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

INTERNATIONAL SOLAR ALLIANCE

CLEAN ENERGY SOLUTIONS CENTER
ASSISTING COUNTRIES WITH CLEAN ENERGY POLICY
An Initiative of the Clean Energy Ministerial

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Overview of Training Course Modules

This Training is part of Module 4, and focuses on the issue of Off-grid demand analysis

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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.

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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)

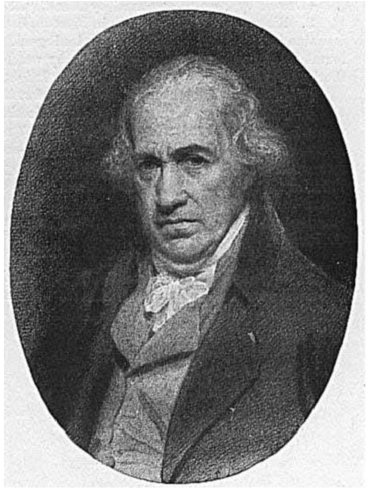
Basics: Energy demand, Power demand

- 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:

$$W = V \cdot A = A^2 \Omega = \frac{kg \cdot m^2}{s^3}$$

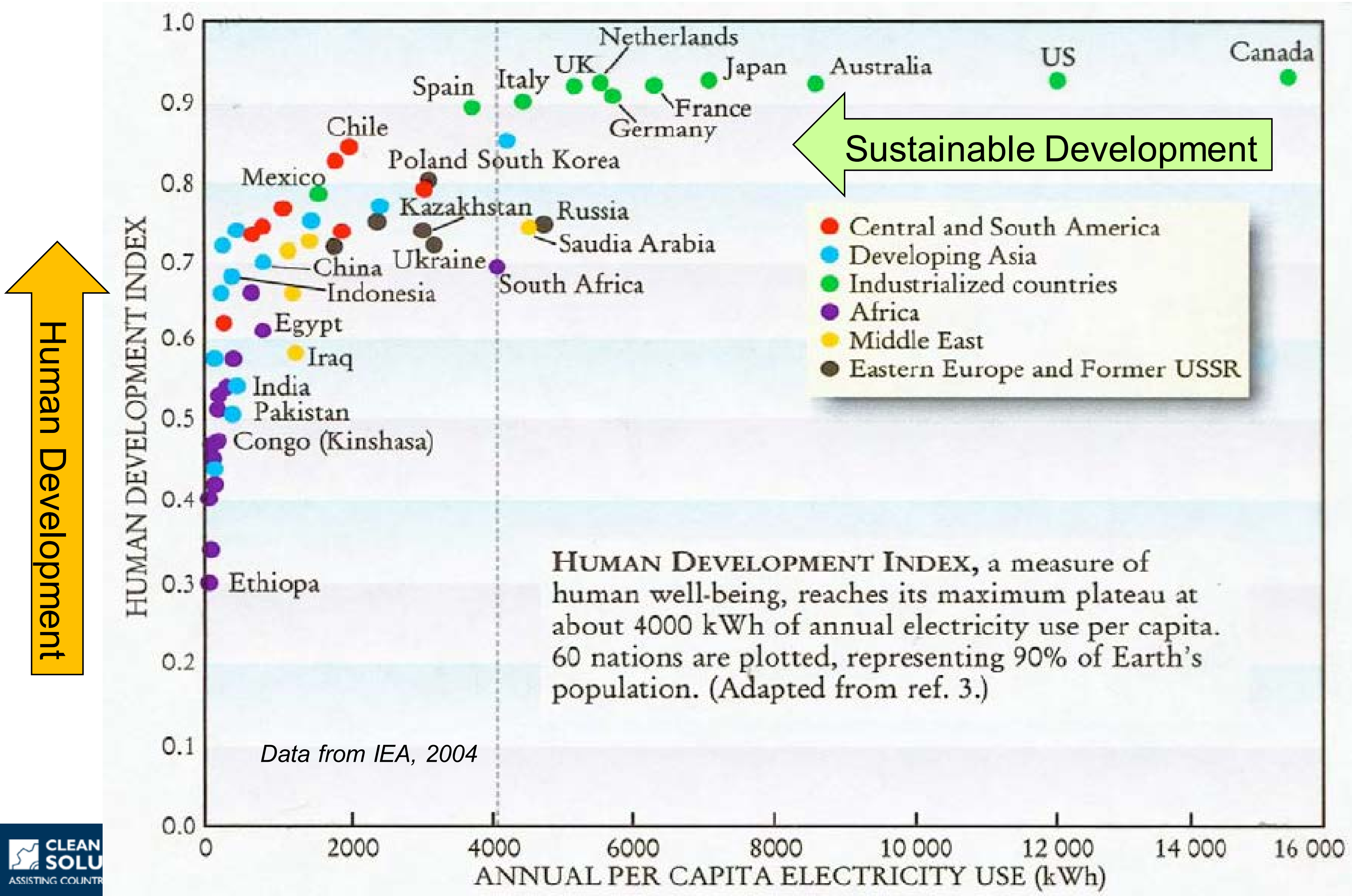


James Watt
(1736 - 1819)

Scottish inventor James Watt was a mechanical engineer who radically improved the steam engine.

- 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: $1\ kWh = 3,6$ MJ

HDI vs electricity consumption



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Electrical energy consumption per capita			
2016			
in kWh/year			
Norway	23.000	Greece	5.001
Canada	15.546	Italy	4.768
Finland	14.654	Malta	4.652
USA	12.984	Slovakia	4.652
Sweden	12.793	United Kingdom	4.652
Luxembourg	10.932	Portugal	4.536
Belgium	7.211	Bulgaria	4.071
Austria	7.094	China	3.927
France	6.629	Hungary	3.838
Germany	6.280	Croatia	3.722
Slovenia	6.280	Poland	3.489
Netherlands	6.164	Lithuania	3.373
Estonia	5.582	Latvia	3.256
European Union (28)	5.466	Romania	2.210
Denmark	5.464	India	806
Spain	5.356	Ghana	355
Czech Republic	5.350	Nigeria	144
Ireland	5.350	South Sudan	40
Cyprus	5.117	Haiti	39

