Sustainable Rural Electrification: Social, economic and technological issues in implementing of RE distributed electricity generation in Africa (part I)

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Current situation

- Majority of villages and households not connected to the grid
- Existing micro grids running with Gensets (many are not working)
- Load shedding and blackouts in national grids

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

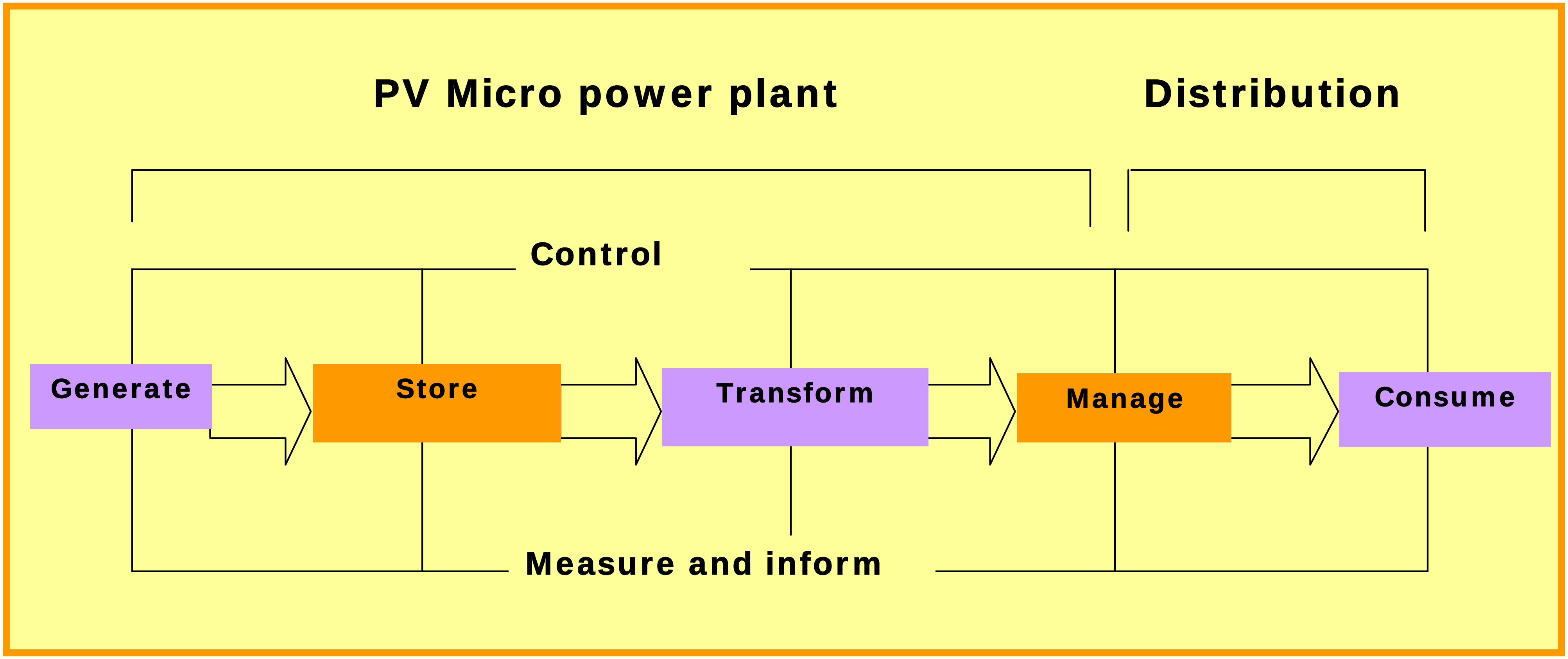
Table B1: Electricity Access in 2005: Regional Aggregates

	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

- 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

Review of PV hybrid configurations and cost structure

Main functions in a RE micro power plant

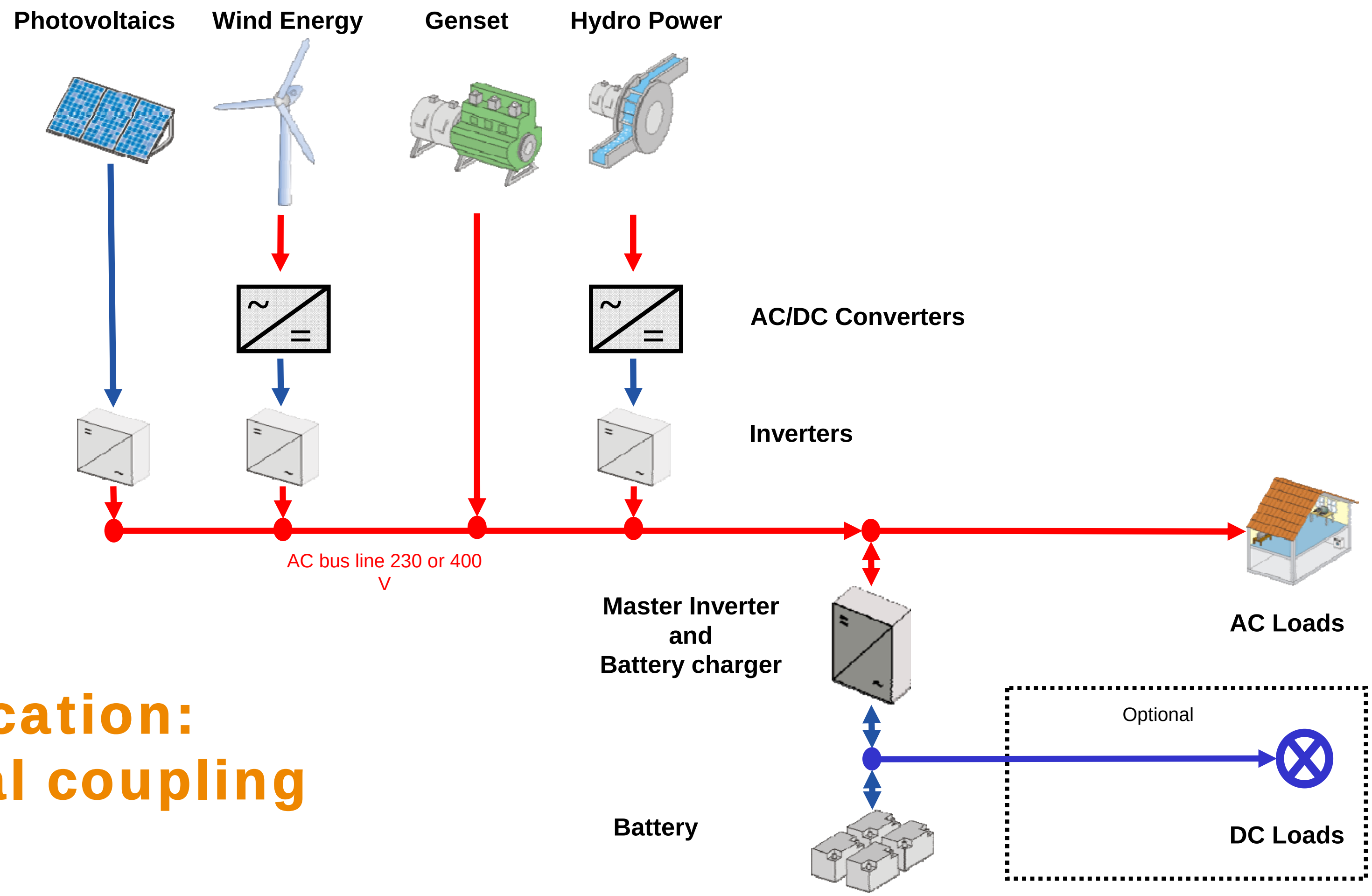


All electricity generators are connected to the AC feeder

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.

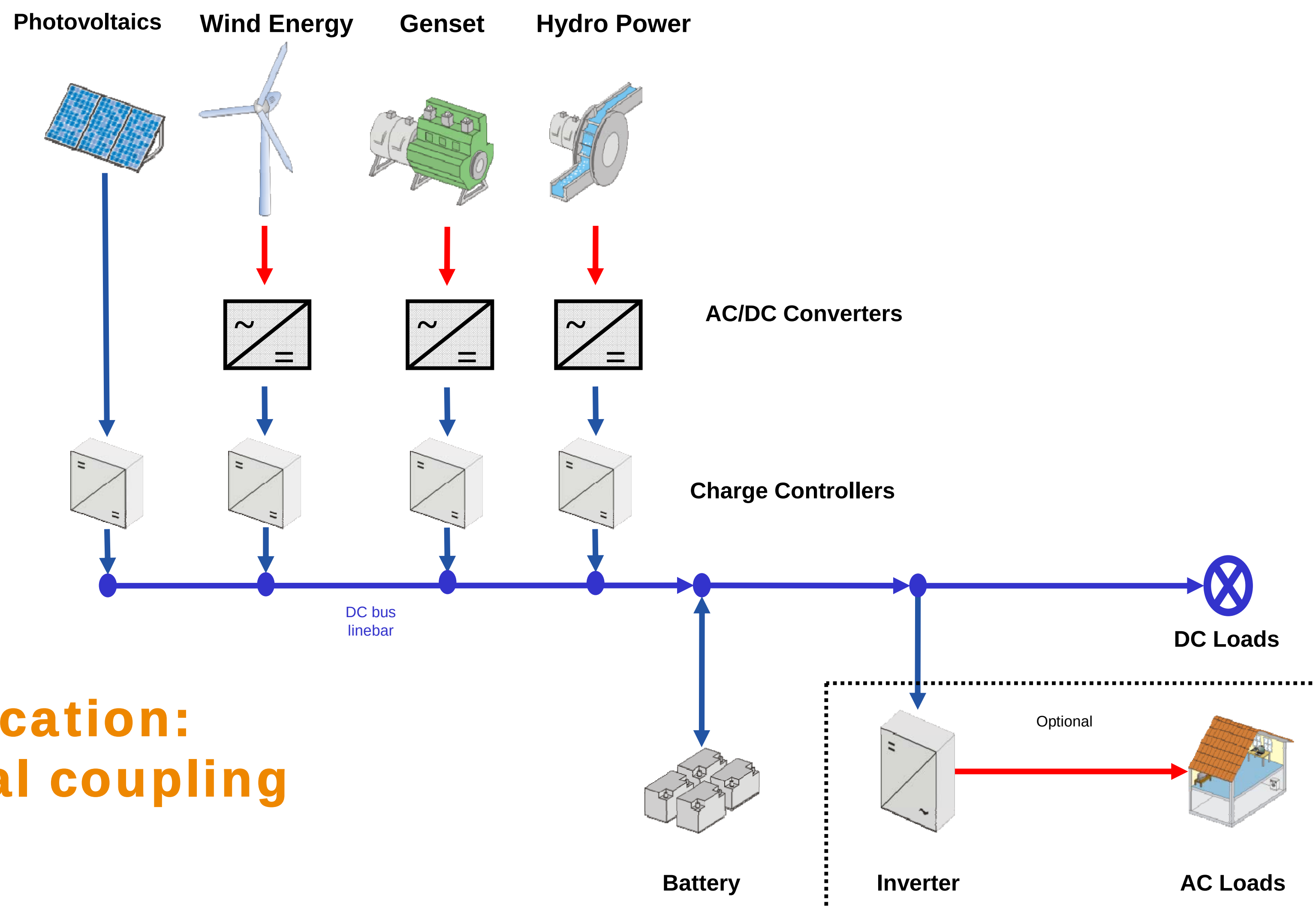


Classification: AC external coupling

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

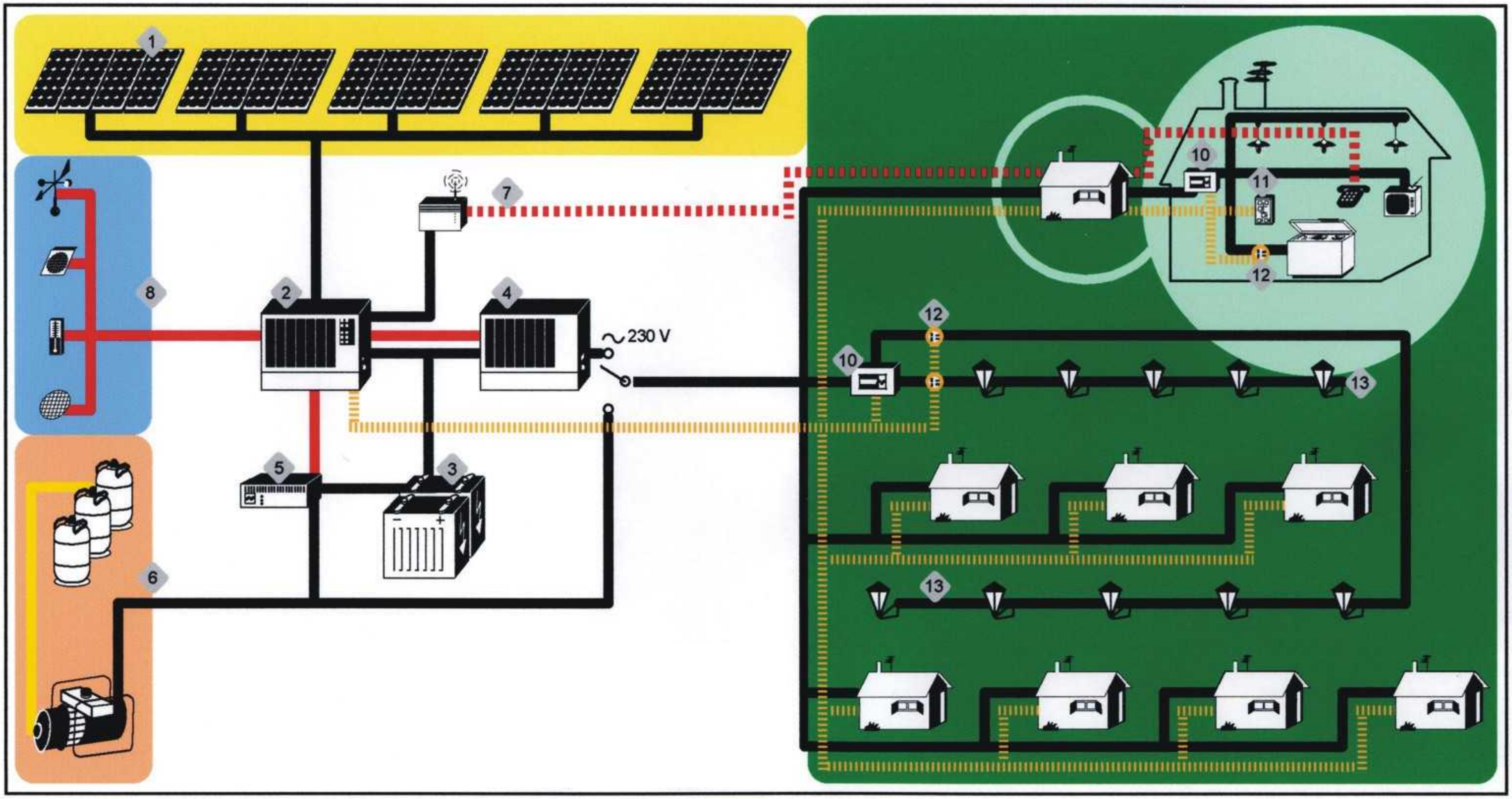
AC generating components need an AC/DC converter.

