Planning for Energy Access – Assessing Electrification Options and Costs

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Agenda

I. Important definitions and background
II. Step 1: Make use of maps and geographic information systems (GIS)
III. Step 2: Analysis of detailed decision parameters (off-grid vs. on-grid)
IV. Step 3: Planning for off-grid technology solutions (mini-grids, solar-home-systems and hybrid systems)
V. Summary and Conclusion

Source: IEA (2015)
Important Definitions and Background
Important definitions:
Energy Access

- Modern energy access
  - NO universally-agreed and universally-adopted definition
  - UN Secretary General’s Advisory Group on Energy and Climate (AGECC)
    - minimum threshold of modern energy services
    - reliable and affordable, sustainable and low-carbon

Source: IEA (2015)
Important definitions: Electrification

• IEA (WEO methodology)
  • „A household having reliable and affordable access to a minimum level of electricity consumption which is increasing over time”
  • More than a first supply;
  • minimum level of electricity (rural = 250 kWh/y; urban = 500 kWh/y).

• Access/electrification rate (cover rate):
  – Access to electricity is the percentage of population with access to electricity (World Bank).
• 1.2 billion people (17% of the global population) have no access to electricity
Energy Access and Rural Electrification

- World electricity demand is expected to double by 2030 (highest increase in developing countries)
- Most developing countries have very good natural conditions for renewable energy sources
- Important piece of the puzzle in combating global climate change
Electrification rates in Africa

• Since 2000, 145 million people in sub-Saharan Africa have gained access to electricity
• The average electrification rate was 32% (up from 23% in 2000)
  – 85% in South Africa
  – Less than 10% in six countries
    • Chad, Central African Republic, DR Congo, Liberia, Malawi and South Sudan
• 59% of the urban population
• 16% rural population
Electrification rates in Africa

Source: Scott 2015
Universal electricity access by 2030: Technological solutions

Off-grid (Mini-grids), 35%
Off-grid (SHS), 18%
Grid-based solutions, 43%

Source: IEA 2014
Step 1: Make use of maps and geographic information systems (GIS)
Use multiple layers of maps (GIS)

1. Resource quality (e.g. solar radiation in a given area, yearly global irradiation (kWh/m2))

2. Electricity grid (distance to the grid)

3. Population density (persons/km2)

4. Road network (for deployment)

5. Terrain/slope (level of difficulty to construct transmission lines)
Ressource mapping (e.g. IRENA – Global Atlas)

Opportunity areas for grid connected and off grid solar PV applications in ECOWAS

• Map shows opportunity areas for grid connected and offgrid PV in the ECOWAS region.

• The maps illustrate the capabilities of the Global Atlas for spatial planning purposes, in the case of the ECOWAS region.

• This demonstration shows a first range of possibilities for opportunity areas, based on a range of assumptions.
  – Yearly global irradiation (kWh/m2)
  – Grid distance (km)
  – Slope (%)
  – Population density (persons/km2)
  – Protected area

Opportunity areas for off-grid solar PV in ECOWAS – 20 km from grid

http://irena.masdar.ac.ae/?map=507
Opportunity areas for off-grid solar PV in ECOWAS – 75 km from grid

http://irena.masdar.ac.ae/?map=507
Opportunity areas for off-grid solar PV in ECOWAS – 150 km from grid

http://irena.masdar.ac.ae/?map=507
Step 2: Analysis of detailed decision parameters (off-grid vs. on-grid)
Parameters for energy access planning decisions

PARAMETERS NEED TO BE CONSIDERED IN CONJUNCTION!

