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Rural PV micro grids in Africa

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Trama TecnoAmbiental (TTA)

- SME Founded in Barcelona en 1986
- Independent Consultants in distributed Renewable Energy
- Consultancy, engineering, research, project management, social aspects, financial, …
- Since 1989: Off-grid rural electrification practitioners
- Design and Project management of RE-hybrid micro-power plants and micro grids for rural electrification in southern Europe, Africa, Latin America, Oceania …

Current situation in Africa

- Low population density and low demand in electricity
- Remoteness thus high costs of grid extension and connection
- High losses on transmission lines and high operation and maintenance costs

Current situation in Africa

- **Majority of villages and households not connected to the grid**
- **Existing micro grids running with Gensets (many are not working)**

Essential to bring electricity for basic needs (high value for the first kWh)

Table B1: Electricity Access in 2005: Regional Aggregates

	Population million	Urban population million	Population without electricity million	Population with electricity million	Electrification rate %	Urban electrification rate %	Rural electrification rate %
Africa	891	343	554	337	37.8	67.9	19.0
North Africa	*153*	*82*	*7*	*146*	*95.5*	*98.7*	*91.8*
Sub-Saharan Africa	*738*	*261*	*547*	*191*	*25.9*	*58.3*	*8.0*
Developing Asia	3 418	1 063	930	2 488	72.8	86.4	65.1
China and East Asia	*1 951*	*772*	*224*	*1 728*	*88.5*	*94.9*	*84.0*
South Asia	*1 467*	*291*	*706*	*760*	*51.8*	*69.7*	*44.7*
Latin America	449	338	45	404	90.0	98.0	65.6
Middle East	186	121	41	145	78.1	86.7	61.8
Developing countries	**4 943**	**1 866**	**1 569**	**3 374**	**68.3**	**85.2**	**56.4**
Transition economies and OECD	**1 510**	**1 090**	**8**	**1 501**	**99.5**	**100.0**	**98.1**
World	**6 452**	**2 956**	**1 577**	**4 875**	**75.6**	**90.4**	**61.7**

Rural Electrification: political, social and technical challenges

- Access to electricity must rank high on the development agenda
- Access to electricity should follow a reliable long term strategy and the legal framework must allow for private and local initiatives
- A close dialogue between policymakers, the private sector and representatives of rural communities needed
- Specific and adapted technical solutions (bottom-up approach answering to communities needs)

Appropriate financing and administrative schemes for rural electrification

Financing Policies

➢ Legitimate public investment needed (could be reduced in the long run)

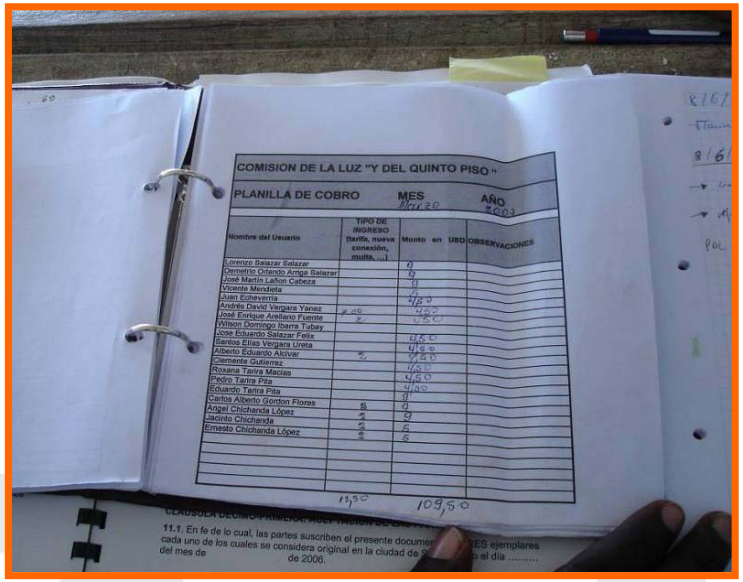
➢ Need of tailored tariff schemes

Administrative Aspects

➢ micro Energy must be defined as a <u>service rather than an installation</u>: Needs a **management model** with at least:

- Clear definition of responsibilities
- O&M service of the plants -> local technicians and training
- Collection of fees and transparent managing of the revenue -> Operator training

➢ Jointly work with electricity consumers on the possibilities and limitations of their power supply

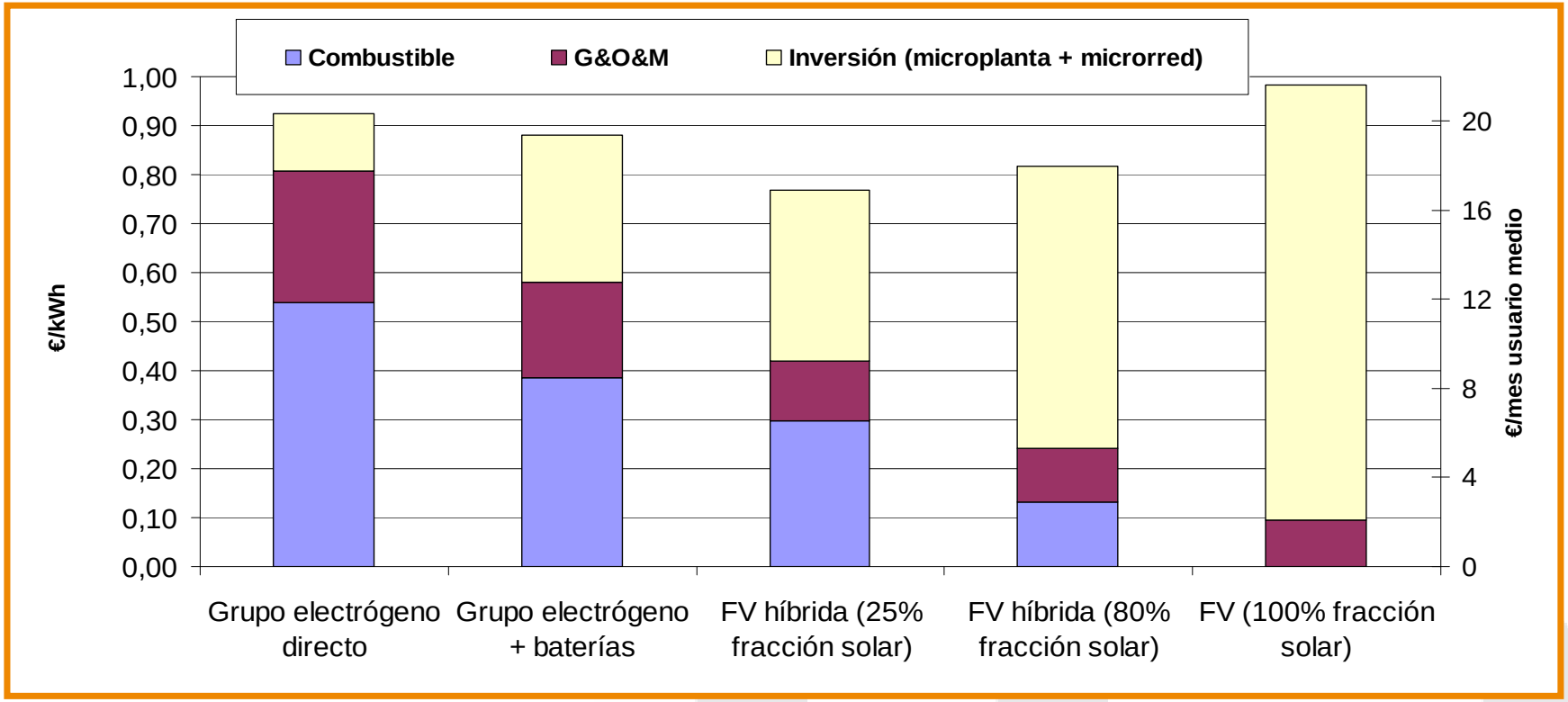


What is a rural PV hybrid micro grid?