446 kWh/month

Electricity 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

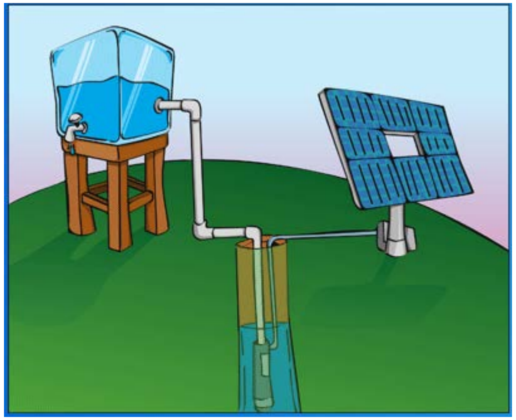
DC loads (mainly for off-grid applications):

- 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



DC water pumping system

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

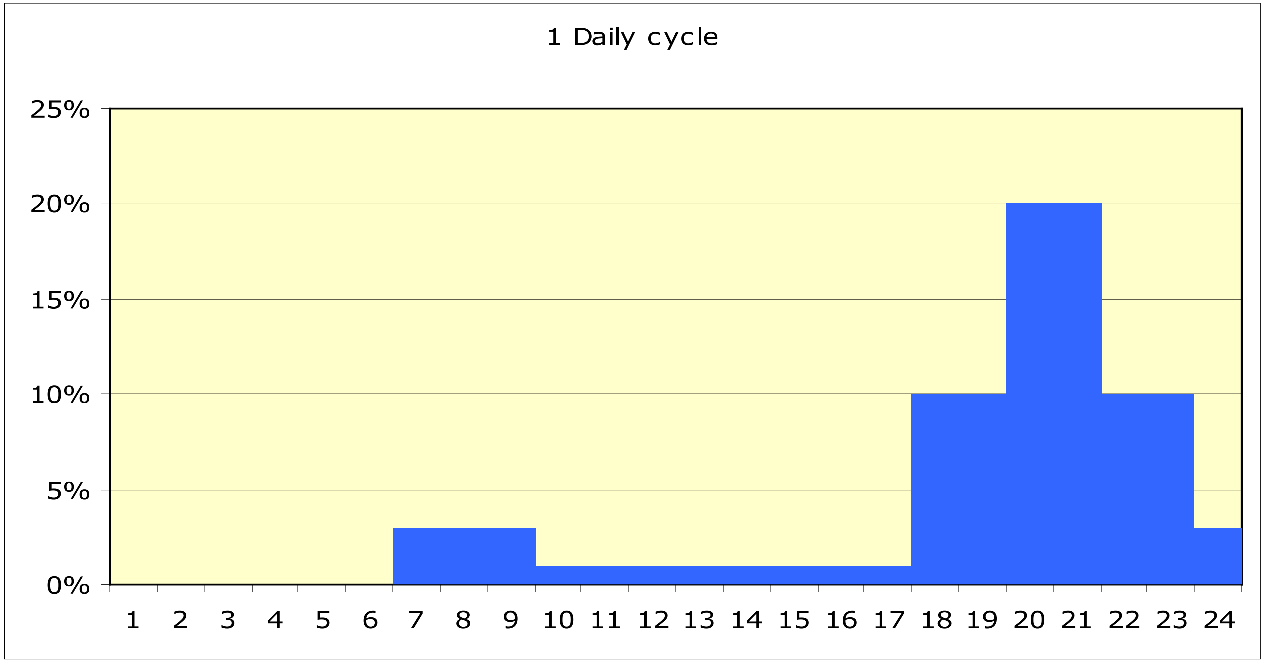
Motor starting currents are significant