- Resource assessment (Solar radiation etc.)
- Cost of DG technologies
- Load density
- Cost for grid expansion (distance)
Parameters for energy access planning decisions

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Grid expansion costs

- New connections in cities with existing grids: starting at 140 US$
- Cost estimates for grid expansion (World Bank): between US$8,000-US$10,000 per km,
- Cost can increase to as much as US$22,000 per km in difficult terrains
- Mini-grids can reduce transmission and distribution losses and theft

Least cost grid expansion plan in Rwanda

- Identify all areas that can be reached by the grid in the near term
- Keep in mind that the economics for off-grid solutions are likely to improve further in the future

More Granular Grid Expansion and Off-grid Solutions

- regional map showing the proposed electrification technology options for the modelled un-electrified communities

Parameters for energy access planning decisions

PARAMETERS NEED TO BE CONSIDERED IN CONJUNCTION!

- Resource assessment (Solar radiation etc.)
- Cost of DG technologies
- Cost for grid expansion (distance)
- Load density
Load density

Electricity consumption + Population density = Load density
Population density

• Focus on grid expansions to areas with high population density
• Most Africans live in sparsely populated rural areas
  – About 60% today
  – About 45% in 2030

Source: http://imgur.com/9CLeRzR
Load density: Electricity consumption per household (kWh)

- Long-term developments unclear:
  - Rural electrification programs are implemented in order to spur economic development in rural areas
  - Once village is connected to the grid/supplied by electricity via off-grid solutions, electricity supply might increase considerably
  - provide estimates of expected consumption growth when planning energy access!

- REMARK(able):
  - Electricity from AA(A) batteries costs between 100-400 US$ per kWh!

Source: Mobisol
Parameters for energy access planning decisions

PARAMETERS NEED TO BE CONSIDERED IN CONJUNCTION!

- Resource assessment (Solar radiation etc.)
- Load density
- Cost of DG technologies
- Cost for grid expansion (distance)
Due to dramatic reductions in PV costs in the past years, PV mini-grids are a viable alternatives to grid extension and diesel mini-grids.

Obstacles: the need for upfront financing, ensuring proper maintenance, intermittency, etc.
Cost of DG technologies: SHS

Source: (Global LEAP, 2016)
Cost of DG technologies: Mini grids

System Parameters: 70kW PV Array; 500KWh Lithium Ion Battery System; 100kVA Diesel Generator
Source: Based on EUEI Mini-grid Policy Toolkit Financial Model, 2015,
http://minigridpolicytoolkit.euei-pdf.org/support-tools
Cost of DG technologies: Batteries

Figure XYZ: Historical and Forecasted Cost Evolution for Lithium-Ion Battery Systems (USD $/kWh)
Source: 2015

Björn Nykvist and Måns Nilsson, 2015
Step 3: Planning for off-grid technology solutions (mini-grids, solar-home-systems and hybrid systems)
Willingness and ability to pay

- End-user perspective important!

- What is the available income of a household/business?
- Is the income regular and foreseeable?
- What is the share already spent on energy today?
- Is (micro-)financing available and used?
- ...

Need for energy + Ability to pay + Willingness to pay = Electrification strategy
Some facts & figures

- Cost of energy from a small, cheap petrol or diesel genset?
  - 1.50…2.00 EUR/kWh

- Average household spending on energy in percent of household income?
  - 5…10% (3 to 15 USD)

- Household / small business spending on kerosene for lamps and candles?
  - around 17 billion USD

- Cost for energy of unelectrified customers?
  - Cell-phone charging: 20 to 80 EUR per kWh (0.10 to 0.40 EUR per charge)

Source: RENAC
Methods for data collection

„Willingness to pay is the maximum amount that an individual indicates that he or she is willing to pay for a good or service.“

– Ask potential customers which service they want and what they are willing to pay.
  ▪ Result: Usually leads to overestimations.

– Ask questions about current energy consumption and expenditures for comparable services.
  ▪ Result: Usually leads to underestimations.

– Ask to sign an unbinding „take or pay“ contract for a specific amount of energy at a specific price.
  ▪ Result: Usually leads to quite accurate estimations.

BUT: „Willingness to pay is however not a fixed value but strongly depends on the quality of services provided and the available alternatives.“

Source: RENAC
Financing off-grid, rural electrification programs

- Cover cost-gap between willingness-to-pay and actual costs
- Subsidies should be as high as necessary, yet as low as possible.

