Engineering, Economics & Regulation for Energy Access in Developing Countries

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Electricity demand & access

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Today’s objectives - 1

1. Understand some key factors that drive the demand for electricity: WTP, ATP, quality of service & access
2. Understand how to include these factors in electrification planning
Today’s objectives - 2

Prepare to address these questions

• Do poor people really matter much about electricity access?
• Is electrification of poor rural areas “economically justified”?
The program for today

1. Understand WTP, ATP, access, reliability, CNSE
2. Review of the meaning of “access”
3. How to estimate WTP
4. How to use this knowledge in electrification planning
Do you think that you understand this curve?
What does the P-Q curve hide?

• The P-Q curve expresses the **willingness to pay (WTP)** or price that a user would pay for a certain amount Q of a good *marginally*
  – Examples?
What does the P-Q curve hide?

• The P-Q curve expresses the willingness to pay (WTP) or price that a user would pay for a certain amount Q of good *marginally*
  – Examples?

• The concept of *consumer surplus*
WTP marginal

PRICE at which the good is offered
CONSUMER SURPLUS

PRICE at which the good can be purchased

WTP marginal

QUANTITY
What does the P-Q curve hide?

• The P-Q curve expresses the willingness to pay (WTP) or price that a user would pay for a certain amount Q of good marginally
  – Examples?

• The concept of consumer surplus

• Thinking of electricity: People understand total better than marginal WTP
  – i.e. how much one would pay for the electricity consumed in one month, rather than how much per kW
WTP (willingness to pay for the quantity)
WTP (willingness to pay for the quantity)
What does the P-Q curve hide?

- The P-Q curve expresses the *willingness to pay* (WTP) or price that a user would pay for a certain amount Q of good *marginally*
- The concept of *consumer surplus*
- Thinking of electricity: People understand total better than *marginal WTP*
- An equivalent term to WTP is the *utility function*
Is WTP as simple a concept as it looks like?

- **Utilitarian WTP**
  - Its value depends on attributes that are directly associated with the instrumental and functional purposes of the commodity

- **Hedonic WTP**
  - Its value depends on the pleasure, happiness, or social stature that the commodity provides
We choose food...
... phone model & how to use it...
... or vehicle
Is “price” a simple concept?

- Price may be the result of a competitive offer of the commodity by diverse agents in an open market
  - Small & medium consumers typically see the same price regardless of the quantity purchased
  - There is also a supplier surplus
- Price may be established as a tariff by a regulatory authority
  - Tariffs may be above or below the actual cost of producing the commodity (non cost-reflective tariffs) & they may depend on the type of consumer &/or the amount purchased
Affordability

• Is affordability or “ability to pay” (ATP) an important factor in electricity supply?
  – For what kind of consumers is ATP important?
Affordability

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  – For what kind of consumers is ATP important?
• Commodities are more or less “affordable”, can we talk about the affordability of consumers?
Affordability

• Is affordability or “ability to pay” (ATP) an important factor in electricity supply?
  – For what kind of consumers is ATP important?

• Commodities are more or less “affordable”, can we talk about the affordability of consumers?
  – We do, but it is an ambiguous concept
  – Its value to purchase a specific good depends on competing uses of money
  – Affordability limits the value of the (real) willingness to pay (i.e. what the consumer wants to & can pay for a specific amount of commodity)
  – Direct monetary subsidies, discounts, financing schemes or tariffs below costs modify the affordability of consumers
WTP (willingness to pay for the quantity)

CONSUMER SURPLUS

AMOUNT TO PAY

AFFORDABILITY

QUANTITY
Although affordability is ideally measured at the household level, a preliminary sense of the affordability of electricity supply in any particular country can be obtained by examining the cost of purchasing the average residential electricity consumption for that country, normalized against the total monthly expenditures of the poorest 40% of the population. A widely used benchmark is that electricity is affordable when it accounts for no more than 5% of a household’s monthly expenditures in countries with tropical climates; this threshold typically increases to 10% of expenditure in temperate climates where electricity may also be used for heating purposes.