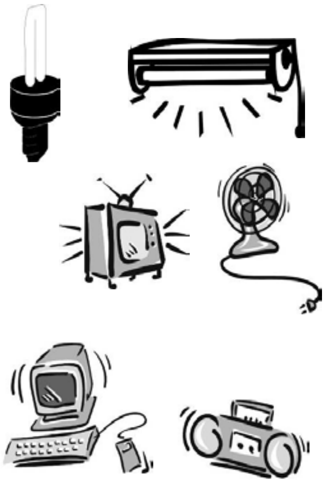
4. Heat-generating appliances

Cookers
Hair dryers

Types of loads

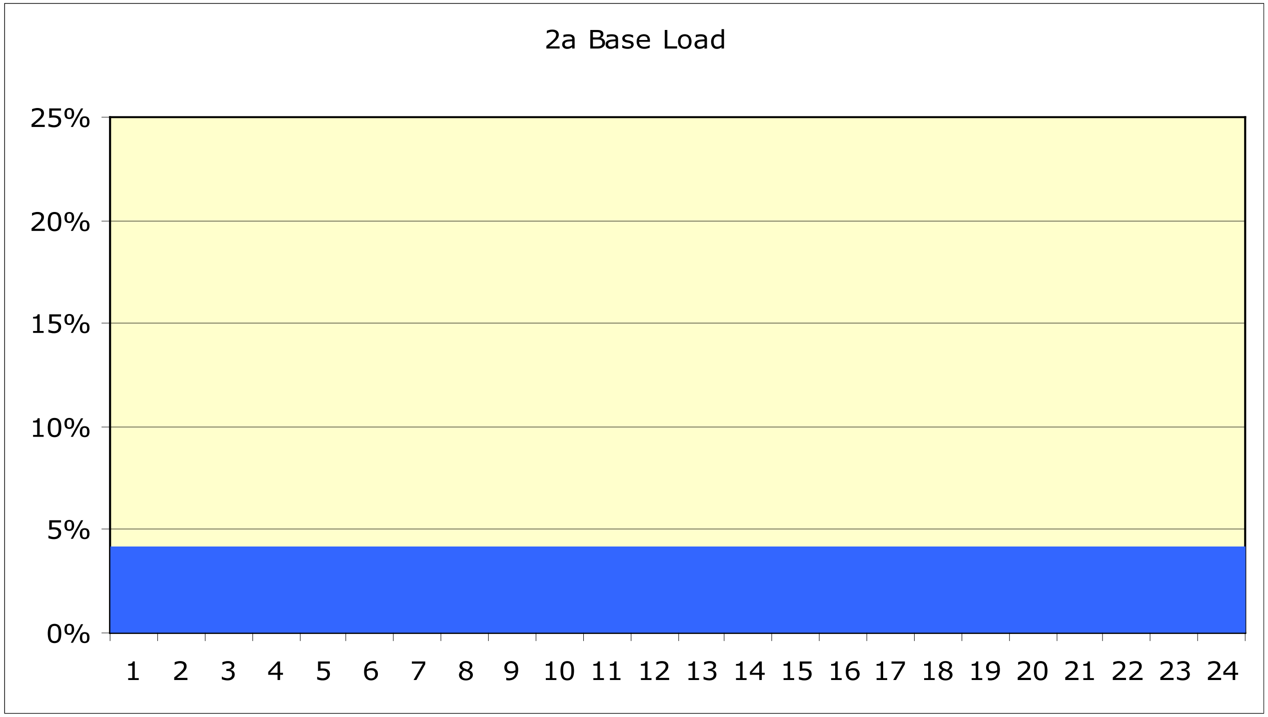
Several types within a Daily cycle

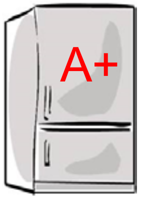




Types of loads

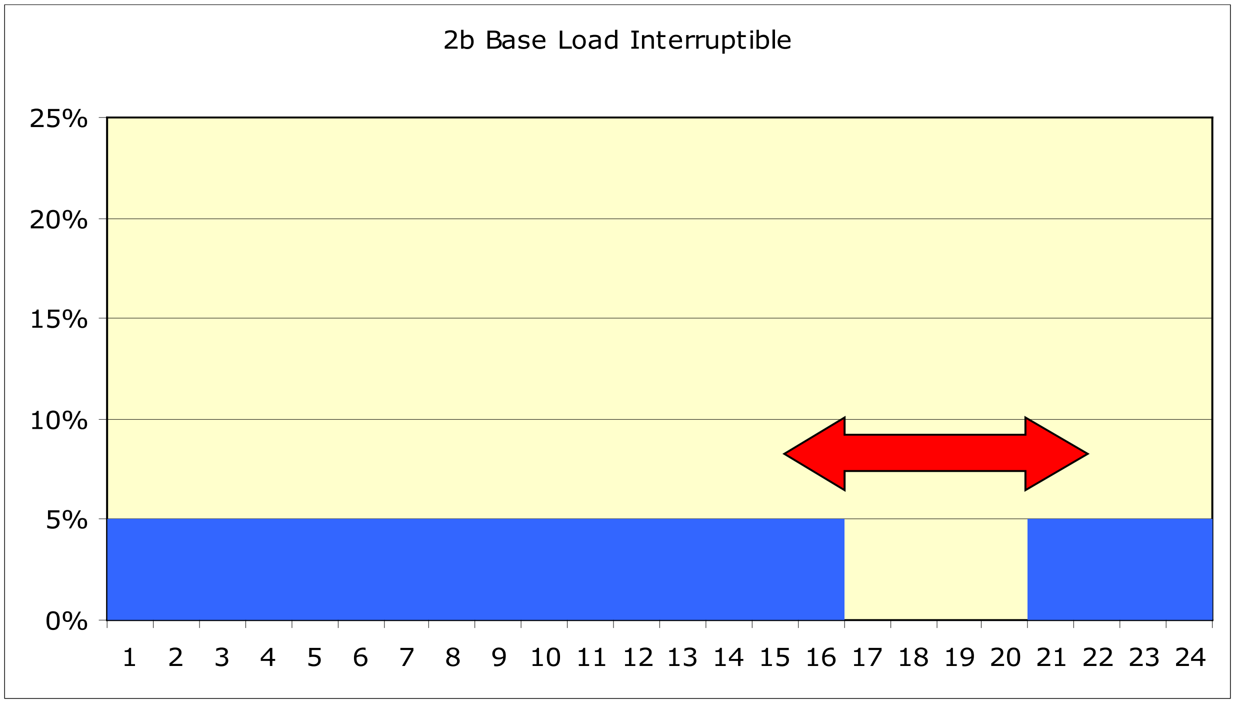
Base load

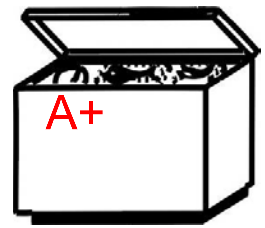


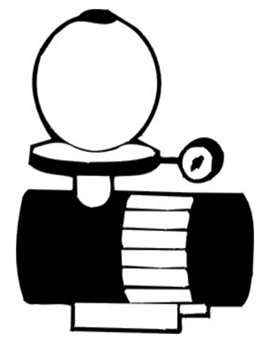


