter alia, education, social, occupational, basic income, and expenditure characteristics	Covered in a simplified manner without assessment of income and expenditure	Not covered separately (already covered by existing surveys)
Household Access to Electricity	Comprehensive assessment based on all attributes: capacity, duration, reliability, quality, affordability, legality, convenience, safety, and health	Simplified assessment based on reduced set of attributes: capacity, duration, reliability, quality	Minimalist assessment-only based on two attributes: capacity and duration
Household Access to Lighting	Comprehensive assessment based on lumen hours of lighting as well as phone charging capability, including use behavior	Simplified assessment based on type of lighting device and phone charging capability	Minimalist assessment based on use of electrical lighting and phone charging capability
Household Access to Cooking	Comprehensive assessment based on all attributes as well as information about ventilation, cooking area, conformity to standards, and maintenance	Simplified assessment based on primary and secondary cooking solutions as well as ventilation, convenience, and affordability	Minimalist assessment based on type of primary and secondary cooking solutions
Household Access to Heating	Comprehensive assessment based on all attributes	Simplified assessment based on capacity, duration, and convenience of primary heating solution	Not included
Energy Access for Productive Uses	Detailed assessment based on all relevant activities and sources of energy	Simplified assessment based on electricity access	Not included
Energy Access for Community Uses	Detailed assessment based on survey of institutions	Simplified assessment based on household interviews	Not included


c) 48 - 20 ÷ 2 - 4 x 7 =
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Guatemala, 19/07/2011
30
x27

12

SECTION III: APPROACH FOR IMPLEMENTATION

ACCESS IMPACT OF UPSTREAM ELECTRICITY PROJECTS

Upstream power projects improve one or more attributes of electricity supply and thus enhance access.

Although the contribution of upstream electricity projects toward expanding access is not always apparent, most interventions do have a certain level of impact on electricity access, as they directly or indirectly improve one or more attributes of electricity supply. Apart from enabling expansion of electricity connections, projects of electricity generation, transmission, and distribution can also be considered as energy access projects, provided that they move consumers to higher tiers of access by improving deficient attributes in the existing electricity system.

LARGE GENERATION, GENERATION REHABILITATION, AND CROSS-BORDER TRANSMISSION PROJECTS

Increased availability of electricity from generation, rehabilitation, and cross-border transmission projects enhances duration of supply, voltage levels, and reliability, thus improving access.

Power shortages in an electrical system can be addressed by adding new generation capacity, rehabilitating existing power plants, or importing electricity from another country or province. Due to the upstream nature of such interventions (as compared to distribution interventions that are downstream), they are generally not perceived as access interventions. However, from the perspective of a multi-tier framework, these interventions enhance the attributes of electricity supply and contribute directly to improved electricity access.

Increased availability of electricity from new generation capacity, rehabilitated capacity, or power imports directly improves the duration of supply in areas that may have previously experienced load shedding. Peaking stations (or peaking imports) improve supply during evening hours, which is usually when households find electricity most useful. Further, the supply voltage is also likely to improve as the grid as a whole receives adequate electricity generation. Reliability of the system improves with frequency stabilization resulting from better matching of supply with demand. Reliability also improves with lesser plant breakdowns following rehabilitation. All of these enable consumers in the target area benefitting from the additional generation to move from access Tiers 2, 3, and 4 to Tiers 3, 4, and 5.

Furthermore, introduction of cheaper sources of power improves affordability, and additional power availability allows more connections.

Introduction of cheaper generation to replace costly fossil fuel-based generation could allow reduction (or lower increase) in tariffs, thus, enhancing affordability. In many cases, this would result in an improvement of the index of access to electricity supply. Also, with increased availability of electricity, the utility is able to expand the number of connections over a period. This would again result in improved access for many households, which would move from access Tiers 0, 1, and 2 to Tiers 3, 4, and 5.

TRANSMISSION, SUB-TRANSMISSION, AND DISTRIBUTION-STRENGTHENING PROJECTS

Transmission projects improve the availability, reliability, and affordability of electricity. Availability is improved through increased capacity to transfer power from other areas. Reliability is improved by building redundancies into the system, which ensure that transmission failures do not cause blackouts. Also, transmission and transformation losses can be particularly high in overloaded systems. Augmentation and strengthening of transmission lines reduce losses, making electricity less costly. Finally, transmission and sub-transmission systems enhance availability of electricity, allowing new connections. On the whole, transmission and sub-transmission projects move consumers from access Tiers 2, 3, and 4 to Tiers 3, 4, and 5 by improving the availability, reliability, and affordability of the energy supply. They also move consumers from supply Tiers 0, 1, and 2 to Tiers 3, 4, and 5 by enabling more connections.

Projects strengthening transmission, sub-transmission, and distribution improve the availability, reliability, and affordability of electricity.

Similar to transmission projects, sub-transmission and distribution-strengthening projects also improve reliability and reduce losses. More importantly, these projects create the necessary infrastructure for connecting new consumers and supporting higher demand for electricity from existing ones. They enable unconnected households (typically Tiers 0, 1, and 2) to get connected (typically Tiers 3, 4, and 5), while also enhancing the tier rating of connected households through improved availability, reliability, and affordability of electricity. Of course, there may be a time lag between sub-transmission and distribution strengthening and implementation of new household connections.

RURAL (AND URBAN) ELECTRIFICATION PROJECTS

Traditionally, electrification is the only activity that is classified as expanding electricity access. However, the traditional classification tends to focus on grid connections. It either ignores mini-grid, off-grid standalone home systems, and solar lanterns, or places them on par with a grid connection. Moreover, it deems all grid connections to be equally effective in providing access to electricity, regardless of the attributes of supply available through the connection. The multi-tier methodology, being technology neutral, assesses the access levels provided by all types of interventions.

Electrification through grid, mini-grid, and off-grid technologies leads to enhanced access.

Central-Grid-Based Rural Electrification

The connection to a well-functioning central grid allows households to gain access to electricity supply for all their electricity needs. Typically the central grid allows as much power to be drawn as needed, constrained only by the current-carrying capacity of the cables and the protective circuit breakers installed. Ideally, a household should move to Tier 5 following its connection to the central grid. However, depending upon the attributes of electricity supply from the grid, the household may actually move only to Tier 2, 3, or 4 due to other supply deficiencies.

Connection to a well-functioning central grid allows access for all electricity needs. However, tiers of access may be limited by other supply deficiencies.

Mini-Grid-Based Rural Electrification

Mini-grids typically impose restrictions on quantity of supply by applying load limitation switches. Access may be limited by capacity, duration, and affordability attributes.

Mini-grid-based electrification may be the supply solution for large sections of households in Sub-Saharan Africa and many countries outside this region. However, it is important to point out that all mini-grids are not alike, and the attributes of electricity available from the mini-grid may vary significantly. Mini-grids typically entail a specific generation facility, which imposes restrictions on the quantity of supply that can be used. Often load limitation switches are applied, with flat-rate monthly charges for an unmetered supply. Therefore, it is important to examine the capacity, availability (duration), and affordability of supply from a mini-grid. Depending upon the supply attributes, mini-grids may move households from Tiers 0, 1, and 2 to Tiers 2, 3, 4, or even 5 (for mini-grids with very large supply capacity).

Off-Grid Standalone Home Systems and Solar Lanterns

Off-grid solutions are a stepping stone to greater electricity access.

In the case of off-grid electricity projects (e.g., solar home systems and fossil fuel-based standalone generators), the beneficiaries are moved from Tier 0 to Tiers 1, 2, and higher, depending on the capacity of the standalone system. Although the impact on the final energy access index is usually lower than the one resulting from grid electricity due to constraints on capacity and availability (duration), standalone solutions would be the stepping stone to greater electricity access for a large proportion of households or the final solution, in many instances.

Solar lanterns only enable households to achieve Tier 1 (or lower) access to electricity. However, this move may still enable a significant step forward in terms of the improvement in quality of life, enabling greater time for work and leisure.

RURAL FEEDER SEGREGATION PROJECTS

Feeder segregation projects can lead to improvements in duration, quality, reliability, and legality, thus providing enhanced access.

Feeder segregation projects have been attempted in India and other countries as a means to segregate politically sensitive and highly subsidized agricultural supplies from rural household supplies of electricity. Whereas the agricultural supply is typically needed for a shorter period during the day (and may be provided during off-peak hours), the household supply is required throughout the day but especially during the evening hours. Feeder segregation projects are aimed at separating the supply for agricultural needs from the household supply. The supply to agricultural feeders is provided for limited hours only, and may be a three-phase supply, whereas the supply to household feeders is active for a longer duration and is provided to customers as a single-phase supply. The feeder segregation also allows clear measurement of agricultural consumption at the feeder level itself for the purpose of estimating the subsidy payment from the government.

Feeder segregation projects can lead to significant improvements in access to household electricity. From the perspective of the proposed multi-tier framework, rural feeder segregation projects should be treated as rural energy access projects.

Using the proposed multi-tier approach, the baseline measurement before the project would reveal that a significant number of households are located at Tier 2 or 3, because:

- Most households would be receiving supply for less than 8 hours during the day.
- Most households would not be receiving enough supply during evening hours.
- Supply to most households would not be reliable due to unannounced load-shedding.
- Many connections would be illegal.
- Households that are distant from the existing transformers would be getting low voltage.

Rural feeder segregation projects can address all of these problems. Such projects aim to deliver continuous supply to households, including the evening hours. With the installation of new transformers, voltage levels and reliability improve. A load-shedding roster system is typically put into place, which reduces unscheduled cut-offs, improving reliability. The feeder segregation program also involves regularization of illegal connections as part of separating household connections from agricultural connections. Thus, the feeder segregation programs can enable a large set of households to move from Tier 2 or Tier 3 supply to Tier 4 or Tier 5 supply.

ENERGY ACCOUNTABILITY AND DISCONNECTION DRIVES

Energy accountability programs entail effective metering to draw energy balances at different levels of the supply system, and introduce accountability for technical and commercial losses. Reduction of commercial losses entails recovery of billed arrears as well as disconnection of illegal connections. Reduction of technical losses also entails strengthening of the distribution network. Drives to disconnect illegal connections may entail legalization of some connections and disconnection of others. As a result, many households will move to higher tiers of access from legalization of connection, whereas some others may slip into off-grid standalone solutions, or lose electricity altogether. On the whole, however, energy accountability drives lead to greater energy availability and improved scheduling of supply, promoting consumers to higher tiers of access to energy supply.

Accountability drives lead to improved legality, availability, and duration, thus taking consumers to higher tiers of access to energy supply.

STRENGTHENING SYSTEM OPERATION, REGULATION, AND POWER MARKETS

Drives to strengthen regulation, markets, and system operation are aimed at establishing an ecosystem in which various elements of the electricity supply chain can develop and function in an efficient manner. These interventions are usually not perceived to be linked with enhanced electricity access. However, their impact on electricity access is obvious when examined from the multi-tier framework perspective.

Strengthening regulation, markets, and system operation fosters an improved power ecosystem. Its impact on access is obvious when examined from the perspective of improved attributes.

Improved system operation through installation of supervisory control and data acquisition (SCADA) systems and strong load dispatch centers allows better management of demand and supply, while ensuring merit-order dispatch. It enables improved voltage and frequency levels in the system due to better oversight. It also enhances duration of supply through efficient use of generation resources, which is particularly true in regard to better managed supply during the evening peak-demand period. Merit-order dispatch also allows lower tariffs through cost-efficient prioritization of generation resources. Improved system operation leads to greater reliability, enhanced duration of supply, improved evening supply, better voltage/frequency levels, and more affordable supply. All of these allow consumers to move from lower to higher tiers of access. Greater availability of electricity from better system operations can also allow more connections to be provided, thus, moving more households toward grid connectivity.

Under the multi-tier framework, electricity access may also improve through tariff rationalization—either as a result of greater affordability with lower tariffs, or through the institution of demand management systems such as time-of-day tariffs. Time-of-day tariffs adjust demand for power in relation to its availability, thereby improving duration of supply, evening supply, voltage levels, and reliability. Also, lifeline tariffs allow poor households to afford electricity for basic needs, thus enhancing their level of access.

Similarly, power markets also provide price signals to sector players (generation, distribution, and trading companies) to adjust demand and supply, while also facilitating electricity trade. Efficient deployment of existing electricity resources and market signals for installation of new capacity both lead to improved access to electricity in terms of attributes as captured through the multi-tier framework. Specific instances of power markets such as power pools, day-ahead markets, power exchanges, and mechanisms for settlement of unscheduled interchanges can be individually examined for their contribution to enhanced access.

Thus, improvements in power markets, regulation, and system operation can together promote consumers from Tiers 2, 3, and 4 to Tiers 3, 4, and 5 over a period.

ENERGY EFFICIENCY INTERVENTIONS

Constraints to different attributes of electricity supply are alleviated through energy efficiency interventions, taking households to higher tiers of access.

Energy efficiency interventions may be targeted at the demand or the supply side of the electricity supply value chain. Supply-side energy efficiency measures overlap with the plant rehabilitation measures discussed earlier, and result in greater availability, affordability, and reliability of supply. Demand-side energy efficiency measures, on the other hand, result in lower consumption of electricity for the same services. This allows more electricity to be available as well as greater affordability through less reliance on costlier sources of generation in the merit order. Further, as energy-efficient devices become more common, a larger number of services would become feasible at lower tiers of access to electricity supply. Thus, constraints pertaining to different attributes of electricity supply get alleviated through energy efficiency interventions, taking households to higher tiers of access to electricity supply and services.

Table 12.1 summarizes the types of electricity projects covered in this chapter.