- A combination of different but complementary energy generators based mainly on photovoltaics or mixed technologies (PV-genset, PV-WGT-genset, etc)
- Multi user solar micro grids (MSG) can provide steady community-level electricity service, such as village electrification, offering also the possibility to be upgraded through grid connection in the future
- Typically total installed power up to 100 kW (according to IEC)
- Distribution line in Low Voltage (up to 1.000V) (only distribution)
- Single or 3-phases

Rural PV Hybrid Micro Grid in West Bank, Palestine

PV Hybrid micro grids more sustainable than fossil fuel electricity generation



Levelized costs for PV and Diesel technologies in microgrid for 340 users in Peru

(D.R. 5%, Diesel: 1 €/l)

http://www.esmap.org/filez/pubs/620200785630_Peru_Solar-Diesel_Amazon_111-07.pdf

Rural micro grids vs. individual solutions

Technology	Advantages	Shortcomings
Small RE individual power plants 	• High flexibility. • Easy to move and share • Load is managed by the user on a day to day basis • Black outs affect only one user	• Limited surge power capacity • Maintenance and repair service complex to organize in rural areas • Monitoring individual plants can be expensive and difficult
Micro grid fed by RE/ Hybrid power plant 	• Improved quality (surge power, load shedding, etc) • Lower investment for compact villages • Efficient maintenance • With genset backup: Power supply also during unfavourable weather conditions	• Higher technological and organizational complexity • If there is a plant failure, everybody is cut off • Social rules required to distribute energy availability • Local management required

- **Challenge: sharing the energy available without conflicts**
- **Energy distribution and metering issues!**

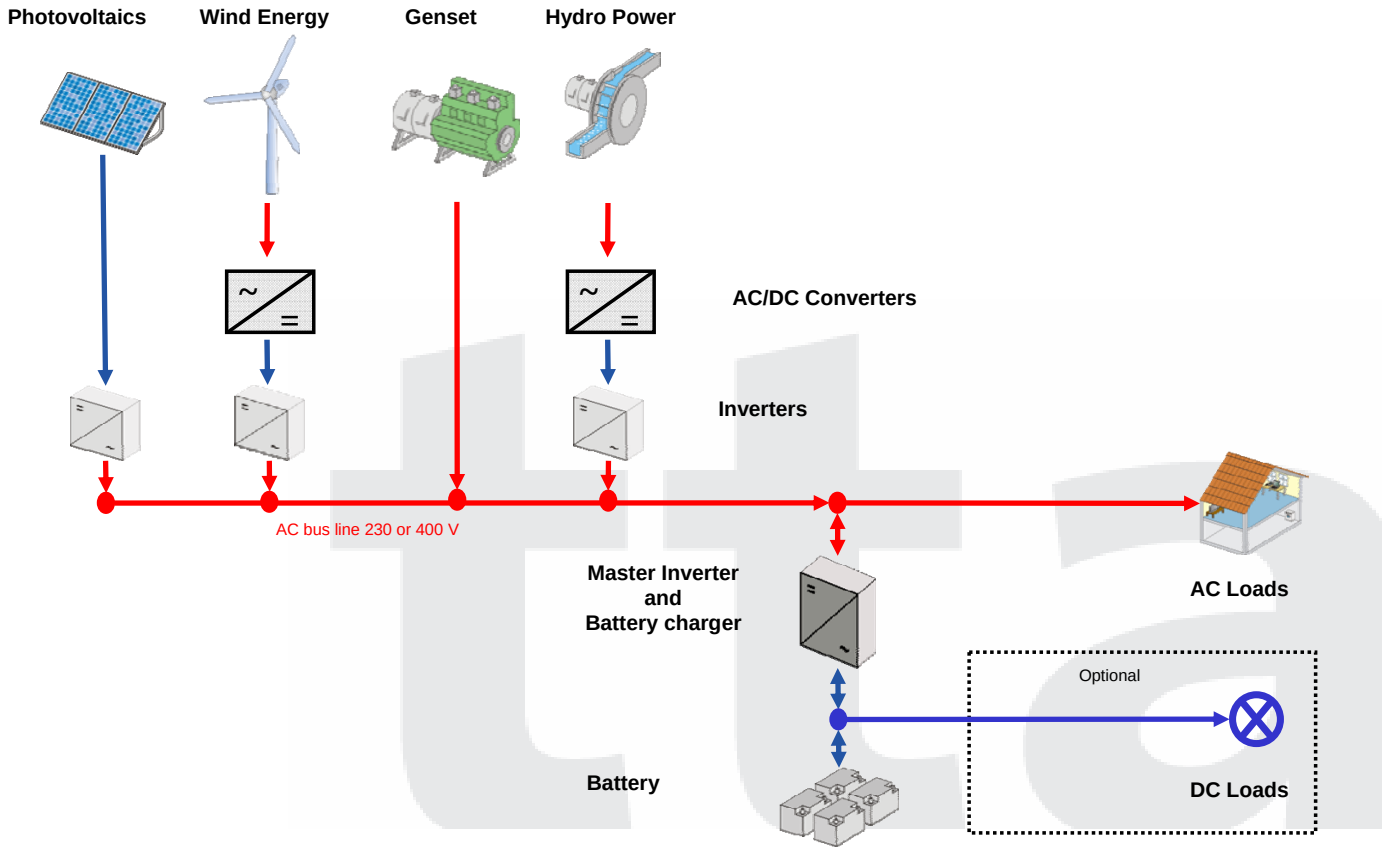
Classification of Hybrid Micro Grids AC coupling

All electricity generators are connected to the AC line.

AC generating components may be directly connected or may need a AC/AC converter to enable stable coupling.

A bidirectional master inverter controls the energy supply for the AC loads and battery charging.

DC loads can be optionally supplied by the battery.