Types of loads

Base load interruptible

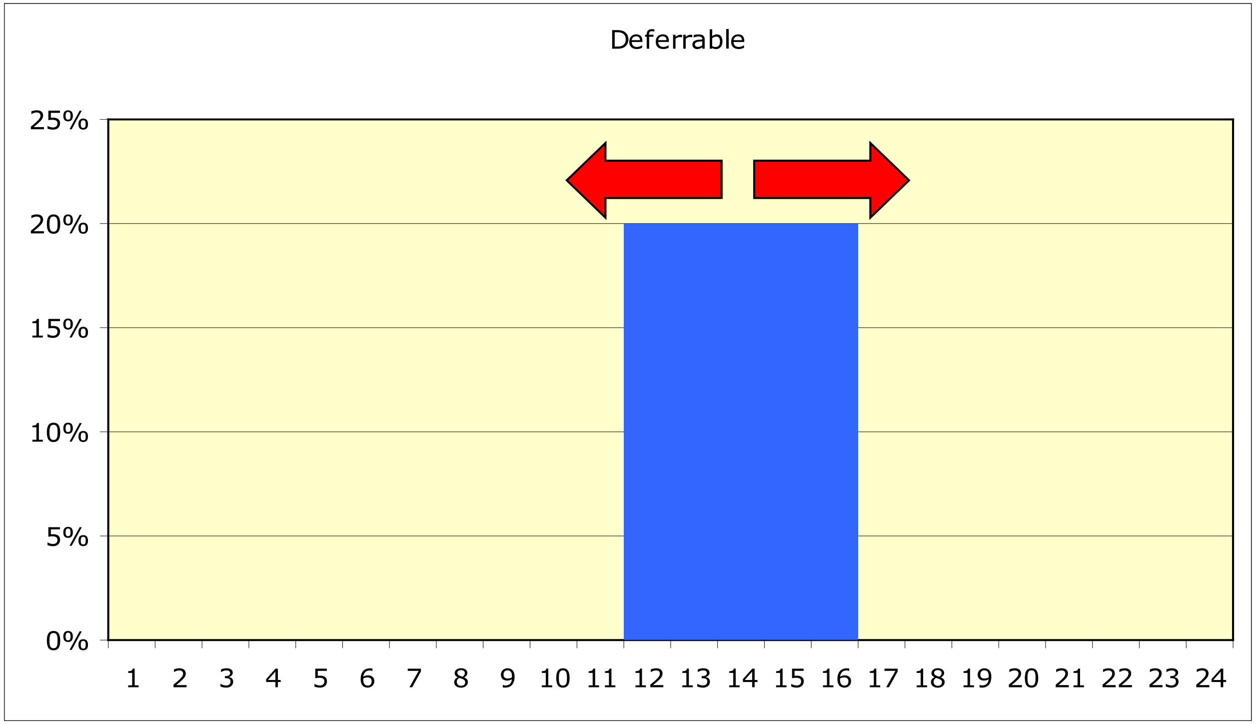






Types of loads

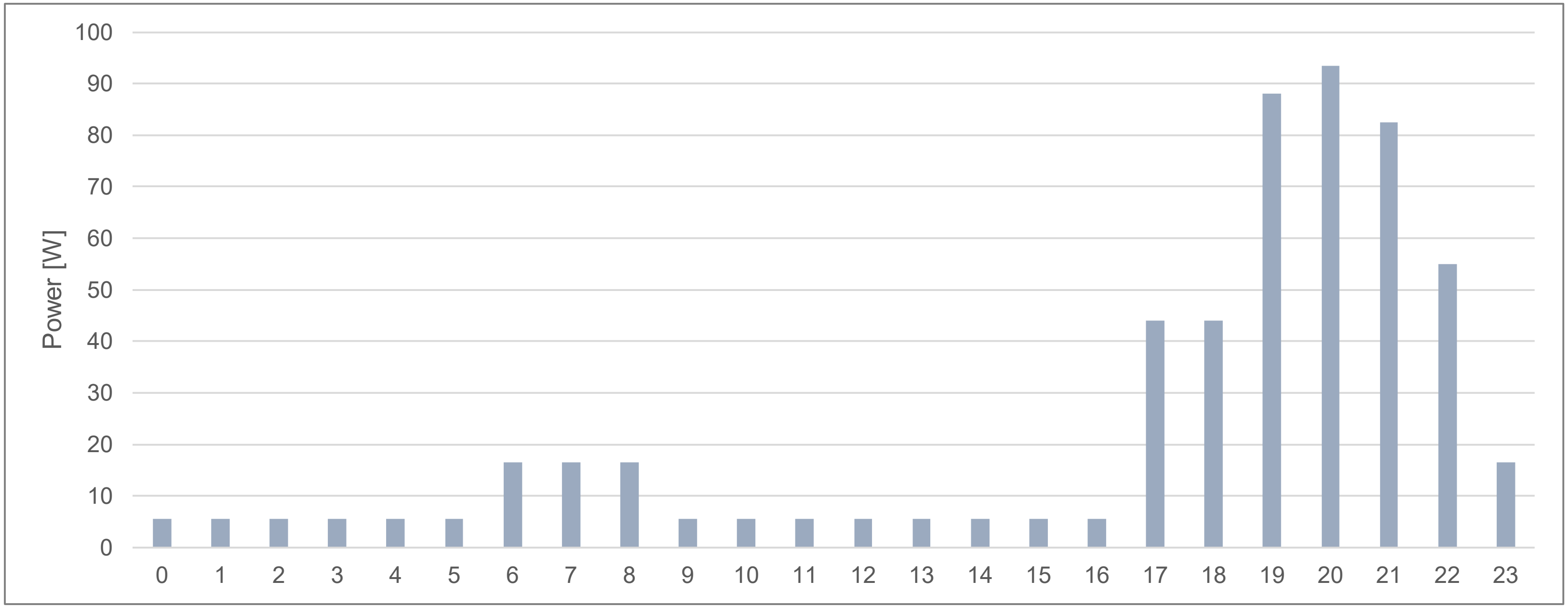
Deferrable



Types of demand - Residential

Typical residential load profile

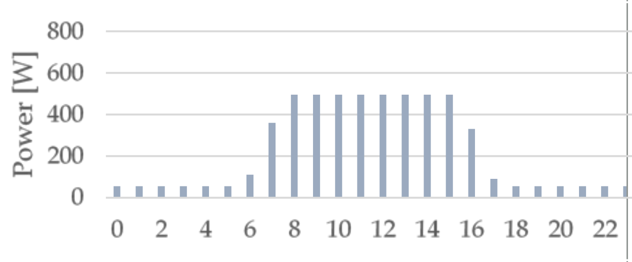
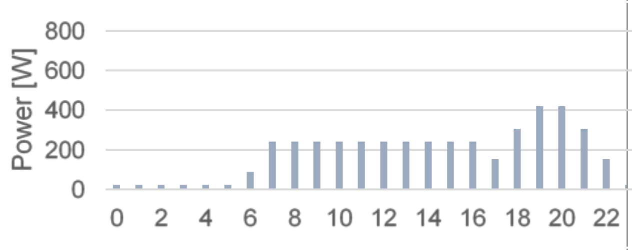
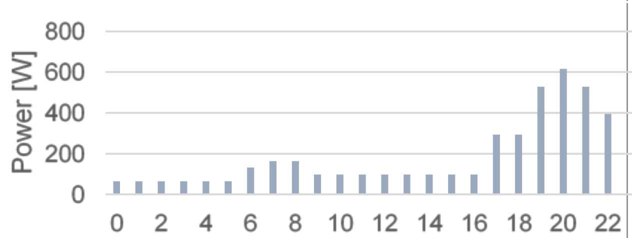
Peak in the morning and evening/night hours