This metric allows for wide variation in access to affordable electricity in both access-deficit and fully electrified countries. In general, electricity is more affordable in fully electrified countries where incomes are typically higher. As a result, electricity expenditures of the bottom 40% in electrified countries amount on average to 4% of their budget, compared to 8% in access-deficit countries. Nevertheless, in 2015, some 30% of the population in universal access countries spent more than 5% of their monthly expenditure on electricity, indicating affordability challenges. These challenges are far greater in access-deficit countries where almost twice as high a share of the population (57%) spent more than 5%. The countries with the least affordable electricity are primarily in Eastern Europe, Latin America, and Sub-Saharan Africa.
Is “electricity” a simple commodity?

• Not really, there is much more than “quantity”, it is a commodity with multiple attributes that determine its value (WTP) for the consumer
Is “electricity” a simple commodity?

• Not really, there is much more than “quantity”, it is a commodity with **multiple attributes** that determine its value (WTP) for the consumer
  
  – The **delivery** (or electrification) **mode** (grid connection, mini-grid, solar home system, solar kit, solar lantern)
WTP (willingness to pay for the quantity)

- MINI-GRID
- GRID CONNECTION

SOLAR KIT 10W
SOLAR KIT 50W

QUANTITY
Is “electricity” a simple commodity?

• Not really, there is much more than “quantity”, it is a commodity with **multiple attributes** that determine its value (WTP) for the consumer
  
  – The **delivery** (or electrification) **mode** (*grid connection*, *mini-grid*, *solar home system*, *solar kit*, *solar lantern*)

  – A large number of other attributes that we encapsulate under the label of **“level of access”**
    
    o Note that the real WTP (limited by the ATP) may want more electricity supply than the existing access level allows
Is “electricity” a simple commodity?

- Not really, there is much more than “quantity”, it is a commodity with **multiple attributes** that determine its value (WTP) for the consumer
  - The **delivery** (or electrification) **mode** *(grid connection, mini-grid, solar home system, solar kit, solar lantern)*
  - A large number of other attributes that we encapsulate under the label of “**level of access**”
    - Note that the real WTP (limited by the ATP) may want more electricity supply than the existing access level allows
- Poor people must worry about how much electricity they can afford & how to get a satisfactory access level by what delivery mode, if given the option
How can WTP be determined?
How can WTP be determined?

- WTP depends on type of consumer, hour of day & day of week, use to be given to electricity, or special circumstances
- Factual existing evidence shows that WTP substantially depends on reliability of supply
  - But it is difficult to elicit this information from consumers (how much would you pay for 1 kWh at 9 pm of next Tuesday?)
- WTP can be more easily estimated by asking how much would someone pay to avoid being curtailed (under every circumstance of interest)
  - This is the Cost of Non-Served Energy (CNSE)
Two CNSEs rather than one

• **Once electrification** with a given electrification mode *has been decided or already exists*
  – CNSE-1 is the loss of welfare of existing customers when the electricity supply fails, which depends on the design of the electrification mode

• **But, when deciding** whether to apply limited funding to electrification or to other purpose
  – CNSE-2 is the loss of welfare of potential customers that permanently lack the services that electricity can provide for them with a given delivery mode (thus, CNSE-2 depends on CNSE-1)

• **Electrification planning** must use CNSE-1
• **Inter-sectorial planning** must use CNSE-2
Let’s focus now on electricity access
There are *(unsatisfactory?)* “official” definitions of electricity access

- The **World Bank’s Sustainable Energy for All Framework’s tiers** range from one watt of peak capacity for four hours a day at the bottom, to over 2,000 watts of capacity for over 22 hours per day at the top-most tier.

- The **International Energy Agency IEA** has defined initial electricity access as 250 kWh per year for rural households and 500 kWh for urban households, projecting that this base level increases to 800 kWh per person by 2030.
  - This initial access level equates to 50-100 kWh/year per person, about 200 times less of that consumed by the average American or Swede, or about 50 times less than the average Bulgarian (lowest in Europe).
Issues – 1 – How much access?