- project planning/pre-investment phase:
  - feasibility studies, business plan development, technical planning, capacity building and transaction costs)

- implementation/construction
  - e.g. as capital subsidies, connection subsidies

- during operation
  - operational subsides, tariff top-ups, cross-subsidies

Source: REN21 2014
Cost of technological solutions

- In-depth analysis of costs of different electrification options

- Several other factors influence the viability of off-grid solutions, e.g. the level of market penetration, transport cost for equipment, transport of fuels (e.g. diesel), etc.
## Matrix for decision making (small hybrid system)

<table>
<thead>
<tr>
<th>Remote village with very few activities</th>
<th>Peak load 30-60 kW</th>
<th>150-300 kWh/day</th>
<th>low growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Option</strong></td>
<td><strong>Key figures for economic / financial analysis</strong></td>
<td><strong>Level of service</strong></td>
<td><strong>Required operating skills</strong></td>
</tr>
<tr>
<td>Grid extension (distance to grid)</td>
<td>MV line cost 8-13 k€ / km</td>
<td>yearly sales 55 to 110 MWh / year</td>
<td>timeline for grid extension</td>
</tr>
<tr>
<td>Diesel-based power plant (initial investment incl. 1 genset 40-70 k€)</td>
<td>actual cost of diesel fuel kWh tariff</td>
<td>-if mandatory subsidy on diesel: for a total of 55 to 110 MWh / year (Ex: 8 to 16 k€/year)* -yearly O&amp;M costs</td>
<td>genset lifespan</td>
</tr>
<tr>
<td>Hybrid-based power plant (Ex: 30 kWp PV)</td>
<td>initial investment 180-250 k€ + battery renewal (8 years) 35-50 k€ kWh tariff</td>
<td>accessible penetration rate &gt; 40% reduced mandatory subsidy on diesel: @40% PV penetration: 30-65 MWh / year (Ex: 3 to 7 k€/year)** reduced O&amp;M costs</td>
<td>-payback period -long lasting PV investment (25yrs) -battery lifespan -increased genset lifespan</td>
</tr>
</tbody>
</table>

Investment data shown for comparing options does not include cost of the local MV / LV grid or minigrid.
Initial investment and battery renewal cost for the PV / diesel hybrid option are based on a 30 kWp system as an example.
*Based on a 30% subsidy on 1.00 €/L fuel price and genset consumption 0.5 L/kWh
**Based on improved genset consumption: 0.35 L/kWh

Source: IEA PVPS 2014 [https://www.iea.org/media/openbulletin/Rural_Electrification_with_PV_Hybrid_systems.pdf](https://www.iea.org/media/openbulletin/Rural_Electrification_with_PV_Hybrid_systems.pdf)
Summary and conclusion
Strategies for energy access planning

• To reach energy access for all by 2030 we need an **integrated strategy** for near-grid and off-grid solutions

• Coordination of responsibilities (several ministries?)

Source: IEA 2014
Strategies for energy access planning

- **Strategy 1: Focus on the “low hanging fruits”**
  
  - Electrification of near-grid households via grid expansion
  
  - Lowest cost per new household connected to the grid (e.g. starting at 140 US$)
  
  - Highest cost efficiency to improve electrification rate
Strategies for energy access planning

- Strategy 2: Develop specific frameworks for remote, rural communities (off-grid and mini-grid solutions)
  - Low ability to pay (even to cover O&M costs of mini-grids)
  - Higher costs ($/kWh)
  - Specific finance mechanism needed (e.g. government fund)
Regional Solutions (e.g. West African Power Pool)

- Foster regional solutions
- Expand existing grid in neighboring countries if closer to rural communities
- Enable cross-border trade

Source: WAPP 2014
List of references and further reading
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List of references and further reading

Further reading

• Mini-Grid Policy Toolkit by EUEI-PDF

• „Scaling up successful micro-utilities for rural electrification“

• „From the bottom up: How small power producers and mini-grids can deliver electrification and renewable energy in Africa“
Thanks for your attention!

