International Solar Alliance
Expert Training Course

Off-grid Demand Analysis

In partnership with the Clean Energy Solutions Center (CESC)

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Supporters of this Expert Training Series
This Training is part of Module 4, and focuses on the issue of Off-grid demand analysis
Expert Trainer: Dr Pol Arranz-Piera

Brief Profile:

- Projects Director and Senior Engineer at AIGUASOL, an international energy consulting, engineering and R&D firm
- Previous experience includes Trama Tecnoambiental (TTA) and URS Corp. (currently AECOM)
- 20+ years of experience in the renewable energy and energy efficiency sectors, covering nearly 40 countries in Europe, The Americas, Africa, the Middle East and Asia
- Associate researcher and lecturer at the Technical University of Catalonia (UPC) on electricity services planning, solar and biomass technologies.
Understanding demand: a critical factor for off-grid PV systems

Basics: Energy demand, Power demand

Types of loads (baseloads, daily cycle, deferrable…)

AC and DC loads

Types of demand (residential, community, productive) examples

Levels of demand, Tiers (Multitier Framework)

Data collection methods and techniques

Projections, scenarios

Demand side management

In conclusion: Influence on PV system designs

References
Introduction: Understanding demand

Electricity is crucial for any human activity

- From the most basic, domestic uses …
  - Lighting, cooking, heating, transport

- to basic services (community/public)…
  - Health, education, communications

- and to any kind of productive, commercial activities
Demand: a critical factor for off-grid PV systems

Especially for 100% solar mini-grids, where the electricity available will be shared among several users

Risk of OVERSIZING (grid extension approach) or UNDERSIZING (not considering potential growth, even short term)

Can lead to:
- Bad quality of service (interruptions, losses…)
- Increased budget (e.g. very large batteries to guarantee a minimum supply in winter)
Basics: Energy demand, Power demand

- **Power demand:**
  - Unit: Watt (W)
  - In terms of classical mechanics:
    \[ W = \frac{J}{s} = \frac{N \cdot m}{s} = \frac{kg \cdot m^2}{s^3} \]
  - In terms of electromagnetism:
    \[ W = V \cdot A = A^2 \Omega = \frac{kg \cdot m^2}{s^3} \]

- **Energy demand:**
  - Unit: Joule (J).
  - But in electricity, the Watt-hour (Wh) is widely used, as it refers to the average power (W) supplied in one (1) hour
  - Conversion: \( 1 \text{ kWh} = 3,6 \text{ MJ} \)
HDI vs electricity consumption

Data from IEA, 2004

HUMAN DEVELOPMENT INDEX, a measure of human well-being, reaches its maximum plateau at about 4000 kWh of annual electricity use per capita. 60 nations are plotted, representing 90% of Earth’s population. (Adapted from ref. 3.)
### Electrical energy consumption per capita

#### 2016

<table>
<thead>
<tr>
<th>Country</th>
<th>Consumption per Capita (kWh/year)</th>
<th>Country</th>
<th>Consumption per Capita (kWh/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>23.000</td>
<td>Greece</td>
<td>5.001</td>
</tr>
<tr>
<td>Canada</td>
<td>15.546</td>
<td>Italy</td>
<td>4.768</td>
</tr>
<tr>
<td>Finland</td>
<td>14.654</td>
<td>Malta</td>
<td>4.652</td>
</tr>
<tr>
<td>USA</td>
<td>12.984</td>
<td>Slovakia</td>
<td>4.652</td>
</tr>
<tr>
<td>Sweden</td>
<td>12.793</td>
<td>United Kingdom</td>
<td>4.652</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>10.932</td>
<td>Portugal</td>
<td>4.536</td>
</tr>
<tr>
<td>Belgium</td>
<td>7.211</td>
<td>Bulgaria</td>
<td>4.071</td>
</tr>
<tr>
<td>Austria</td>
<td>7.094</td>
<td>China</td>
<td>3.927</td>
</tr>
<tr>
<td>France</td>
<td>6.629</td>
<td>Hungary</td>
<td>3.838</td>
</tr>
<tr>
<td>Germany</td>
<td>6.280</td>
<td>Croatia</td>
<td>3.722</td>
</tr>
<tr>
<td>Slovenia</td>
<td>6.280</td>
<td>Poland</td>
<td>3.489</td>
</tr>
<tr>
<td>Netherlands</td>
<td>6.164</td>
<td>Lithuania</td>
<td>3.373</td>
</tr>
<tr>
<td>Estonia</td>
<td>5.582</td>
<td>Latvia</td>
<td>3.256</td>
</tr>
<tr>
<td>European Union (28)</td>
<td>5.466</td>
<td>Romania</td>
<td>2.210</td>
</tr>
<tr>
<td>Denmark</td>
<td>5.464</td>
<td>India</td>
<td>806</td>
</tr>
<tr>
<td>Spain</td>
<td>5.356</td>
<td>Ghana</td>
<td>355</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>5.350</td>
<td>Nigeria</td>
<td>144</td>
</tr>
<tr>
<td>Ireland</td>
<td>5.350</td>
<td>South Sudan</td>
<td>40</td>
</tr>
<tr>
<td>Cyprus</td>
<td>5.117</td>
<td>Haiti</td>
<td>39</td>
</tr>
</tbody>
</table>