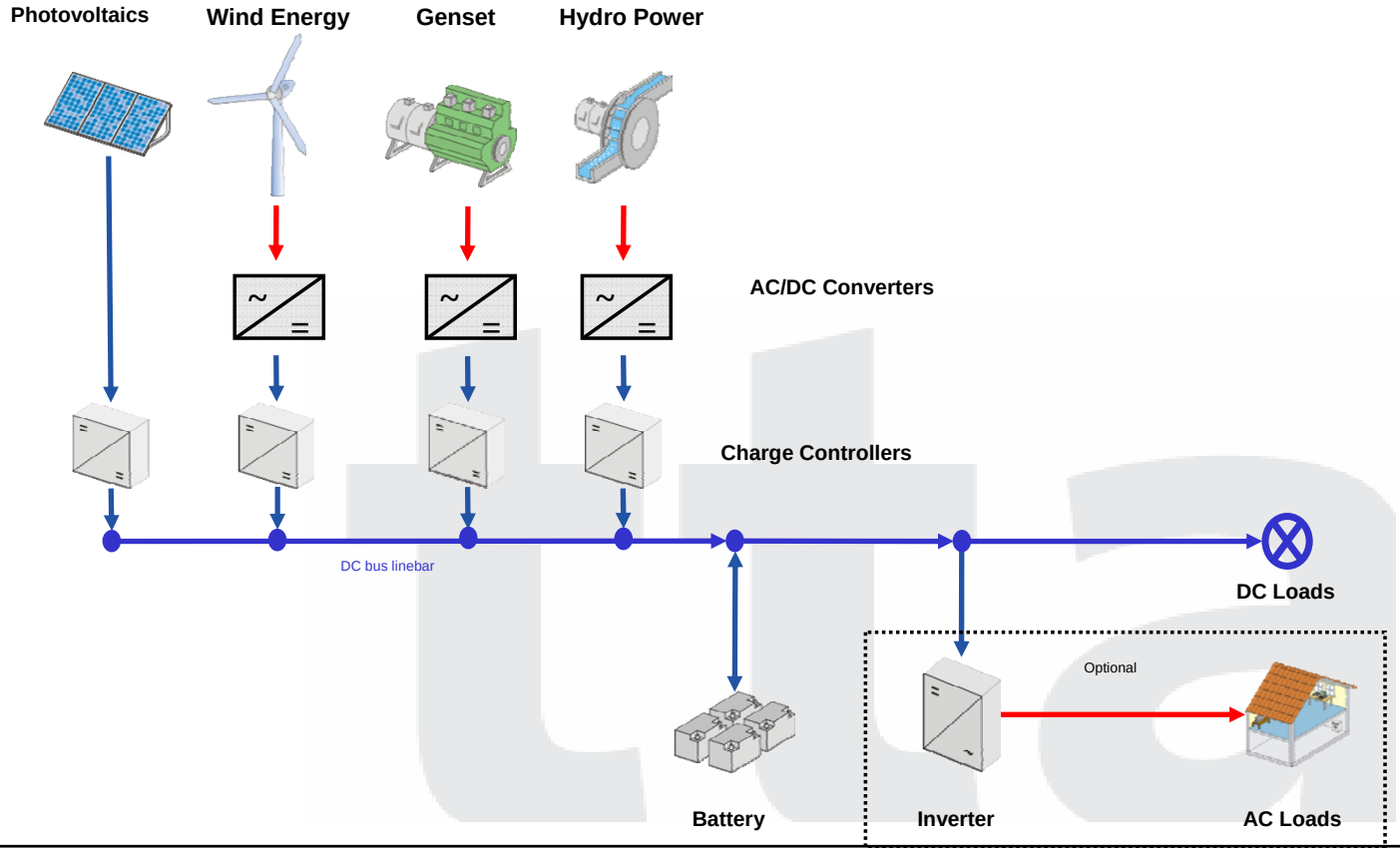


Classification of Hybrid Micro Grids DC coupling

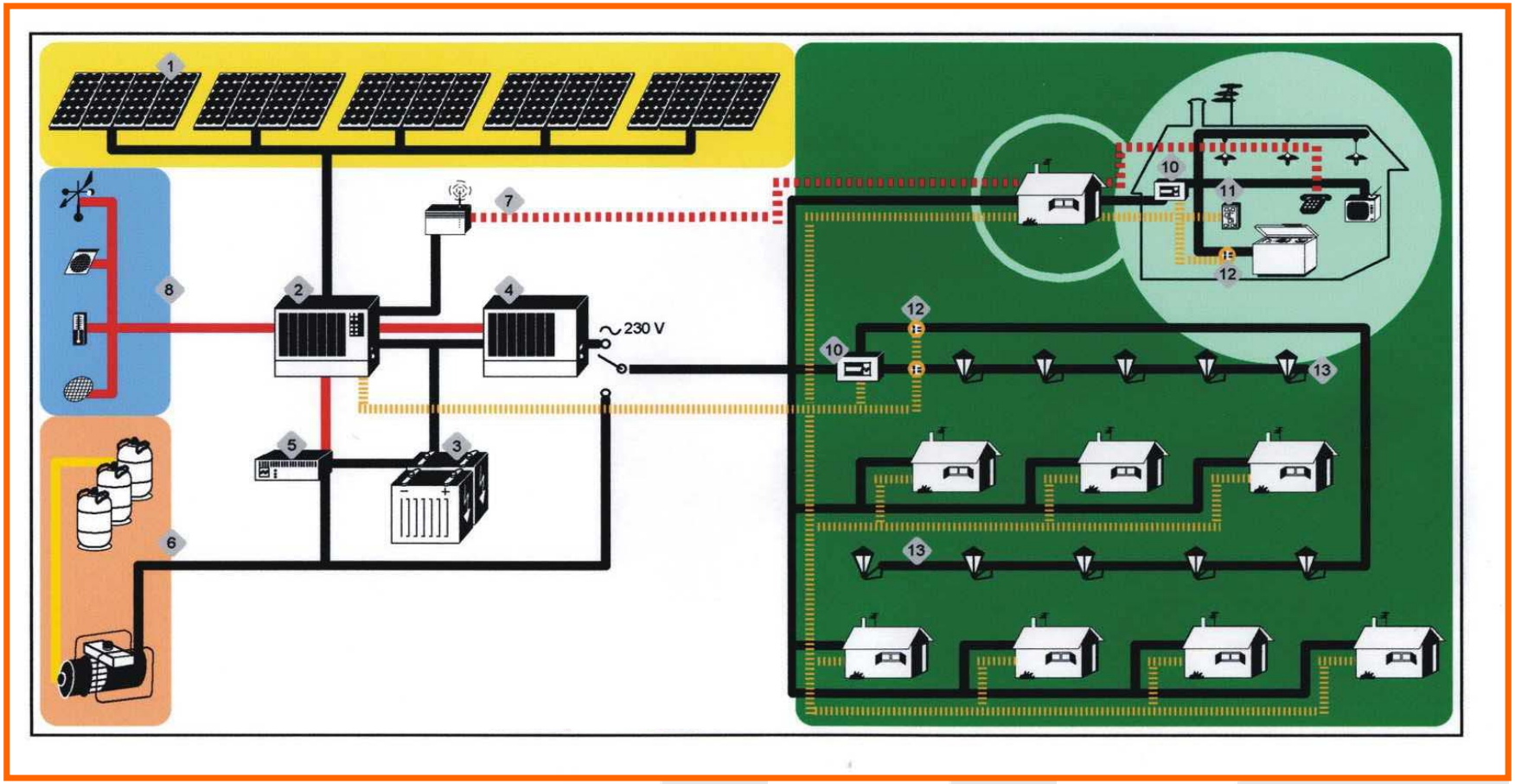
All electricity generators are connected to a DC bus bar from which the battery is charged.

AC generating components need an AC/DC converter.

The battery, protected from over charge and discharge by a charge controller, supplies DC loads and AC loads through the inverter.



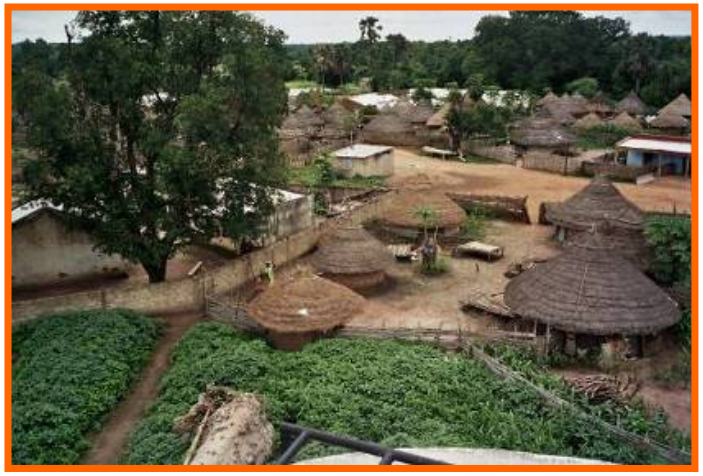
MSG (Multi user Solar Grid) up to 150 kWh/day

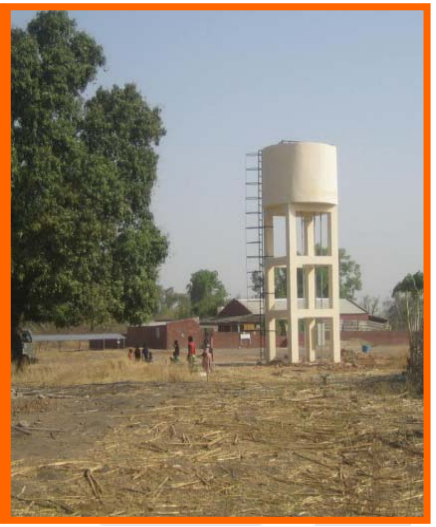


Typical layout: DC coupled micro power plant + AC single phase grid + individual energy allowance

Examples MSG in Africa (i)