TABLE 12.1

Characteristics of Electricity Projects

PROJECT INTERVENTION	GRID CONNECTIVITY	PEAK AVAILABLE CAPACITY	LEGALITY	EVENING SUPPLY	QUALITY	DURATION	RELIABILITY	AFFORDABILITY	LIKELY TIER MOVEMENT
1. Large generation	Increased connectivity over a period			Improved evening supply in areas with peaking shortage, especially with peaking stations	Improved voltage levels in supply shortage areas	Improved hours of supply in load-shedding areas, especially from base-load generation		Improved affordability when cheaper generation is added	0, 1, 2 → 3, 4, 5 3, 4 → 4, 5
2. Generation rehabilitation with efficiency and capacity increase	Increased connectivity over a period			Improved evening supply in peaking shortage areas	Improved voltage levels in supply shortage areas	Improved hours of supply in load-shedding areas	Improved reliability from lower plant breakdown	Improved affordability as generation is cheaper	0, 1, 2 → 3, 4, 5 3, 4 → 4, 5
3. Cross-border electricity trade (import)	Increased connectivity over a period			Improved evening supply in peaking shortage areas	Improved voltage levels in supply shortage areas	Improved hours of supply in load-shedding areas, especially from base-load generation		Improved affordability when cheaper power is imported	0, 1, 2 → 3, 4, 5 3, 4 → 4, 5
4. Transmission	Increased connectivity over a period						Increased reliability from built-in system redundancies	Improved affordability from lower system losses	0, 1, 2 → 3, 4, 5 3, 4 → 4, 5

(continued)

TABLE 12.1 continued

Characteristics of Electricity Projects

PROJECT INTERVENTION	GRID CONNECTIVITY	PEAK AVAILABLE CAPACITY	LEGALITY	EVENING SUPPLY	QUALITY	DURATION	RELIABILITY	AFFORDABILITY	LIKELY TIER MOVEMENT
5. Distribution and subtransmission	Increased connectivity over a period		Increased number of legal connections over a period		Improved voltage levels from distribution strengthening		Improved reliability from distribution strengthening		0, 1, 2 → 3, 4, 5 3, 4 → 4, 5
6. Rural electrification through new grid connections	Immediate increase in connectivity	Increases as people connect to supply from grid				Increased duration of supply in case of little or poor access from off-grid solutions		Typically grid electricity is more affordable than off-grid or coping solutions	0, 1, 2 → 3, 4, 5
7. Off-grid solutions (mini-grid and standalone solutions)		Increases as people move to standalone off-grid solutions	No legality issues	Supply available in the evening	Quality usually not an issue	4–5 hours of electricity access	Usually no reliability issues		0, 1→1, 2, 3
8. Lighting programs		Increases as people move to off-grid lighting		Lighting access in evening		4–5 hours of electricity access			0→1

PROJECT INTERVENTION	GRID CONNECTIVITY	PEAK AVAILABLE CAPACITY	LEGALITY	EVENING SUPPLY	QUALITY	DURATION	RELIABILITY	AFFORDABILITY	LIKELY TIER MOVEMENT
9. Rural feeder segregation			Improved legality, as illegal connections are legalized	Improves with assured supply in the evening	Improved voltage levels in erstwhile long-distance low-tension (LT) supply areas	Improved duration from assured regular supply to households	Improved reliability from transformer load balancing and new segregated feeders	Improved affordability from reduction in transformer and commercial losses	3, 4 → 4, 5
10. Energy accountability programs		May reduce, as illegal connections are disconnected	Improved legality, as illegal connections are legalized			May improve from closer monitoring and better management	May improve from closer monitoring and better management	Improved affordability from reduction in commercial losses	3, 4 → 4, 5
11. Disconnection drives		May reduce, as illegal connections are disconnected	Improved legality, as illegal connections are legalized					Improved affordability from reduction in commercial losses	3 → 4, 5 3 → 0, 1, 2
12. Improved system operation function				Improved evening supply from better management of peaking generation	Improved voltage and frequency from better monitoring	Improved duration of supply from efficient use of generation resources	Improved reliability from better system regulation	Improved affordability through better dispatch sequencing	3, 4 → 4, 5

(*continued*)

TABLE 12.1 continued

Characteristics of Electricity Projects

PROJECT INTERVENTION	GRID CONNECTIVITY	PEAK AVAILABLE CAPACITY	LEGALITY	EVENING SUPPLY	QUALITY	DURATION	RELIABILITY	AFFORDABILITY	LIKELY TIER MOVEMENT
13. Tariff rationalization				May improve evening supply through time-of-day tariffs				May reduce with increase in tariffs; lifeline tariffs improve affordability	4, 5 → 3, 4 2, 3 → 3, 4, 5
14, Setting up of power pools	Increased connectivity over a period			Improved evening supply in peaking shortage areas	Improved voltage levels in supply shortage areas	Improved hours of supply in load-shedding areas, especially from base-load generation		Improved affordability when cheaper power is imported	0, 1, 2 → 3, 4, 5 3, 4 → 4, 5
15. Setting up of day-ahead power market				Improved evening supply in peaking shortage areas	Improved voltage levels in supply shortage areas	Improved hours of supply in load-shedding areas		Improved affordability	3, 4 → 4, 5
16. Energy efficiency projects				Power available for wider evening consumption		More power is available for longer duration of supply		Increased affordability with lower consumption	3, 4 → 4, 5

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CONCLUSION AND NEXT STEPS

The use of multi-tier frameworks for measuring energy access is currently constrained by limited availability of data. The GTF 2013 Report proposed to implement the multi-tier frameworks over the medium term by alleviating the data constraints.

The use of multi-tier frameworks for measuring energy access is currently constrained by limited availability of data—mainly in existing household surveys. The Global Tracking Framework (GTF) 2013 Report proposed to implement the multi-tier frameworks over the medium term by alleviating the data constraints. It proposed to develop standardized survey instruments, conduct periodic household energy surveys, analyze the data to assess various aspects of energy access, and make such data available in the public domain. Apart from multi-tier tracking of energy access, such surveys could potentially serve the data needs of multiple stakeholders, including government, regulators, utilities, project developers, civil society organizations, developmental agencies, financial institutions, appliance manufacturers, international programs, and academia. The detailed frameworks and survey instruments presented in this report pave the way for wider use of multi-tier measurement by strengthening the availability of data, as envisaged in the GTF 2013.

A four-pronged approach encompassing existing household surveys, global survey, country-level surveys, and program- or project-level measurement is suggested.

A four-pronged approach is suggested for strengthening the availability of data for monitoring progress on expansion of energy access:

1. Incorporation of the minimalistic framework into existing household survey questionnaires (such as DHS and LSMS)
2. Global survey for baseline assessment using simplified framework
3. Detailed country-level surveys using the comprehensive framework
4. Adoption of multi-tier measurement approach by programs and projects

The survey instruments created for the four-pronged approach are being piloted across selected countries. The piloting of multi-tier frameworks through household energy surveys is being supported by ESMAP. Household energy surveys themselves are being funded through a variety of sources across multilateral, bilateral, nongovernmental, and national agencies. Even as they are being validated and strengthened through pilot surveys, these survey instruments are now available for deployment. However, translation into local languages and customization to suit local contexts may still be needed.

INCORPORATION INTO EXISTING HOUSEHOLD SURVEY QUESTIONNAIRES

Existing household surveys should be expanded to include questions from the minimalistic framework.

Existing household surveys such as DHS and LSMS cover a wide range of information pertaining to multiple sectors, and offer limited space for energy-related questions. The minimalistic framework has been specifically formulated to leverage the limited space for additional questions in existing household surveys. This minimalistic approach needs to be implemented by expanding existing household surveys through a dialogue with the International Household Survey Network.

GLOBAL SURVEY TO ESTABLISH BASELINE FOR SE4All

In order to establish the multi-tier baseline for the purposes of SE4All, a global survey would be required, covering at least the top 30 to 40 energy access-deficit countries, and representing about 80 to 90 percent of the binary energy access-deficit population. This global household survey would be centrally administered through a suitable survey agency that has outreach in the selected countries. Such a global survey is likely to be constrained in terms of length of the questionnaire as well as the sample size in each country (in view of the costs involved). Therefore, the simplified version of multi-tier framework and survey instrument would be used for this survey. The survey is being planned for 2015, and necessary funding is being arranged for the same. Similar surveys can be organized periodically (every two to three years) for tracking progress under SE4All.

Global household energy surveys covering at least the top 30 to 40 energy-access-deficit countries can be used to establish multi-tier baseline and track progress under SE4All.

DETAILED COUNTRY-LEVEL SURVEYS

At present, various international and national agencies conduct household energy surveys for their own project, program, or planning needs. This results in significant expense of time, effort, and resources for collecting overlapping data, even as data from different surveys are not comparable due to lack of standardization of questionnaires, sampling strategies, and coverage. SE4All offers a unique opportunity to integrate all such survey efforts into a standardized household energy survey (customized to specific country needs) conducted every two to three years at the country level that could serve the needs of the multi-tier framework as well as the requirements of most stakeholders. Such surveys would use the comprehensive framework, encompassing all attributes across all locales, and can also provide an energy access diagnostic review for the country.

Detailed country-level surveys using the comprehensive survey instrument can be used for energy access diagnostic review.

ADOPTION OF MULTI-TIER MEASUREMENT APPROACH BY PROGRAMS AND PROJECTS

The multi-tier approach can be adopted by various agencies for programs and projects for supply-side and demand-side measurement. Many agencies were involved in the development of the multi-tier frameworks. As mentioned earlier, supply-side measurement can be based on the performance characteristics of solutions supplied, whereas demand-side measurement can be done through household surveys using the proposed survey instruments.

A combination of the four approaches described can be used for regular tracking of progress on expansion of energy access. Periodic global and country-level surveys would form the backbone of such a tracking mechanism, and data and information from programs and projects could be used to track incremental progress in between two global surveys.

The multi-tier approach can be adopted by various agencies for programs and projects for supply-side as well as demand-side measurement.

ANNEX 1 | ALTERNATIVE METHODS FOR CALCULATING THE ENERGY ACCESS INDEX

This annex presents and assesses alternatives to the method used in this report to calculate the Access Index (AI) for individual sectors such as household electricity or cooking solutions. The objective is to stimulate further discussion about the method that is most appropriate for calculating the sectoral Access Indices. The focus of the discussion is the policy implications of each method, and not the methodological issues associated with the different methods.

ANALYSIS OF THE CURRENT METHOD

The formula used in this report:

$$\text{Access Index}\quad AI = \sum_{k=0}^{5} (P_k * 20 * k)$$

where k: tier number

P_k: proportion of households at the kth tier

In this formulation, the range of AI is from 0 to 100.

The above formula is a special case of a more general formula:

$$\text{Access Index}\quad AI = \sum_{k=0}^{5} (P_k * V_k)$$

where V_k is a value associated with tier k

The report's formula is the special case $V_k = 20 * k$.

In this case, the term V_k has an intuitive interpretation that the value of $\boldsymbol{V_k}$ measures the degree of access enjoyed by people in Tier *k*. For example,

$\boldsymbol{V_5}$ = 100, i.e., people in Tier 5 are assessed to have full 100% access

$\boldsymbol{V_1}$ = 20, i.e., people in Tier 1 are assessed to have partial 20% access

$\boldsymbol{V_0}$ = 0, i.e., people in Tier 1 are assessed to have 0% access

The value of AI can be interpreted as the overall access percentage in the particular sector (e.g., cooking or electricity), for the region or country. Thus, a value of AI = 32 implies that the measured access rate is 32%, as illustrated in Table A1.1. The P_k values are hypothetical, and could represent a city where the bulk of the people are in the lower tiers, with a small number of people in the upper tiers.

This calculation can be interpreted in this way:

- Tier 5 contribution to AI is 10% derived from the data that 10% of the population has full 100% access.
- Tier 4 contribution to AI is 0% because there is no one in Tier 4.

TABLE A1.1

Calculation of Access Index

TIER	ACCESS %	PROPORTION OF PEOPLE	CONTRIBUTION OF EACH TIER TO AI
k	V_k	P	$P * V_k$
0	0	0.00	0.00
1	20	0.80	16.00
2	40	0.00	0.00
3	60	0.10	6.00
4	80	0.00	0.00
5	100	0.10	10.00
Total		1.00	**32.00**

- Tier 3 contribution to AI is 6%, derived from the data that 10% of the population has 60% access.
- Tier 2 contribution to AI is 0% because there is no one in Tier 2.
- Tier 1 contribution to AI is 16%, derived from the data that 80% of the population has 20% access.
- Tier 0 contribution to AI is pre-set at 0% because people in this Tier are assumed to have 0% access.

Thus, the access rate is calculated to be 32, even though only 10% of the people are in Tier 5. The remaining 22% comes from the partial access that people in the other categories have.

A Mathematical Interpretation

In mathematical terms, AI is a weighted arithmetic mean of the values of V_k, with the weights defined as the values of the corresponding proportion, P_k, such that the sum of the weights is equal to 1. Since the V_k values are pre-fixed, the value of AI changes when the weights P_k change. In policy terms, the value of the index AI increases when people are shifted from lower tiers to higher tiers.

From a mathematical perspective, there is no reason why the pre-set values of V_k have to be in the specific pattern used above, i.e., 0, 20, 40, . . . , 100. For example, mathematically speaking, the index AI would still remain a weighted arithmetic mean if an analyst chose to set the value at Tier 2 as $V_2 = 37$, while retaining the other five values of V_k. This value $V_2 = 37$ implies that the analyst states that people in Tier 2 have access that is assessed to be 37% of the full access enjoyed by people at Tier 5. Or, an analyst could set the value for Tier 1 as $V_1 = 1$, while retaining the other five values of V_k. Or, the analyst could change any group of values in the above scheme.

However, the value of the highest tier V_5 cannot be more than 100 if the calculated index is to be bounded by 100, and the values of the other V_k must be less than or equal to 100. In other words, the assessed value of the access in each tier must be less than or equal to 100. Based on these observations, the alternative formulations for the Access Index are considered later in this annex.

From a mathematical perspective, there is no reason why some measure of central tendency other than the weighted arithmetic mean cannot be used to calculate the access index. In other words, while the arithmetic mean is the most commonly used measure of central tendency, there are other measure of central tendency, such as the median or the geometric mean, that are often used. These alternative formulations are also considered later in this annex.

Adverse Policy Implications of Using the Weighted Arithmetic Mean Formulation

The ultimate purpose of defining an access index is to measure the progress in increasing access, as measured by the defined index. Hence, it is important to understand how the access index changes in response to schemes that are aimed at people located in the various tiers.