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



Classification:
DC internal coupling

Multi user Solar Grid (MSG)



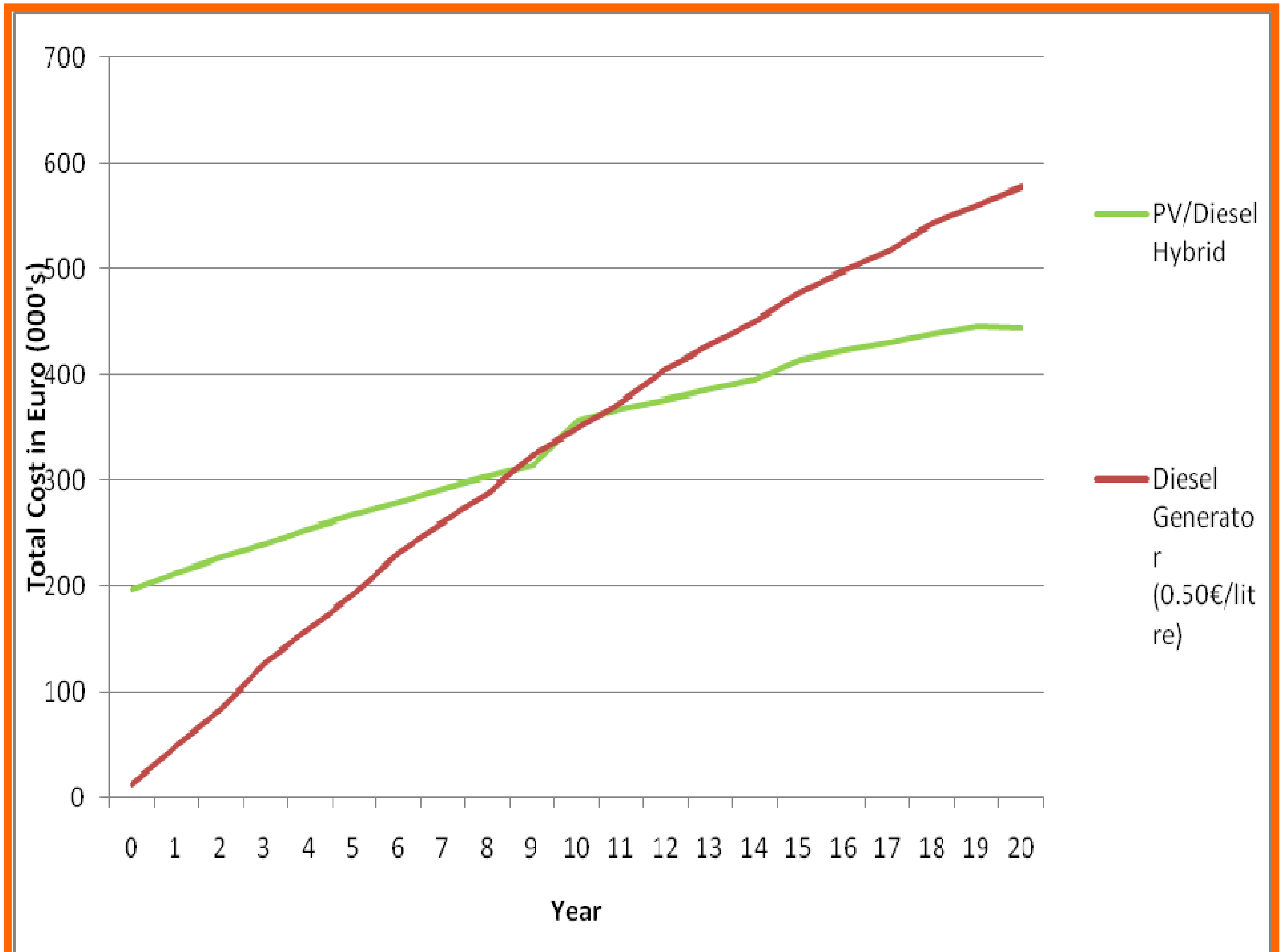
Typical layout: DC coupled micro power plant + AC single phase grid + individual energy allowance

What is a rural PV hybrid micro grid?

- A combination of different but complementary energy generators based mainly on RE or mixed technologies (PV-genset, PV-WGT-genset, etc)
- Multi user solar micro grids (MSG) provide steady community-level electricity service, such as village electrification, offering also the possibility to be interconnected in the future
- Typically total installed power up to 100 kW (according to IEC definition)
- Distribution feeder in Low Voltage AC (230V, 120V, etc.) (only distribution)
- Single or 3-phases

Rural PV Hybrid Micro Grid in West Bank, Palestine

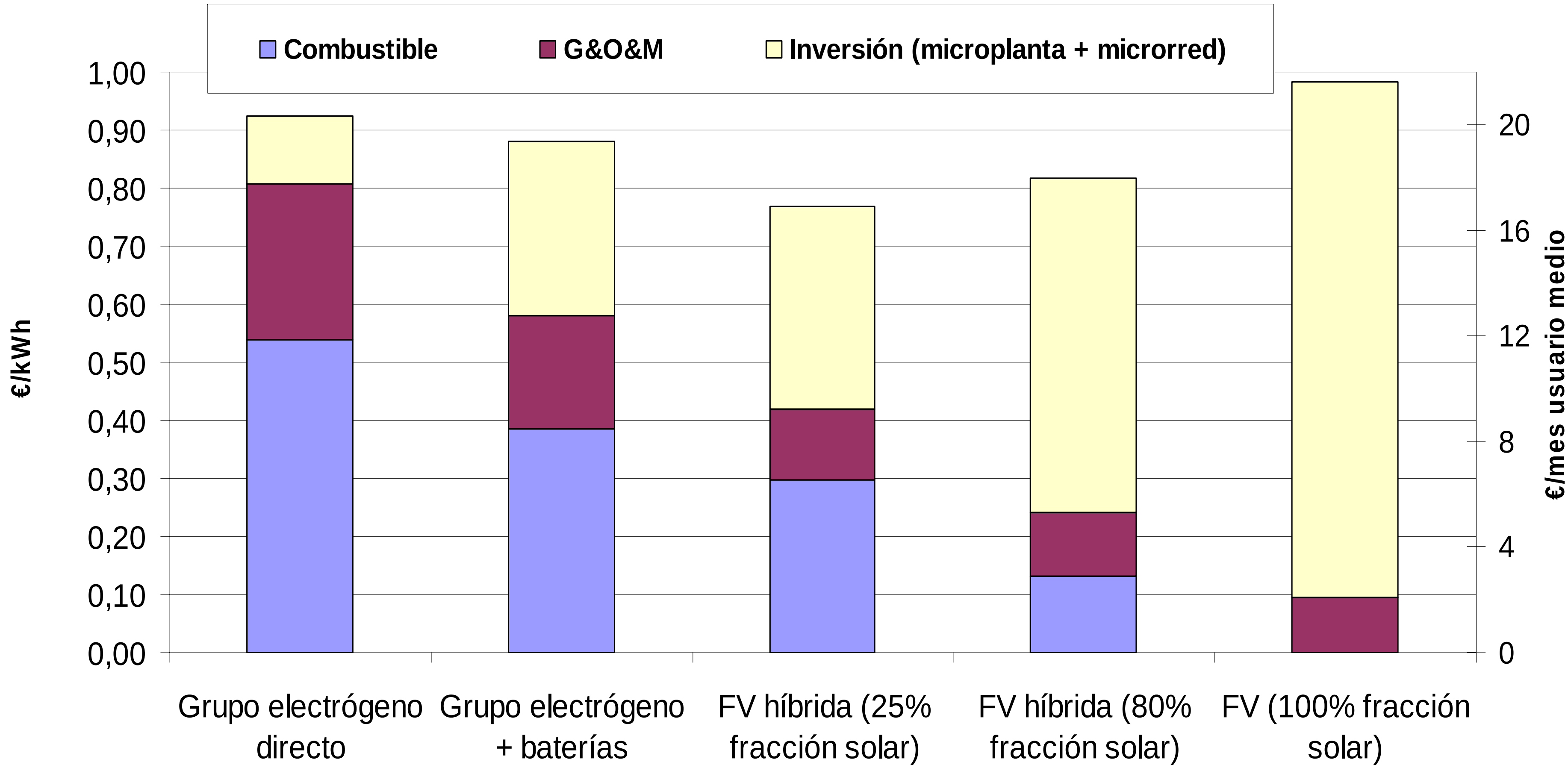
Decentralised renewables vs gensets



Comparison:

Cumulative costs diesel vs. PV/diesel hybrid system Source: *ARE-Mauricio Solano*

PV Hybrid micro grids more sustainable than fossil fuel electricity generation



Levelized costs for PV-Diesel technology in MSG for 340 users in Peru (D.R. 5%, Fuel: 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 RE/ Hybrid power plant 	• Improved quality (surge power, load management, 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!**

Characteristics of the communities in the selection process

- Social structure
- Income and willingness to pay
- Demand (load)

Understanding demand

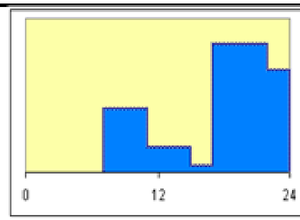
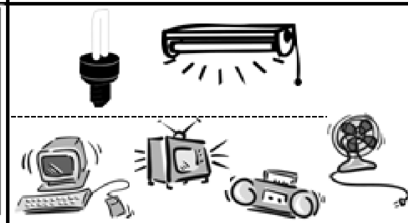
DEMAND SEGMENTATION

We group the households according to Energy Daily demand because this also defines the load profile.

	Category A	Category B	Category C
Type of use	Individual basic "very low and low energy consumption" (lighting and audio/video).	Individual medium services (same as category 1 + freezer or refrigerator and appliances) Or community services (health care centre: lighting and freezer, etc.)	Individual high services (same as category 2 + washing machine, vacuum cleaner, small tools, etc.) Or public lighting
Essential consumption characteristics	•Low number of receivers •Low power of receivers •Slim rigid load profile (P1)	•Medium number of receivers •Receivers more powerful •Slim rigid and base load profiles (P1+P2+P3) •or Multiple basic users (P1+P1+ .. n)	•High number of receivers •Some receivers are powerful •High instantaneous power inrush •"Variable" load profile (P1+P2+P4+P5) •or Multiple users (P1+P1+P2+ .. n)
Probable hourly avg power	$Pn \leq 50$ W	0,1 kW < Pn < 1,5 kW	0,3 kW $\leq Pn$ < 3 kW
Probable surge power	$Ps = 100\ W$	$Ps = Pn + 1\ kW$	$Ps = Pn + 2\ kW$
Average daily energy demand	$E \leq 550$ Wh/d	$E \leq$2,2 kWh/d	E < 5 kWh/d

Typical load profiles

Profile 1- Daily Cycle rigid slim loads

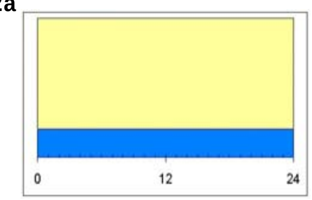
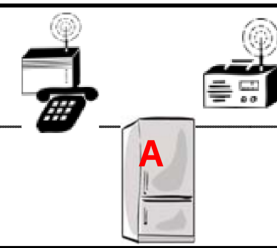
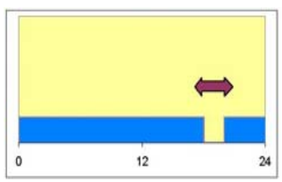
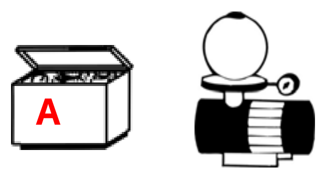
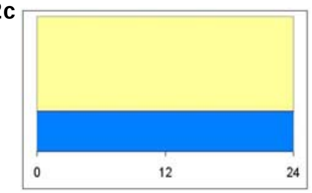
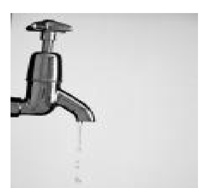
PROFILE	LOAD	AVOIDABLE	DEFERABLE	INTERRUPT.	MODULABLE	TYPICAL DAILY RANGE (Wh/day)	
1 		NO	NO	NO	YES	275	550
						275	550