Diakha Madina, Senegal



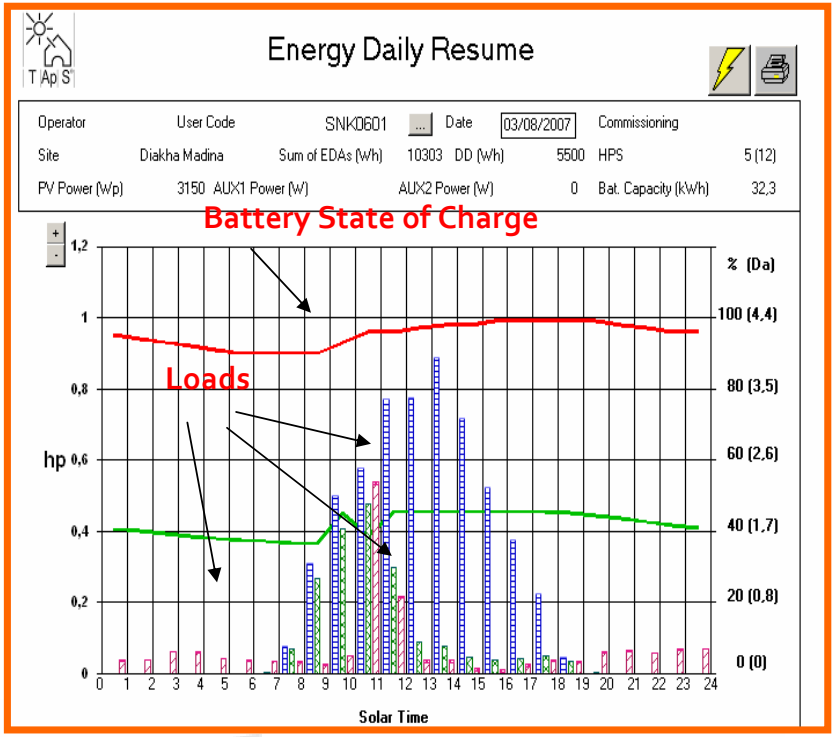


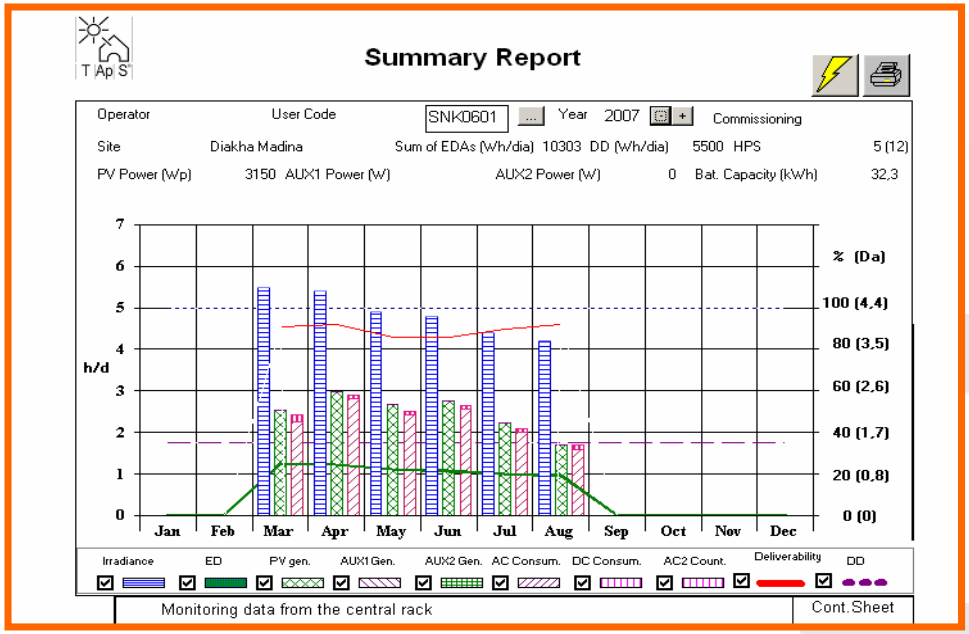
Diakha Madina, Senegal

PV GENERATOR	
PV installed capacity	3.150 Wp
PV Module model	PW750 75 Wp 12V
Nº PV modules	42
Orientation/Inclination	0º S / 10º S
PV Area	46 m²
ENERGY	
Rated Energy Output (Wh/day)	4.803
Irradiation (ĞpHp)	5 HPS
Month of design	December
BATTERY	
Nº cells	24
Battery type	Tudor 6 OPzS 420
Capacity (C100)	672 Ah
Autonomy	4 days
CHARGE CONTROLLER	
Regulation capacity	4.000 Wp
Mode of charge control	MPP Tracker
INVERTER	
Input / Output voltage	48 V DC / 230 V AC
Nominal Power	3.600 W
DC/DC Converter (12 V)	10A máxima de corriente
Harmonic distorsion	< 2,5%
PUBLIC LIGHTING	
Number	2
Type of lamp	70 W / electronic ballast
WATER PUMP	
Power of the pump	1.100 W
Flow	5m³/h
Depth	49 m
Height of the tank	7 m
Tank capacity	20 m³
BACK-UP GENSET	
Nominal power	4,2 kW single phase
Fuel	Diesel

Operation Monitoring

- Monitoring
  - Battery SOC, PV generation, AC loads, Solar radiation
- Main results:
  - Excellent average state of charge of the battery
  - Good value for the Performance Ratio
  - No water supply interruption



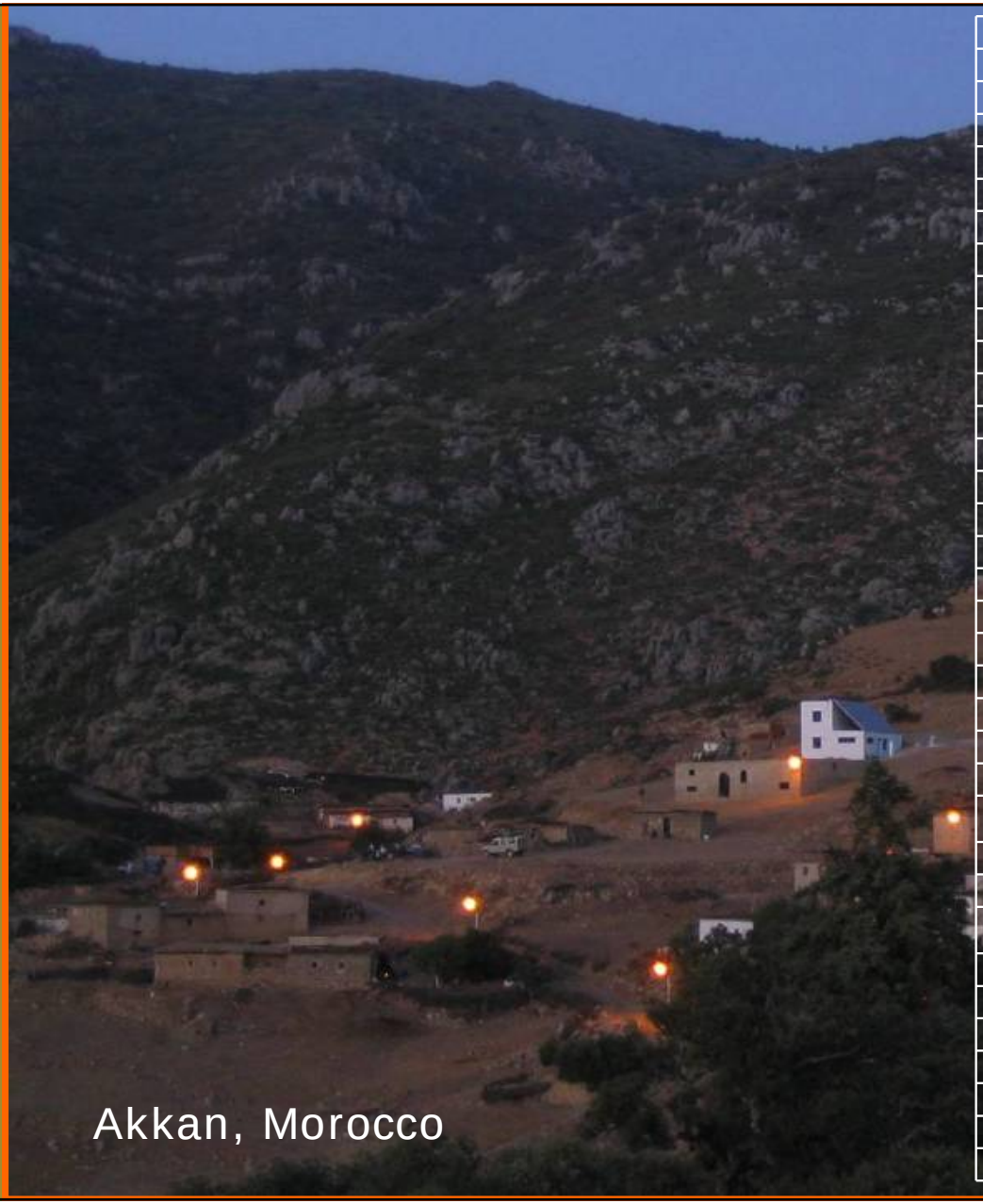


Load and applications:

- Health centre
- Water pump
- Public lighting

Examples MSG in Africa (ii)

Akkan, Morocco



Akkan, Morocco

PV HYBRID POWER PLANT	
PV GENERATOR	
Installed PV capacity	5.760 Wp
Module type	80 Wp 36 cell – mono crystalline
Number of modules	72
Inclination / orientation	43º / +5º S
PV CHARGE CONTROLLER	
Rated power	6.000 Wp
Control algorithm	MPPT - Boost
BACK UP GENSET	
Rated power	8,2 kVA single phase
Fuel	Diesel
BATTERY	
Number of elements (voltage)	24 (48V)
Model	Hawker 2AT1500
Capacity (C100)	1.500 Ah
Autonomy	4 days
INVERTER	
Voltage input / output	48 V DC / 230 V AC
Rated power	7.200 W
Harmonic distortion	< 2,5%
ELECTRICITY DISPENSER – METER	
Input	230 V AC 50 Hz
Maximum current	10 A
Algorithm	Configurable Daily Energy Allowance
STREET LIGHTING	
Number of lamps	13
Type	70 W hp sodium / 2 level ballast
Total power - high	910 W
Total power - low	683 W
INDIVIDUAL DAILY ALLOWANCES	
Households 275 Wh/day	23
Households 550 Wh/day	3
School 550 Wh/day	1
Mosque 550 Wh/day	1

Demand Segmentation

	Household "very low"	Household "low"	Public lighting	Community buildings
Type of use	• Low power of receivers • Slim rigid load profile (P1)	(same as category "very low" but more hours – no refrigerator) • Low power of receivers •Slim rigid load profile (P1)	Evening street illumination 13 Lamps – 70W hp sodium/ dual level	School, Mosque and community building • Low power of receivers
Maximum power	$P \leq 100$ W	$P \leq 100$ W	$683W \leq P < 910W$	$2\ kW \leq P$
Energy Daily Allowance	$E \leq 275$ Wh	$E \leq 550$ Wh	$E < 4$ kWh	$E < 550$ Wh

Fees paid for EDA: **- 50 Dh (4,5 €) for 275 Wh/day**

- 100 Dh (9 €) for 500 Wh/day

Site


ESPAGNE
Tanger
Rabat
Chefchaouen
Casablanca
Tinghir
Marrakech
Erfoud
Agadir
Quarzazate
Tigrit
Dakhla

Technological Configuration – Multiuse building ("Casa de la Luz")