• **How much** access is “access”?  
  – Technology advances in the *efficiency of appliances* & the availability of efficient appliances render definitions based on kW & kWh useless  
  – Should access be a **minimum level of services** (*& not amount of consumption*) provided by electricity?  
  – Should the supply of electricity be such that it **does not limit the electricity services that a household could afford**?  
  – Should “access” include **community & productive uses**?
Issues – 2 – How reliable?

• Is unreliable access, “access”? What other attributes should be also considered to characterize access?
  – peak capacity
  – duration or availability (e.g. number of hours during day or night)
  – quality (e.g. voltage)
  – affordability
  – legality
  – safety
Microgrid generation samples dispatch and reliability

**DEMAND** per customer

**DISPATCH** sample day

**RELIABILITY** % per hour
Issues – 3 – Beyond electricity

- **Energy access** has a multidimensional dimension **irreducible to merely two services**.

- "**Energy access**" typically focuses on **electricity** services, and, to a lesser extent, **clean cooking**. However, **mobility** and **mechanical power** are also essential energy services.
For a thorough discussion about the meaning of energy access consult this reference.
Let’s try our own definition for electricity access…
I like this definition that is based on essential services…

• The minimum standard will depend on the specific region, among other factors. However, it has been proposed that a **minimum standard of living requires an electricity access that could provide:**
  – 300 lux of lighting during at least 4 night hours,
  – utilization of radio, TV, cell phone and computer,
  – and extension of the life of perishable food by 50% longer than at ambient temperature.
  – In addition, electricity supply must be affordable and have a minimum level of reliability (electricity is available when needed) and quality of service (voltage level stays within a prescribed range)

(Source: Julio Eisman, Acciona Microenergía)
… but I like this one best…

- Perfect electricity access should not limit the consumption that the consumers can afford (both in terms of utilization of the existing appliances or the ones that the consumer can afford to purchase, at household, community, commercial & industrial levels)
… but I like this one best…

• Perfect electricity access should not limit the consumption that the consumers can afford (both in terms of utilization of the existing appliances or the ones that the consumer can afford to purchase, at household, community, commercial & industrial levels)

• Public intervention may change the affordability by applying social tariffs up to certain amount of electricity. Then we are back to the problem of defining a minimum level of services.
... but I like this one best...

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• The same concept can be extended to cooking, heating, mobility and mechanical power
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• Public intervention may change the affordability by applying social tariffs up to certain amount of electricity. Then we are back to the problem of defining a minimum level of services.

• The same concept can be extended to cooking, heating, mobility and mechanical power
How to use the reliability of access in electrification planning?
Should a target of uniform quality of service for all customers, regardless whether they are located in an urban, semi-urban or rural area, be established?

• **YES**, in the long term at least, since everybody has the right to the same good level of service.

• **NO**, above a minimum service level, since the cost to achieve this goal is not justified.
What happens with other ”essential commodities”?

- Should the same level of **air quality** *(above a minimum level)* be required in urban & rural areas?

- Should the same level of access to **education** *(well-equipped schools, universities, libraries, cultural events, etc.)* be required anywhere?

- Idem for **emergency health care**, **security**, **transportation** infrastructure, etc.
Let’s examine reliability targets in rural & urban areas conceptually...
SUPPLY COST

[Graph showing two curves on a 2D axis with labels for x-axis: RELIABILITY and y-axis: SUPPLY COST. The curves intersect at a point labeled "same reliability line."
Requiring the same reliability implies very different supply costs per customer. Are these extra costs justified?
SUPPLY COST

NSE: NON SERVED ENERGY (kWh)
CNSE: COST OF NSE ($/kWh)

same CNSE line
Valuing each kWh of NSE the same for all customers results in different levels of reliability for different zones.
From a societal viewpoint, is it justified to incur in very high costs to improve welfare of rural customers just a little? Is there a better use for these funds?
Implications on planning -1