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Additional slides
Technologies for universal electrification in Sub-Saharan Africa

Source: Scott 2015 based on IEA 2014 and Szarca 2011
Assessing resource availability – KSA solar map

- Renewable energy atlas was launched in Dec 2013:
- Existing resource maps are important elements for Statement of Opportunities (SOO) for project developers
- Onsite measurement required for financing


Planning energy access: Parameters for cost calculation

<table>
<thead>
<tr>
<th>Grid Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transformer Capacities Available (kW)</td>
</tr>
<tr>
<td>Distribution loss</td>
</tr>
<tr>
<td>Installation cost per connection</td>
</tr>
<tr>
<td>Voltage Line cost per meter</td>
</tr>
<tr>
<td>Voltage Line lifetime</td>
</tr>
<tr>
<td>Voltage Lines O&amp;M costs per year</td>
</tr>
<tr>
<td>Cost of transformers</td>
</tr>
<tr>
<td>Transformer lifetime</td>
</tr>
<tr>
<td>Transformer O&amp;M costs</td>
</tr>
</tbody>
</table>

Source: Kemausuor et al 2011
Planning energy access: Parameters for cost calculation

<table>
<thead>
<tr>
<th><strong>Diesel Generator</strong></th>
<th><strong>Solar System</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Available System Capacities (kW)</strong></td>
<td><strong>Available System Capacities (kW)</strong></td>
</tr>
<tr>
<td>Diesel fuel (litres) consumed per kWh</td>
<td>PV balance (other accessories, excluding battery) cost as fraction of panel cost</td>
</tr>
<tr>
<td>Diesel generator cost per kWh of energy produced</td>
<td>PV panel lifetime</td>
</tr>
<tr>
<td>Diesel generator installation cost (as fraction of generator cost)</td>
<td>PV balance (other accessories, excluding battery) life time</td>
</tr>
<tr>
<td>Diesel generator lifetime</td>
<td>PV battery cost per kWh</td>
</tr>
<tr>
<td>Diesel generator O&amp;M cost per year (as fraction of generator cost)</td>
<td>PV battery lifetime</td>
</tr>
<tr>
<td>Distribution Loss</td>
<td>PV battery kWh per PV component kW</td>
</tr>
<tr>
<td><strong>Source:</strong> Kemausuor et al 2011</td>
<td>PV component efficiency loss</td>
</tr>
<tr>
<td></td>
<td>PV component O&amp;M cost per year as fraction of component cost</td>
</tr>
<tr>
<td></td>
<td>PV panel cost per PV component kilowatt</td>
</tr>
</tbody>
</table>
# Planning energy access: Parameters for cost calculation

**Socio-economic**

<table>
<thead>
<tr>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic Growth Rate</td>
</tr>
<tr>
<td>Population Growth Rates</td>
</tr>
<tr>
<td>Electricity Demand Growth</td>
</tr>
<tr>
<td>Elasticity of Electricity Demand</td>
</tr>
<tr>
<td>Interest Rate</td>
</tr>
</tbody>
</table>

Source: Kemausuor et al 2011
## Planning energy access: Parameters for cost calculation

### Costs for Grid and off-grid (solar, diesel) technologies

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials for grid extension (poles, wire, transformers, etc.), and for off-grid (solar and diesel generation equipment)</td>
<td>Recurring costs (operations &amp; maintenance), and “soft costs” such as system design and installation</td>
</tr>
<tr>
<td>Electricity connection fees for households, businesses (single-phase and three-phase)</td>
<td></td>
</tr>
</tbody>
</table>

Source: Kemausuor et al 2011
IRENA – Global Atlas
(example ECOWAS)

• Geographic coverage: The Economic Community of West African States (ECOWAS)
• Source: ECOWAS Center for Renewable Energy and Energy Efficiency
• Website: www.ecreee.org
• Direct access: Search ‘ECREEE’ through the Global Atlas Data Browser.
• Detailed description and original website: www.ecowrex.org