Technological Configuration – PV hybrid micro power plant



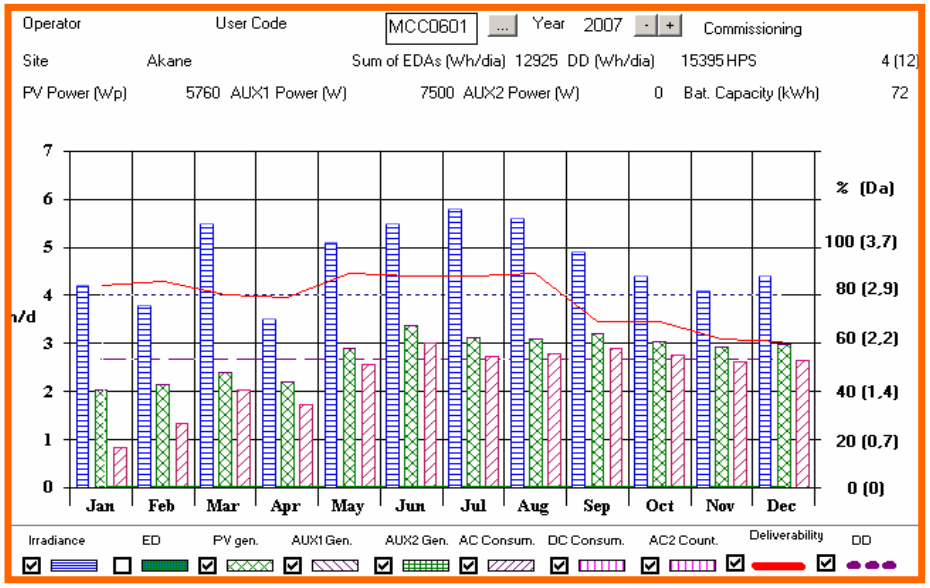


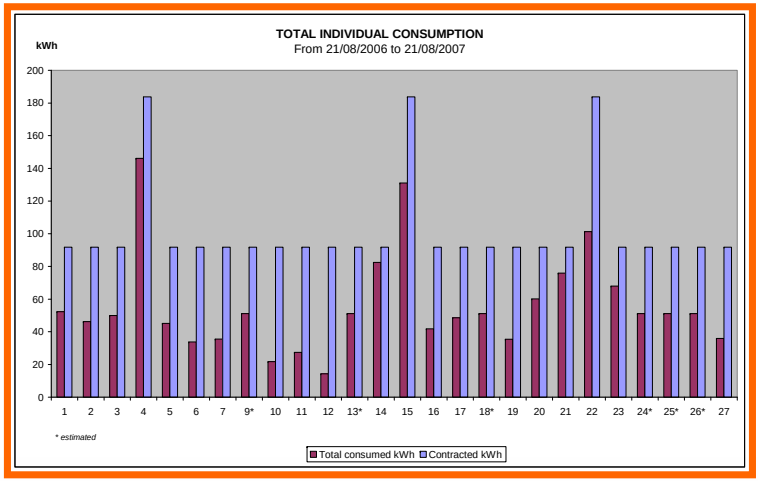

Technological Configuration – single phase LV distribution grid

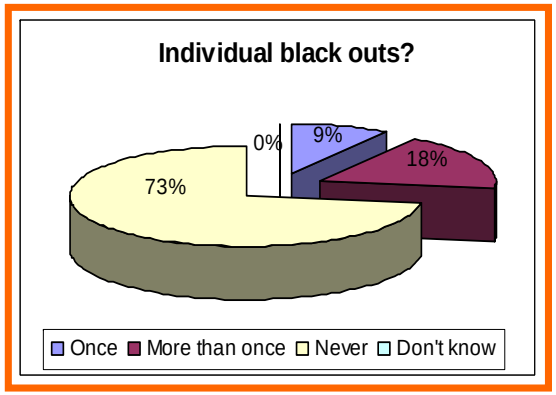
Technological Configuration – user interface and loads