One implication of the AI is that it does not matter whether an energy project moves a person from Tier 0 to Tier 1, or Tier 4 to Tier 5—the increase in the AI is the same. Thus, in some cases, this is likely to be an incentive for project formulators to move people from Tier 4 to Tier 5 than to move people from Tier 0 to Tier 1; this will be the case where it is simpler to mover people from Tier 4 to Tier 5 than from Tier 0 to Tier 1. This uniformity across the tier spectrum is an inherent implication of the formula used to define AI—irrespective of whether this uniformity is desirable from a policy perspective.

A second policy implication is that this access index gives no additional weightage to projects that move people from Tier 0 and Tier 1 to Tiers 2 and 3. If, for example, the benefits of moving a person from Tier 0 to Tier 2 are more than the benefits of moving a person from Tier 3 to Tier 5, then the access index AI does not take account of this difference.

Example 1: Impact of two projects focused on different tiers on AI.

Consider the impact of two different energy access projects—Projects A and B—on the AI, using the data in Table A1.2.

Project A: The focus is on the population in a low tier. The project:

- Moves 10% of the population from Tier 1 to Tier 3.
- The proportion in Tier 1 declines from 0.80 to 0.70; the proportion in Tier 3 increases from 0.10 to 0.20.
- All other tiers are left unchanged.
- Project A helps 10% of the population, and increases AI from 32.00 to 36.00.

Project B: The focus is on the people in a higher tier. The project:

- Moves 10% of the population from Tier 3 to Tier 5.
- The proportion in Tier 3 declines from 0.10 to 0.00; the proportion in Tier 5 increases from 0.10 to 0.20.

TABLE A1.2

Impact of Two Different Projects on Access Index

		INITIAL		POST PROJECT			
				PROJECT A		PROJECT B	
TIER	ACCESS %	PROPORTION	CONTRIBUTION TO AI	PROPORTION	CONTRIBUTION TO AI	PROPORTION	CONTRIBUTION TO AI
k	V_k	P	$P*V_k$	P	$P*V_k$	P	$P*V_k$
0	0	0.00	0.00	0.00	0.00	0.00	0.00
1	20	0.80	16.00	0.70	14.00	0.80	16.00
2	40	0.00	0.00	0.00	0.00	0.00	0.00
3	60	0.10	6.00	0.20	12.00	0.00	0.00
4	800	0.00	0.00	0.00	0.00	0.00	0.00
5	100	0.10	10.00	0.10	10.00	0.20	20.00
Total		1.00	**32.00**	1.00	**36.00**	1.00	**36.00**

- All other tiers are left unchanged.
- Project B helps 10% of the people, and increases AI from 32.00 to 36.00.

The policy implication is that Projects A and B are equivalent in terms of raising the value of AI.

Conclusion

The above discussion shows that the access index AI has the potential for providing misleading assessments of projects that are designed to increase the welfare/benefits of the potential beneficiaries. Mathematically, this problem arises because the formula for AI has these features: (i) use of a weighted arithmetic mean, and (ii) the values of $\boldsymbol{V_k}$ increase in the 0, 20, 40, . . . , 100 pattern.

Thus, mathematically, any alternative method has to change one or both of these features.

ANALYSIS OF ALTERNATIVE METHODS

Alternative 1: Median

The median is a commonly used alternative to the arithmetic mean as a measure of central tendency. In general, with grouped data, it is possible to define the median class and a median value.[58]

It is possible to apply the median class[59] to access index case. In the case of data shown in Table A1.1, the median class before the project is Tier 1 (the tier that contains at least 50% of people). Irrespective of whether Project A or Project B is undertaken, the median class does not change. Thus, even though there has been progress in improving access under either of these two projects, the median class indicator does not reflect this progress. Hence, the median class indicator is not usable.

Mathematically, the median itself cannot be calculated unless there the grouped categories have lower and upper values. For example, Tier 0 would have to be defined as the range 0 to 0, Tier 1 would have to be defined as the range 1 to 20, Tier 2 would have to be defined as the range 21 to 40, and Tier 5 would have to be defined as the range 81 to 100. Since such a formulation is not envisaged for the analysis of access, the median cannot be calculated in this case.

Hence, for the access index, the median in not a viable alternative to the arithmetic mean.

Alternative 2: Geometric Mean

The geometric mean is also a commonly used alternative to the arithmetic mean. For example, the U.S. Environmental Protection Agency uses the geometric mean in determining the average level of microorganism in water bodies.[60] Further, in the face of strong criticism about the implications of the use of an arithmetic mean, the Human Development Index prepared by the United Nations Development Programme switched to a geometric mean.[61]

For the access index, the weighted geometric mean (GMI) can be defined as:

$$\text{GMI} = V_0\text{^}P_0 * V_1\text{^}P_1 * V_2\text{^}P_2 * V_3\text{^}P_3 * V_4\text{^}P_4 * V_5\text{^}P_5$$

where the symbol ^ indicated "raised to the power of" and * indicates multiplication.

To calculate the GMI, it is more practical to first find the value of the log of GMI,

$$\text{GMI} = P_0 * \ln V_0 + P_1 * \ln V_1 + P_2 * \ln V_2 + P_3 * \ln V_3 + P_4 * \ln V_4 + P_5 * \ln V_5$$

and then convert it back to GMI.

$\text{GMI} = \exp (\ln \text{GMI})$

The geometric mean cannot be defined if one of the product variables is equal to the zero, because the product itself becomes equal to zero. The geometric mean can still be used by making a de minimus adjustment, and setting V_0 equal to a small non-zero value. Here, this change is implemented by setting

$V_0 = 1.$

which states that people in Tier 0 have 1% access. This change has no appreciable impact on the value of the calculated AI.

Example 2: Assessing two projects with AI and GMI.

This example uses hypothetical data in which the bulk of the population is in the lower tiers, and there are some people in every tier, as shown in Table A1.3.

Project C moves 5% of the population from Tier 0 to Tier 2, leaving other Tiers unchanged.

Project D moves 5% of the people from Tier 3 to Tier 5, leaving other Tiers unchanged.

The AI formula rates Projects C and D as equal in raising the access index. However, as shown above, the GMI formula rates Project C superior to Project D.

A comparison of Tables A1.3 and A1.4 shows that the geometric mean rates Project C (which is aimed at people in Tier 0) higher than Project D (which is aimed at people in Tier 3), while arithmetic mean rates the two projects as equal. Thus, this is a desirable aspect of the geometric mean.

However, it is worth noting that the geometric mean's access rate with Project D is only 8.90. This is the calculated value even though a proportion of the population in Tier 5 is 0.10 (i.e., 10% of the population enjoys full access).[62]

It is difficult to accept that the access rate is lower than the percentage of the population that enjoys full access (i.e., with Project D, the access rate should be at least 10%, as 10% of the people have full access).

The conclusion is that the non-transparent and complex nature of the geometric mean may lead to unacceptable results. This probably makes the geometric mean unsuitable for calculating the access rate.

TABLE A1.3

Calculating Access Index with V0 = 1 for Two Projects

		INITIAL		POST-PROJECT			
				PROJECT C		PROJECT D	
TIER	ACCESS %	PROPORTION	CONTRIBUTION TO AI	PROPORTION	CONTRIBUTION TO AI	PROPORTION	CONTRIBUTION TO AI
k	V_k	P	$P*V_k$	P	$P*V_k$	P	$P*V_k$
0	1	0.40	0.40	0.35	0.35	0.40	0.40
1	20	0.25	5.00	0.25	5.00	0.25	5.00
2	40	0.15	6.00	0.20	8.00	0.15	6.00
3	60	0.10	6.00	0.10	6.00	0.05	3.00
4	80	0.05	4.00	0.05	4.00	0.05	4.00
5	100	0.05	5.00	0.05	5.00	0.10	10.00
Total		1.00	**26.4**	1.00	**28.4**	1.00	**28.4**

TABLE A1.4

Using Geometric Mean with V0 = 1 with Hypothetical Data

		INITIAL		POST-PROJECT			
				PROJECT C		PROJECT D	
TIER	IN ACCESS %	PROPORTION	CONTRIBUTION TO GMI	PROPORTION	CONTRIBUTION TO GMI	PROPORTION	CONTRIBUTION TO GMI
k	$\ln V$	P	$P \ast \ln V$	P	$P \ast \ln V$	P	$P \ast \ln V$
0	0	0.40	0.00	0.35	0.00	0.40	0.00
1	2.996	0.25	0.75	0.25	0.75	0.25	0.75
2	3.689	0.15	0.55	0.20	0.74	0.15	0.55
3	4.094	0.10	0.41	0.10	0.41	0.05	0.20
4	4.382	0.05	0.22	0.05	0.22	0.05	0.22
5	4.605	0.05	0.23	0.05	0.23	0.10	0.46
ln GMI		1.00	**2.16**	1.00	**2.35**	1.00	**2.19**
GMI			**8.7**		**10.4**		**8.9**

Alternative 3: Arithmetic Mean with a Different Set of V_k Values

One reason behind the concern with the weighted arithmetic mean is that the values associated with the different tiers follow the pattern 0, 20, 40, . . . , 100. Hence, it is meaningful to ask what the is origin and rationale for these V_k, and whether these values can be changed.

These values are the result of setting $V_k = 20 \ast k$. However, there is no direct or compelling link between the values of ordinal value of 0 in Tier 0, of 1 in Tier 1, . . . , and 5 in Tier 5 and the associated assessment of access as 0%, 20%, . . . , 100%.

In the absence of this link, it is reasonable to ask, for example, whether it is the case that the partial access in Tier 2 (40%) is necessarily twice the partial access in Tier 1 (20%), and half of the access in Tier 4 (80%)? And, is this necessarily true identically for all the sectors—cooking, electricity, heating—even though the tiers in each of the sectors have not been designed with this property in mind?

And, it is worth asking whether changing them could produce an access index that does not have the policy concerns discussed at the beginning of this annex.

In particular, consider a system of V_k that places relatively higher values for Tiers 1, 2, and 3, which may be appropriate for focusing energy access efforts on the relatively poorer and deprived sections of any society.

Table A1.5 is comparable to Table A1.3, which ranks Projects C and D as equivalent. However, the different set of V_k values used in Table A1.5 lead to the result that Project C, which focuses on people in Tier 0 is better than Project D, which is aimed at people in Tier 3.

What is the reason for the difference? In Table A1.5, the value of V_2 is set = 55, while in Table A1.3, it is $V_2 = 40$. Thus, given the higher partial (55%) access in Tier 2, the value of AI increases more than in Table A1.3.

What is the rationale for arbitrarily setting $V_2 = 55$ instead of $V_2 = 40$? The answer is that both the values—55 and 40—are arbitrary. Hence, both of them need to be justified, not just $V_2 = 55$. In the end, the value of V_2 has to reflect an assessment of the extent of the access provided by being in Tier 2.

From the electricity perspective, Tier 2 provides the household with limited electricity from a solar home system or a mini-grid. Is this worth 40% or 55% of the benefits from at least 22 hours of electricity per day from the grid? The answer has to depend upon how the beneficiaries themselves assess the benefits. People may consider a huge leap in benefits when moving from no electricity (Tier 0) to Tier 2; or, they may consider this limited availability as providing only a limited benefit and may want to be

TABLE A1.5

Using Arithmetic Mean with Different Set of V_k Values

		INITIAL		POST-PROJECT			
				PROJECT C		PROJECT D	
TIER	ACCESS %	PROPORTION	CONTRIBUTION TO MAI	PROPORTION	CONTRIBUTION TO MAI	PROPORTION	CONTRIBUTION TO MAI
k	V_k	P	$P*V_k$	P	$P*V_k$	P	$P*V_k$
0	0	0.40	0.00	0.35	0.00	0.40	0.00
1	30	0.25	7.50	0.25	7.50	0.25	7.50
2	55	0.15	8.25	0.20	11.00	0.15	8.25
3	75	0.10	7.50	0.10	7.50	0.05	3.75
4	95	0.05	4.75	0.05	4.75	0.05	4.75
5	100	0.05	5.00	0.05	5.00	0.10	10.00
MAI		1.00	**33.0**	1.00	**35.8**	1.00	**34.3**

moved to Tier 5, or at least Tier 4. Or, different beneficiaries may subscribe to different values of the benefit.

What is clear that is that the judgmental values of V_k assumed in Table A1.5 produce an access index that shows that Project C is better than Project D. The reason is that judgmental values give greater weights to the lower tiers—and in a transparent manner.

Thus, it is clear that the choice of the values of V_k directly affects the weights that an access index assigns to different tiers. Further, it is possible to choose values of V_k such that there is greater weight on the lower tiers, in accordance with analyst or policy-makers views about the relative benefits of moving people up to different tiers.

Clearly, this subjectivity can be seen as a weakness of the modified access index. However, this should be seen as a limited weakness because the seemingly objective values of 0, 20, 40, 60, . . . , 100 themselves have no compelling basis.

Further, the ability to choose the values of V_k implies that different values can be chosen for the different sectoral indices. This would likely introduce an additional element of realism to the calculated access values, because there is no compelling reason to believe that the Tier 2 in cooking should be assessed in identically the same was as Tier 2 in electricity.

Finally, it may be meaningful to arrive at an 'internationally accepted set of V_k values' to calculate the access rates in different countries, while letting each country define for itself its own set of V_k values. This would be similar to the international poverty line of $1.25 per day per capita, with countries free to define their own poverty lines.

The conclusion is that choosing V_k subjectively makes it possible to use the weighted arithmetic mean while avoiding the policy concerns identified at the beginning of this annex. At the same time, it would mean reaching a consensus across communities, countries, programs and organizations—which may not be easily reached—to choose the V_k values.

CONCLUSION AND WAY FORWARD

It is clear that there are legitimate concerns with the access index AI, based on the arithmetic mean, used in this report. However, it is not possible to simply and clearly eliminate these concerns by using alternative measures of central tendency, such as the median or the geometric mean, as they introduce their own weaknesses, which make these alternative measures unsuitable for the access index.

With the arithmetic mean, a simple, transparent way to overcome the concerns is to set values of V_k based on the benefits derived by the consumers in each Tier, instead of the $V_k = 20*k$ formula used in the report. Thus, the goal should be to derive these V_k values, and use them, in the access index with a weighted arithmetic mean.

However, it is not easy to quantify these benefits in an objective manner. This would require both further research as well as discussions with practitioners and policy makers.