Profile 2- Base Load

2a-Base Load

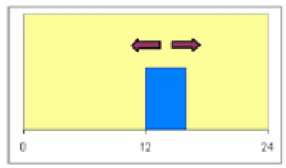
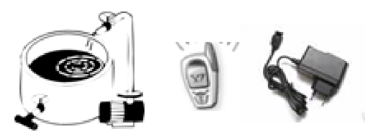
2b- Base Load Interruptible

2c- Base Load- Stand-by

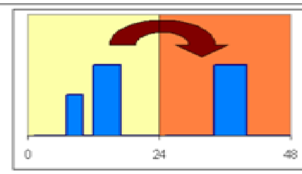
PROFILE	LOAD	AVOIDABLE	DEFERABLE	INTERRUPT.	MODULABLE	TYPICAL DAILY RANGE (Wh/day)	
2a 		NO	NO	NO	NO	275	275
						550	1100
2b 		NO	NO	YES	NO	550	1100
2c 		YES	NO	YES	YES	0	1100

Typical load profiles

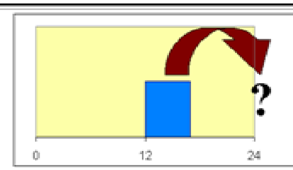
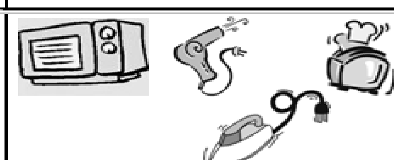
Profile 3- Daily Deferrable load

PROFILE	LOAD	AVOIDABLE	DEFERABLE	INTERRUPT.	MODULABLE	TYPICAL DAILY RANGE (Wh/day)	
3 		NO	YES	YES	NO	275	UP TO 5000

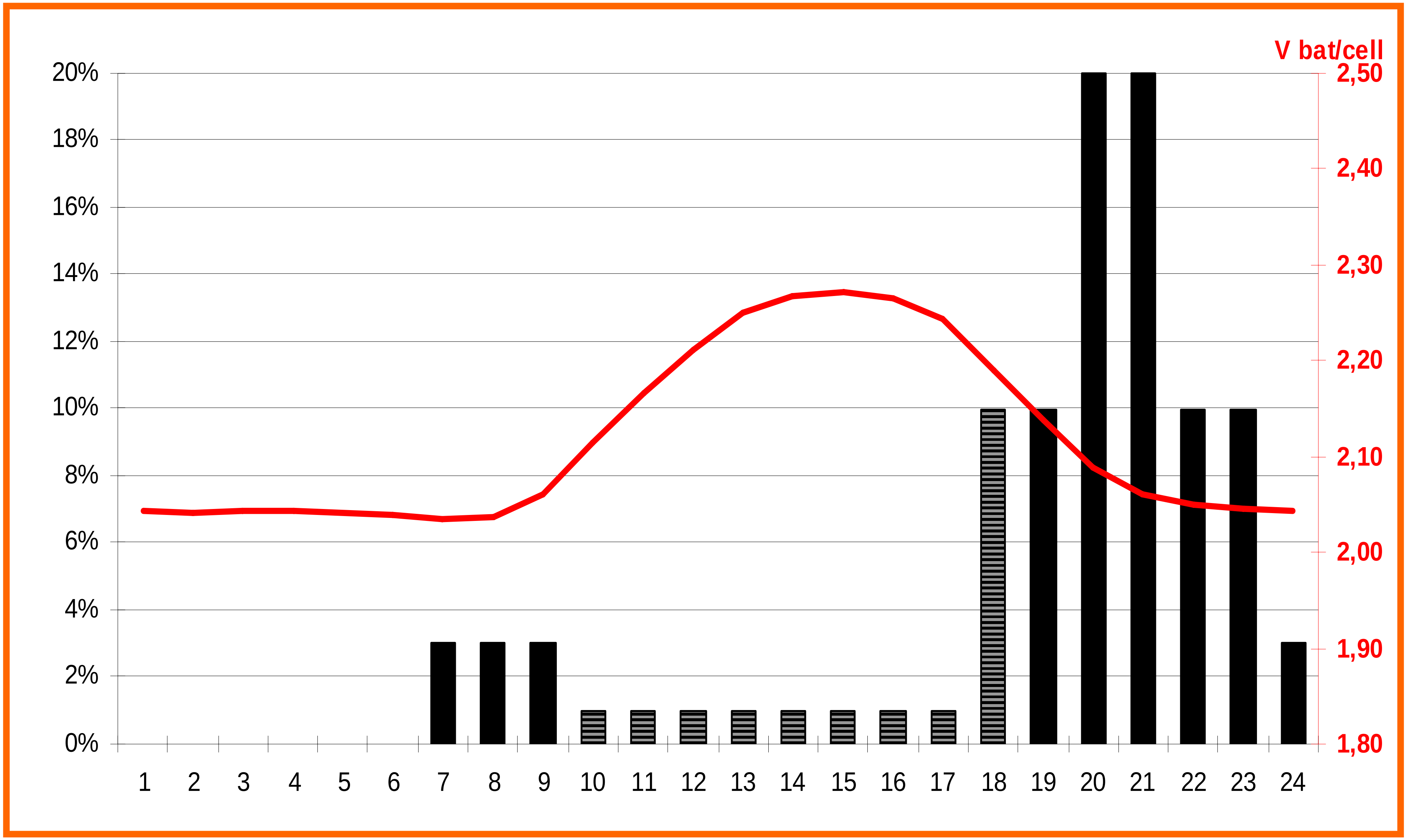
Profile 4- Periodical Deferrable load

PROFILE	LOAD	AVOIDABLE	DEFERABLE	INTERRUPT.	MODULABLE	TYPICAL DAILY RANGE (Wh/day)	
4 		NO	YES	SOME	NO	275	1100

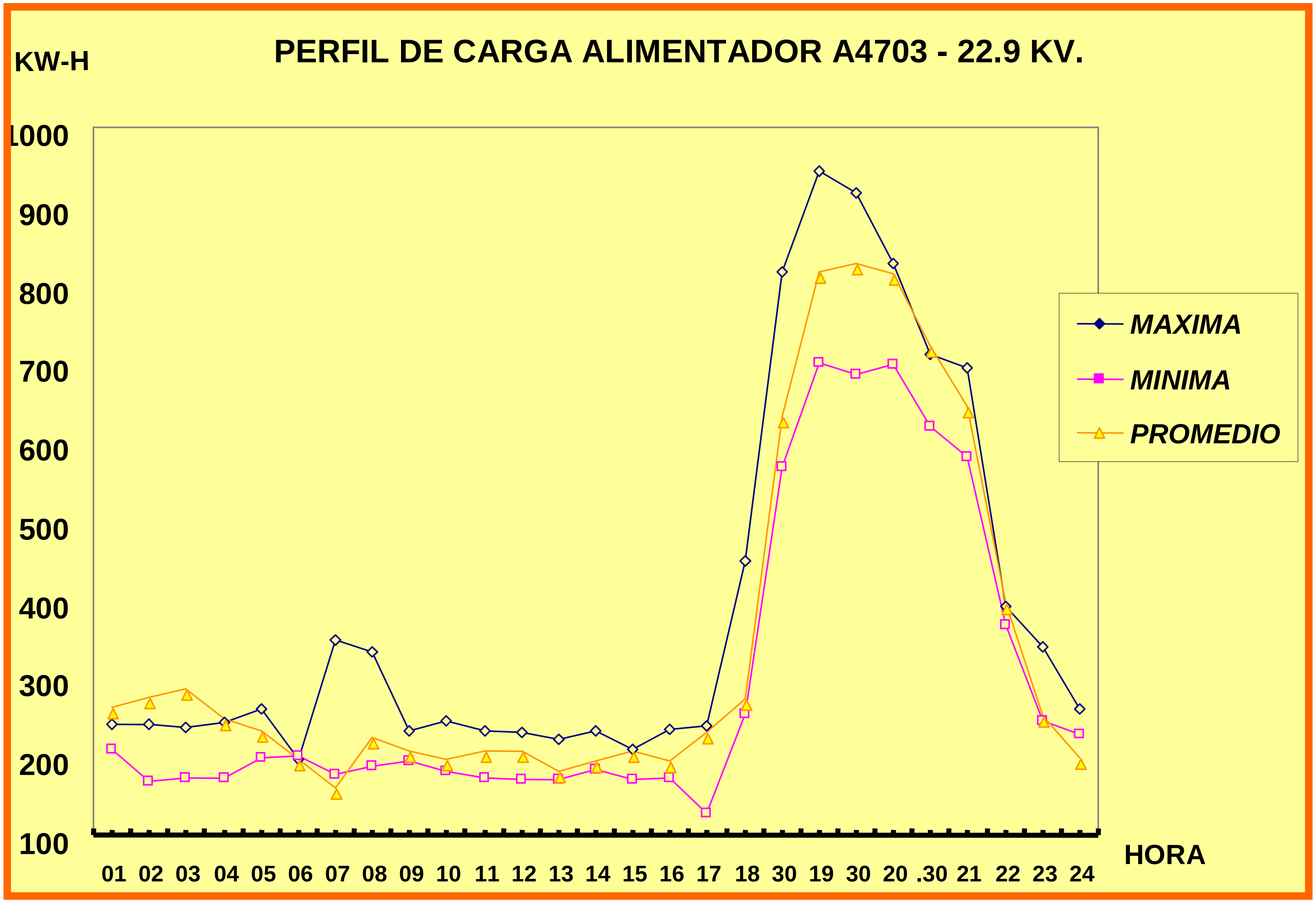
Profile 5- " Dump or ballast" load

PROFILE	LOAD	AVOIDABLE	DEFERABLE	INTERRUPT.	MODULABLE	TYPICAL DAILY RANGE (Wh/day)	
5 		YES	YES	YES	YES	550	1100

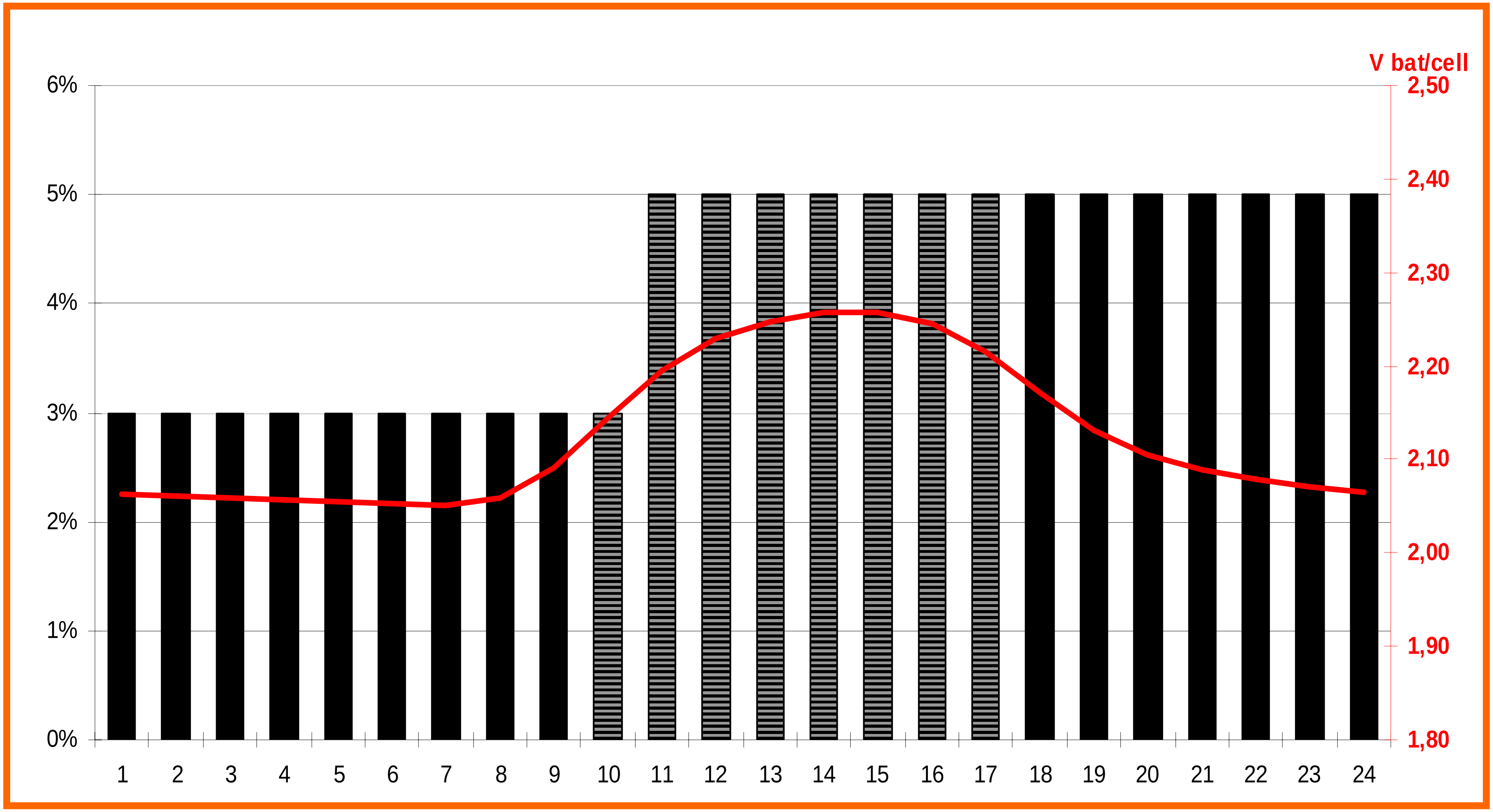
DAILY AVERAGE NORMALIZED LOAD PROFILES (IDEALIZED) CATEGORY A



Example of P1 aggregate for a village with 900 users in South America



DAILY NORMALIZED AVERAGE LOAD PROFILES (IDEALIZED) CATEGORY B and C



DAILY NORMALIZED AVERAGE LOAD PROFILES in MSG

- The aggregate of the individual load profiles (idealized) and the singular profiles like water pumping, public lighting, businesses, etc. but we can have large uncertainties:
  - Will some users consume less than foreseen?
  - What are the technical implications if someone consumes more than allowed?
  - What are the economic implications if someone consumes more than allowed?