• “Minimum cost planning” must find the optimal trade-off between the cost of the provision of supply & the loss of welfare caused by the failure of supply to meet the demand

• CNSE must capture
  – the different utility value of electricity for different customers, uses, & moments in time
  – the actual or perceived limitations imposed or advantages associated to the several delivery modes that can be adopted
Implications on planning -2

• Diverse reliability levels “happen” as a consequence of minimum cost electrification planning
  – unless prescribed by the planner from the outset
• CNSE is a critical input to the optimization planning process
  – CNSE must reflect the loss of utility caused by electrical supply failures & the actual or perceived limitations of the delivery modes
What is done elsewhere?
The practice in countries with 100% electricity access

- Planning practices are different in areas with different demand densities *(underground vs overhead, three vs single phase, circuit redundancy, level of automation)* resulting in different *(high, in any case)* reliability levels

- However, economic incentives for average quality of service performance not always distinguish among areas
  - e.g. Germany, Italy, Portugal, Spain, Slovenia, or Sweden use different reliability targets for urban, rural & semi-urban areas
  - e.g. Finland, France, Ireland, or The Netherlands do not make any difference

And how about access-deficit countries?

- Reliability levels are much worse in general.
- Off-grid solutions are a real alternative, resulting in a multiplicity of access levels, qualities of service & customer perceptions.
- Budget constraints force the adoption of second best solutions (cheaper but meeting minimum requirements) and to establish time priorities in the provision of access.
Average number of disruptions and duration in access deficit countries 2015

Source: IFC, Doing Business report, Getting Electricity, 2016
Note: Analysis includes 66 out of 98 access-deficit countries.
Reliability of the main grid has a profound planning impact
Uganda – Southern territories
Forced 100% Grid Extension

Results obtained with the REM planning model
http://universalaccess.mit.edu/#/main
Uganda – Southern territories
100% Grid Reliability

Results obtained with the REM planning model
http://universalaccess.mit.edu/#/main
Uganda – Southern territories
85% Grid Reliability

Results obtained with the REM planning model
http://universalaccess.mit.edu/#/main

- Red: Extension 11kV
- Blue: Extension 400V
- Orange: Microgrid 11kV
- Green: Microgrid 400V
- Purple: Stand-Alone
Remember this definition of access

• Perfect electricity access should not limit the consumption that the consumers can afford (both in terms of utilization of the existing appliances or the ones that the consumer can afford to purchase, at household, community, commercial & industrial levels)

• Public intervention may change the affordability by applying social tariffs up to certain amount of electricity. Then we are back to the problem of defining a minimum level of services.
Implications on planning

• Strictly, there is no need to provide access beyond what customers can afford (including any subsidies)

• However, an integral approach to electrification must combine electricity access with promotion of productive uses of electricity
  – enabling economic development,
  – increasing the demand significantly
  – as well as the affordability
Cajamarca (Peru)
Location of buildings
Cajamarca (Peru)

Base case (estimated household demand: 185.5 kWh/year)
Cajamarca (Peru)
Demand growth (500 kWh/year & household)
Establishing priorities
The obvious strategy

• Give priority to **critical & productive** loads
  – health centers, schools, community centers
  – local industries, productive uses of electricity (irrigation pumps, electric mills, mechanical workshops, Internet centers, etc.)