Hence, the way forward is to treat the formula used in this report as an interim place holder and a starting point for further analysis aimed at deriving a robust, acceptable set of values of the benefits V_k enjoyed by the people in different Tiers.

ENDNOTES

[58] See http://people.umass.edu/biep540w/pdf/Grouped%20Data%20Calculation.pdf.

[59] Class Median is the first class with the value of cumulative frequency equal at least n/2, i.e., the first class which cumulatively included 50% of the population.

[60] http://www.epa.gov/region1/eco/beaches/qa.html.

[61] See http://hdr.undp.org/en/content/why-geometric-mean-better-suited-hdi-arithmetic-mean.

[62] The mathematical reason is that Project D still leaves a significant number of people in Tier 0.

ANNEX 2 | ASSESSMENT OF SUPPLY REQUIREMENTS OF DIFFERENT ELECTRICITY SERVICES

Electricity supply is only useful if it allows the desired energy services to be run adequately. Different energy services require different levels of electricity supply. Some attributes, such as quality of supply, legality of connection, and affordability, are essential for using almost any energy service. Others, such as quantity, duration of supply, and evening supply, vary in importance according to the type of energy service.

Although a plethora of websites give power consumption data for home appliances, it appears that there is almost no published research specifically addressing power consumption of home appliances in developing countries. The requirements in terms of duration of supply are challenging to establish, as the use of each appliance will vary with household characteristics (location, climate, income, preferences, etc.). The analysis in Table A2.1 attempts to establish a reference in watts for each appliance, based on a combination of sources.

TABLE A2.1

Electricity Supply Requirements for Electricity Services

1. LIGHTING	
Task lighting	Task lighting is used to increase the luminance (i.e., the luminous intensity per unit area of light) in a reading or working area. The task area may range from a very small surface up to about as far as one may reach with the hands. The appliance of reference is a portable desk lamp or a bulb hanging above a table. There is no universal definition of adequate or minimum light for households, despite available norms on lighting intensities required in schools or hospitals. EnDev (2012)[a] considers a value of 100 lux covering the surface size of a large book (0.1 m^2) in a distance of 0.8 m as sufficient for one person (equivalent of 10 lumens incident over the surface of the book). This intensity should be available for 4 or 5 hours per day. This value can be compared to a 25-W incandescent bulb or a 6-W compact fluorescent lamp (CFL) (EnDev 2012). Mahapatra et al. (2009)[b] consider a reasonable lighting level (illuminance) in the range of 100 to 200 lux (lumen/m^2). In their study, the efficacy (lumens/W) of an incandescent lamp is 12 lumens, and that of a fluorescent lamp is 51 lumens (p. 273, table 3). In the proposed framework, the minimum requirement for adequate task lighting corresponds to 6 W, referring to a 6-W CFL. This can also be achieved through an light-emitting diode (LED) lamp of about 1 W.
General lighting	General lighting is used to increase the luminance in a household's room (a larger surface compared to task lighting). The light should be able to provide enough ambient light to light a room. EnDev (2012) considers a value of 300 lumens for a household of up to five people, during 4 or 5 hours per day, as a standard. This value can be compared to a 25-W incandescent bulb or a 6-W CFL (EnDev 2012). Practical Action (2012)[c] also considers minimum standards for lighting to be 300 lumens for a minimum of 4 hours per night at household level (p. 42, table 3.1). In the proposed framework, the minimum requirement for adequate general lighting corresponds to 12 W, which refers to two 6-W CFL lamps, enabling multiple lights within the household.

2. INFORMATION, COMMUNICATION AND ENTERTAINMENT

Radio	Although dry-cell battery-powered radios consume around 2 W to 4 W, plug-in electric radio power consumption is usually around 7 W (EnDev 2012), 10 W (General Electric 2012[d]), and 13 W (Rogers et al. 2008[e]). Four hours per day is the minimum standard proposed by EnDev (2012). The proposed framework takes an average power requirement of 4 W for a radio, and a minimum of 2 W.
Phone charging	Phone charging requires an average of 4 W of power, a value consistent across various sources. A minimum of 2 W is considered for very simple phones.
Television	Although EnDev (2012) considers a television of 20 W, power consumption for television varies widely. A 12-inch black-and-white TV consumes 20 W, a 19-inch color TV consumes 70 W, and a 25-inch color TV consumes 150 W. A liquid crystal display (LCD) TV needs 213 W, and a plasma TV consumes 339 W (Wholesalesolar 2012[f]). The proposed framework considers a minimum power requirement of 20 W for television, and a higher 40 W for average power requirement.
Computer	Power consumption for computers varies widely from 20 W (Absak 2012[g]) to 250 W (Wholesalesolar 2012). The proposed framework considers an average power consumption of 70 W, also in line with Rogers et al. (2008).
Printing	Average power consumption for printers varies across sources from 45 W (General Electric, 2012) to 100 W (Absak 2012). The proposed framework selected the lower end of 45 W as a minimum value.

3. FOOD PRESERVATION

Refrigeration	Practical Action's (2012) Total Energy Access (TEA) minimum standard for food cooling requires that households be able to extend life of perishable foods by at least 50% over that allowed by ambient storage. There is a range of cooling devices that can keep food cold—electric, solar, or gas refrigerators or passive cooling devices such as a "zeer" pot or cold box. A single-door 12-cubic-foot refrigerator requires 225 W (Abaris 2012). For a 16- to 20-cubic-foot refrigerator, the power needed ranges between 380 W and 420 W (Oksolar 2012[h]). A freezer consumes 245 W to 475 W (8 to 20 cubic foot, respectively [Abaris 2012]). Refrigerators actually cycle on and off as needed to maintain interior temperatures. The wattage mentioned above corresponds to the power required when the refrigerator compressor kicks on. Although the device is plugged in 24 hours a day, it is estimated that this power is required for about one-fourth of the time (6 hours per day). The proposed framework considers as adequate refrigeration an electric refrigerator of 300 W.

4. MECHANICAL/THERMAL LOAD AND LABOR/TIME SAVING

Food processor	Food processor refers to appliances such as blenders, mixers, and choppers. Wattage varies with motor capacity and size, from 150 W to as high as 1,000 W. This framework considers a low average of 200 W.
Washing machine	According to various sources, a washing machine consumes 500 W (Absak 2012; Oksolar 2012).
Iron	Power consumption for flat irons is fairly homogeneous across sources at 1,100 W.
Hair dryer	Power needed for hair dryers varies substantially from 1,000 W to 2,500 W across various sources. The framework considers a minimum requirement of 1,200 W.
Water pump	Certain households may have a well within their property or operate an individual water pump from the nearby spring source. A standard of 20–25 liters per person per day from max 1,000 meters and with a collection time of less than 30 min is stated by WHO/OHCHR/UN-Habitat (2006).[i] A household of five people would require around 100 liters per day. Taking as a reference well pumps of 1/3 to 1 hp (480 W–1,200 W) (Wholesalesolar 2012; ConsumerReports 2012[j]), this framework sets a minimum requirement of 500 W.

(*continued*)

TABLE A2.1

Electricity Supply Requirements for Electricity Services (*continued*)

5. COOKING AND WATER HEATING

Rice cooker	A rice cooker is included within the electricity applications as it is a very popular appliance in Asia. According to an informal web research, wattage for rice cookers starts at 300 W and can reach 1,000 W based on the size. This framework considers a rice cooker of 400 W as an average power requirement.
Electric toaster	Power consumptions for electric toasters range from 800 W to 1,200 W. An average power requirement of 1,000 W is considered in this framework.
Microwave	Across various sources, power consumption of a microwave ranges from 500 W to 2,000 W. This framework considers a standard power requirement of 1,250 W for a microwave.
Electric stove	Electric stove refers here to electric burners only (or hot plate), not considering the oven. It is considered as a replacement for other types of cookstoves that only provide burners. Across sources, electric burners consume about 1,500 W.
Water heating	A standard of 20–25 liters per person per day from max 1,000 meters and with a collection time of less than 30 min is stated by WHO/OHCHR/UN-Habitat (2006). A household of five people would require around 100 liters of water per day. The WHO standard does not mention any minimum requirement for hot water. Water heating in the proposed framework refers to boilers that heat running water within the household. Assuming that half of the WHO minimum quantity standard should be hot water, the power consumption for heating 50 liters in tanks follows the equation: gallons∗temperature rise (F)/372∗heat-up time (hr) = kW. To raise temperature to 100° Fahrenheit (body temperature) in 1 hour for 50 liters of water, the wattage required is approximately 3,500 W (Tempco 2012[k]).

6. SPACE COOLING AND HEATING

Climate control applications are climate dependent and only required in certain areas, for a certain period of time. Cooling is desirable in areas where the maximum daytime indoor air temperature is higher than 30° Celsius, whereas heating is desirable in areas where the maximum daytime indoor temperature drops below 18° Celsius (Practical Action, 2012).

Air circulation	Power consumption of electric fans varies based on the size. Power consumptions for ceiling fans range from 10–50 W (Absak 2012) to 75 W (General Electric 2012) to 100 W (Wholesalesolar 2012) and 150 W (Abaris 2012[l]). Table fans vary from 10 to 25 W (Absak 2012). The proposed framework considers 20 W as the minimum power requirement, and a higher average requirement of 40 W.
Air cooling	An informal web search found that air coolers usually consume from 200 W to 300 W. Air cooling power consumption is set at 240 W, in line with Rogers et al. (2008).
Air conditioning	Power consumption for central air conditioning varies from 2,000 W to 5,000 W, confirmed across a range of sources, whereas room air conditioning varies from 600 W to 2,400 W depending on the size (Abaris 2012). The proposed framework considers an average 1,500-W room air conditioner.
Room heaters	Most sources mention a 1,500-W power demand for portable heaters, although for small heaters the power required could decrease to 750 W (Abaris 2012). The proposed framework considers an electric heater of 1,500 W as a standard requirement.

[a] *EnDev (2012). Access to Modern Energy. Energizing Development. Energypedia.info. Available at: https://energypedia.info.php/Access_to_Modern_energy.*

[b] *Mahapatra S., Chanakya H. N., Dasappa, S. (2009). Evaluation of various energy devices for domestic lighting in India: Technology, economics and CO2 emissions. Energy for Sustainable Development, 13, 271–279.*

[c] *Practical Action (2012). Poor People's Energy Outlook 2012, Rugby, UK.*

[d] *General Electric (2012). Home appliance energy use. Data visualization. Available at: https://visualization.geblogs.com/visualization/appliances.*

[e] *Rogers, J.; Suphachasalai, S.; Narain, M.; Sahai, G.; Bhattacharya, S.; Varma, B. (2008). Residential Consumption of Electricity in India. Documentation of Data and Methodology. The World Bank.*

[f] *Wholesalesolar (2012). How Much Power Do your Appliances Use? Available at: http//www.wholesolar.com/StartHere/HowtoSaveEnergy/PowerTable.html.*

[g] *Absak (2012). Average Power Consumption of Household Appliances. Available at: www.absak.com/library/power-consumption-table.*

[h] *Oksolar (2012). Appliance typical power consumption information. Available at: www.oksolar.com/technical/consumption.html.*

[i] *OHCHR/UN-Habitat (2006). The Right to Water (Fact. Sheet No. 35).*

[j] *ConsumerReports (2012). Power play. Available at: www.consumerreports.org/cro/resources/images/video/wattage_calculator/wattage_calculator.html.*

[k] *Tempco (2012). Wattage Estimation Table. Kilowatt Hours to Heat Water. Available at: www.tempco.com/Engineering/wattage_estimation_tables.htm.*

[l] *Abaris (2012). Energy Consumption of Various Appliances in Watts. Available at: www.abaris.net/info/wattage_energy_consumption.htm.*

ANNEX 3 | ESTIMATION OF ATTRIBUTES THROUGH SURVEY INFORMATION

Many attributes of energy may not be easily amenable to data gathering through interviews due to the technical nature of such attributes. This annex suggests approaches for estimating the attributes based on survey information using simplifications and assumptions. Such assumptions would provide a rough but conservative estimate of the attributes.

CAPACITY OF ELECTRICITY SUPPLY

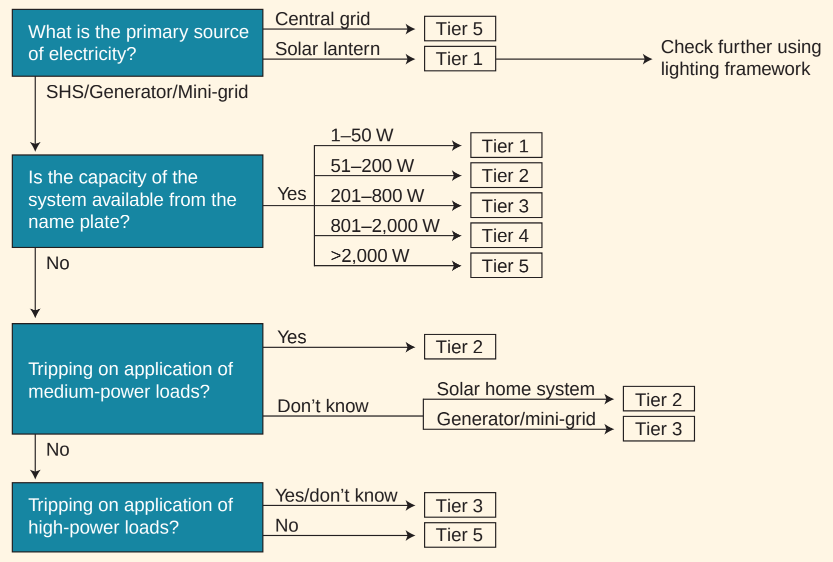
Capacity of electricity supply may be constrained by the technology involved, even as the same technology may be capable of delivering different tiers of supply. For example, mini-grids may be supplying power at Tier 2 to Tier 5 depending on the generation capacity installed.

Capacity of the electricity supply system can be estimated in three steps (Figure A3.1):

1. Type of primary energy source
2. Any written indication (such as name plate) if available
3. Experience of load limitation

FIGURE A3.1

Decision Tree for Capacity of Household Electricity Supply



Legality of Connection

Respondents are expected to be reluctant in sharing information about the legality of their electricity connection, fearing possible disconnection. Therefore, this information has to be obtained through indirect questions. Nonetheless, the assessment of legality of connection remains prone to errors and would typically report a lower incidence of illegal connections than actually present (Figure A3.2).