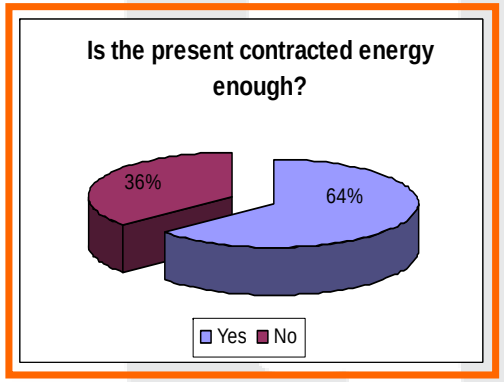
Performance assessment after 1 year

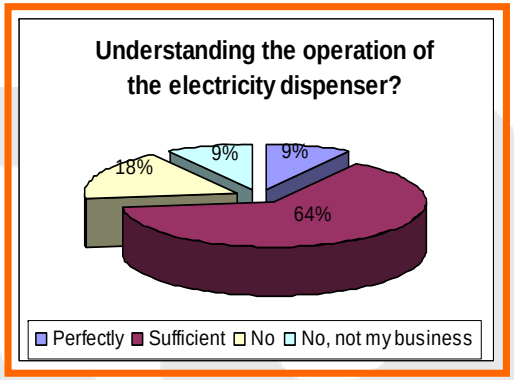
Technology performance



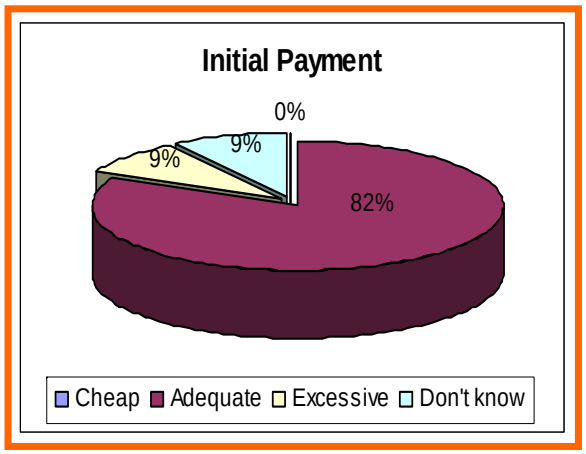


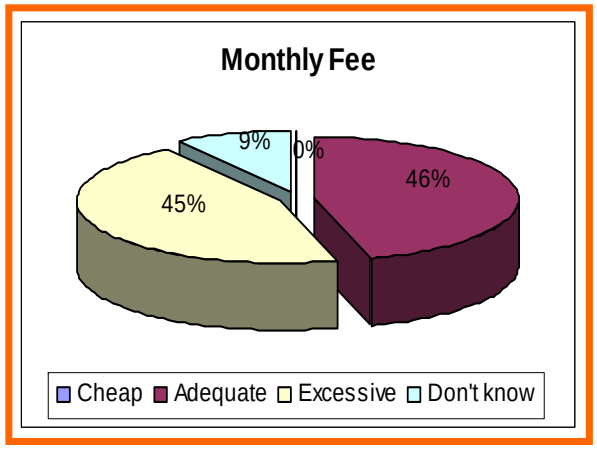


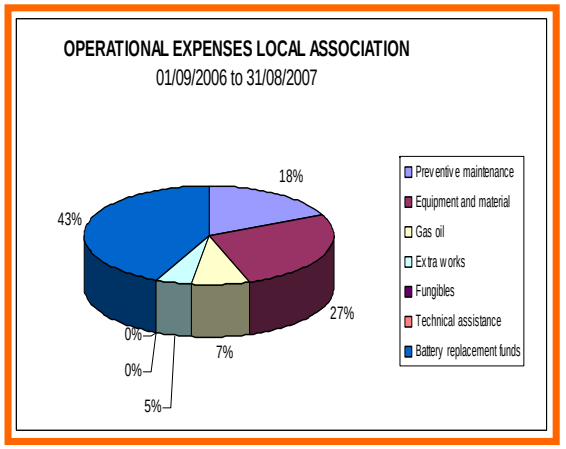


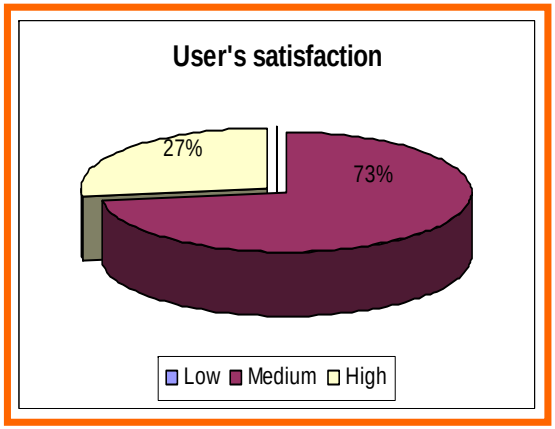


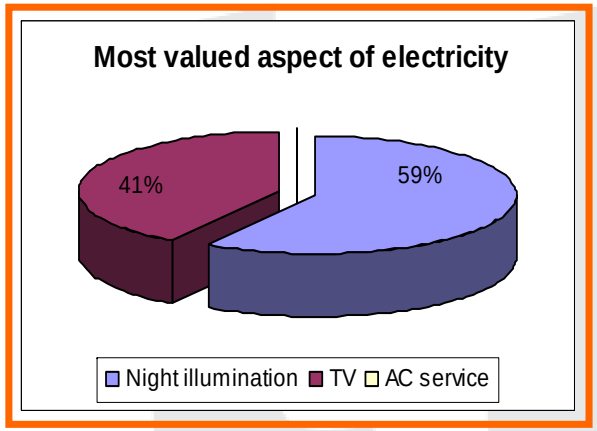
Economical and social

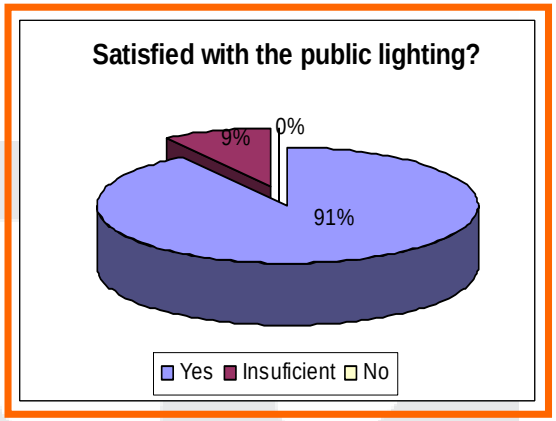




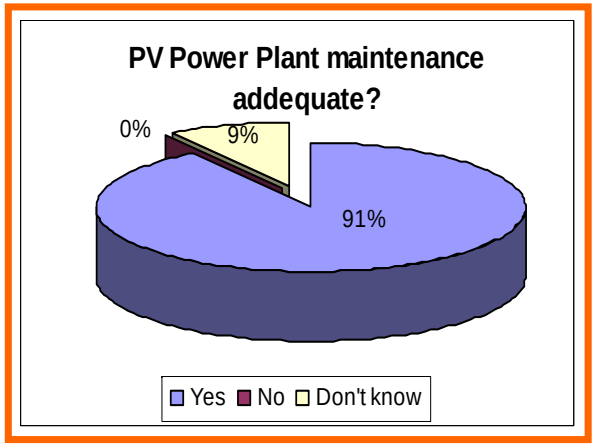


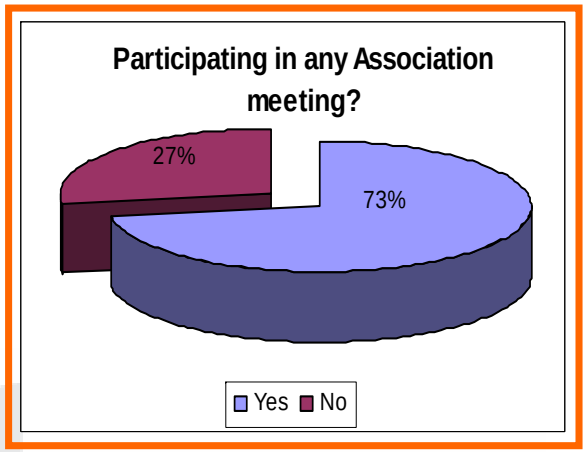






Organizational and institutional





Some relevant critical issues for RE Rural microgrids

- Ownership and management scheme
- Load management, invoicing and tariffs
- Future expandability and interconnection

Business models for rural electrification

- Community based
- Private sector based
- The utility based
- Combination of the above

PV rural Micro grid: Load Management

WHY IS IT SO IMPORTANT FOR PV POWER SUPPLY ?

- PV rural electrification technology is a least-cost option for many applications but:
  - It has high levelized costs
  - It can assure a limited energy daily allowance
  - It can supply extra energy under certain conditions
  - Requires sharing the energy available without conflicts
- Energy distribution and control issues!

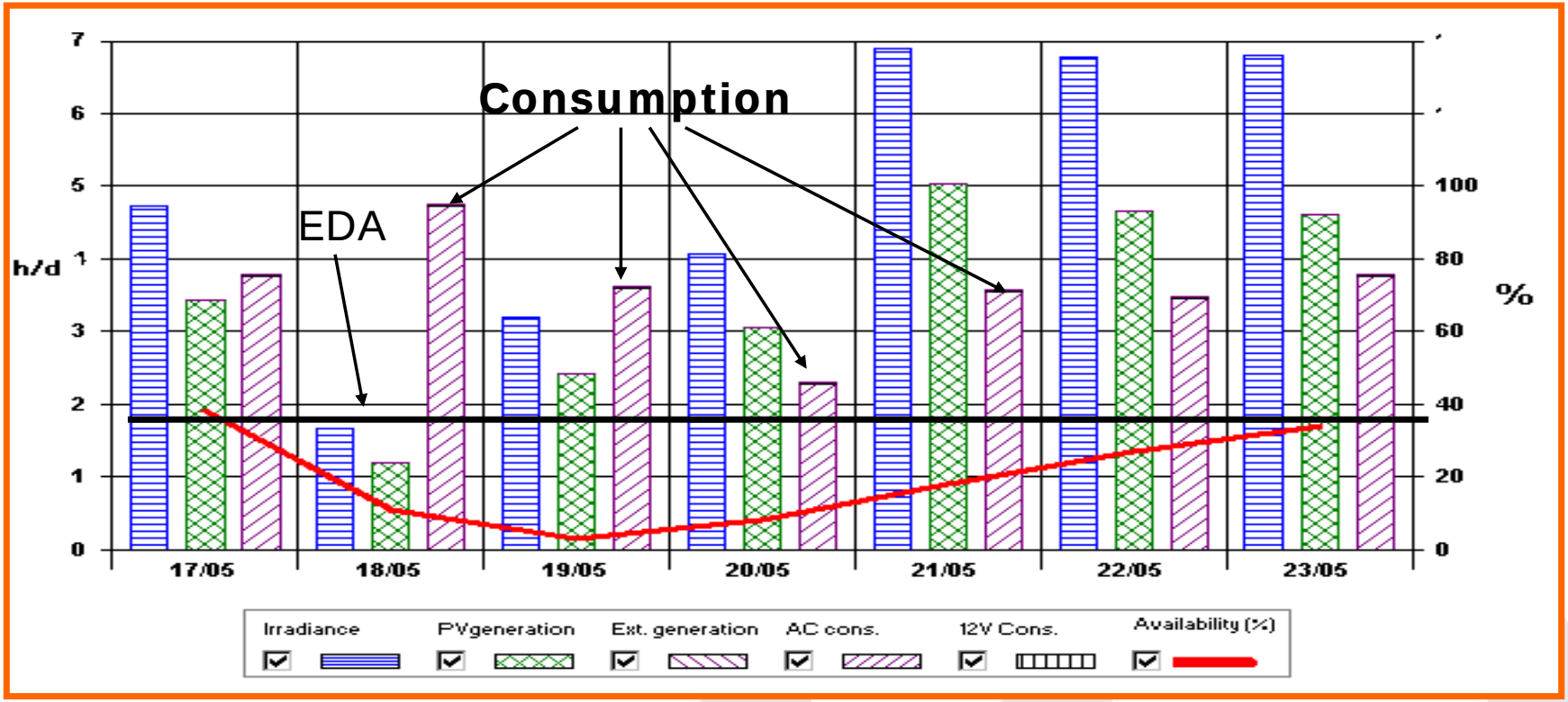
Energy Daily Allowance

- Traditionally in grid connection: users pay for consumed kWh
- In autonomous electrification with RE: Key aspect is the constrain on available energy
- Tariffs in rural RE micro grids must reflect this idea
- Tariff based on the **Energy Daily Allowance** (similar to fee for service ≠ prepayment)
- Clearer and easier financial planning for operator and for client
- It reduces transaction costs