• Decision on **what to electrify first** must be dictated by the potential **impact** on the country’s welfare & some sort of **bootstrapping** strategy
Questions or comments?
Annex

A comprehensive definition of access
For a thorough discussion about the meaning of energy access consult this reference.
“Energy access” has multiple dimensions

Overall Energy Access Index

- Index of Household Access to Energy
  - HH Electricity Index
  - HH Cooking Index
  - HH Heating Index

- Index of Access to Energy for Productive Engagements
- Index of Access to Energy for Community Facilities
  - Street Lighting Index
  - Health Facilities Index
  - Education Facilities Index
  - Community Buildings Index
  - Public Offices Index

Note: HH = household
Household access to electricity...
## Multi-tier Matrix for Measuring Access to Household Electricity Supply

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Tier 0</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
<th>Tier 4</th>
<th>Tier 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Peak Capacity</strong></td>
<td></td>
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</tr>
<tr>
<td>Power capacity ratings &amp; (in W or daily Wh)</td>
<td>Min 3 W</td>
<td>Min 50 W</td>
<td>Min 200 W</td>
<td>Min 800 W</td>
<td>Min 2 kW</td>
<td></td>
</tr>
<tr>
<td>OR Services</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Lighting of 1,000 lmhr/day</td>
<td>Min 12 Wh</td>
<td>Min 200 Wh</td>
<td>Min 1.0 kWh</td>
<td>Min 3.4 kWh</td>
<td>Min 8.2 kWh</td>
<td></td>
</tr>
<tr>
<td><strong>2. Availability (Duration)</strong></td>
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<tr>
<td>Hours per day</td>
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<tr>
<td>Min 4 hrs</td>
<td>Min 4 hrs</td>
<td>Min 8 hrs</td>
<td>Min 16 hrs</td>
<td>Min 23 hrs</td>
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<tr>
<td>Hours per evening</td>
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<tr>
<td>Min 1 hr</td>
<td>Min 2 hrs</td>
<td>Min 3 hrs</td>
<td>Min 4 hrs</td>
<td>Min 4 hrs</td>
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<tr>
<td><strong>3. Reliability</strong></td>
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<tr>
<td>Max 14 disruptions per week</td>
<td>Max 3 disruptions per week of total duration &lt;2 hrs</td>
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<td></td>
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<tr>
<td><strong>4. Quality</strong></td>
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<tr>
<td>Voltage problems do not affect the use of desired appliances</td>
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<tr>
<td><strong>5. Affordability</strong></td>
<td></td>
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</tr>
<tr>
<td>Cost of a standard consumption package of 365 kWh/year &lt; 5% of household income</td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>6. Legality</strong></td>
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<td></td>
</tr>
<tr>
<td>Bill is paid to the utility, pre-paid card seller, or authorized representative</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td><strong>7. Health &amp; Safety</strong></td>
<td></td>
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</tr>
<tr>
<td>Absence of past accidents and perception of high risk in the future</td>
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<td></td>
</tr>
</tbody>
</table>
### Multi-tier Matrix for Measuring Access to Household Electricity Services

<table>
<thead>
<tr>
<th>Tier criteria</th>
<th>TIER 0</th>
<th>TIER 1</th>
<th>TIER 2</th>
<th>TIER 3</th>
<th>TIER 4</th>
<th>TIER 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Task lighting AND Phone charging</td>
<td>General lighting AND Phone Charging AND Television AND Fan (if needed)</td>
<td>Tier 2 AND Any medium-power appliances</td>
<td>Tier 3 AND Any high-power appliances</td>
<td>Tier 2 AND Any very high-power appliances</td>
<td></td>
</tr>
</tbody>
</table>

### Multi-tier Matrix for Measuring Household Electricity Consumption

<table>
<thead>
<tr>
<th></th>
<th>TIER 0</th>
<th>TIER 1</th>
<th>TIER 2</th>
<th>TIER 3</th>
<th>TIER 4</th>
<th>TIER 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual consumption levels, in kWhs</td>
<td>≥4.5</td>
<td>≥73</td>
<td>≥365</td>
<td>≥1,250</td>
<td>≥3,000</td>
<td></td>
</tr>
<tr>
<td>Daily consumption levels, in Whs</td>
<td>≥12</td>
<td>≥200</td>
<td>≥1,000</td>
<td>≥3,425</td>
<td>≥8,219</td>
<td></td>
</tr>
</tbody>
</table>
Household access to cooking solutions...
## Multi-tier Matrix for Measuring Access to Cooking Solutions