Capacity of Solar Panels

The solar panel should be measured with a small ruler or measuring tape or a ruler, if possible. If it is not possible to measure because the panel is mounted on the roof permanently, a visual assessment of the dimensions should be made to the nearest 5 cm on each dimension.

The assumption for the typical efficiency of solar panels used in small-scale household systems often used for Tier 1 access is based on the relationship shown in Figure A3.3, which shows how the area of panels as measured by the outside edges relates to laboratory-measured power. The line of best fit has a slope equal to 1/1000th of the efficiency percentile. In this case the best estimate for efficiency is therefore 8%.

Performance of Solar Lanterns/Home Systems

There are two possibilities in assessing the performance of solar lanterns or solar home systems, depending on whether the product observed in the household can be matched with a known brand and model.

1. **Successfully identified products**

First, the solution observed in the household needs to be identified and matched with a known brand and model. To successfully identify a solutions, the following three criteria need to be satisfied.

i. The solar panel dimensions are within 20% of the expected dimensions.

FIGURE A3.2

Decision Tree for Legality of Connection

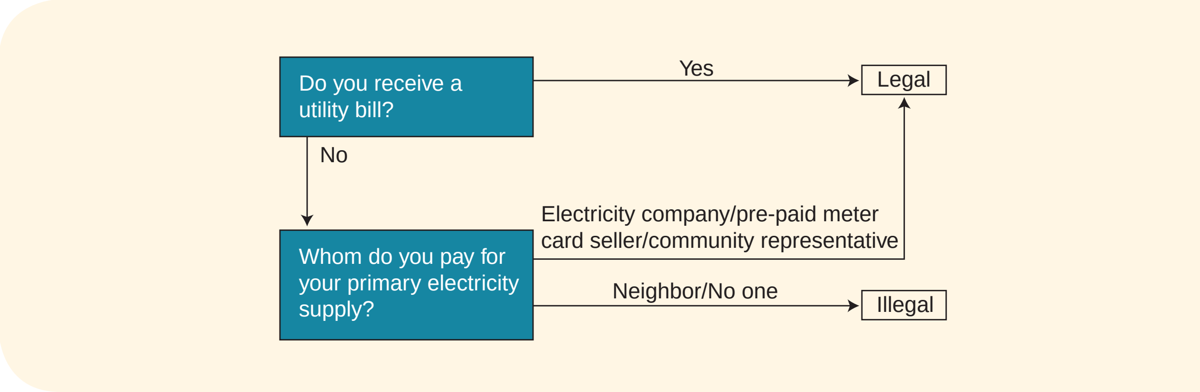
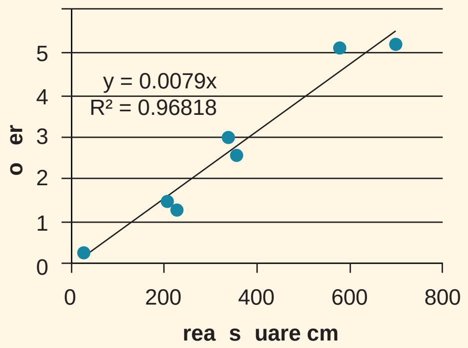


FIGURE A3.3

Power Rating versus Surface Area of Solar Panels



ii. The number of light sources connected to the system is less than or equal to the maximum number that is possible to be attached. For many larger systems the maximum is essentially unlimited, but for smaller pico-solar systems there are often constraints on the number of ports.

iii. The type of lights matches the expected type (if applicable).

If the product is successfully identified, the known performance of the corresponding brand and model can be used to estimate the household tier level (up to 1).

2. Misidentified or unidentified products.

If the product cannot be successfully identified and matched to a known brand and model, the following formulas may be used to estimate the lighting and phone-charging capabilities.

First, the energy available for use is estimated through the formula:

$$E = 1000 \times A_{pv} \times G_{std} \times n_{pv} \times n_{sys}$$

where:

E = Typical daily energy available (Wh)

A_{pv} = Area of solar panel (m^2)

G_{std} = Solar resource (kWh/m^2/day) [assume 5 if no better local estimate]

n_{pv} = Solar panel efficiency (fraction) [assume 8%]

n_{sys} = Other system level-efficiency (fraction) [assume 60%]

Second, the maximum energy available for the lighting service is estimated through the formula:

$$L_{max} = E \times \theta$$

where:

L_{max} = maximum daily lighting service (lumen-hours)

E = Typical daily energy available (Wh), from the previous formula

θ = Lumen efficacy of light source (lumens/watt); based on year of purchase and technology type (to be periodically updated):

Light-emitting diode (LED) (pre-2010) = 60 lm/W

LED (2010–2012) = 80 lm/W

LED (2012–2014) = 90 lm/W

LED (2014+) = 100 lm/W

Compact fluorescent lamp (CFL) (any) = 50 lm/W

Incandescent (any) = 10 lm/W

Finally, the last step is to determine if mobile charging is possible based on the presence of auxiliary ports and whether people report being able to recharge mobile phones using the system. The maximum lighting service and maximum mobile charging levels are used to estimate the number of people served, assuming that a fraction of each is available for use and the fractions must add to 1. For example, 75% of the maximum lighting service can be accounted for if 25% of the maximum mobile charging service is used, and so forth. The household tier is the number of people served based on the estimate divided by the household size (up to 1).

APPROACHES FOR ASSESSING THE EMISSION PERFORMANCE OF COOKING SOLUTIONS DURING SURVEYS

This note suggests an approach for rough and conservative assessment of mapping of cooking solutions to IWA tiers for household air pollution. The likely household air pollution of the cooking solution needs to be assessed during household surveys based on the characteristics of the cookstove.

The assessment involves two aspects: (a) fuel and (b) cookstove technology.

1. Emission performance assessment based only on fuel used.

During household energy surveys, fuels used for each of the cooking solutions need to be identified. An assessment of the emission performance of the cooking solution can be undertaken as follows:

- Certain fuels have been identified in the WHO Guidelines on Indoor Air Quality as meeting the Emission Rate Target regardless of the cookstove design. These include electricity and solar energy.
- Certain fuels have been identified in the WHO Guidelines on Indoor Air Quality as meeting the Interim Emission Rate Target regardless of the cookstove design. These include biogas, LPG,

ethanol, and natural gas—together called BLEN fuels. Together with electricity and solar energy, these fuels are called BLEENS.

- Certain fuels have been identified in the WHO Guidelines on Indoor Air Quality as being injurious to health due to heavy emission of pollutants other than particulate matter ($PM_{2.5}$) and carbon monoxide (CO). These include kerosene and coal. These cooking solutions need to be assessed for other relevant emissions/pollutants apart from $PM_{2.5}$ and CO based on the quality of the fuel used in the national or sub-national geography (for example, the presence of arsenic, mercury, and selenium in coal varies across countries), as well as the cookstove being used (for example, kerosene may emit harmful cyclical pollutants with certain types of cookstoves). Apart from an evaluation of $PM_{2.5}$ and CO performance, such an assessment of coal and kerosene will need to be consistent with any guidelines for other pollutants provided by WHO.
- The emissions performance of other solid fuels, such as wood, biomass, charcoal, and so forth, is cookstove dependent. Cooking solutions that are used with these fuels need to be examined further based on the types of cookstove used.
- Emission performance assessment based on fuel used as well as cookstove design.

2. Emission performance of non-BLEENS cooking solutions can to be assessed during household energy surveys as follows:

- **Actual field measurement of household air pollution (and/or other technical parameters):** Actual performance of the cooking solution with respect to household air pollution can be measured either under standard conditions or under normal cooking practices of the household by setting up appropriate instrumentation and conducting direct measurement over a few days. Such measurement can be an intensive exercise, which may not be replicable across hundreds of households participating in the energy survey.
- **Assessment based on certification and labeling:** This can be done in cases where the cookstove model has been tested in the laboratory (or in the field) and the product carries a visual label that indicates likely performance under standard conditions. Such labeling could be similar to a star rating program.
- **Assessment based on brand or program marking:** This can be done where a prototype (or a sample) of the model has been tested in the laboratory (or in the field), but has not been certified for performance on a mass-production scale, or labeled to indicate the likely performance of the individual product. In this case, the model can be identified in the field based on the brand/model name or program marking, and performance under standard conditions can be inferred based on laboratory/field test report of the prototype or the sample.
- **Assessment based on shape, model type, fuel used, and manufacturing technology:** In most cases at present, the cooking solution model may not have been tested under standard conditions, and the necessary instrumentation for actual field testing also may not feasible due to logistical or funding constraints. Under such circumstances, the only feasible approach for assessing the likely indoor air quality (IAQ) performance is to estimate it based on the visible characteristics such as shape, model type, fuel used, and manufacturing technology of the cookstove.

ANNEX 4 | ENERGY APPLICATIONS FOR PRODUCTIVE AND COMMUNITY USES

TABLE A4.1

Energy Applications and Sub-Applications

APPLICATION CATEGORY	DESCRIPTION	SUB-APPLICATIONS
1. Lighting	Use of energy to light working spaces to enable workers to undertake tasks and for the comfort of customers (particularly in retail and hospitality)	Task lighting General lighting Security lighting
2. Information and Communication Technology (ICT)	Use of energy for computing, electronics, and other communication and audiovisual purposes	Mobile telephony Media (radio, television, sound systems) Computing Internet Photography Photocopying Printing
3. Motive Power	Mechanical uses of energy in which motion (either linear or rotational) is imparted to machinery. It is acknowledged that absorption cooling does not involve motive power. However, cooling as a whole will be analyzed as a motive-power application for simplicity reasons.	Ploughing Harrowing Planting Irrigation Hoeing/weeding Harvesting, logging/felling Digging Lifting Grinding Milling Hulling Sawing Planning Drilling Turning Pumping Throwing (pots) Sewing Cutting Spinning Weaving Cooling Refrigeration Freezing Mechanical printing

APPLICATION CATEGORY	DESCRIPTION	SUB-APPLICATIONS
4. Space Heating	Use of energy to heat interior working spaces for the welfare and comfort of workers and customers	Local space heating Central space heating
5. Product Heating	Uses of energy for heating as a direct part of the production process	Heating Cooking Baking Firing Drying Water boiling Steam production Distilling Brewing Curing Smoking Forging Smelting Annealing Welding Soldering Ironing Incubating Pasteurizing Dissolving substances Sterilizing


Mafte
Energize your day
Top-of-the-world Goodness!
1/-
Yetu
TO
AMBA
Top-of-the-w Goodness!

REFERENCES

Abraham, R. 2007. "Mobile Phones and Economic Development: Evidence from the Fishing Industry in India." *Information Technologies and International Development* 4: 5–17.

Adair-Rohani, H., et al. 2013. "Limited Electricity Access in Health Facilities of Sub-Saharan Africa: A Systematic Review of Data on Electricity Access, Sources, and Reliability." *Global Health: Science and Practice* 1(2): 249–261.

ADB (Asian Development Bank). 2005. *Assessing the Impact of Transport and Energy Infrastructure on Poverty Reduction.* Manila: ADB.

Afrane-Okese, Y. 2001. "Socio-economic Assessment of the Energy Burden on Low-Income Households in Urban Botswana." Paper presented at the "Domestic Use of Energy Conference," Cape Town, Cape Technicon, April 10–12.

AGECC (Advisory Group on Energy and Climate Change). 2010. *Energy for a Sustainable Future.* The Secretary General's Advisory Group on Energy and Climate Change, Summary Report and Recommendations. New York: United Nations.

Aker, J. C., and I. M. Mbiti. 2010. "Mobile Phones and Economic Development in Africa." *Journal of Economic Perspectives* 24: 207–232.

Alstone, P., A. Jacobson, and E. Mills. 2010. *Illumination Sufficiency Survey Techniques: In-situ Measurements of Lighting System Performance and a User Preference Survey for Illuminance in an Off-Grid, African Setting.* Berkeley, CA: Lawrence Berkeley National Laboratory Lumina Project.

Alstone, P., C. Niethammer, B. Mendonça, and A. Eftimie. 2011. "Expanding Women's Role in Africa's Modern Off-Grid Lighting Market." Lighting Africa Project International Finance Corporation (IFC) Washington DC.

Alstone, P., D. Gershenson, and D. M. Kammen. 2014a. "Decentralized Energy Systems for the Poor Dramatically Advance Electricity Access and Promote Climate Stabilization." *National Climate Change* [in review].

Alstone, P., K. Radecsky, A. Jacobson, and E. Mills. 2014b. "Field Study Methods and Results from a Market Trial of LED Lighting for Night Market Vendors in Rural Kenya." *Light & Engineering* 22(2): 23–37 (2014). http://evanmills.lbl.gov/pubs/pdf/2014_AlstoneEtAl_Field-Study-Methods-LED.pdf.

Alstone, P., J. Tracy, K. Gauna, A. Jacobson, and E. Mills. 2014c. Setting Household Off-grid Illumination Targets. *Lighting Global*. Washington DC: World Bank.

Andersen T. B., and C-J. Dalgaard. 2013. "Power Outages and Economic Growth in Africa." *Energy Economics* 38: 19–23.

Andreatta, D., and A. Wohlgemuth. 2010. "An Investigation of Skirts." Presentation at ETHOS conference, January 29–31, Kirkland, Washington.

Apple, J., et al. 2010. "Characterization of Particulate Matter Size Distributions and Indoor Concentrations from Kerosene and Diesel Lamps." *Indoor Air* 20: 399–411.

Arnold, J., E. Michael, G. Köhlin, and R. Persson. 2006. "Woodfuels, Livelihoods, and Policy Interventions: Changing Perspectives." *World Development* 34(3): 596–611.

Azevedo, I. L., M. G. Morgan, and F. Morgan. 2009. "The Transition to Solid-State Lighting." *Proceedings of the IEEE* 97: 481–510.

Bacon R., S. Bhattacharya, and M. Kojima. 2010. *Expenditure of Low-Income Households on Energy. Evidence from Africa and Asia.* Extractive Industries for Development Series #16, June. Washington, DC: World Bank. http://siteresources.worldbank.org/EXTOGMC/Resources/336929-1266963339030/eifd16_expenditure.pdf.