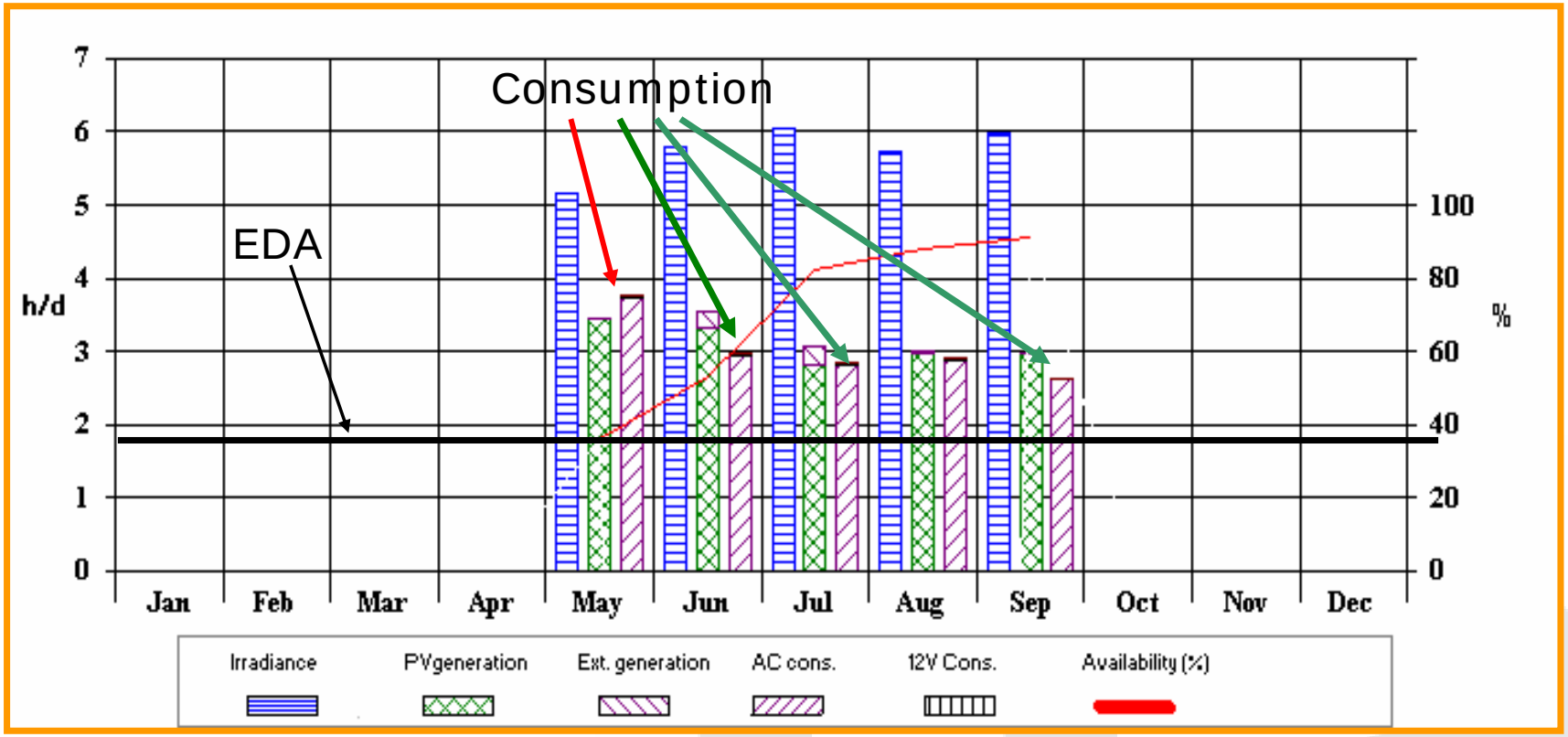
Load management tools

- User information interface + training
- Automatic total load disconnect
- Automatic selective load switching
- Individual Energy allowance (in micro grids)

Two users exceed design limit in a micro grid



Operation after the Electricity Dispensers solved the problem



Electricity Dispenser / meter

Single phase electrical energy meter with dispenser function (patented)

Built in main circuit breaker:

•Energy Daily Allowance management

•Maximum current overload protection

Auxiliary smart switch for:

•load shifting

Smart card for:

•Tariff management

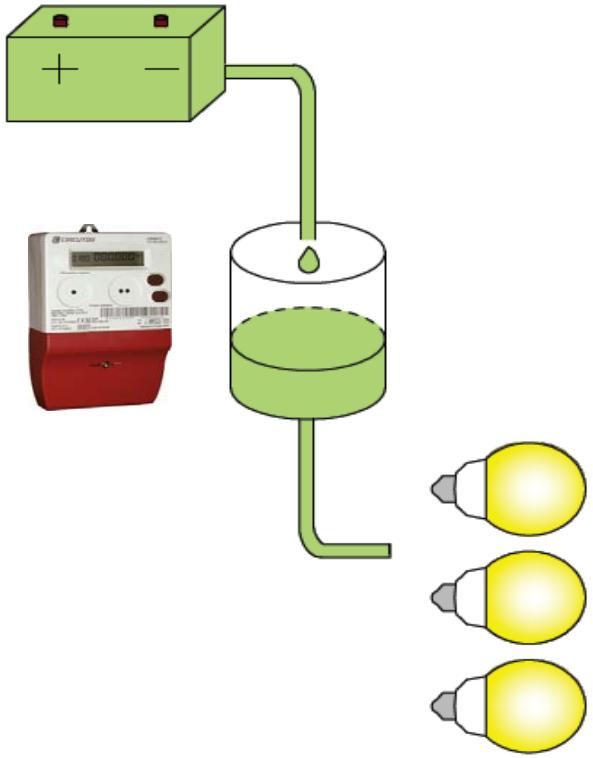
•Energy Allowance transfer

Modbus communication protocol

Certified energy meter (MID EN 50470-1 and EN 50470-3)

Electricity Dispenser / meter

HOW IT WORKS



Balanced consumption

*As an analogy, we can imagine the **dispenser** as a buffer water tank*

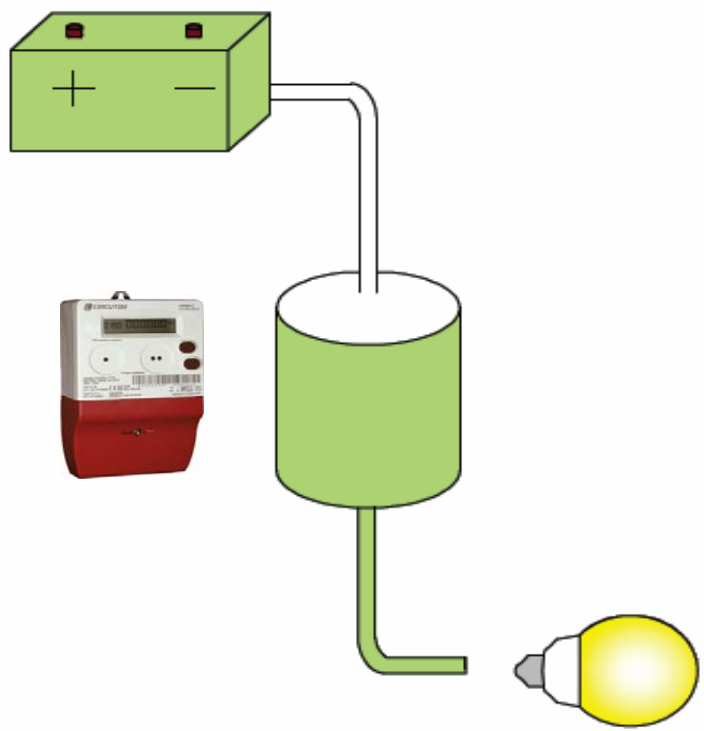
*The tank gets a constant trickle inflow from the micro-grid proportional to the contracted **energy daily allowance***

The tank empties as energy is consumed

When the consumption is equal to the fill up rate we are in balanced consumption

Electricity Dispenser / meter

HOW IT WORKS



Low consumption

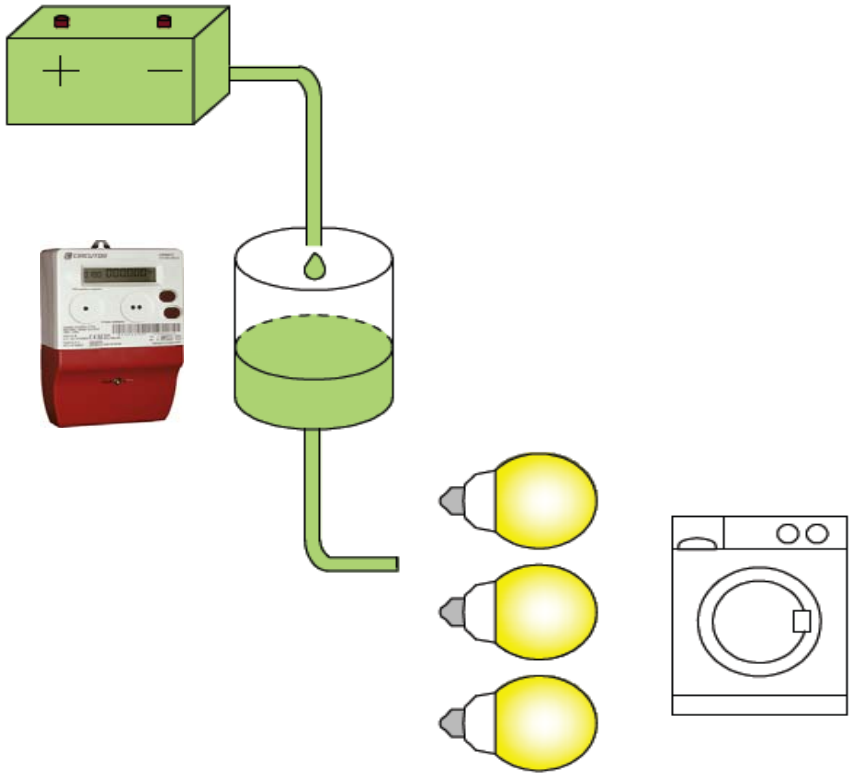
If the consumption is low the tank will top up

The tank has a capacity equivalent to several days of ***energy daily allowance***

You can use this energy anytime but you cannot store more units than the tank's capacity