Source: TTA

Types of demand - Commercial

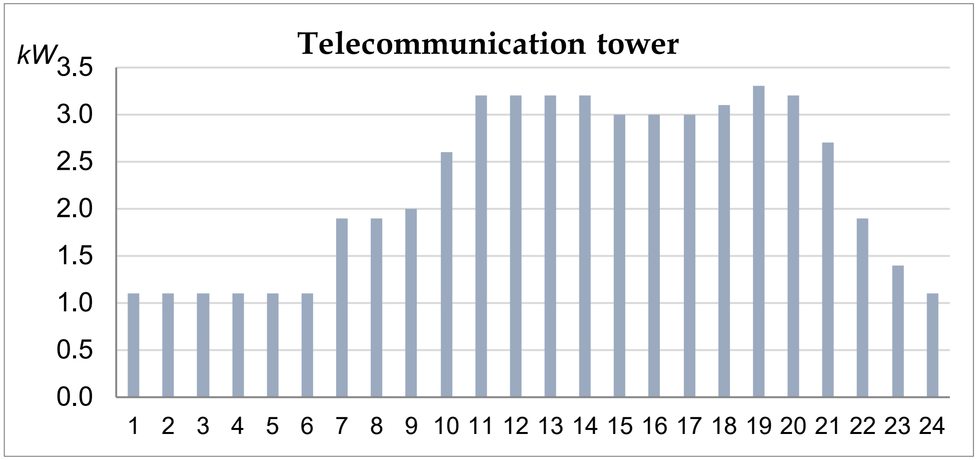
Typical commercial load profiles

Category	Share of connected Shops	EDA (Wh/day)	Load profile
SH-basic	50%	550	
SH-medium	40%	2,200	
SH-high	10%	4,400	

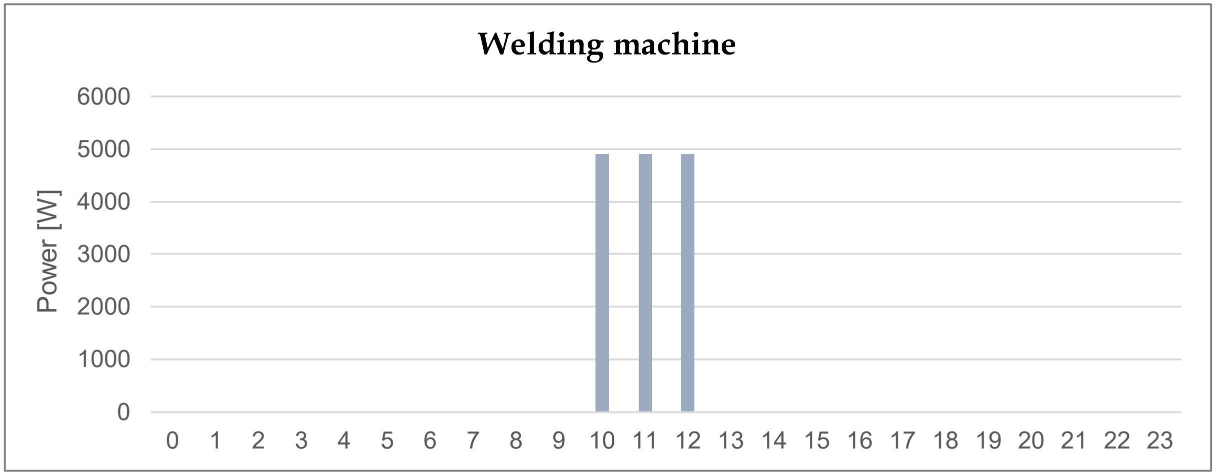
Source: TTA

Types of demand - Productive

Examples of productive load profiles



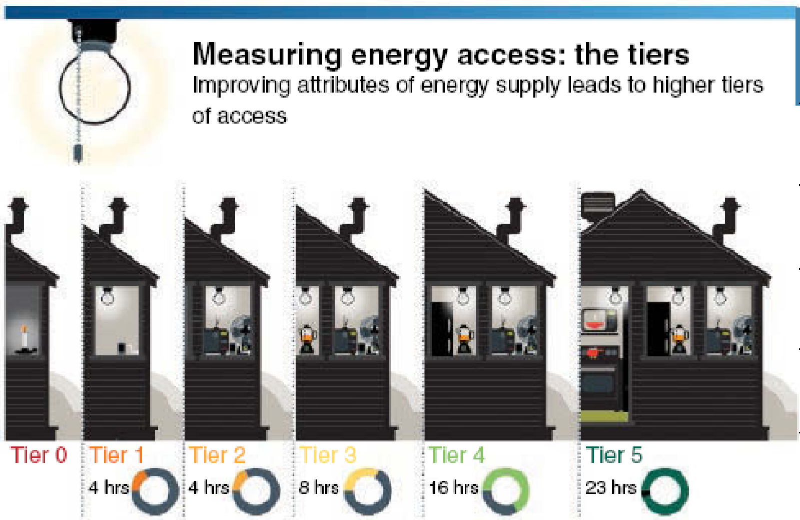
Source: TTA



Levels of demand in rural communities

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

The Multi-Tier Framework (MTF)



Load level	Indicative electric appliances	Capacity tier typically needed to power the load
Very low load (3–49 W)	Task lighting, phone charging, radio	Tier 1
Low load (50–199 W)	Multipoint general lighting, television, computer printer fan	Tier 2
Medium load (200–799 W)	Air cooler, refrigerator, freezer, food processor, water pump, rice cooker	Tier 3
High load (800–1,999 W)	Washing machine, iron, hair dryer, toaster, microwave	Tier 4
Very high load (2,000 W or more)	Air conditioner, space heater, vacuum cleaner, water heater, electric cookstove	Tier 5

Source: The World Bank, 2015

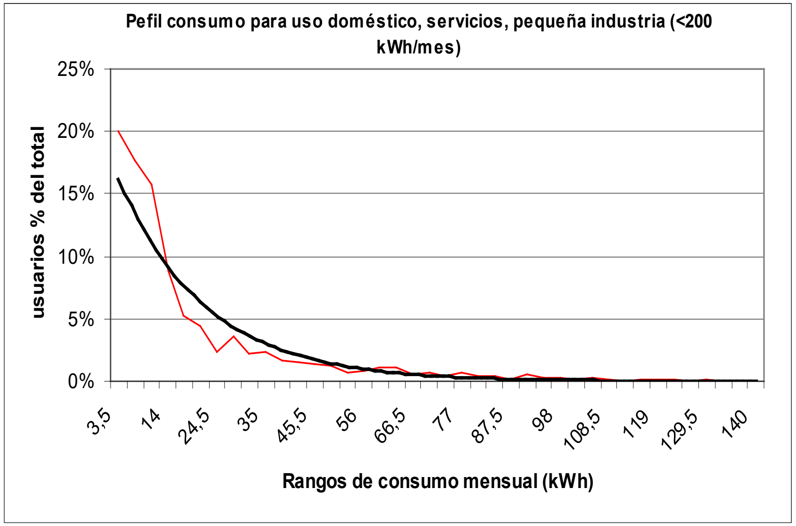
Demand: a critical factor for off-grid PV systems