Badkar, M. 2012. "Why India Has These Massive Power Blackout Problems." *Business Insider,* July 31. http://www.businessinsider.com/indias-power-outages-2012-7.

Baker, M., and P. Alstone. 2011. "The Off-Grid Lighting Market in Sub-Saharan Africa: Market Research Synthesis Report, IFC, and the World Bank." http://www.lightingafrica.org/component/docman/doc_download/128-market-research-synthesis-.

Baldwin, S. 1986. *Biomass Stoves: Engineering Design, Development, and Dissemination*. VITA and PU/CEES Report No. 224. Arlington, VA, and Princeton, NJ.

Banerjee S., Q. Wodon, A. Diallo, T. Pushak, H. Uddin, C. Tsimpo, and V. Foster. 2008. *Africa Infrastructure Country Diagnostic. Access, Affordability, and Alternatives: Modern Infrastructure Services in Africa.* Washington, DC: World Bank. http://mpra.ub.uni-muenchen.de/27740/1/MPRA_paper_27740.pdf.

Banerjee, S., A. Singh, and H. Samad. 2011. *Power and People: The Benefits of Renewable Energy in Nepal.* Washington, DC: World Bank.

Banerjee, S., M. Bhatia, G. Elizondo Azuela, I. Jaques, A. Sarkar, E. Portale, I. Bushueva, N. Angelou, and J. Gustavo Inon. 2013. *Global Tracking Framework* (vol. 3). Working Paper 77889. Washington, DC: World Bank. http://documents.worldbank.org/curated/en/2013/05/17765643/global-tracking-framework-vol-3-3-main-report.

Barnes, D. 1988. *Electric Power for Rural Growth: How Electricity Affects Rural Life in Developing Countries.* Boulder, CO: Westview.

Barnes, D. F., S. R. Khandker, and H. A. Samad. 2011. "Energy Poverty in Rural Bangladesh." *Energy Policy* 39: 894–904.

Barnes, D., and W. Floor. 1996. Rural Energy in Developing Countries: A Challenge for Economic Development. *Annual Review of Energy and the Environment* 21: 497–530.

Berkeley Air Monitoring Group. 2012. "Stove Performance Inventory Report." Prepared for the Global Alliance for Clean Cookstoves United Nations Foundation, October.

Beyer, F. R., and K. Ker. 2009. "Street Lighting for Preventing Road Traffic Injuries. Cochrane Database of Systematic Reviews." doi: 10.1002/14651858.CD004728.pub2.

Bhatia, B., and M. Gulati. 2004. "Reforming the Power Sector. Controlling Electricity Theft and Improving Revenue. Public Policy for the Private Sector." Note No. 272, September, Private Sector Development Vice Presidency. Washington, DC: World Bank.

Bigg, T., and D. Satterthwaite. 2005. *How to Make Poverty History: The Central Role of Local Organizations in Meeting the MDGs.* London: International Institute for Environment and Development.

Blackden, M., and Q. Wodon. 2006. *Gender, Time Use, and Poverty in Sub-Saharan Africa.* Discussion Paper No. 73. Washington, DC: World Bank.

Blumenthal, R. 2009. "A Retrospective Descriptive Study of Electrocution Deaths in Gauteng, South Africa: 2001–2004." *Burns* 35(6): 888–894.

Bond, T. C. 2009. "What Is Black Carbon and Where Does It Come From?" Presentation at ICCT Workshop on Black Carbon, Mexico City, Mexico, October 19.

Brouwer, R., and M. P. Falcao. 2004. "Wood Fuel Consumption in Maputo, Mozambique." *Biomass and Bioenergy* 27: 233–245.

Bruce, N. G., R. Perez-Padilla, and R. Albalak. 2000. "Indoor Air Pollution in Developing Countries: A Major Environmental and Public Health Challenge." *Bulletin of the World Health Organization* 78: 1078–1092.

Burrell, J., and J. Matovu. 2008. *Livelihoods and the Mobile Phone in Rural Uganda.* The Grameen Foundation. http://www.grameenfoundation.applab.org/uploads/burrell_needs_assessment_final-1.pdf.

Cabraal, A. R., D. F. Barnes, and S. G. Agarwal. 2005. “Productive Uses of Energy for Rural Development. *Annual Review of Environment and Resources* 30, 117–144.

Calderon, C. 2009. “Infrastructure and Growth in Africa.” Policy Research Working Paper No. 4914, Africa Region, African Sustainable Development Front Office, World Bank, Washington, DC.

Campbell, B. M., S. J. Vermeulen, J. J. Mangono, and R. Mabugu. 2003. The Energy Transition in Action: Urban Domestic Fuel Choices in a Changing Zimbabwe. *Energy Policy* 31: 553–562.

Cecelski, E. 2004. “Re-thinking Gender and Energy: Old and New Directions.” ENERGIA/EASE Discussion Paper, Energy, Environment and Development (EED), World Bank, Washington, DC.

Chakravorty, U., M. Pelli, and B. U. Marchand. 2014. “Does the Quality of Electricity Matter? Evidence from Rural India.” *Journal of Economic Behavior & Organization 107A:* 228–247.

Chidumayo, E. N., and D. J. Gumbo. 2013. “The Environmental Impacts of Charcoal Production in Tropical Ecosystems of the World: A Synthesis.” *Energy for Sustainable Development* 17(2): 86–94.

Clancy, J. S., M. Skutsch, and S. Bachelor. 2003. “The Gender-Energy-Poverty Nexus: Finding the Energy to Address Gender Concerns in Development.” DFID Project CNTR998521. London, UK: Department for International Development.

Collings, S. 2011. *Phone Charging Micro-Businesses in Tanzania and Uganda.* London, UK: GVEP International. http://www.gvepinternational.org/sites/default/files/phone_charging_businesses_report_with_gsma_final_for_web_0.pdf.

Córdoba-Aguilar, H. 1992. “Firewood Use and the Effect on the Ecosystem—A Case Study of the Sierra of Piura, Northwestern Peru.” *GeoJournal* 26 (3), 297–309.

Dalberg Global Development Advisors. 2013. “Lighting Africa Market Trends Report 2012.” *Lighting Africa.* http://www.lightingafrica.org/resources/market-research/market-trends-.html.

Davis M. 1998. Rural Household Energy Consumption: The Effects of Access to Electricity: Evidence from South Africa. *Energy Policy* 26: 207–217.

Dehejia, V. 2012. “The Cookstove Conundrum.” *New York Times.* http://india.blogs.nytimes.com/2012/04/23/the-cookstove-conundrum/?goback=%2Egde_72869_member_117853732.

Deininger, K., S. Jin et al. 2007. Sri Lanka’s Rural Non-Farm Economy: Removing Constraints to Pro-Poor Growth.” *World Development* 35 (12), 2056–2078.

Desai, S., R. Vanneman, and National Council of Applied Economic Research, New Delhi. 2008. “India Human Development Survey (IHDS), 2005: Version 8.” http://www.icpsr.umich.edu/DSDR/studies/22626/version/8.

DFID (Department for International Development). 2011. *Renewable Energy: Solar Lighting—The Madhya Pradesh Rural Livelihoods Project—An Ally in Eliminating Poverty in India.* London, UK.

Dherani, M., D. Pope, M. Mascarenhas, K. R. Smith, M. Weber, and N. Bruce. 2008. “Indoor Air Pollution from Unprocessed Solid Fuel Use and Pneumonia Risk in Children Aged Under Five Years: A Systematic Review and Meta-Analysis.” *Bulletin of the World Health Organization* 86 (5): 390–398.

Dinkelman, T. (2011). “The Effects of Rural Electrification on Employment: New Evidence from South Africa.” *American Economic Review* 101(7): 3078–3108.

Donner, J. 2006. “The Social and Economic Implications of Mobile Telephony in Rwanda: An Ownership/Access Typology.” *Knowledge, Technology, and Policy* 19: 17–28.

Donner, J., and C. A. Tellez. 2008. Mobile Banking and Economic Development: Linking Adoption, Impact, and Use.” *Asian Journal of Communication* 18: 318–332.

Duflo, E., M. Greenstone, and R. Hanna. 2008. “Indoor Air Pollution, Health and Economic Well-Being.” *S.A.P.I.EN.S* 1(1). http://sapiens.revues.org/130.

Eberhard, A., V. Foster, C. Briceño-Garmendia, F. Ouedraogo, D. Camos, and M. Shkaratan. 2008. "Underpowered: The State of the Power Sector in Sub-Saharan Africa." AICD Background Paper 6. Washington, DC: World Bank.

EC (European Commission). 2006. *The Role of Energy Services in the Health, Education and Water Sectors and Cross-Sectoral Linkages.* Brussels: ENABLE Project.

Edwards R., K. R. Smith, J. Zhang, and Y. Ma. 2004. "Implications of Changes in Household Stoves and Fuel Use in China." *Energy Policy* 32: 395–411.

EHP (Environmental Health Perspectives). 2014. http://ehp.niehs.nih.gov/wp-content/uploads/122/4/ehp.1307049.pdf.

Ekouevi, K., and V. Tuntivate. 2012. *Household Energy Access for Cooking and Heating: Lessons Learned and the Way Forward.* World Bank Studies. Washington, DC: World Bank.

Ekouevi, K., K. Kennedy Freeman, and R. Soni. 2014. Understanding the Differences between Cookstoves. *Live Wire* 2014/7, 88058. Washington, DC: World Bank.

Ektvedt, T. M. 2011. "Firewood Consumption amongst Poor Inhabitants in a Semi-Arid Tropical Forest: A Case Study from Piura, Northern Peru." *Norwegian Journal of Geography* 65: 28–41.

Elias, R. J., and D. G. Victor. 2005. Energy Transitions in Developing Countries: A Review of Concepts and Literature. Working Paper No. 40, Program on Energy and Sustainable Development. Stanford University, USA. http://iis-db.stanford.edu/pubs/20910/energy_transitions.pdf.

EnDev (Energising Development Progam). 2011. *EnDev's Understanding of Access to Modern Energy Services.* Eschborn, Germany: GIZ and NL Agency.

Enterprise Surveys. 2014. *Infrastructure Data.* Washington, DC: World Bank. http://www.enterprisesurveys.org.

ESMAP (Energy Sector Management Assistance Program). 1999. *Household Energy Strategies for Urban India: The Case of Hyderabad.* Washington, DC: UNDP/World Bank Energy Sector Management Assistance Programme.

———. 2002. *Rural Electrification and Development in the Philippines: Measuring the Social and Economic Benefits.* Report 255/02, Washington, DC: ESMAP/World Bank.

———. 2004. *The Impact of Energy on Women's Lives in Rural India.* Washington, DC: ESMAP/World Bank.

———. 2008. *Maximizing the Productive Uses of Electricity to Increase the Impact of Rural Electrification Programs.* Washington, DC: ESMAP/World Bank.

———. 2011. *Energy Access and Productive Uses for the Urban Poor: Final Report on Ghana Scoping Study.* Washington, DC: ESMAP/World Bank.

Estache, A., B. Speciale, and D. Veredas. 2005 (Unpublished). *How Much Does Infrastructure Matter to Growth in Sub-Saharan Africa?* Washington DC: World Bank.

EUEI (European Union Energy Initiative). 2014. *Productive Use of Thermal Energy. An Overview of Technology Options and Approaches for Promotion.* https://energypedia.info/images/2/24/Productive_Use_of_Thermal_Energy_Overview.pdf.

EUEI. 2011. *Productive Use of Energy—PRODUSE: A Manual for Electrification Practitioners.* Germany: European Union Energy Initiative.

Fankhauser, S., and S. Tepic. 2005. *Can Poor Consumers Pay for Energy and Water? An Affordability Analysis for Transition Countries.* London: European Bank for Reconstruction and Development.

Finucane, J., and C. Purcell. 2010. *Photovoltaics for community service facilities: guidance for sustainability.* Washington, DC: ESMAP/World Bank. http://documents.worldbank.org/curated/en/2010/01/14582258/photovoltaics-community-service-facilities-guidance-sustainability.

Foster, V., and C. Briceno-Garmendia. 2010. *Africa's Infrastructure: A Time for Transformation.* Washington, DC: International Bank for Reconstruction and Development (IBRD) and World Bank.

Foster, V., and J-P. Tre. 2000. *Measuring the Impact of Energy Interventions on the Poor—An Illustration from Guatemala.* London: Infrastructure for Development. http://siteresources.worldbank.org/ INTPSIA/ Resources/490023 1120845825946/guatemala_impact_of_energy_reform.pdf.

Fouquet, R., and P. J. G. Pearson. 2006. "Seven Centuries of Energy Services: The Price and Use of Light in the United Kingdom (1300–2000)." *Energy Journal* 27: 139–177.

FRES (Foundation Rural Energy Services). 2013. "Socio-economic Impact Assessment of Rural Electrification." Price Waterhouse Cooper (July). http://www.fres.nl/wp-content/uploads/2014/12/01072013_PwC_Socioecomonic_study_EN_F.pdf.

Gibson, J., and S. Olivia. 2010. "The Effect of Infrastructure Access and Quality on Non- Farm Enterprises in Rural Indonesia." *World Development* 38 (5): 717–726.

Goedhuys, M., and L. Sleuwaegen. 2010. "High-Growth Entrepreneurial Firms in Africa: A Quantile Regression Approach." *Small Business Economics* 34: 31–51.

Goldstein, J., and J. Rotich. 2008. "Digitally Networked Technology in Kenya's 2007–2008 Post-Election Crisis." Berkman Center Research Publications. http://unpan1.un.org/intradoc/groups/public/documents/un-dpadm/unpan042523.pdf.

Grogan, L. 2008. "Community Electrification and Labour Market Development." Working Paper, Department of Economics, University of Guelph. Ontario, Canada.

Grogan, L., and A. Sadanand, A. 2012. "Rural Electrification and Employment in Poor Countries: Evidence from Nicaragua." *World Development* 43: 252–265.

GSMA (Groupe Speciale Mobile Association). 2011. *Green Power for Mobile: Charging Choices 2011.* Mobile Phone Charging in the Developing World. London, UK: GSM Association. http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2012/04/greenpowerformobilechargingchoices2011-1.pdf.