<table>
<thead>
<tr>
<th>Attributes</th>
<th>LEVEL 0</th>
<th>LEVEL 1</th>
<th>LEVEL 2</th>
<th>LEVEL 3</th>
<th>LEVEL 4</th>
<th>LEVEL 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Indoor Air Quality</td>
<td>PM$_2.5$ (µg/m$^3$)</td>
<td>[To be specified by a competent agency, such as WHO, based on health risks]</td>
<td>Primary solution meets Tier 1 efficiency requirements</td>
<td>Primary solution meets Tier 2 efficiency requirements</td>
<td>Primary solution meets Tier 3 efficiency requirements</td>
<td>&lt;35 (WHO guidelines)</td>
</tr>
<tr>
<td></td>
<td>CO (mg/m$^3$)</td>
<td>[To be specified by a competent agency, such as WHO, based on health risks]</td>
<td>Primary solution meets Tier 2 efficiency requirements</td>
<td>Primary solution meets Tier 3 efficiency requirements</td>
<td>Primary solution meets Tier 1-4 efficiency requirements</td>
<td>&lt;7 (WHO guideline)</td>
</tr>
<tr>
<td>2. Cookstove Efficiency (not to be applied if cooking solution is also used for space heating)</td>
<td>Primary solution meets Tier 1 efficiency requirements</td>
<td>Primary solution meets Tier 2 efficiency requirements</td>
<td>Primary solution meets Tier 3 efficiency requirements</td>
<td>Primary solution meets Tier 4 efficiency requirements</td>
<td>Primary solution meets Tier 4 efficiency requirements</td>
<td>&lt;7 (WHO guideline)</td>
</tr>
<tr>
<td>3. Convenience</td>
<td>Fuel acquisition and preparation time (hrs/week)</td>
<td>&lt;7</td>
<td>&lt;3</td>
<td>&lt;1.5</td>
<td>&lt;0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stove preparation time (min/mess)</td>
<td>&lt;15</td>
<td>&lt;10</td>
<td>&lt;5</td>
<td>&lt;2</td>
<td></td>
</tr>
<tr>
<td>4. Safety of Primary Cookstove</td>
<td>IWA safety tiers</td>
<td>Primary solution meets (provisional) IWA Tier 1 for Safety</td>
<td>Primary solution meets (provisional) IWA Tier 2</td>
<td>Primary solution meets (provisional) IWA Tier 3</td>
<td>Primary solution meets (provisional) IWA Tier 4</td>
<td></td>
</tr>
<tr>
<td>5. Affordability</td>
<td>No accidents over the past year that required professional medical attention</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Quality of Primary Fuel: variations in heat rate due to fuel quality that affects ease of cooking</td>
<td>Levelized cost of cooking solution (e.g., cookstove and fuel) &lt;5% of household income</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Availability of Primary Fuel</td>
<td>Primary fuel is readily available for at least 80% of the year</td>
<td>Primary fuel is readily available throughout the year</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Household access to space heating...
<table>
<thead>
<tr>
<th>ATTRIBUTES</th>
<th>LEVEL 0</th>
<th>LEVEL 1</th>
<th>LEVEL 2</th>
<th>LEVEL 3</th>
<th>LEVEL 4</th>
<th>LEVEL 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Personal space around individuals is heated</td>
<td>At least one room has heating</td>
<td>All rooms in the household have heating</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration</td>
<td></td>
<td>At least half the time when needed (&gt; 50% of the time)</td>
<td>Most hours when needed (&gt; 75% of the time)</td>
<td>Almost all hours when needed (&gt; 95% of the time)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td></td>
<td>Comfortable temperature at least 50% of the time</td>
<td>Comfortable temperature at least 75% of the time</td>
<td>Comfortable temperature all the time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Convenience (fuel collection time in hrs/week)</td>
<td>&lt;7</td>
<td>&lt;3</td>
<td>&lt;1.5</td>
<td>&lt;0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affordability</td>
<td></td>
<td></td>
<td>Cost ≤ 2 times the grid tariff</td>
<td>Cost ≤ the grid tariff</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability (number of disruptions/day)</td>
<td>&lt;7</td>
<td>&lt;3</td>
<td>&lt;3 (total duration &lt; 2 hours)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indoor Air Quality</td>
<td>PM$_{2.5}$ (µg/m$^3$)</td>
<td>[To be specified by a competent agency, such as WHO, based on health risks]</td>
<td>[To be specified by a competent agency, such as WHO, based on health risks]</td>
<td>[To be specified by a competent agency, such as WHO, based on health risks]</td>
<td>&lt;35 (WHO IT-1)</td>
<td>&lt;10 (WHO guideline)</td>
</tr>
<tr>
<td></td>
<td>CO (mg/m$^3$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No accidents (burns or unintended fires) over the past year that required professional medical attention</td>
</tr>
</tbody>
</table>
Access to street lighting...
## Multi-tier Matrix for Access to Street Lighting