#### Electrical consumption per country

(key aspects: average users, climatic area, efficiency, access to electricity)

Source: Eurostat, IEA
Types of loads – AC vs DC

AC loads:
• Residential/commercial: Lighting, TVs, Fans, Refrigerators, kitchens
• Productive: telecom towers, water pumps, grain mills, wood treatment

DC loads (mainly for off-grid applications):
• Residential/commercial: Lighting, TVs, Fans, Refrigerators
• Productive: poultry incubators, water pumps, grain mills

✓ Selection depends on distribution system
✓ Generally, AC appliances are still cheaper

Source: Efficiency for Access Coalition, 2018; GIZ, 2015
Types of loads – Classification

1. Lighting
2. Communications
   - Mobile phone
   - Television
   - Radio
   Most popular initial uses of electricity in most rural settings

3. Motor-based applications
   - e.g. Refrigerators
     - Mixers
     - Water pumping
     - Entertainment
     - Industrial equipment
   Socio economic development for the community
   Motor starting currents are significant

4. Heat-generating appliances
   - Cookers
   - Hair dryers
Types of loads

Several types within a Daily cycle
Types of loads

Base load
Types of loads

Base load interruptible

![Diagram showing base load interruptible with percentage ranges and hours of availability.]
Types of loads

Deferrable

<table>
<thead>
<tr>
<th>Time (1-24)</th>
<th>0%</th>
<th>5%</th>
<th>10%</th>
<th>15%</th>
<th>20%</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-17</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Types of demand - Residential

Typical residential load profile

Peak in the morning and evening/night hours

Source: TTA
### Typical commercial load profiles

<table>
<thead>
<tr>
<th>Category</th>
<th>Share of connected Shops</th>
<th>EDA (Wh/day)</th>
<th>Load profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>SH-basic</td>
<td>50%</td>
<td>550</td>
<td><img src="image" alt="Graph of SH-basic load profile" /></td>
</tr>
<tr>
<td>SH-medium</td>
<td>40%</td>
<td>2,200</td>
<td><img src="image" alt="Graph of SH-medium load profile" /></td>
</tr>
<tr>
<td>SH-high</td>
<td>10%</td>
<td>4,400</td>
<td><img src="image" alt="Graph of SH-high load profile" /></td>
</tr>
</tbody>
</table>

Source: TTA
Types of demand - Productive

Examples of productive load profiles

Telecommunication tower

Welding machine

Source: TTA
## Levels of demand in rural communities

<table>
<thead>
<tr>
<th>Category</th>
<th>Demand level - reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Basic Domestic</td>
<td>up to 20 kWh/month - 500W (DC or AC) per household</td>
</tr>
<tr>
<td>(lighting, communication)</td>
<td></td>
</tr>
<tr>
<td><strong>2</strong> Medium domestic (1+ small low consumption fridge)</td>
<td>up to 50 kWh/month - 1000W (AC) per household</td>
</tr>
<tr>
<td><strong>3</strong> Community (2+ community premises)</td>
<td>Medium domestic + school, health centre (50 kWh/month - 1000W) + public lighting (20kWh/month - 80W for each 200m²)</td>
</tr>
<tr>
<td><strong>4</strong> 3 + small productive uses</td>
<td>Above the previous values</td>
</tr>
</tbody>
</table>
The Multi-Tier Framework (MTF)

Measuring energy access: the tiers
Improving attributes of energy supply leads to higher tiers of access

<table>
<thead>
<tr>
<th>Load level</th>
<th>Indicative electric appliances</th>
<th>Capacity tier typically needed to power the load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low load (3–49 W)</td>
<td>Task lighting, phone charging, radio</td>
<td>Tier 1</td>
</tr>
<tr>
<td>Low load (50–199 W)</td>
<td>Multipoint general lighting, television, computer printer fan</td>
<td>Tier 2</td>
</tr>
<tr>
<td>Medium load (200–799 W)</td>
<td>Air cooler, refrigerator, freezer, food processor, water pump, rice cooker</td>
<td>Tier 3</td>
</tr>
<tr>
<td>High load (800–1999 W)</td>
<td>Washing machine, iron, hair dryer, toaster, microwave</td>
<td>Tier 4</td>
</tr>
<tr>
<td>Very high load (2,000 W or more)</td>
<td>Air conditioner, space heater, vacuum cleaner, water heater, electric cookstove</td>
<td>Tier 5</td>
</tr>
</tbody>
</table>