Gupta, B. D., R. A. Mehta, and M. M. Trangadia. 2012. "Profile of Deaths Due to Electrocution: A Retrospective Study." *Journal of Indian Academy of Forensic Medicine* 34 (1) 46–48.

Gustafsson, Ö., M. Kruså, Z. Zencak, R. J. Sheesley, L. Granat, E. Engström, P. S. Praveen, P. S. P. Rao, C. Leck, and H. Rodhe. 2009. "Brown Clouds over South Asia: Biomass or Fossil Fuel Combustion?" *Science* 323(5913): 495–498.

Gwavuya, S. G., S. Abele, I. Barfuss, M. Zeller, and J. Müller. 2012. "Household Energy Economics in Rural Ethiopia: A Cost-Benefit Analysis of Biogas Energy." *Renewable Energy* 48: 202–209.

HEDON. 2011. "E-Consultation: Defining Energy Access." Background Paper 1. Practical Action and GIZ.

Heikkinen, M. V. J., J. K. Nurminen, T. Smura, and H. Hämmäinen. 2012. "Energy Efficiency of Mobile Handsets: Measuring User Attitudes and Behavior." *Telematics and Informatics* 29: 387–399.

Heltberg, R. 2004. "Fuel Switching: Evidence from Eight Developing Countries." *Energy Economics* 26 (5): 869–887.

Heltberg R. 2005. "Factors Determining Household Fuel Choice in Guatemala." *Environment and Development Economics* 10: 337–361.

Hosier, R. H., and J. Dowd. 1988. Household Fuel Choice in Zimbabwe: An Empirical Test of the Energy Ladder Hypothesis." *Resources Energy* 9: 337–361.

Hosier, R., and W. Kipondya. 1993. "Urban Household Energy Use in Tanzania: Prices, Substitutes and Poverty." *Energy Policy* 21: 453–473.

Hughes, N., and S. Lonie. 2007. "M-PESA: Mobile Money for the 'Unbanked.'" *Innovations* (Winter/Spring Vol 2). No 1-2: 63–81.

IAEA (International Atomic Energy Agency). 2005. Energy Indicators for Sustainable Development: Guidelines and Methodologies. Vienna: International Atomic Energy Agency.

IEA (International Energy Agency). 2010. Energy Poverty—How to Make Modern Energy Access Universal? Paris: IEA/OECD. http://www.se4all.org/wp-content/uploads/2013/09/Special_Excerpt_of_WEO_2010.pdf.

———. 2012. World Energy Outlook 2012. Paris: IEA. http://www.worldenergyoutlook.org/media/weowebsite/energydevelopment/2012updates/Measuringprogresstowardsenergyforall_WEO2012.pdf.

IEC (International Electrotechnical Commission). 2013. Technical Specifications (TS) 62257-9-5:2013. Recommendations for Small Renewable Energy and Hybrid Systems for Rural Electrification—Part 9-5: Integrated system—Selection of stand-alone lighting kits for rural electrification. https://webstore.iec.ch/publication/6662&preview=1

IEG (Independent Evaluation Group). 2009. "Reducing Technical and Non-Technical Losses in the Power Sector." Background Paper for the World Bank Group Energy Sector Strategy, July. World Bank: Washington, DC.

———. 2010. "Addressing the Electricity Access Gap." Background Paper for the World Bank Group Energy Sector Strategy, June. World Bank: Washington, DC.

Ilskog, E. 2011. "The Zanzibar Blackout—A Case Study on Consequences from an Electricity Power Crisis." *KTH Technology and Health.* http://www.diva-portal.org/smash/get/diva2:450394/FULLTEXT01.pdf.

IMF (International Monetary Fund). 2008. *Regional Economic Outlook: Sub-Saharan Africa*. Washington, DC: IMF.

International Telecommunications Union. 2014. "World Telecommunication/ICT Indicators Database." http://www.itu.int/en/ITU-D/Statistics/Pages/publications/wtid.aspx.

IPA Energy. 2003. "Can the Poor Pay for Power? The Affordability of Electricity in Southeast Europe." http://www.ebrd.com/country/sector/energyef/about/powersee.pdf.

Jack, W., and T. Suri. 2014. "Risk Sharing and Transactions Costs: Evidence from Kenya's Mobile Money Revolution." *American Economic Review* 104: 183–223.

Jacobson, A. 2007. "Connective Power: Solar Electrification and Social Change in Kenya." *World Development* 35: 144–162.

Jacobson, A., N. L. Lam, T. C. Bond, and N. Hultman. 2013. "Black Carbon and Kerosene Lighting: An Opportunity for Rapid Action on Climate Change and Clean Energy for Development." The Brookings Institution. http://www.brookings.edu/research/papers/2013/04/climate-change-clean-energy-development-hultman.

Jamil, F. 2013. "On the Electricity Shortage, Price and Electricity Theft Nexus." *Energy Policy* 54: 267–272.

Jensen, R. 2007. "The Digital Provide: Information (Technology), Market Performance, and Welfare in the South Indian Fisheries Sector." *Quarterly Journal of Economics* 122: 879–924.

Jimenez, A. C., and K. Olson. 1998. *Renewable Energy for Rural Health Facilities.* Colorado: National Renewable Energy Laboratory (NREL).

Johnson M., R. Edwards, L. Morawska, K. R. Smith, and M. Nicas. 2014. "WHO IAQ Guidelines: Household Fuel Combustion—Review 3: Model Linking Emissions and Air Quality." http://www.who.int/indoorair/guidelines/hhfc/Review_3.pdf

Johnson, N. 2012. "Proposed Safety Tiers for Cookstoves." *Partnership for Clean Indoor Air.* http://www.pciaonline.org/files/10-Performance-Measures-web.pdf

Jones, C. I. 2011. "Intermediate Goods and Weak Links in the Theory of Economic Development." *American Economic Journal: Macroeconomics* 3: 1–28.

Joon V., A. Chandra, and M. Bhattacharya. 2009. "Household Energy Consumption Pattern and Socio-Cultural Dimensions Associated with It: A Case Study of Rural Haryana, India." *Biomass and Bioenergy* 33 (11): 1509–1512.

Kakkar D., and F. Mustafa. 2013. Powerless (Katiyabaaz). http://www.powerless-film.com/.

Karekezi, S., and J. Kimani. 2002. "Status of Power Sector Reform in Africa: Impact on the Poor." *Energy Policy* 30, 923–945.

Kemmler, A. 2007. "Factors Influencing Household Access to Electricity in India." *Energy for Sustainable Development* 11 (4): 13–20.

Kendall, J., B. Maurer, P. Machoka, and C. Veniard. 2011. "An Emerging Platform: From Money Transfer System to Mobile Money Ecosystem." *Innovations* 6: 49–64.

Khandker, S. R., D. F. Barnes, and H. A. Samad. 2009. "Welfare Impacts of Rural Electrification. A Case Study from Bangladesh." Policy Research Working Paper 4859, Development Research Group Sustainable Rural and Urban Development Team. Washington, DC: World Bank.

Khandker, S., D. Barnes, and H. Samad. 2012a. "The Welfare Impacts of Rural Electrification in Bangladesh." *Energy Journal* 33 (1): 199–218.

Khandker, S., H. Samad, A. Rubaba, and D. Barnes. 2012b. Who Benefits Most from Rural Electrification? Evidence in India. Policy Research Working Paper No. WPS 6095. Washington, DC: World Bank.

Khandker, S., D. Barnes, and H. Samad. 2013. "Welfare Impacts of Rural Electrification: A Panel Data Analysis from Vietnam." *Economic Development and Cultural Change* 61 (3): 659–692.

Khanna, M., and N. D. Rao. 2009. "Supply and Demand of Electricity in the Developing World." *Annual Review of Resource Economics* 1 (1): 567–596.

Kopacz, M., D. Mauzerall, J. Wang, E. Leibensperger, D. Henze, and K. Singh. 2011. "Origin and Radiative Forcing of Black Carbon Transported to the Himalayas and Tibetan Plateau." *Atmospheric Chemistry and Physics* 11: 2837–2852.

Kshirsagar, M. P., and V. R. Kalamkar. 2014. "A Comprehensive Review on Biomass Cookstoves and a Systematic Approach for Modern Cookstove Design." *Renewable and Sustainable Energy Reviews* 30: 580–603.

Kumar S., A. K. Verma, and U. S. Singh. 2014. "Electrocution-Related Mortality in Northern India—A 5-Year Retrospective Study." *Egyptian Journal of Forensic Sciences* 4 (1):1–6.

Kumar, S., and G. Rauniyar. 2011. "Is Electrification Welfare Improving?: Non-Experimental Evidence from Rural Bhutan." PRA Paper No. 31482. http://mpra.ub.uni-muenchen.de/31482/.

Lam, N. L., et al. 2012. "Household Light Makes Global Heat: High Black Carbon Emissions from Kerosene Wick Lamps." *Environmental Science and Technology* 46: 13531–13538.

Leach, G. 1992. "The Energy Transition." *Energy Policy* 20: 116–123.

Leach, G., and R. Mearns. 1988. *Beyond the Woodfuel Crisis.* London: Earthscan.

Lighting Africa. 2008. *Quantitative Research.* https://www.lightingafrica.org/resources/market-research/quantitative-research/.

Lighting Global. 2015. Products. http://www.lightingglobal.org/products

Lim, S. S., et al. 2012. "A Comparative Risk Assessment of Burden of Disease and Injury Attributable to 67 Risk Factors and Risk Factor Clusters in 21 Regions, 1990−2010: A Systematic Analysis for the Global Burden of Disease Study 2010." *The Lancet* 380 (9859): 2224−2260. http://www.ncbi.nlm.nih.gov/pubmed/23245609.

Link, C. F., W. G. Axinn, and D. J. Ghimire. 2012. "Household Energy Consumption: Community Context and the Fuelwood Transition." *Social Science Research* 41 (3): 598−611.

Lipscomb, M., A. M. Mobarak, and T. Barnam. 2011. "Development Effects of Electrification: Evidence from the Geologic Placement of Hydropower Plants in Brazil." CEPR Discussion Paper No. DP8427.

Lipscomb, M., M. Mobarak, and T. Barham. 2013. “Development Effects of Electrification: Evidence from the Topographic Placement of Hydropower Plants in Brazil.” *American Economic Journal: Applied Economics* 5(2): 200–231.

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 for Rural Households.’’ *World Development* 28(12): 2083–2103.

Masera, O. R., R. Diaz, and V. Berrueta. 2005. “From Cookstoves to Cooking Systems: The Integrated Program on Sustainable Household Energy Use in Mexico.” *Energy for Sustainable Development* 9 (1): 25−36.

Mashreky, S. R., A. Rahmana, T. F. Khan, L. SvanstrÖm, and F. Rahmana. 2010. “Epidemiology of Childhood Electrocution in Bangladesh: Findings of National Injury Survey.” *Burns* 36 (7): 1092–1095.

McGranahan, G. 1991. “Fuelwood, Subsistence Foraging, and the Decline of Common Property.” *World Development* 19 (10): 1275–1287.

Menon S., J. Hansen, L. Nazarenko, and Y. Luo. 2002. “Climate Effects of Black Carbon. Aerosols in China and India.” *Sciencemag* 297 (September 27). http://pubs.giss.nasa.gov/docs/2002/2002_Menon_etal_2.pdf.

Mills, E. 2003. “Technical and Economic Performance Analysis of Kerosene Lamps and Alternative Approaches to Illumination in Developing Countries.” Lawrence Berkeley National Laboratory. http://evanmills.lbl.gov/pubs/pdf/offgrid-lighting.pdf.

Mills, E. 2012. *Health Impacts of Fuel Based Lighting.* Berkeley, CA: Lawrence Berkeley National Laboratory Lumina Project.

Mink, T., P. Alstone, J. Tracy, and A. Jacobson. 2010. “LED Flashlights in the Kenyan Market: Quality Problems Confirmed by Laboratory Testing.” Lighting Africa. http://lightingafrica.org/resources/technical-res.html.

Mkinga, M. 2014. “Consumers Up in Arms over Irregular Electricity Supply.” *The Citizen Reporter,* January 21. http://www.thecitizen.co.tz/News/Consumers-up-in-arms-over-electricity-/-/1840392/2154160/-/aw14ekz/-/index.html.

Modi, V. 2005. “Improving Electricity Services in Rural India.” CGSD Working Paper No. 30. New York: Center on Globalization and Sustainable Development.

Modi, V., S. McDade, D. Lallement, and L. Saghir. 2005. *Energy Services for the Millennium Development Goals*. New York: UNDP and World Bank.

Murphy, J. T. 2001. “Making the Energy Transition in Rural East Africa: Is Leapfrogging an Alternative?” *Technological Forecasting and Social Change* 68 (2): 173–193.

Musoke, M. G. N. 2002. *Maternal Health Care in Rural Uganda: Leveraging Traditional and Modern Knowledge Systems.* Washington, DC: World Bank.

Mwampamba, T. H. 2007. “Has the Woodfuel Crisis Returned? Urban Charcoal Consumption in Tanzania and Its Implications to Present and Future Forest Availability.” *Energy Policy* 35 (8): 4221–4234.

Niethammer, C., and P. Alstone. 2012. “Expanding Women’s Role in Africa’s Modern Off-Grid Lighting Market: Enhancing Profitability and Improving Lives.” *Gender and Development* 20: 145–157.

Nique, M., and F. Arab. 2013. *Sustainable Energy and Water Access through M2M Connectivity.* Berkeley, CA: GSM Association.

Nussbaumer, P., M. Bazilian, V. Modi and K. K. Yumkella. 2012. Measuring Energy Poverty: Focusing on What Matters. *Renewable and Sustainable Energy Reviews* 16 (2012) 231–243.

Ozturk I. 2010. “A Literature Survey on Energy-Growth Nexus.” *Energy Policy* 38: 340–349.

PAC (Practical Action Consulting). 2009. *Expanding Energy Access in Developing Countries. The Role of Mechanical Power.* Rugby, UK: Practical Action.

———. 2010. *Poor People’s Energy Outlook 2010.* Rugby, UK: Practical Action.