RE rural Micro grid: Load Management

WHY IS IT SO IMPORTANT FOR ASSURED 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!**

Load management tools

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

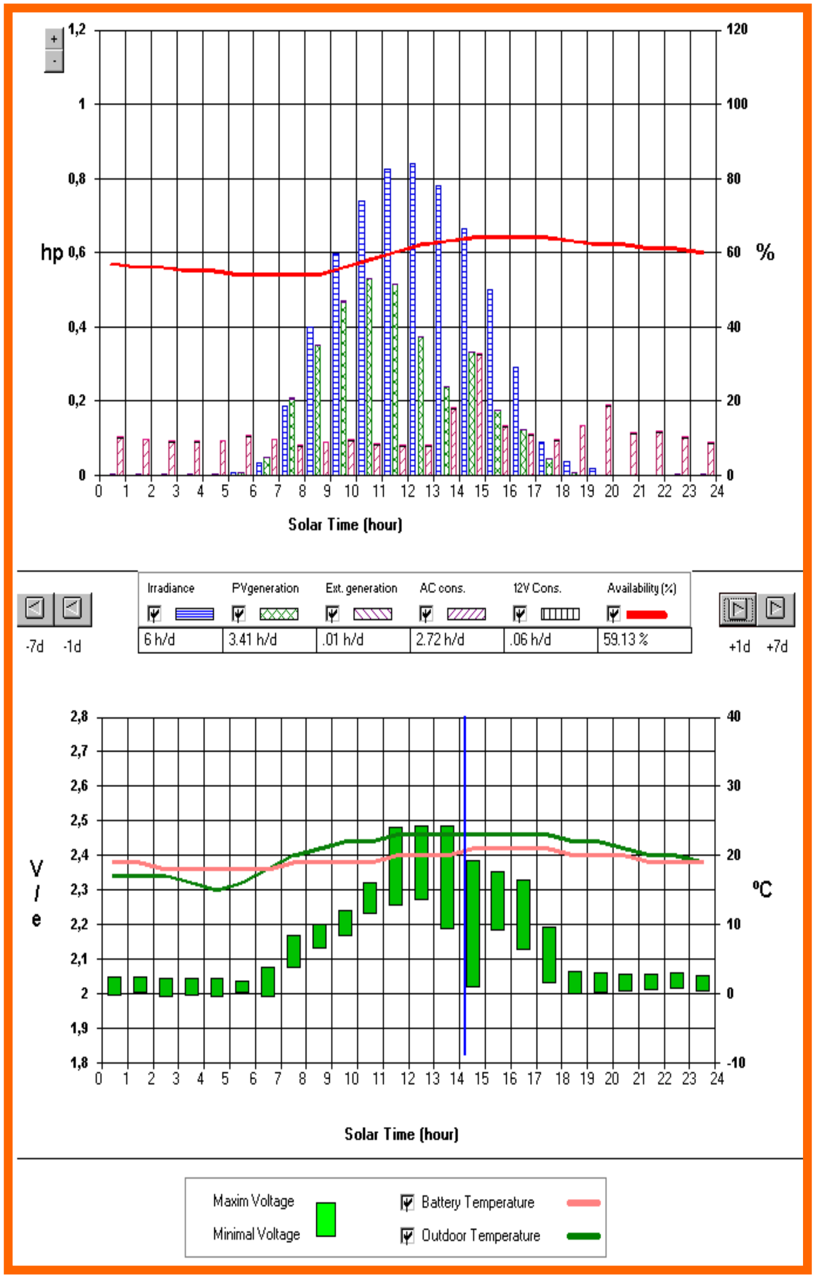
Strategies of load management:

- <u>Disconnect loads to protect the battery:</u> traditionally based on battery voltage. But this does not provide adequate information to user

- <u>Find and try to eliminate parasitic stand-by loads:</u> the most important and difficult ! Undetected by performance indicators !

- <u>Time shift deferrable loads to only sunny days:</u> Battery SoC is higher… battery could be smaller…

- <u>Time shift deferrable and ballast loads to surplus energy status:</u> PR is higher… generator size could be smaller; HBI is higher… longer battery life, better autonomy



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
- In rural RE micro grids user should pay for availability of energy, not for the consumed energy
- 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

Tariffs and fees

TARIFF PARAMETERS

- Energy and power limitation and guidance according to energy allowance contracted
- User pays for availability of energy, not for the consumed energy

WHY FIXED FEES?

- To manage demand consumption
- To have a predictable income and cash flow
- To reduce transaction costs
- To reduce unpaid invoices

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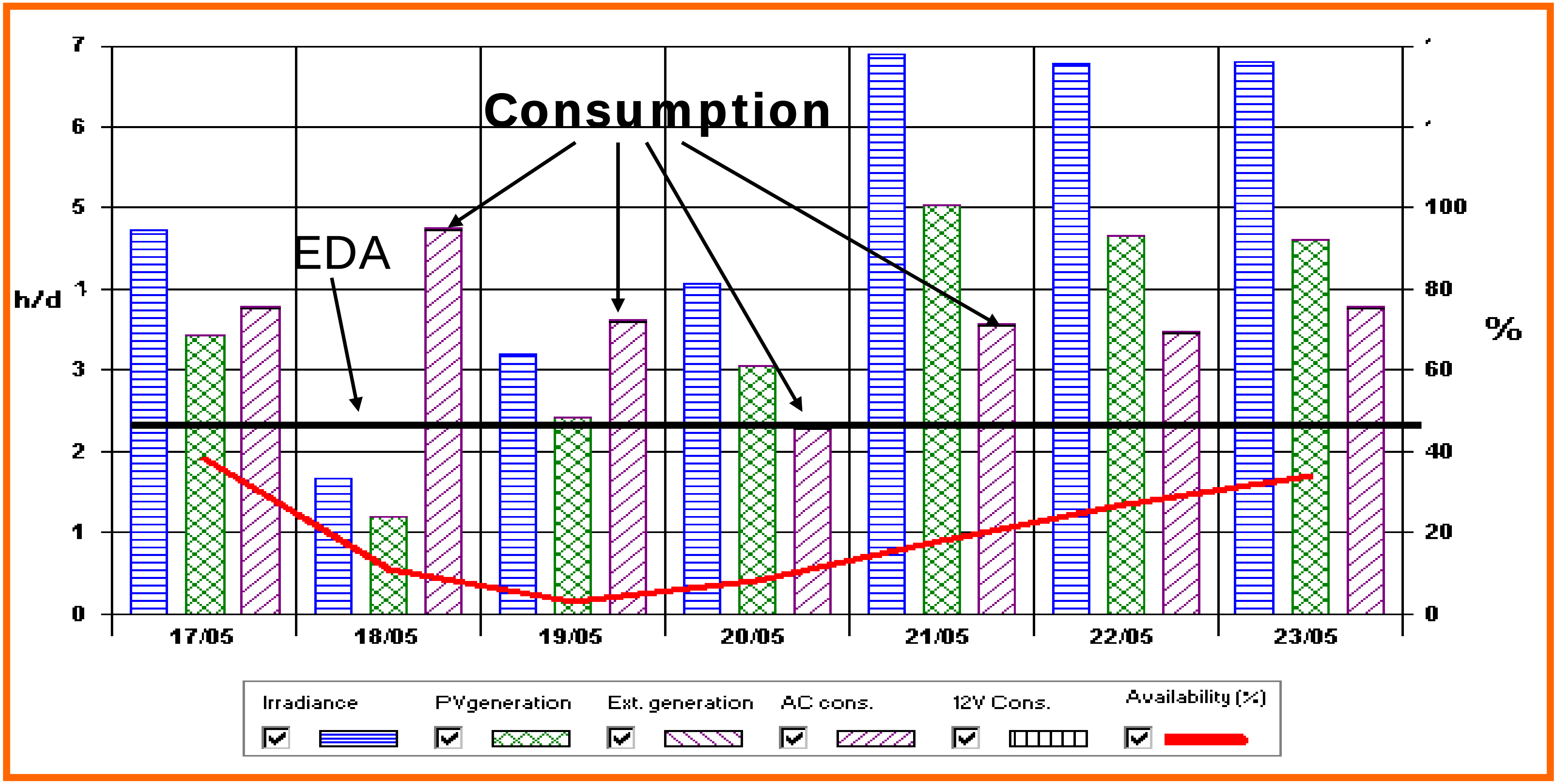
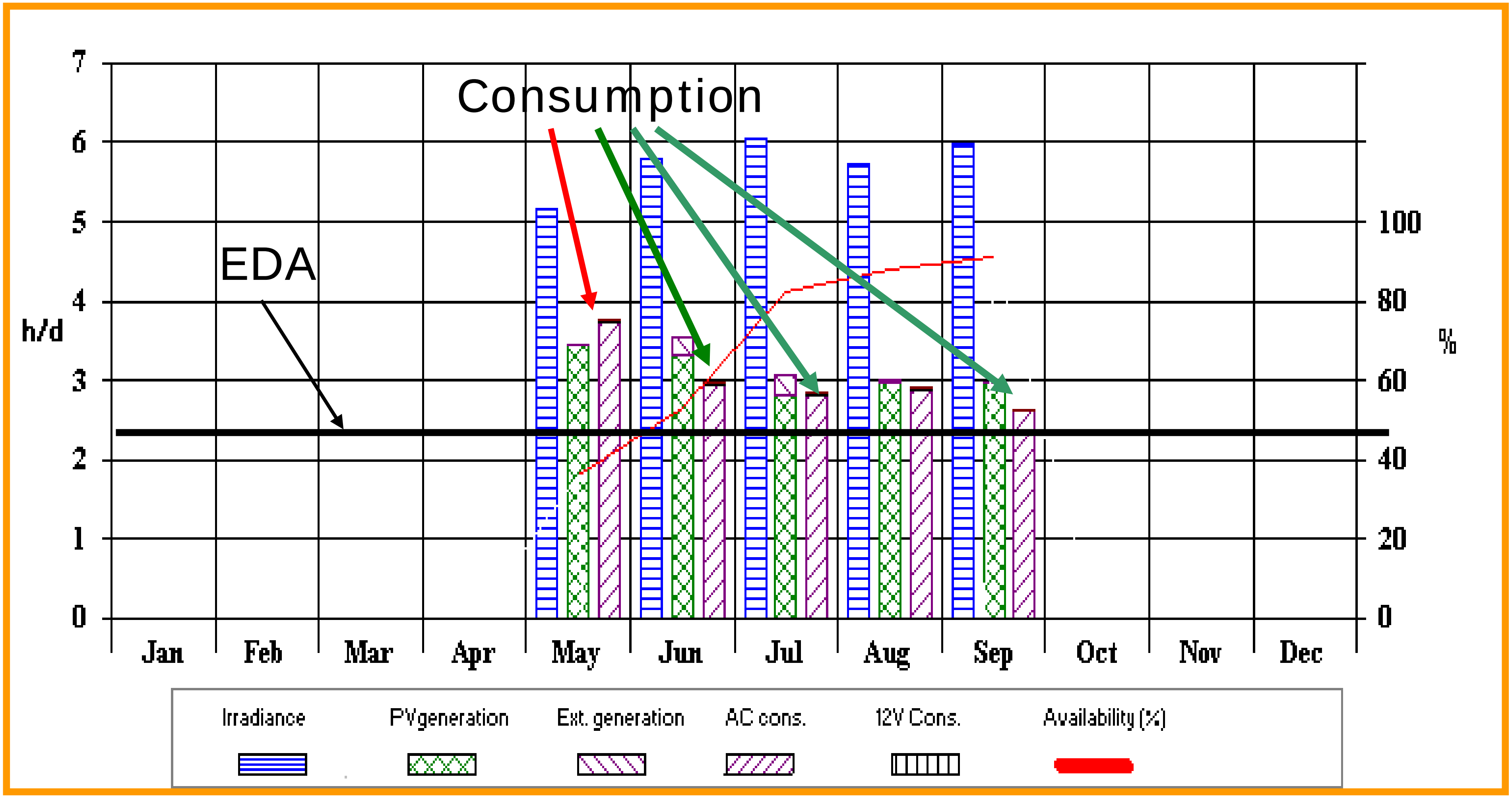
Two users exceed design limit in a micro grid