<table>
<thead>
<tr>
<th>ATTRIBUTES</th>
<th>TIER 0</th>
<th>TIER 1</th>
<th>TIER 2</th>
<th>TIER 3</th>
<th>TIER 4</th>
<th>TIER 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>STREET LIGHTING</td>
<td>At least one functional street lamp in the neighborhood</td>
<td>At least 25% of the neighborhood is covered by functional street lamps</td>
<td>At least 50% of the neighborhood is covered by functional street lamps</td>
<td>At least 75% of the neighborhood is covered by functional street lamps</td>
<td>At least 95% of the neighborhood is covered by functional street lamps</td>
<td></td>
</tr>
<tr>
<td>1. Capacity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Availability</td>
<td></td>
<td>Street lighting functions for at least 2 night hours each day</td>
<td>Street lighting functions for at least 4 night hours each day</td>
<td>Street lighting functions for at least 50% of night hours each day</td>
<td>Street lighting functions for at least 75% of night hours each day</td>
<td>Street lighting functions for at least 95% of night hours each day</td>
</tr>
<tr>
<td>(duration)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Reliability</td>
<td></td>
<td></td>
<td></td>
<td>No reliability issues perceived by users</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Quality</td>
<td></td>
<td></td>
<td></td>
<td>No brightness issues perceived by users</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Safety</td>
<td></td>
<td></td>
<td></td>
<td>No perceived risk of electrocution due to poor installation or maintenance</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Access to productive applications of energy…
<table>
<thead>
<tr>
<th>ATTRIBUTES (Duration) of Daily Supply</th>
<th>TIER 0</th>
<th>TIER 1</th>
<th>TIER 2</th>
<th>TIER 3</th>
<th>TIER 4</th>
<th>TIER 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>Power</td>
<td>Min 3 W</td>
<td>Min 50 W</td>
<td>Min 200 W</td>
<td>Min 800 W</td>
<td>Min 2 kW</td>
</tr>
<tr>
<td></td>
<td>Daily Supply Capacity</td>
<td>Min 12 Wh</td>
<td>Min 200 Wh</td>
<td>Min 1.0 kWh</td>
<td>Min 3.4 kWh</td>
<td>Min 8.2 kWh</td>
</tr>
<tr>
<td>Typical Technology</td>
<td>Solar lanterns</td>
<td>Standalone solar systems</td>
<td>Generator or mini-grid</td>
<td>Generator or grid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both</td>
<td>Nonelectric (fuels, RME, RTE, AP, HP)</td>
<td>Available nonelectric energy partially meets requirements</td>
<td>Available nonelectric energy largely meets requirements</td>
<td>Available nonelectric energy fully meets requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Both</td>
<td>No relevant application is missing solely due to capacity constraints</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Availability</td>
<td>Electricity</td>
<td>Min 2 hrs</td>
<td>Min 4 hrs</td>
<td>Half of the working hours (min 50%)</td>
<td>Most of the working hours (min 75%)</td>
<td>Almost all working hours (min 95%)</td>
</tr>
<tr>
<td></td>
<td>Nonelectric (fuels, RME, RTE, AP, HP)</td>
<td>Available nonelectric energy partially meets requirements</td>
<td>Available nonelectric energy largely meets requirements</td>
<td>Available nonelectric energy fully meets requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Both</td>
<td>Longer working hours are not prevented solely by lack of adequate availability (duration) of supply</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Reliability</td>
<td>Reliability issues with moderate impact</td>
<td>No reliability issues or little (or no) impact</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Quality</td>
<td>Quality issues with moderate impact</td>
<td>No quality issues or little (or no) impact</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Affordability</td>
<td>Variable energy cost ≤ 2 times the grid tariff</td>
<td>Variable energy cost ≤ the grid tariff</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATTRIBUTES</td>
<td>TIER 0</td>
<td>TIER 1</td>
<td>TIER 2</td>
<td>TIER 3</td>
<td>TIER 4</td>
<td>TIER 5</td>
</tr>
<tr>
<td>------------</td>
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<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>6. Legality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Energy bill is paid to the utility, pre-paid card seller, authorized representative, or legal market operator</td>
</tr>
<tr>
<td>7. Convenience</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Convenience issues cause moderate impact</td>
</tr>
<tr>
<td>8. Health (IAQ from use of fuels)</td>
<td>PM2.5 (µg/m³)</td>
<td>[To be specified by competent agency such as WHO]</td>
<td>[To be specified by competent agency such as WHO]</td>
<td>[To be specified by competent agency such as WHO]</td>
<td>&lt; 35 (WHO IT-1)</td>
<td>&lt; 10 (WHO guideline)</td>
</tr>
<tr>
<td></td>
<td>CO (mg/m³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt; 7 (WHO guideline)</td>
</tr>
<tr>
<td></td>
<td>OR Use of fuels (BLEENS)</td>
<td>Use of non-BLEENS solutions (if any) outdoors or with smoke extraction</td>
<td></td>
<td>Use of BLEENS or equivalent solutions only (if any)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Safety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Energy solutions caused accidents that did not require professional medical assistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Energy solutions did not cause any accidents</td>
</tr>
</tbody>
</table>
Energy access in community infrastructure
### Multi-tier Matrix for Measuring Access in Community Infrastructure (Survey of Institutions)