———. 2012. *Poor People's Energy Outlook 2012.* Rugby, UK: Practical Action.

———. 2013. *Poor People's Energy Outlook 2013.* Energy for Community Services. Rugby, UK: Practical Action.

Parikh, J. 2011. "Hardships and Health Impacts on Women Due to Traditional Cooking Fuels: A Case Study of Himachal Pradesh, India." *Energy Policy* 39 (12): 7587–7594.

Patinkin, J. 2013. "The Illegal, Dangerous, Unreliable Electrical System That Everyone Supports." Informal City Dialogues, Nairobi, June 3. http://nextcity.org/informalcity/entry/the-illegal-dangerous-unreliable-electrical-system-that-everyone-supports.

Payne, J. E. 2010. "A Survey of the Electricity Consumption-Growth Literature." *Applied Energy* 87 (3): 723–731.

PCIA (Partnership for Clean Indoor Air). 2012a. "Proceedings." http://www.pciaonline.org/proceedings.

———. 2012b. "ISO IWA Cookstoves." http://cleancookstoves.org/resources_files/iso-iwa-cookstoves.pdf.

———. 2012c. "International Workshop Agreement on Cookstoves Unanimously Approved." http://pciaonline.org/news/cookstoves-iwa-unanimously-approved.

Ramanathan, V., and G. Carmichael. 2008. "Global and Regional Climate Changes Due to Black Carbon." *Nature Geoscience* 1 (4): 221–227.

Rao, N. D. 2013. "Does (Better) Electricity Supply Increase Household Enterprise Income in India?" *Energy Policy* 57: 532–541.

Rehfuess, E., S. Mehta, and A. Pruss-Ustun. 2006. "Assessing Household Solid Fuel Use: Multiple Implications for the Millennium Development Goals." *Environmental Health Perspectives* 114 (3): 373–378.

Reijnders, L. 2006. "Conditions for the Sustainability of Biomass Based Fuel Use." *Energy Policy* 34 (7): 863–876.

REMMP (Renewable Energy Microfinance and Microenterprise Program). 2014. "Pay-As-You-Go Technologies in Consumer Energy Finance." REMMP/USAID/Arc Finance. http://www.arcfinance.org/pdfs/pubs/REMMP_Briefing_Note_PayGo.pdf.

REN21. 2007. *Renewables 2007 Global Status Report* Paris: REN21.

Roach, M., and C. Ward. 2011. *Harnessing the Full Potential of Mobile for Off-Grid Energy.* London, UK: GSMA/IFC. http://www.gsma.com/mobilefordevelopment/wp-content/uploads/2012/04/cpwhitepaper161211interactive2.pdf.

Sadeque, Z., D. Rysankova, R. Elahi, and R. Soni. 2014. *Scaling Up Access to Electricity: The Case of Bangladesh.* Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/18679.

Sagebiel J., and K. Rommel. 2014. "Preferences for Electricity Supply Attributes in Emerging Megacities—Policy Implications from a Discrete Choice Experiment of Private Households in Hyderabad, India." *Energy for Sustainable Development* 21: 89–99.

Samad, H., S. Khandker, M. Asaduzzaman, and M. Yunus. 2013. "The Benefits of Solar Home Systems: An Analysis from Bangladesh." Policy Research Working Paper 6724. Washington, DC: World Bank.

Santosh, H. M., M. M. Granger, and S. Eswaran. 2014. "When Does Unreliable Grid Supply Become Unacceptable Policy? Costs of Power Supply and Outages in Rural India." *Energy Policy* 68(C): 158–169.

Schmid, B., E. Thomas, J. Olivier, and J. R. Cochrane. 2008. The Contribution of Religious Entities to Health in Sub-Saharan Africa. Study Commissioned by Bill and Melinda Gates Foundation. Cape Town: African Religious Health Assets Programme. http://www.arhap.uct.ac.za/pub_Gates2008.php.

Schnitzer, D., D. S. Lounsbury, J. P. Carvallo, R. Deshmukh, J. Apt, and D. M. Kammen. 2014. Microgrids for Rural Electrification. Washington, DC: United Nations Foundation.

SE4All (Sustainable Energy for All). 2012. "About Us." http://www.se4all.org/about-us/.

Shyu C. W. 2013. "End-Users' Experiences with Electricity Supply from Stand-Alone Mini-Grid Solar PV Power Stations in Rural Areas of Western China." Energy for Sustainable Development 17 (4): 391–400.

Smith, K. 1987. “The Biofuel Transition.” *Pacific and Asian Journal of Energy* 1 (1): 13–32.

Smith, K. R., R. Uma, V. V. N. Kishore, J. Zhang, V. Joshi, and M. A. K. Khalil. 2000. “Greenhouse Implications of Household Stoves: An Analysis for India.” *Annual Review of Energy and the Environment* 25: 741–763.

Smith, K. R., S. Mehta, and M. Maeusezahl-Feuz. 2004. “Indoor Air Pollution from Household Use of Solid Fuels.” In *Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors,* ed. M. Ezzati, A. D. Lopez, A. Rodgers, and C. J. L. Murray, 1435–1493. Geneva: World Health Organization.

Smith, T. B. 2004. “Electricity Theft: Comparative Analysis.” *Energy Policy* 32: 2067–2076.

Soussan, J., P. O’Keefe, and B. Munslow. 1990. “Urban Fuelwood Challenges and Dilemmas.” *Energy Policy* 18: 572–582.

Srinivasan, J., and J. Burrell. 2013. “Revisiting the Fishers of Kerala, India.” Proceedings of the Sixth International Conference on Information and Communication Technologies and Development: Full Papers 1: 56–66. doi:10.1145/2516604.2516618.

Straub, S. 2008. “Infrastructure and Growth in Developing Countries: Recent Advances and Research Challenges.” Policy Research Working Paper 4460, Development Research Department. Washington, DC: World Bank.

Tanburn, J., and A. D. Singh. 2001. “ICTs and Enterprises in Developing Countries: Hype of Opportunity?” Seed Working Paper No.17, Series on Innovation and Sustainability in Business Support Services (FIT), InFocus Programme on Boosting Employment through Small Enterprise Development Job Creation and Enterprise Department. Geneva: International Labour Office.

The Alliance (Global Alliance for Clean Cookstoves). 2011. “Igniting Change: A Strategy for Universal Adoption of Clean Cookstoves and Fuels.” (November.) http://www.cleancookstoves.org/resources/fact-sheets/igniting-change.pdf.

———. 2013. “Clean Cooking Catalog.” http://catalog.cleancookstoves.org/#/stoves.

———. 2014. “The Alliance Mission and Goals.” http://www.cleancookstoves.org/the-alliance/.

Toman, M., and B. Jemelkova. 2002. “Energy and Economic Development: An Assessment of the State of Knowledge.” Discussion Paper Series DP 03-13. Washington, DC: Resources for the Future.

Tracy, J., and A. Jacobson. 2012. “The True Cost of Kerosene in Rural Africa.” Lighting Africa. http://www.lightingafrica.org/component/docman/doc_download/237-kerosene-pricing-lighting-africa-report.html.

Tsao, J., and P. Waide. 2010. “The World’s Appetite for Light: Empirical Data and Trends Spanning Three Centuries and Six Continents.” *Leukos* 6: 259–281.

UN (United Nations). 2010. *The Millennium Development Goals Report.* New York: United Nations.

UNDATA. 2014. “Energy Statistics Database.” http://data.un.org/Data.aspx?d=EDATA&f=cmID%3aEL%3btrID%3a1233.

UNDP (United Nations Development Programme). 2005. *Energizing the Millennium Development Goals: A Guide to Energy’s Role in Reducing Poverty.* New York: UNDP.

UNDP and WHO (United Nations Development Programme and World Health Organization). 2009. *The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa.* New York: UNDP and WHO.

UNEP (United Nations Environment Programme). 2012. “Philips Unveils Solar LED Street Lights in Nairobi as Part of UNEP Enlighten Project, Nairobi.” (July 5.) http://www.unep.org/Documents.Multilingual/Default.Print.asp?DocumentID=2691&ArticleID=9210.

UNEP and WMO (United Nations Environmental Programme and World Meteorological Organization). 2011. *Integrated Assessment of Black Carbon and Tropospheric Ozone: Summary for Decision Makers*. Nairobi: UNEP and WMO.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2005. *The Quality Imperative. Education for All. Global Monitoring Report*. Paris. http://unesdoc.unesco.org/images/0013/001373/137333e.pdf.

———. 2008. *A View Inside Primary Schools—A World Education Indicators (WEI) Cross-National Study.* Montreal: UNESCO Institute for Statistics.

———. 2011. “Sub-Saharan Africa: Measuring the Quality of School Conditions and Teaching Resources.” www.uis.unesco.org/Education/Pages/regional-datacollections.aspx.

USDOE (U.S. Department of Energy). 2013. “Solid State Lighting Research and Development: Multi-Year Program Plan.” Lighting Research and Development, Building Technologies Program, Office of Energy Efficiency. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2013_web.pdf.

Valer, L. R., A. Mocelin, R. Zilles, E. Moura, and A. C. S. Nascimento. 2014. “Assessment of Socioeconomic Impacts of Access to Electricity in Brazilian Amazon: Case Study in Two Communities in Mamirauá Reserve.” *Energy for Sustainable Development* 20: 58–65.

van der Kroon, Bianca, Roy Brouwer, and Pieter J. H. van Beukering. 2013. “The Energy Ladder: Theoretical Myth or Empirical Truth? Results from a Meta-Analysis.” *Renewable and Sustainable Energy Reviews* 20: 504–513.

Venkataraman, C., G. Habib, A. Eiguren-Fernandez, A. Miguel, and S. Friedlander. 2005. “Residential Biofuels in South Asia: Carbonaceous Aerosol Emissions and Climate Impacts.” *Science* 307 (5714): 1454–1456.

Wamukonya, N., and M. Davis. 2001. “Socio-economic Impacts of Rural Electrification in Namibia: Comparisons between Grid, Solar and Unelectrified Households.” *Energy for Sustainable Development* 5 (3): 5–13.

Wang, X., J. Franco, O. R. Masera, K. Troncoso, and M. X. Rivera. 2013. *What Have We Learned about Household Biomass Cooking in Central America?* ESMAP Report No. 76222. Washington, DC: ESMAP/World Bank.

WB (World Bank). 2002. *Rural Electrification and Development in the Philippines: Measuring the Social and Economic Benefits.* ESMAP Report No. 255/02. Washington DC: ESMAP/World Bank.

———. 2008. *The Welfare Impact of Rural Electrification: A Reassessment of the Costs and Benefits.* An IEG Impact Evaluation. Washington, DC: World Bank.

———. 2009. *Reducing Technical and Non-Technical Losses in the Power Sector. Background Paper for the World Bank Group Energy Sector Strategy.* Washington, DC: World Bank.

———. 2011a. *One Goal, Two Paths: Achieving Universal Access to Modern Energy in East Asia and the Pacific.* Washington, DC: World Bank.

———. 2011b. *Household Cookstoves, Environment, Health, and Climate Change: A New Look at the Old Problem.* Washington, DC: World Bank.

———. 2012. M*aximizing Mobile: Information and Communication Technologies for Development.* Washington, DC: World Bank.

White, R. 2002. “Experience, Strategies, and Project Development.” Workshop Synth. Rep., GEF-FAO Workshop on Productive Uses of Renewable Energy, UN Food and Agriculture Organization, June 18–20, Rome, Italy.

WHO (World Health Organization). 2002. *World Health Report 2002: Reducing Risks, Promoting Healthy Life.* Geneva: WHO.

———. 2003. *Monitoring Vaccine Wastage at Country Level. Guidelines for Programme Managers*. Vaccines and Biologicals. Geneva: WHO.

———. 2004. “Energy, Sustainable Development and Health.” Background Document, Fourth Ministerial Conference on Environment and Health, Budapest, Hungary, June 23–25.

———. 2005. Air Quality Guidelines. Global Update 2005. Particular Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide. Geneva: WHO. http://www.euro.who.int/__data/assets/pdf_file/0005/78638/E90038.pdf

———. 2006. F*uel for Life: Household Energy and Health.* Geneva: WHO.

———. 2007a. “Strengthening Health Systems to Improve Health Outcomes. WHO’s Framework for Action. Everybody’s Business.” http://www.who.int/healthsystems/strategy/everybodys_business.pdf.

———. 2007b. “Guidelines for Health and Safety Standards in Early Years Programmes in the Independent Schools.” http://www.sec.gov.qa/En/SECInstitutes/EducationInstitute/Offices/Documents/EY_Health_and_Safety_E.pdf.

———. 2010. WHO Guidelines for Indoor Air Quality. Selected Pollutants. Geneva: WHO. http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf

———. 2012a. “Maternal Mortality.” Media Centre, Fact Sheet 348, updated May 2014. http://www.who.int/mediacentre/factsheets/fs348/en/index.html.

———. 2012b. “World Health Statistics.” http://www.who.ihnt/gho/publications/world_health_statistics/EN_WHS2012_Full.pdf.

———. 2014a. “Household Air Pollution and Health.” Fact Sheet 292, Media Centre (updated March 2014). http://www.who.int/mediacentre/factsheets/fs292/en/.

———.2014b. WHO Guidelines for Indoor Air Quality. Household Fuel Combustion. Geneva: WHO. http://apps.who.int/iris/bitstream/10665/141496/1/9789241548885_eng.pdf?ua=1

WHO (World Health Organization) and World Bank. 2014. *Access to Modern Energy Services for Health Facilities in Resource-Constrained Settings. A Review of Status, Significance, Challenges and Measurement.* Geneva: WHO. http://apps.who.int/iris/bitstream/10665/156847/1/9789241507646_eng.pdf.

Wijayatunga, P. D. C., and M. S. Jayalath. 2008. “Economic Impact of Electricity Supply Interruptions on the Industrial Sector of Bangladesh.” *Energy for Sustainable Development* 12 (3): 5–12.

Winkler, H., A. F. Simoes, E. Lebre La Rovere, M. Alam, A. Rahman, and S. Mwakasonda. 2011. “Access and Affordability of Electricity in Developing Countries.” *World Development* 39 (6): 1037–1050.

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