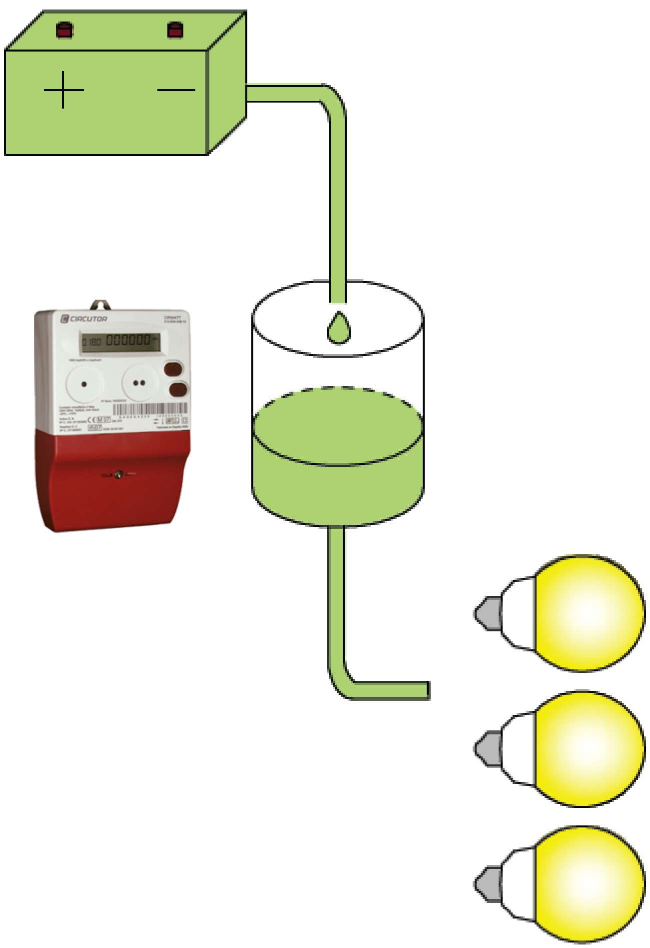


Operation with energy allowance solved the problem



Electricity Dispenser / meter

HOW IT WORKS



Balanced consumption

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

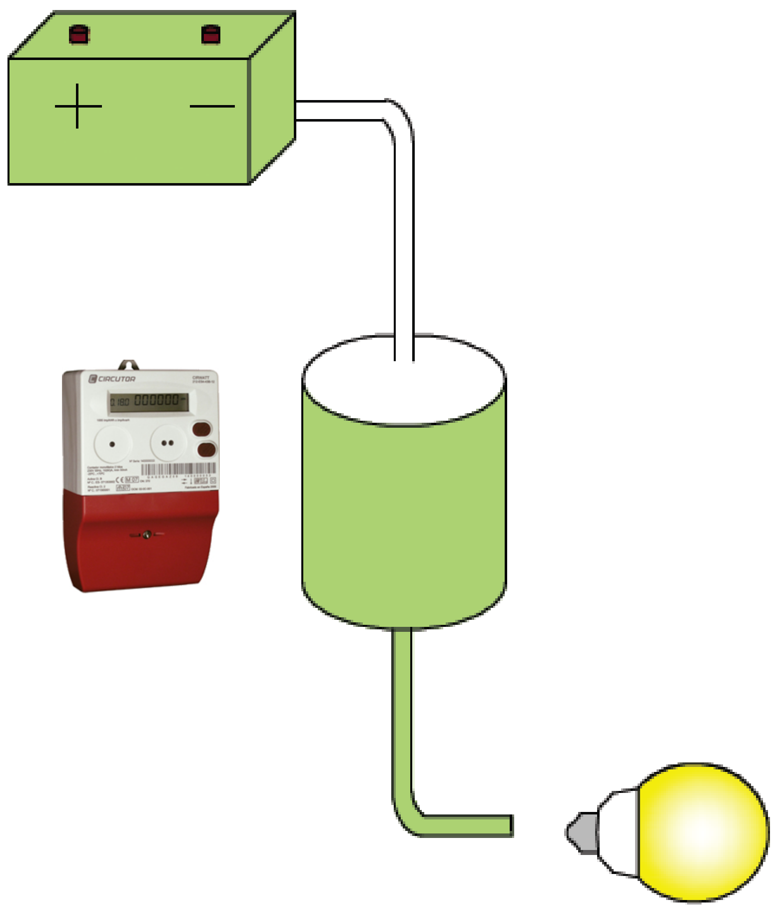
*The tank gets a constant trickle inflow from the micro-grid proportional to the contracted **energy daily allowance***

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



<u>Low consumption</u>

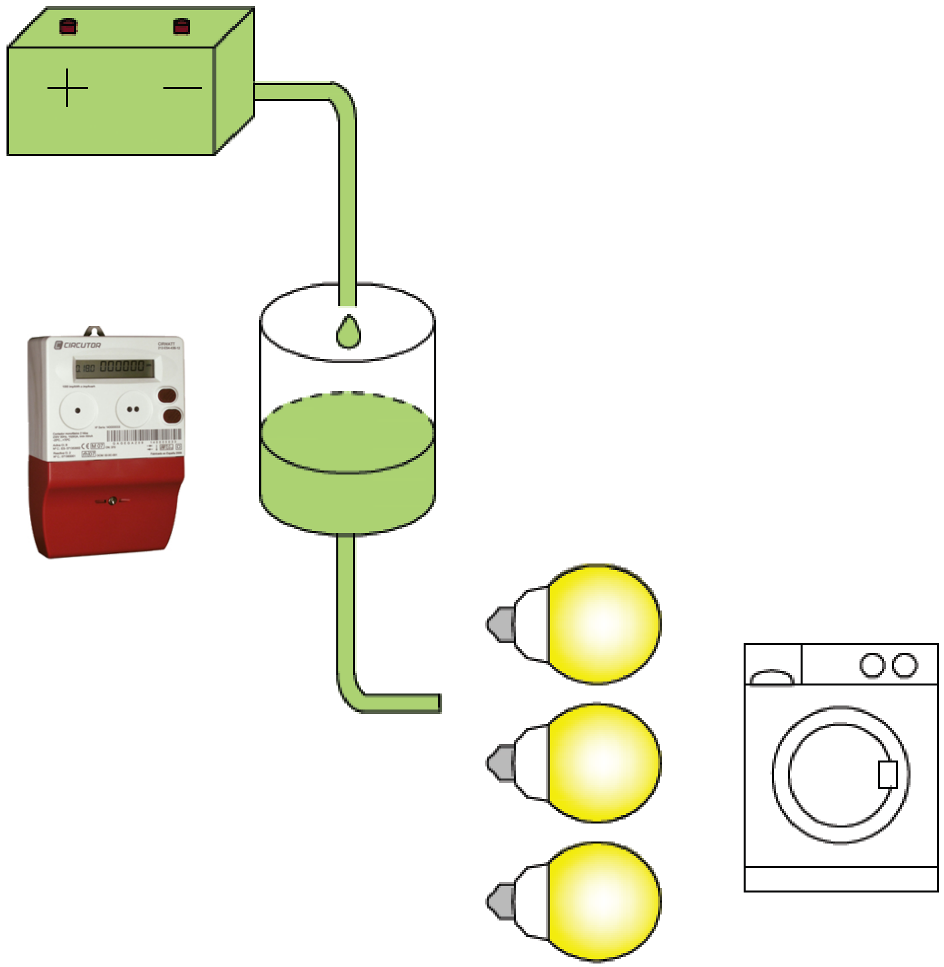
If the consumption is low the tank will top up

*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

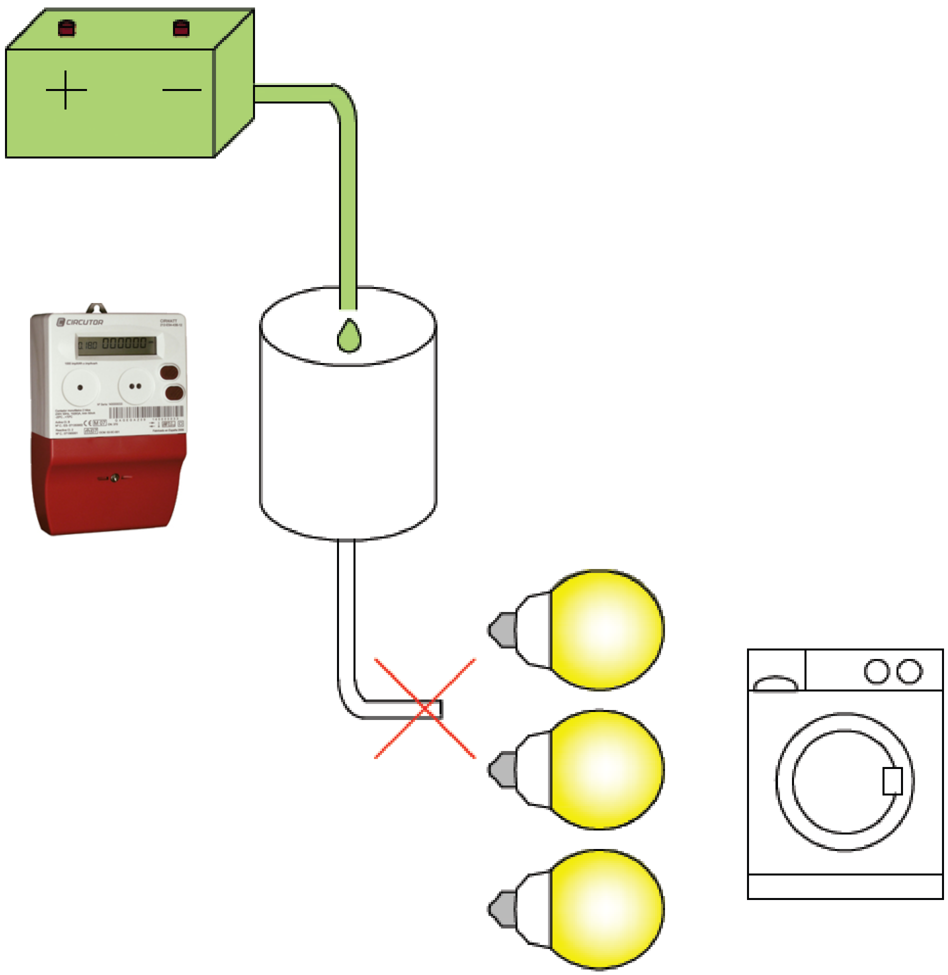


High consumption

At higher consumption the tank gradually empties

Electricity Dispenser / meter

HOW IT WORKS



Continuous high consumption

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

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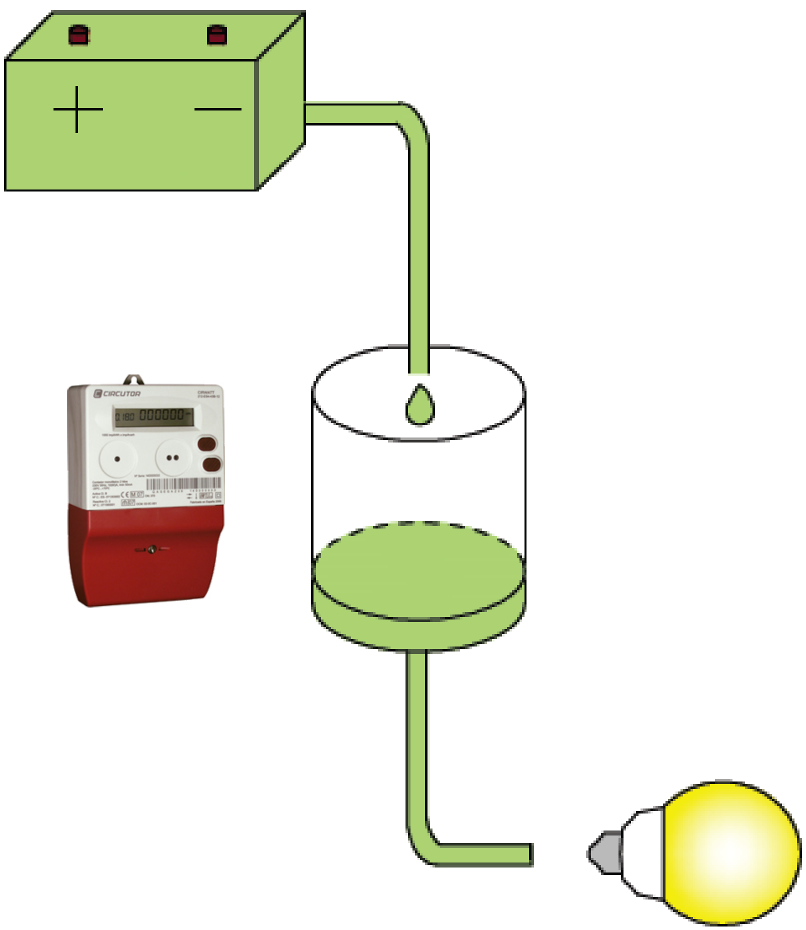
Electricity Dispenser / meter

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***

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Electricity Dispenser / meter