Source: The World Bank, 2015
Demand: a critical factor for off-grid PV systems

Mitigation strategies:

1. ASSESS THE ENERGY DEMAND THROUGH SURVEYS and QUESTIONNAIRES
   - The users are not experts
   - Define users’ demand requirements
   - Consider socio-economic data

2. COMPARATIVE DEMAND CHARACTERISATION
   - Assessment of load categories based on data analysis of similar villages
Data collection methods and techniques

1. Surveys and questionnaires

Objectives:
- To obtain the necessary data for the power plant design
- To influence on the consumption rationalization

Problem:
- The users are not experts
- The current and future demand estimation is a critical factor for the design

Methodology:
- To guide the users through their potential demand requirements
- To consider socio-economic data

Online tools:
https://d-lab.mit.edu/research/energy/energy-needs-assessment-toolkit
http://www.minigridbuilder.com/
Data collection methods and techniques

2. Comparative demand characterisation

Assessment of load categories based on histogram of similar villages

## Data collection methods and techniques

### Demand survey results

<table>
<thead>
<tr>
<th>Type</th>
<th>Cat. 1</th>
<th>EDA (Wh/day)</th>
<th>Share</th>
<th>Cat. 2</th>
<th>EDA (Wh/day)</th>
<th>Share</th>
<th>Cat. 3</th>
<th>EDA (Wh/day)</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Households (HH)</td>
<td>HH-basic</td>
<td>275</td>
<td>25%</td>
<td>HH-medium</td>
<td>550</td>
<td>60%</td>
<td>HH-high</td>
<td>1,650</td>
<td>15%</td>
</tr>
<tr>
<td>Commercial (CO)</td>
<td>CO-basic</td>
<td>550</td>
<td>50%</td>
<td>CO-medium</td>
<td>1,650</td>
<td>38%</td>
<td>CO-high</td>
<td>3,850</td>
<td>13%</td>
</tr>
<tr>
<td>Welding machines (WM)</td>
<td>WM-basic</td>
<td>14,850</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Places of worship (PW)</td>
<td>PW-mosque</td>
<td>550</td>
<td>50%</td>
<td>PW-church</td>
<td>1,650</td>
<td>50%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Education centres (EC)</td>
<td>EC-basic</td>
<td>550</td>
<td>33%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health facilities (HF)</td>
<td>HF-basic</td>
<td>550</td>
<td>50%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Community buildings (CB)</td>
<td>CB-basic</td>
<td>550</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telecom towers (TT)</td>
<td>TT-basic</td>
<td>5,500</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grain mills (GM)</td>
<td>GM-basic</td>
<td>2,200</td>
<td>50%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish conservation (FC)</td>
<td>FC-basic</td>
<td>3,300</td>
<td>33%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: TTA
## Projections, Scenarios

<table>
<thead>
<tr>
<th>Community</th>
<th>Electricity (kWh/month)</th>
<th>Power peak (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Scenario 1</td>
</tr>
<tr>
<td>Seneso</td>
<td>4385</td>
<td>6300</td>
</tr>
<tr>
<td>Boniafo</td>
<td>3443</td>
<td>5595</td>
</tr>
<tr>
<td>Bompa</td>
<td>5422</td>
<td>9602</td>
</tr>
<tr>
<td>Jaman Nkwanta</td>
<td>5174</td>
<td>8822</td>
</tr>
<tr>
<td>Nakpaye</td>
<td>2938</td>
<td>4076</td>
</tr>
</tbody>
</table>

### Daily Load Curve in Baseline Scenario (2017)

#### Daily Load Curve in Scenario 2 (2027)
- Population growth + increased expenditure + increased productive activities
Demand side management

Definition

- Is the modification of consumers’ energy demand, actively or automatically, in order to achieve a specific service supply goal

Example of goal

- Shift demand during sunshine hours
- Shave peaks of loads
- Consume when energy is cheaper

Methods

- Price incentives
- Automatic disconnection
- Energy efficiency
Demand side management

Example: Monte Trigo mini-grid, Cape Verde

Deferrable loads

- Day light sensor
- Battery end of absorption
- Diesel genset ON
- ICE MACHINES ON

Periodically deferrable load: Ice-making machine

On when excess energy is available
Demand side management

Example: Monte Trigo mini-grid, Cape Verde

Load shifting

February 2012

August 2012
Demand side management

Automatic, linked to battery SOC

Incentives to shift demand and follow energy generation pattern
In conclusion: Influence on PV system design

- **Load profile (daily/night)**
  - Battery sizing
  - AC, DC, AC/DC-coupling

- **Type of loads (currents, single/3 phases)**
  - Inverter type

- **Type of customers (residential, productive)**
  - Evolution of productive uses can require expansion of the PV generator

- **Demand evolution**
  - If uncertain, modular systems might be preferred

- **Grid arrival**
  - Require grid compatible inverters
  - Appropriate meters
References

Thanks for your attention!