Mitigation strategies:

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

ENERGY EFFICIENCY: MANDATORY IN ALL PROJECTS

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

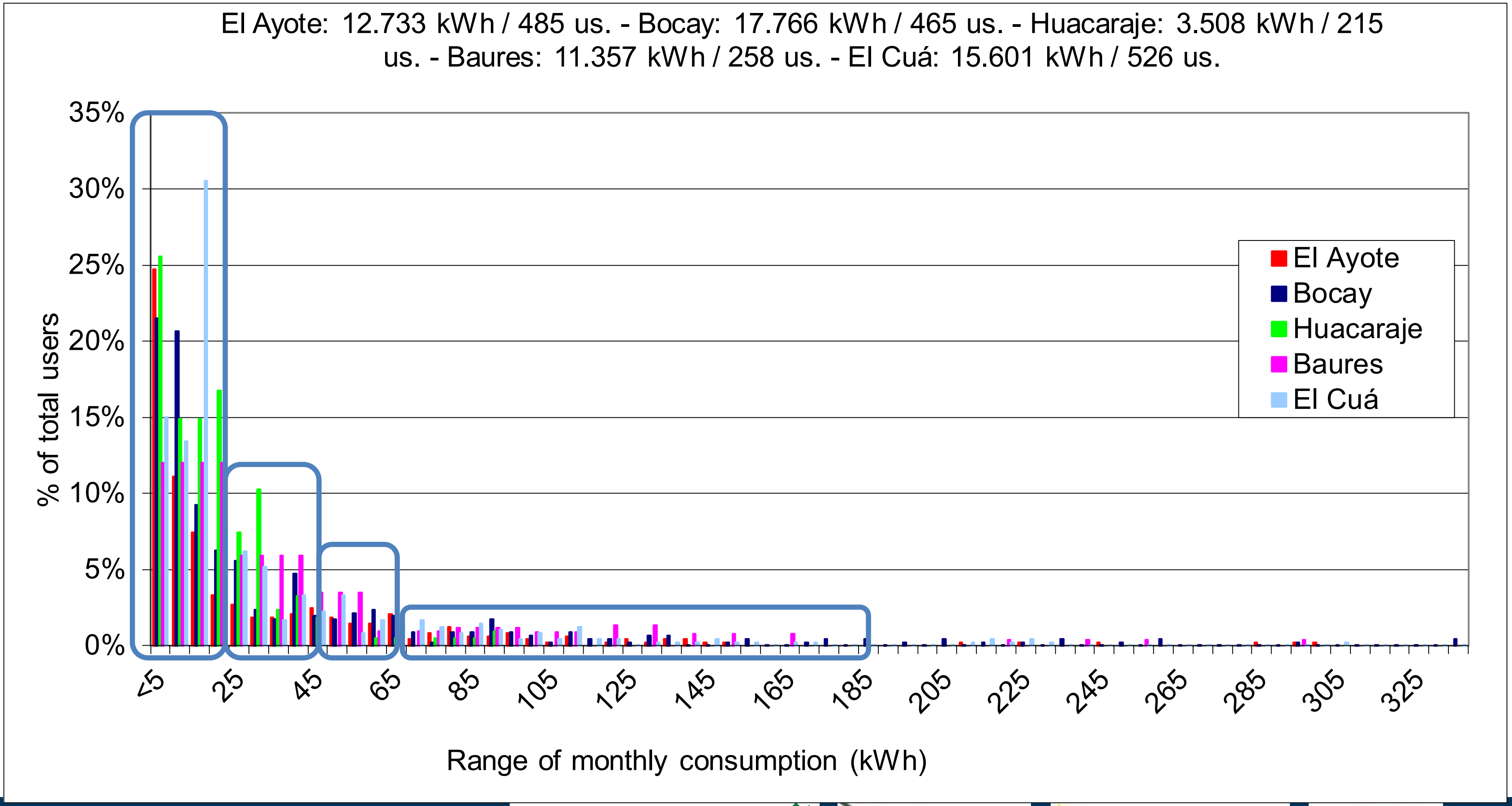
https://energypedia.info/wiki/Catalogue_of_Mini-Grid_Tools

http://www.minigridbuilder.com/

Data collection methods and techniques

2. Comparative demand characterisation

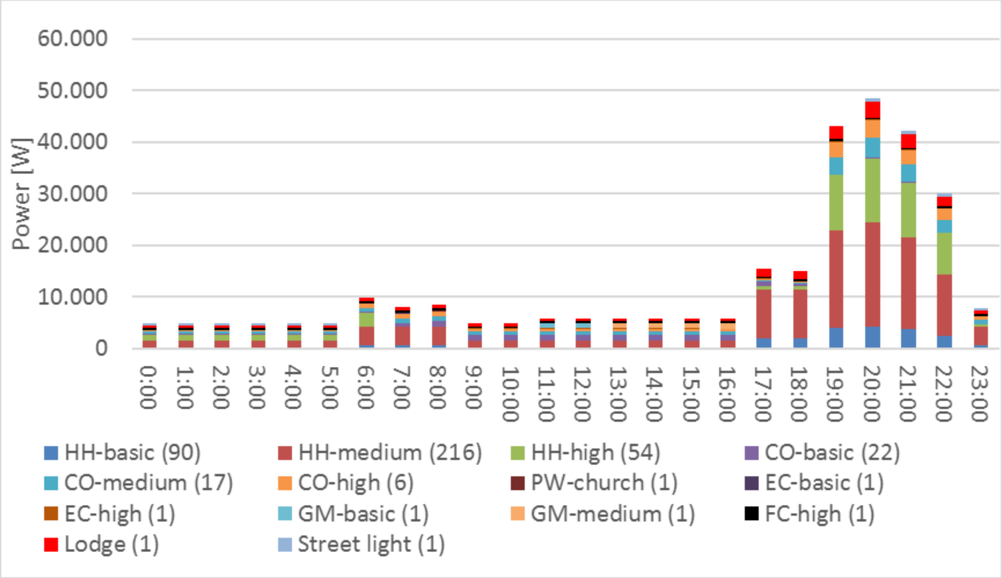
Assessment of load categories based on histogram of similar villages