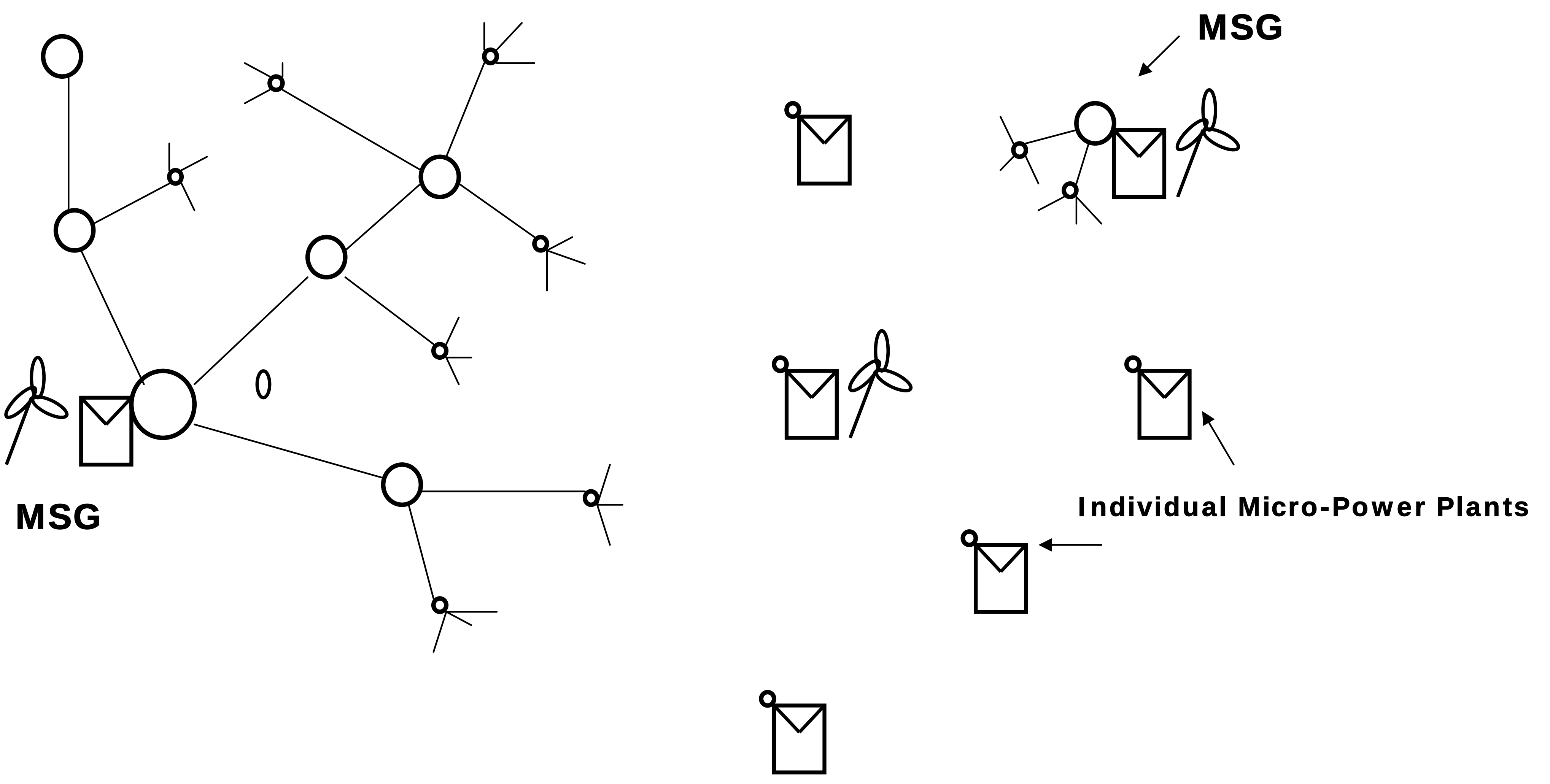
- Limitation of energy to the contracted **energy daily allowance** with virtual storage
- The user pays a fixed monthly fee
- Flexibility to defer consumption and to consume at different dispensers

Key points in the preparatory work for increasing the community acceptance

Key points in the preparatory work for increasing the community acceptance

- Life cycle cost analysis
- The environmental dimension
- A long term perspective on fuel prices
- The socio-economic and cultural dimension
- Institutional framework
- Organizational model
- Technical requirements of the power system and
- Measures to improve energy efficiency

VISION: Universal electrification-individual plants and micro grids under one operational scheme



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)

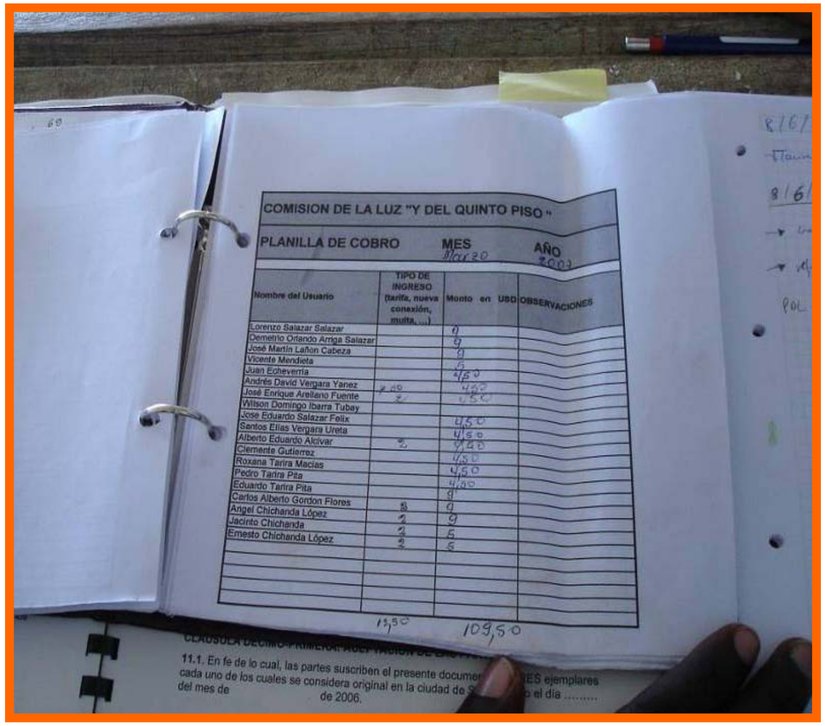
➢ Need of tailored tariff schemes

Administrative Aspects

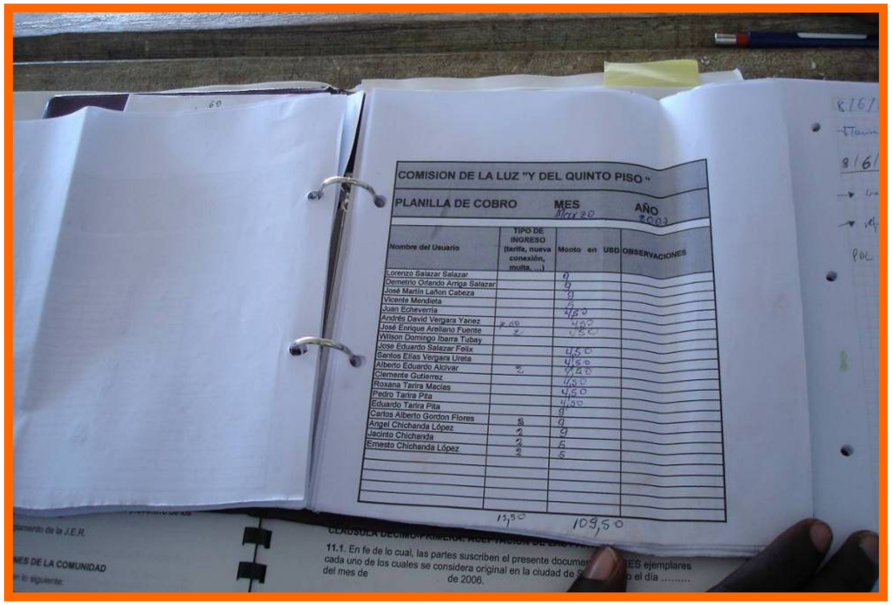
➢ micro Energy must be defined as a service rather than an installation: Needs a **management model** with at least:

- 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



Business models for rural electrification



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

Sustainable Rural Electrification: Social, economic and technological issues in implementing of RE distributed electricity generation in Africa (part II)

Case studies from different developing countries on the implementation of distributed electricity generation system for rural population

- MSG in Morocco
- MSG in Palestine (DVD)
- MSG in Senegal
- RE back up in Lebannon

Examples MSG in Africa

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 550 Wh/day

Site


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

Technological Configuration – Multiuse building (“Casa de la Luz”)