Electricity Dispenser / meter

HOW IT WORKS

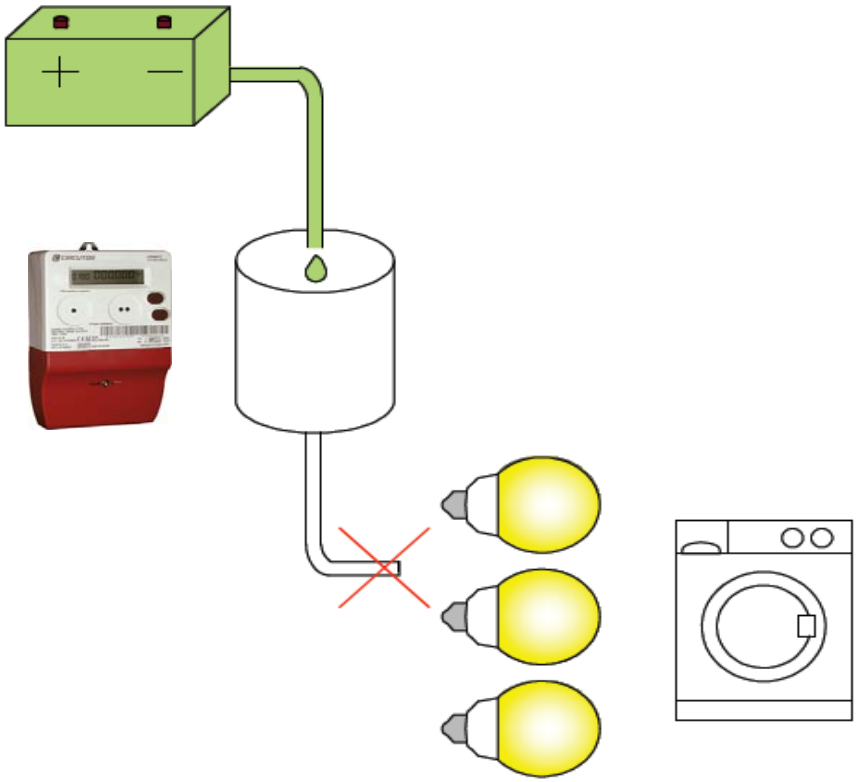


<u>High consumption</u>

At higher consumption the tank gradually empties

Electricity Dispenser / meter

HOW IT WORKS



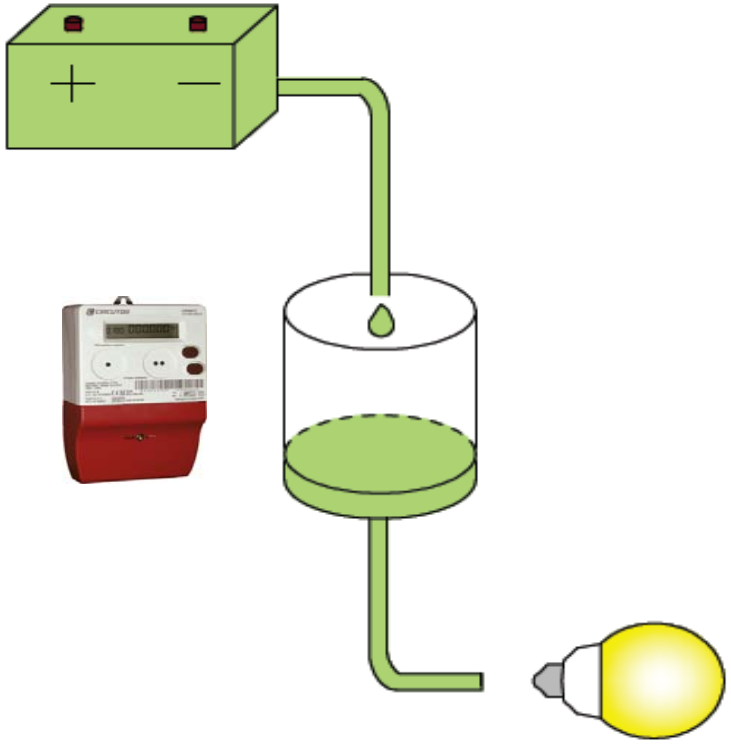
<u>Continuous high consumption</u>

If the tank becomes empty the dispenser will cut off the electricity supply

Then you must reduce the consumption rate as the dispenser will continue to replenish the tank at the set rate

Electricity Dispenser / meter

HOW IT WORKS



Reactivation of service

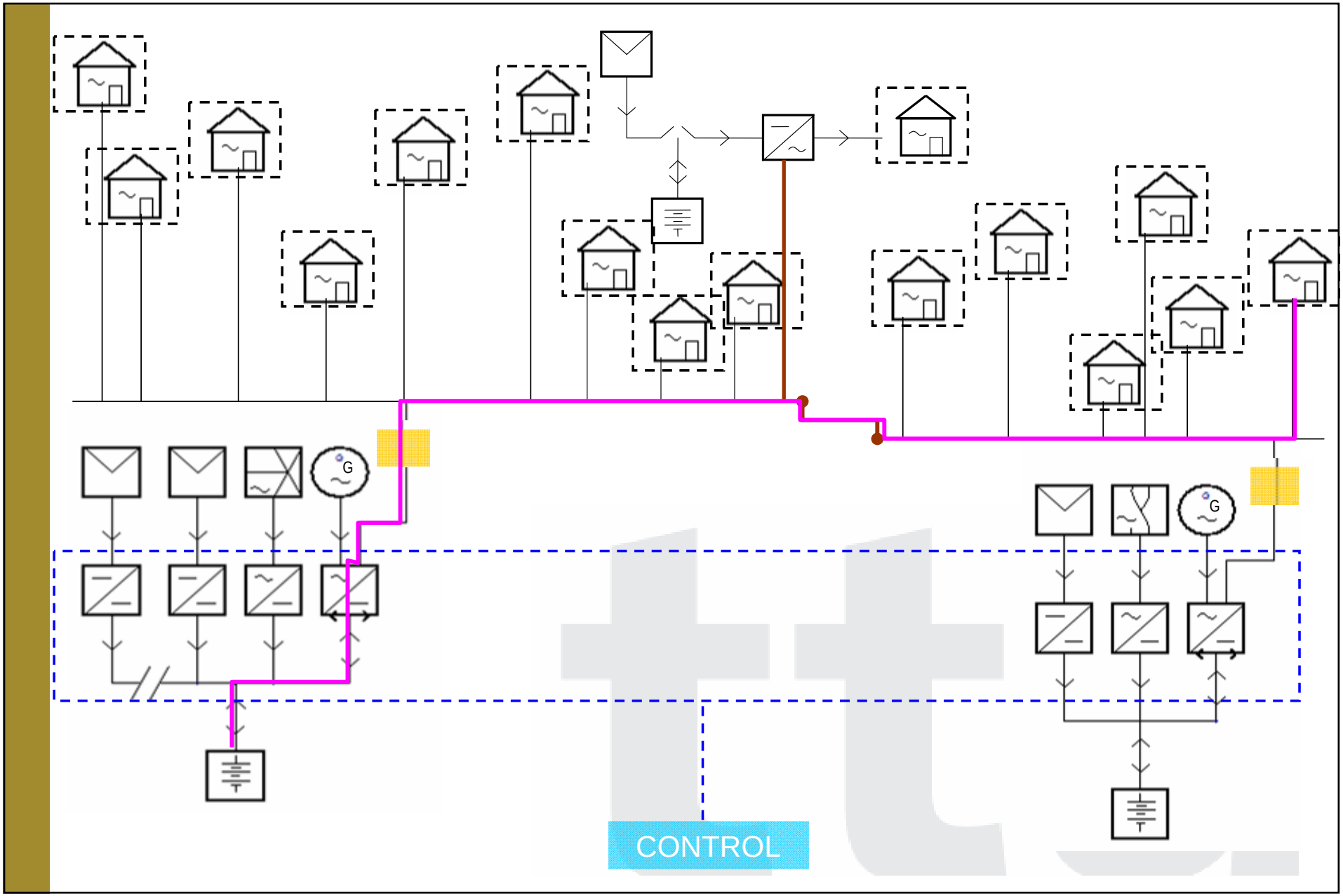
After a few minutes you can resume the energy consumption al a lower rate

The tank is refilled constantly from the micro-grid according to the contracted ***energy daily allowance***

Electricity Dispenser / meter

- Limitation of energy to the contracted **energy daily allowance** with virtual storage
- The user pays a fixed monthly fee
- Flexibility to defer consumption and to consume at different dispensers

Future expandability and interconnection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CONTROL

Present and future potential

Short-term (0-2 years)

- Remote villages where the grid extension is too expensive and not cost effective: rural micro-grid for basic needs (health, school, water, etc)
- Villages with obsolete diesel genset because of the high running costs: refurbishing distribution grid, adding a RE power plant, installing electricity dispensers, etc

Medium-term (5-6 years)

- Remote villages not connected to the grid: extension of the micro-grid to private applications and productive uses
- Remote villages connected but with weak grids and frequent black outs

Long-term (10 years onwards)

- Remote villages not connected to the grid: interconnection of several micro-grids between them or/and the national grid

tta Trama TecnoAmbiental

Thanks for your attention!