Data collection methods and techniques

Demand survey results

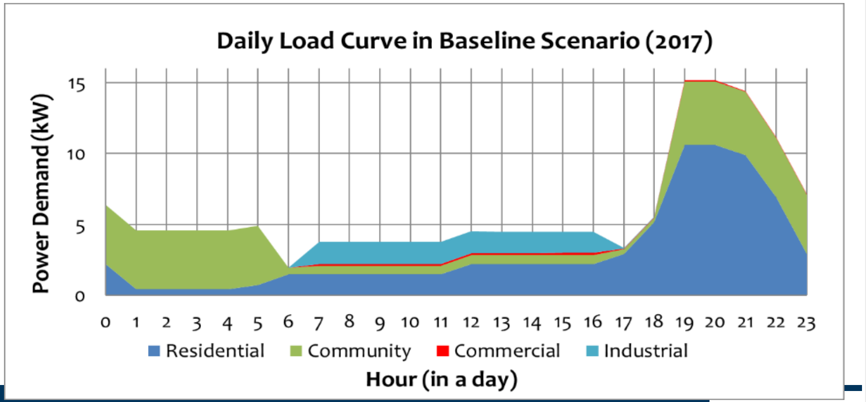
Type	Cat. 1	EDA (Wh/day)	Share	Cat. 2	EDA (Wh/day)	Share	Cat. 3	EDA (Wh/day)	Share
Households (HH)	HH-basic	275	25%	HH-medium	550	60%	HH-high	1,650	15%
Commercial (CO)	CO-basic	550	50%	CO-medium	1,650	38%	CO-high	3,850	13%
Welding machines (WM)	WM-basic	14,850	100%						
Places of worship (PW)	PW-mosque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

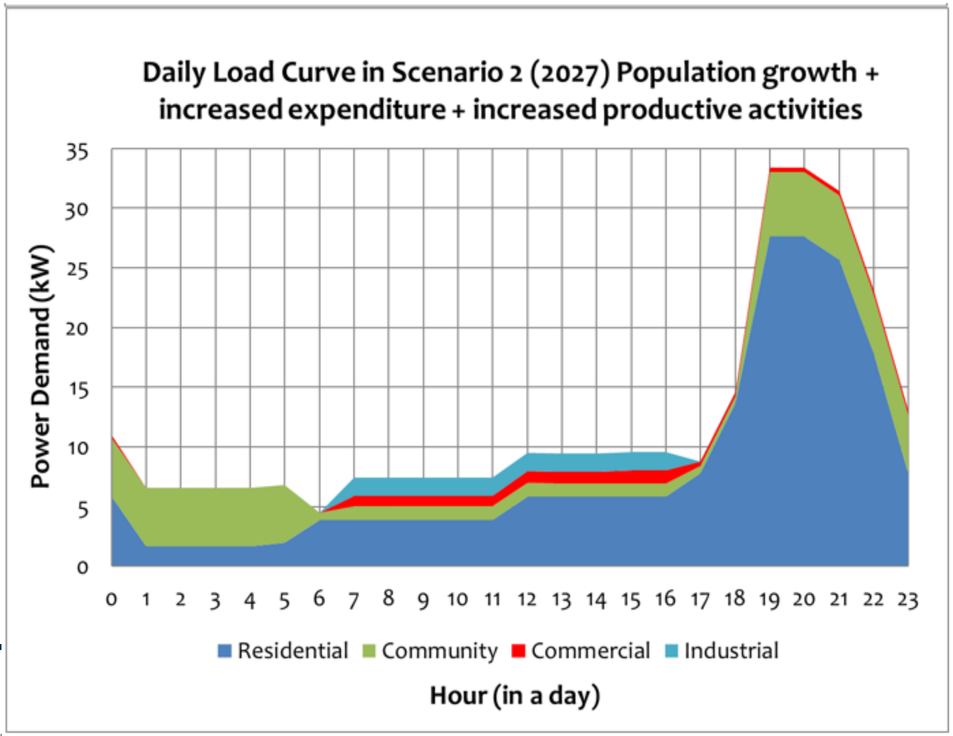


Source: TTA

Projections, Scenarios

Community	Electricity (kWh/month)			Power peak (kW)		
	Baseline	Scenario 1	Scenario 2	Baseline	Scenario 1	Scenario 2
Seneso	4385	6300	9340	15.1	23.5	33.5
Boniafo	3443	5595	8126	12.7	22.5	29.7
Bompa	5422	9602	12972	21.2	40.4	53.4
Jaman Nkwanta	5174	8822	11683	18.9	35.8	47.3
Nakpaye	2938	4076	6147	8.4	13.5	18.1





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

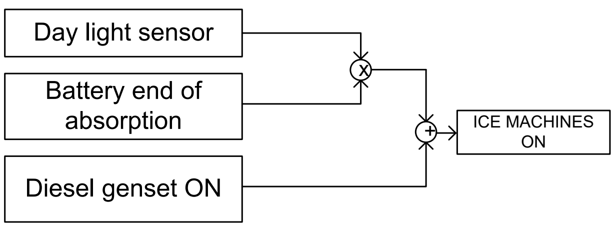
Methods

- Price incentives
- Automatic disconnection
- Energy efficiency

Demand side management

Example: Monte Trigo mini-grid, Cape Verde

Deferrable loads



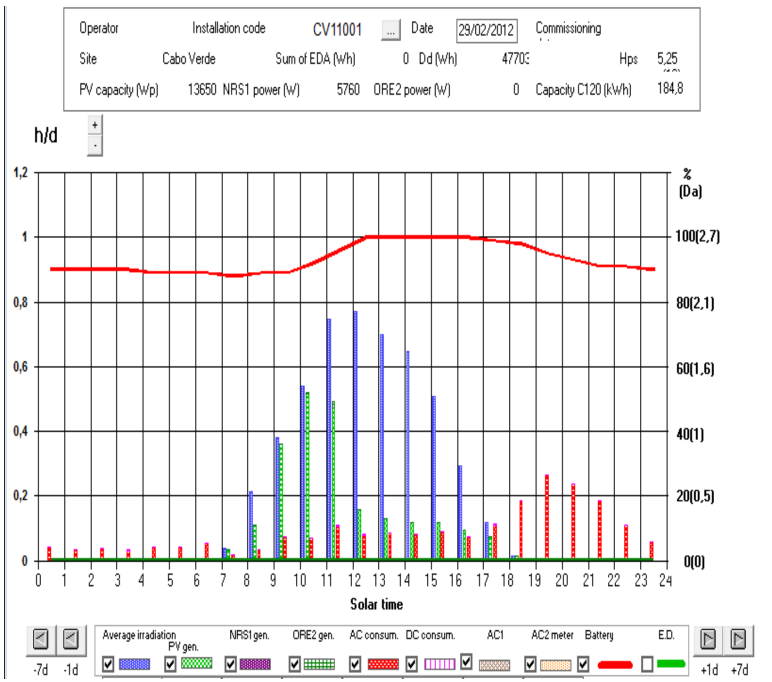
Periodically deferrable load: Ice-making machine