Technological Configuration – PV hybrid micro power plant






Technological Configuration – single phase LV distribution grid

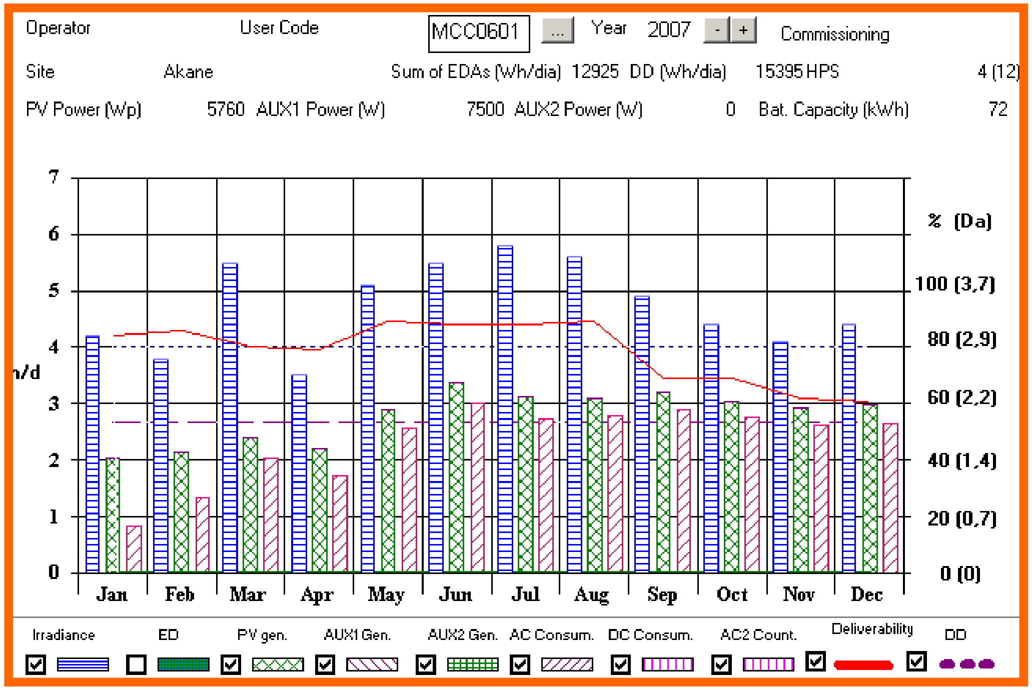


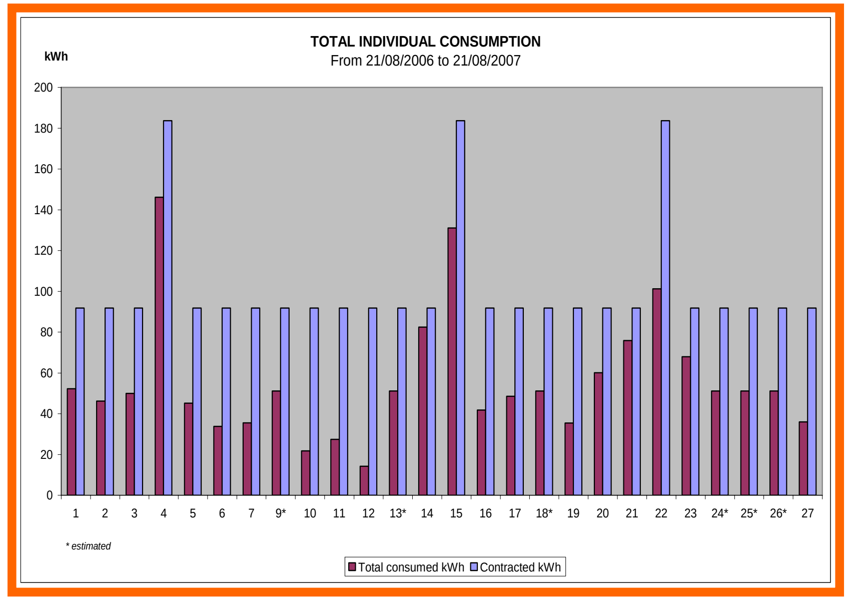


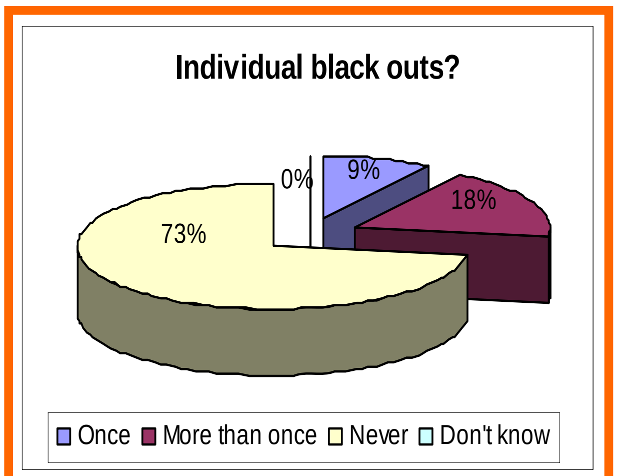

Technological Configuration – user interface and loads

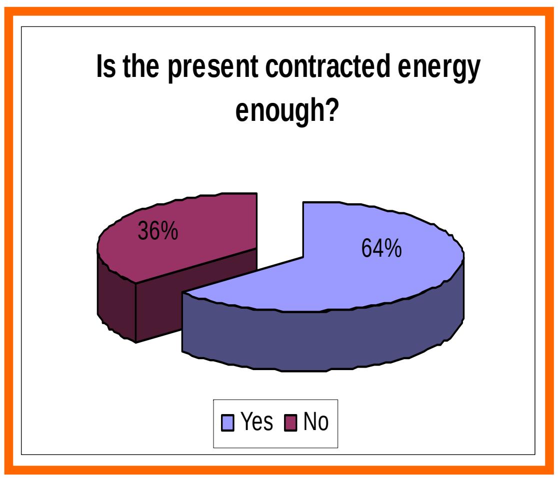
Performance assessment after 1 year

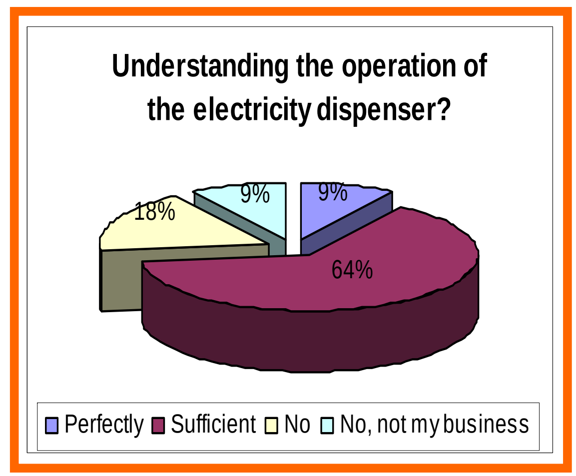
Technology performance



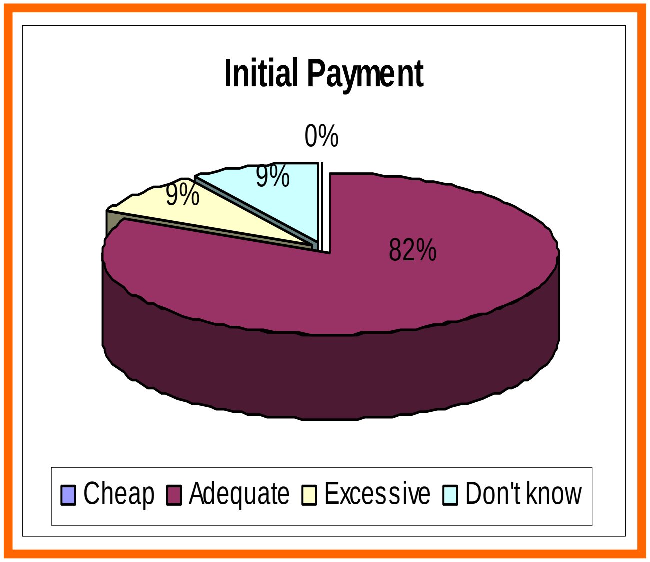


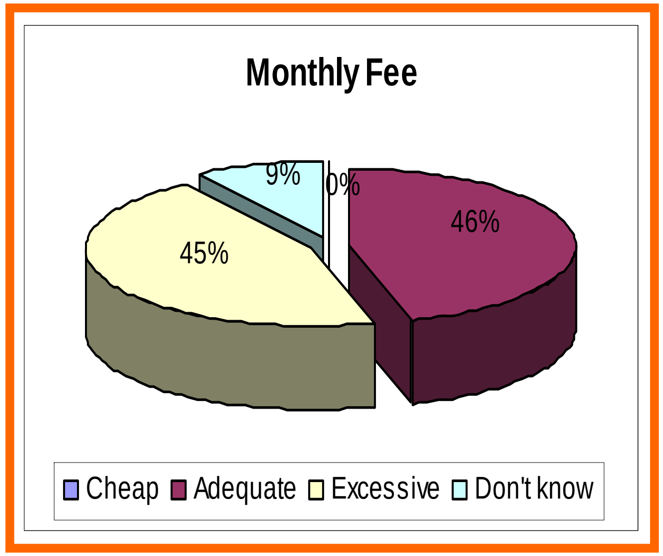


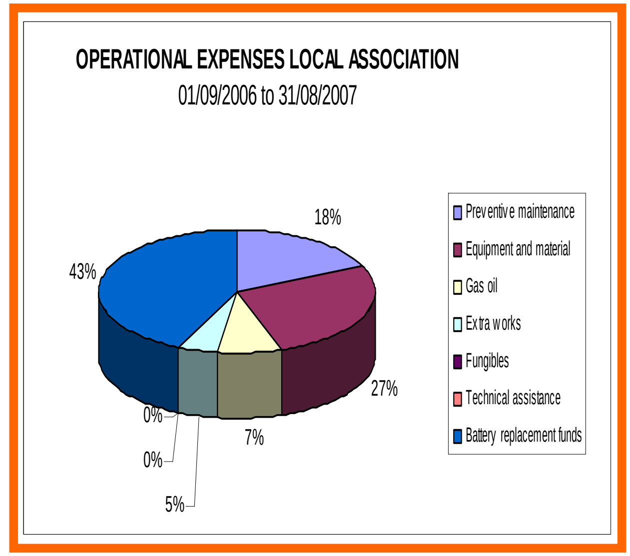


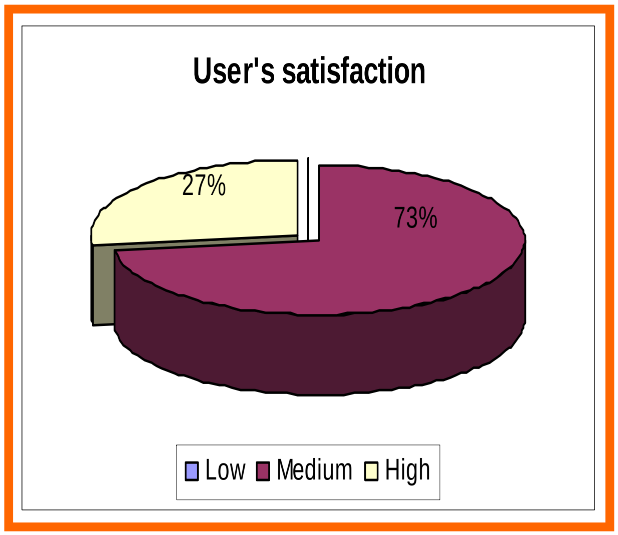


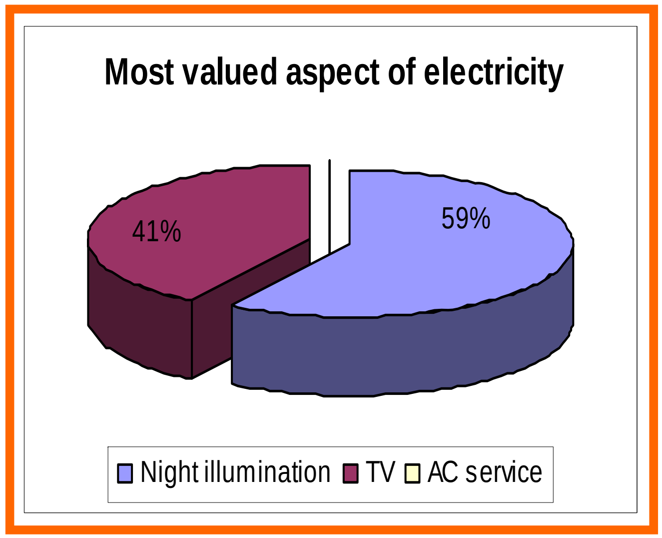
Economical and social

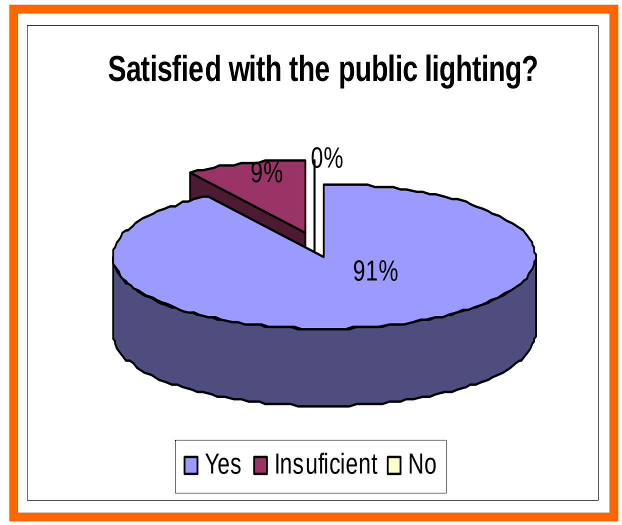




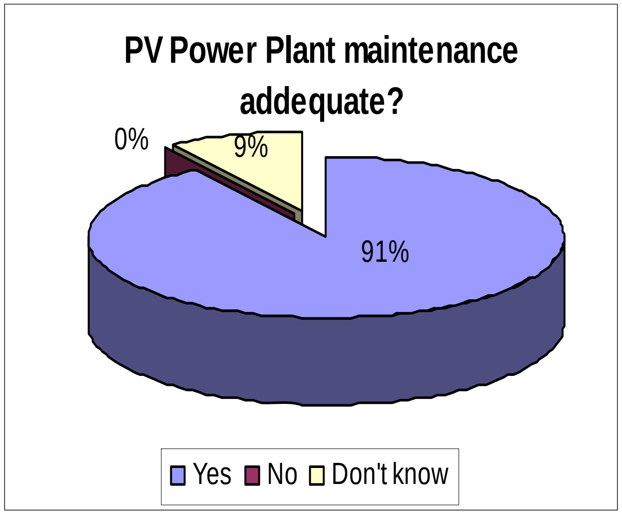


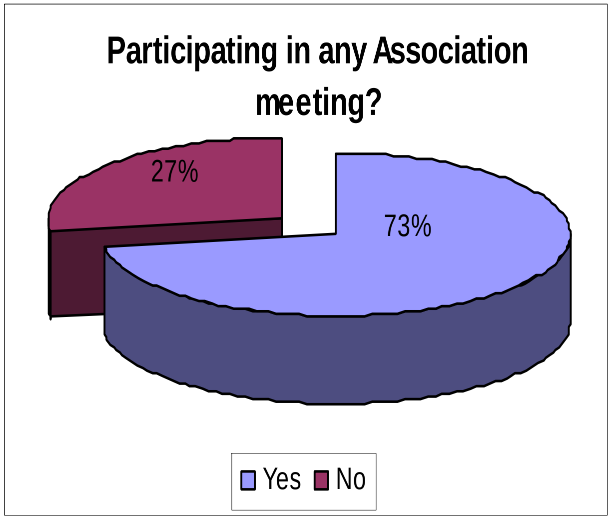




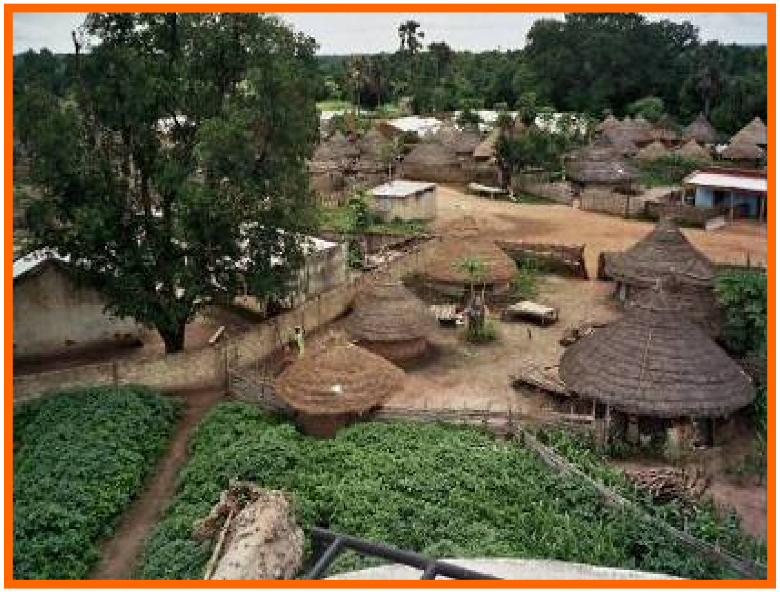


Organizational and institutional





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 m^2
ENERGY	
Rated Energy Output (Wh/day)	4.803
Irradiation (ḠpHp)	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	5m^3/h
Depth	49 m
Height of the tank	7 m
Tank capacity	20 m^3
BACK-UP GENSET	
Nominal power	4,2 kW single phase
Fuel	Diesel