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Tier 0</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
<th>Tier 4</th>
<th>Tier 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Capacity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electricity</strong></td>
<td>Power</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capacity</td>
<td>Min 3 W</td>
<td>Min 50 W</td>
<td></td>
<td>Min 200 W</td>
<td></td>
<td>Min 800 W or Min 2 kWb</td>
</tr>
<tr>
<td>Typical Technology</td>
<td>Solar lanterns</td>
<td>Standalone solar systems</td>
<td>Generator or mini-grid</td>
<td>Generator or grid</td>
<td>Grid</td>
<td></td>
</tr>
<tr>
<td>Nonelectric (fuels, RME, RTE)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both</td>
<td>No relevant application is missing solely due to capacity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2. Availability (duration) of Daily Supply</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Electricity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>Min 4 hrs</td>
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<td>Most of the working hours (Min 75%)</td>
<td>Almost all working hours (Min 95%)</td>
</tr>
<tr>
<td>Nonelectric (fuels, RME, RTE)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration</td>
<td>Operating hours and/or provision of services are not restricted solely by inadequate availability (duration) of supply</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3. Reliability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reliability issues have moderate impact</td>
<td>No reliability issues or little (or no) impact</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4. Quality</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Quality issues have moderate impact</td>
<td>No quality issues or little (or no) impact</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Variable Energy Cost</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤ 2 times the grid tariff</td>
<td>≤ the grid tariff</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5. Affordability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Financial Sustainability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>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</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>