On when excess energy is available

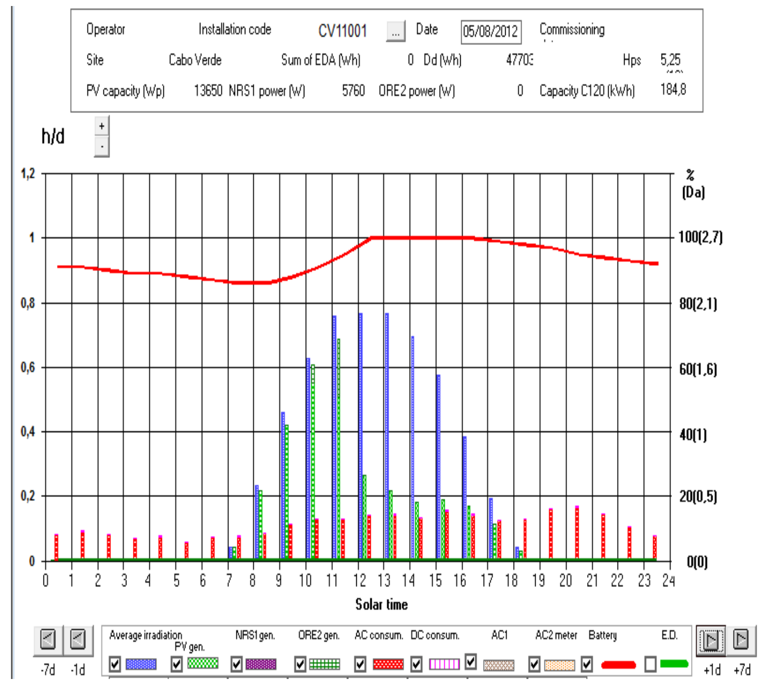
Demand side management

Example: Monte Trigo mini-grid, Cape Verde

Load shifting



February 2012

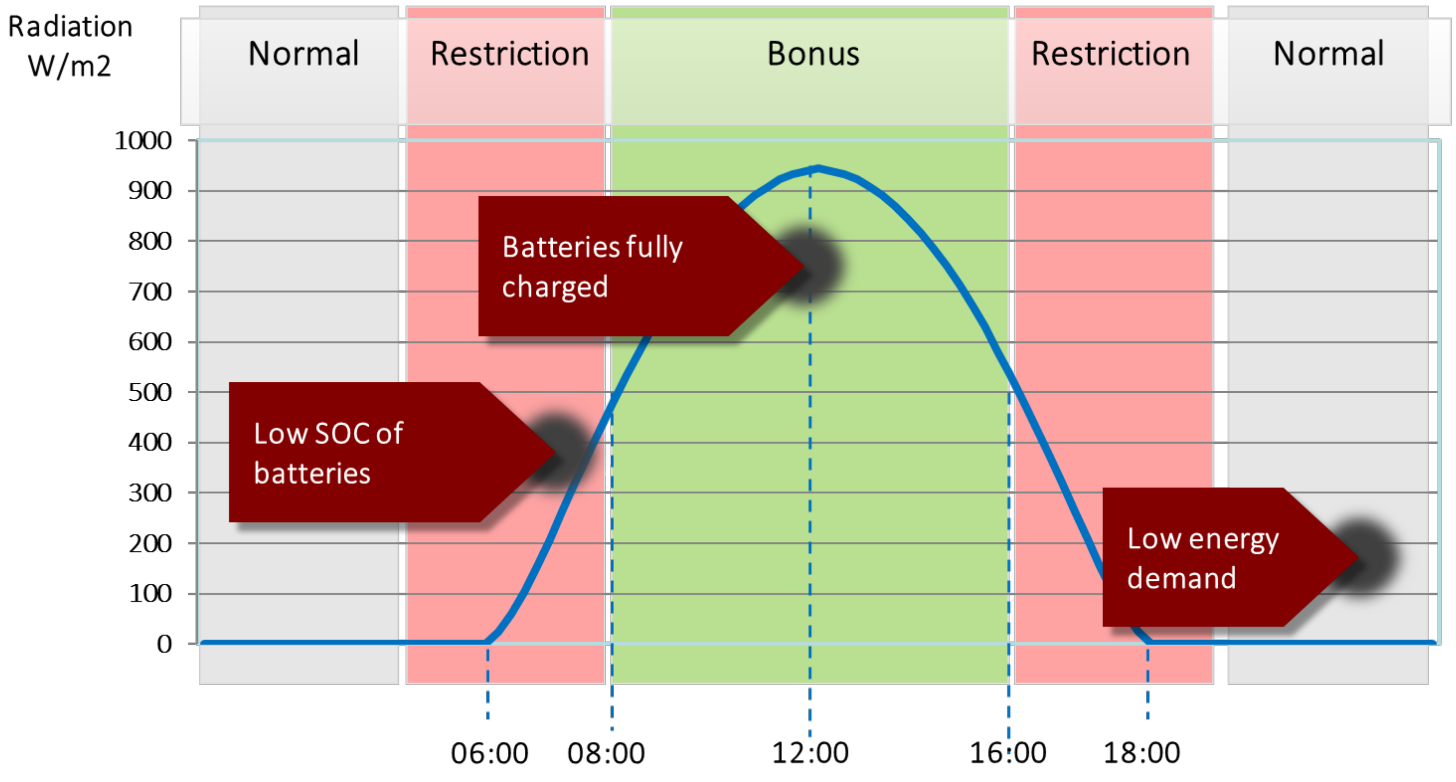


August 2012

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

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Thanks for your attention!

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