Grid interconnected PV back up

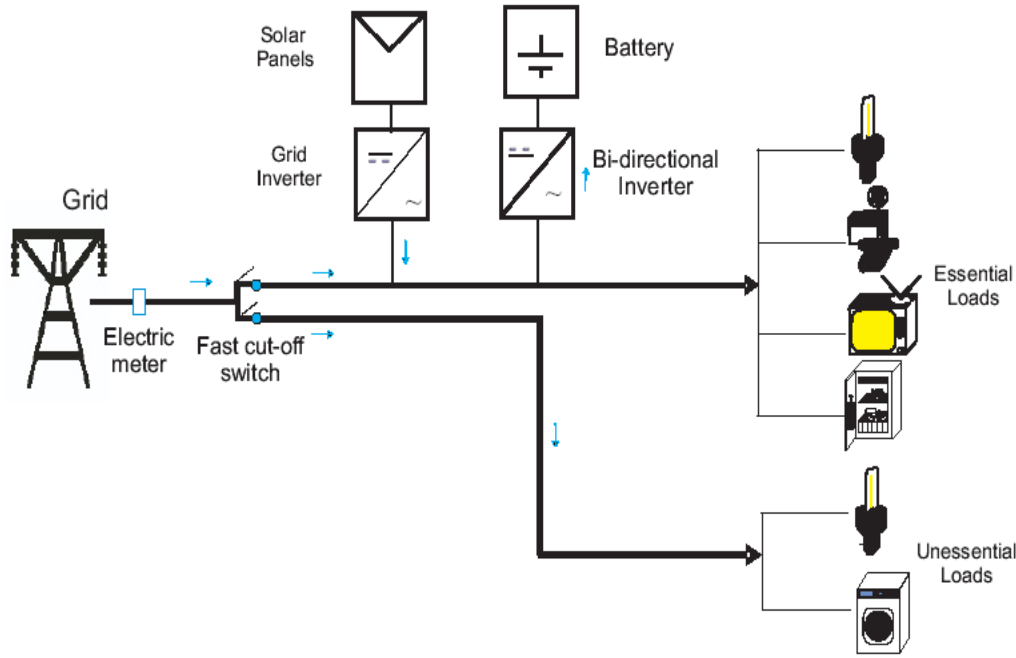
Design principles PV back up

✓ Implementation in buildings with available space of the roof without shadow

✓ Area available for requires STC capacity

✓ PV facility generates at daytime with storage possibility in order to reduce the energy bill and dependency

✓ Net metering recomended



Operation:

✓ When the grid is on:

During the daytime, the PV feeds the load and reduces the utility bill. Both PV and grid feeds the battery

✓ When the grid is off:

The PV feeds directly the loads with the support of the battery

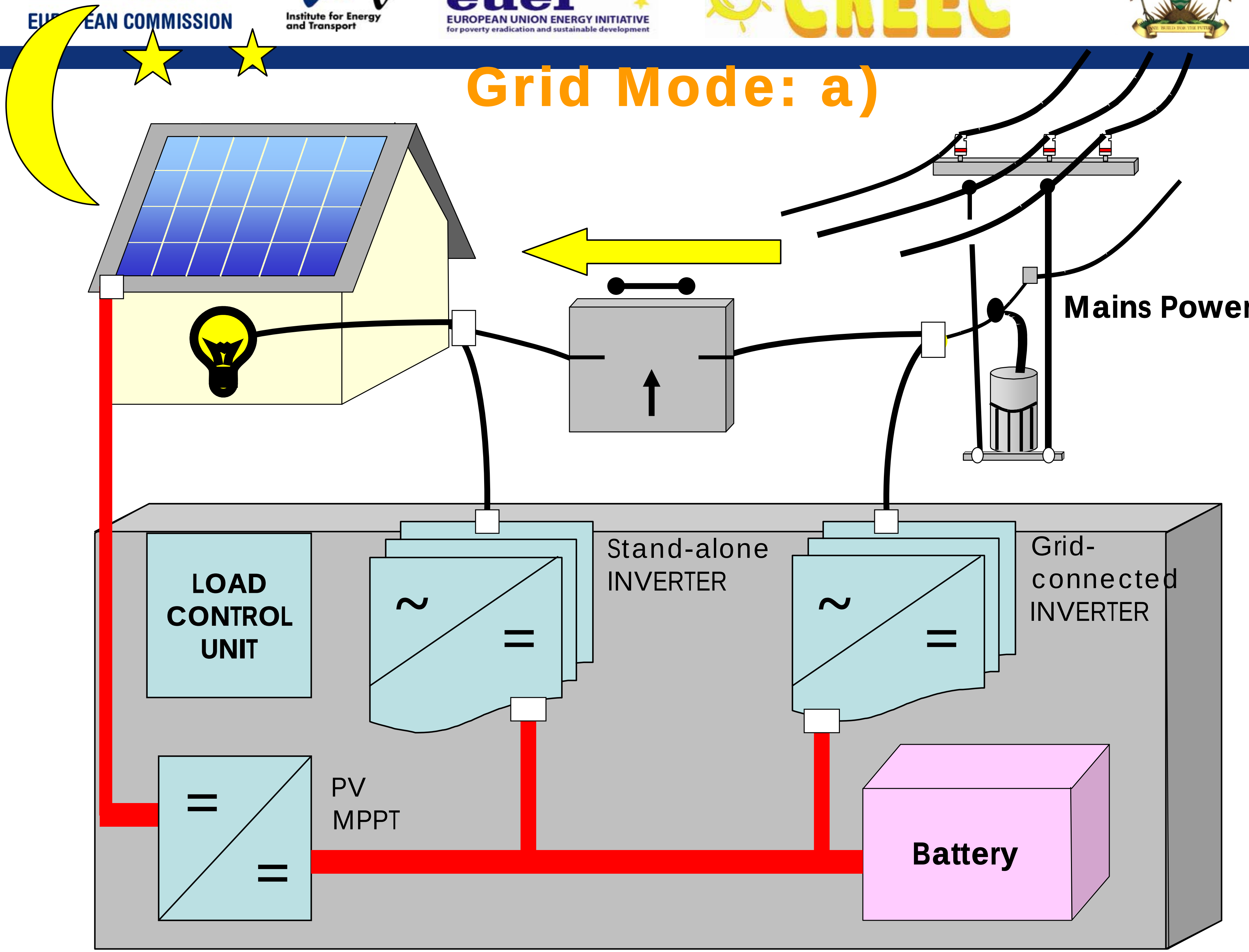
Main advantages:

✓ Continuous supply for essential loads in case of interruption of the grid

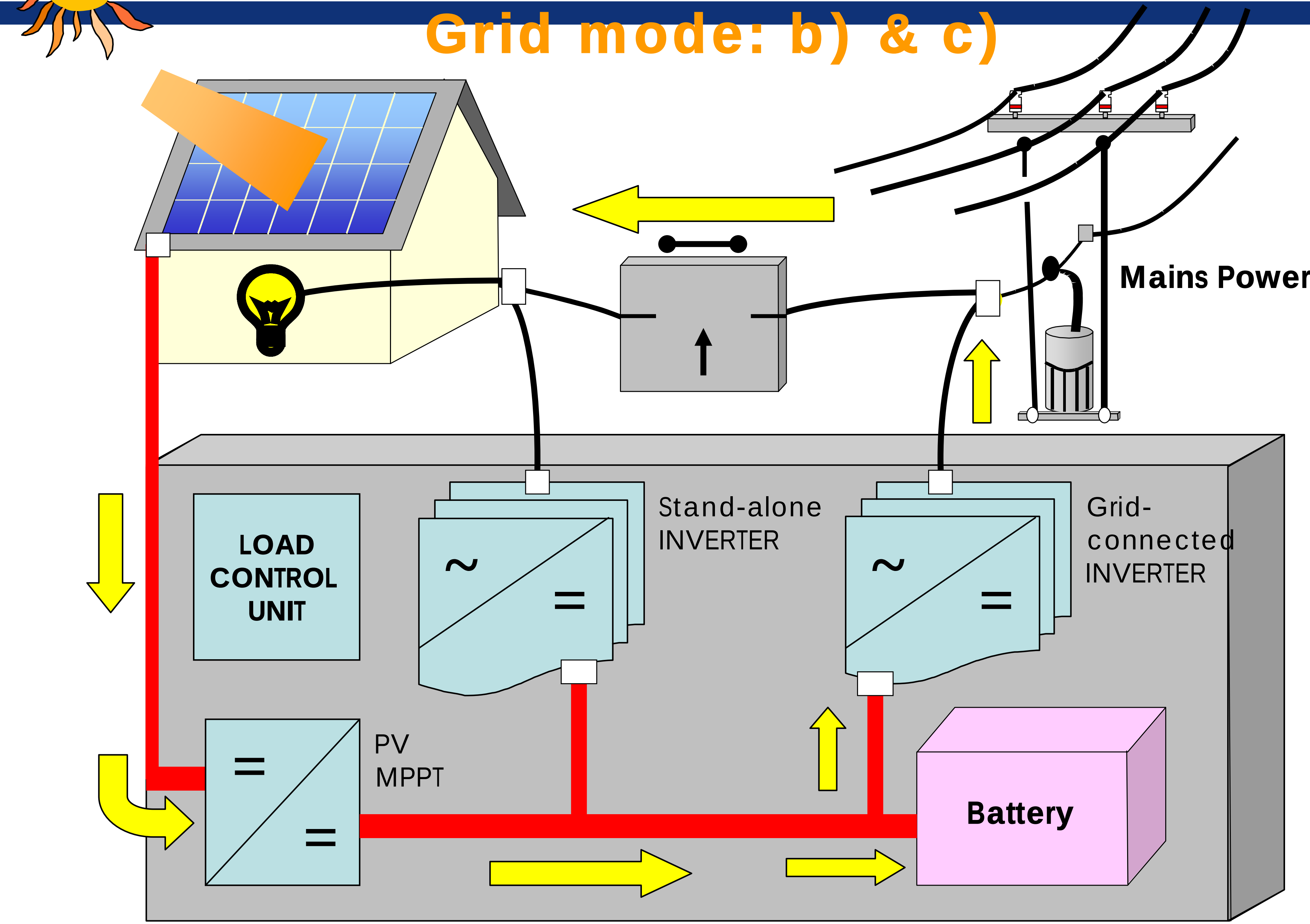
✓ Decrease of the energy from utility

✓ No need to contract a back-up generator

Grid Mode: a)

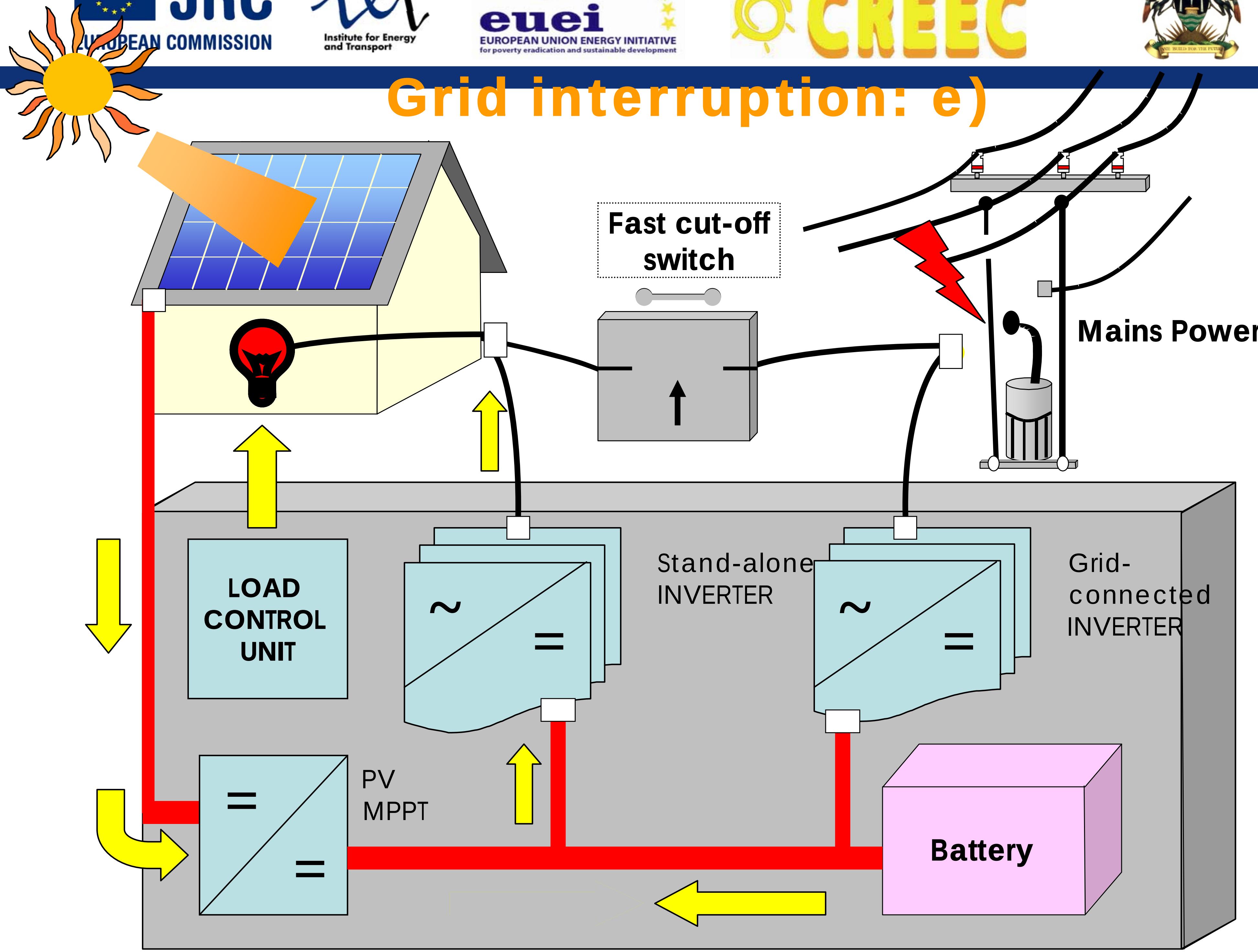

Mains Power
LOAD CONTROL UNIT
Stand-alone INVERTER
Grid-connected INVERTER
PV MPPT
Battery

Grid mode: b) & c)

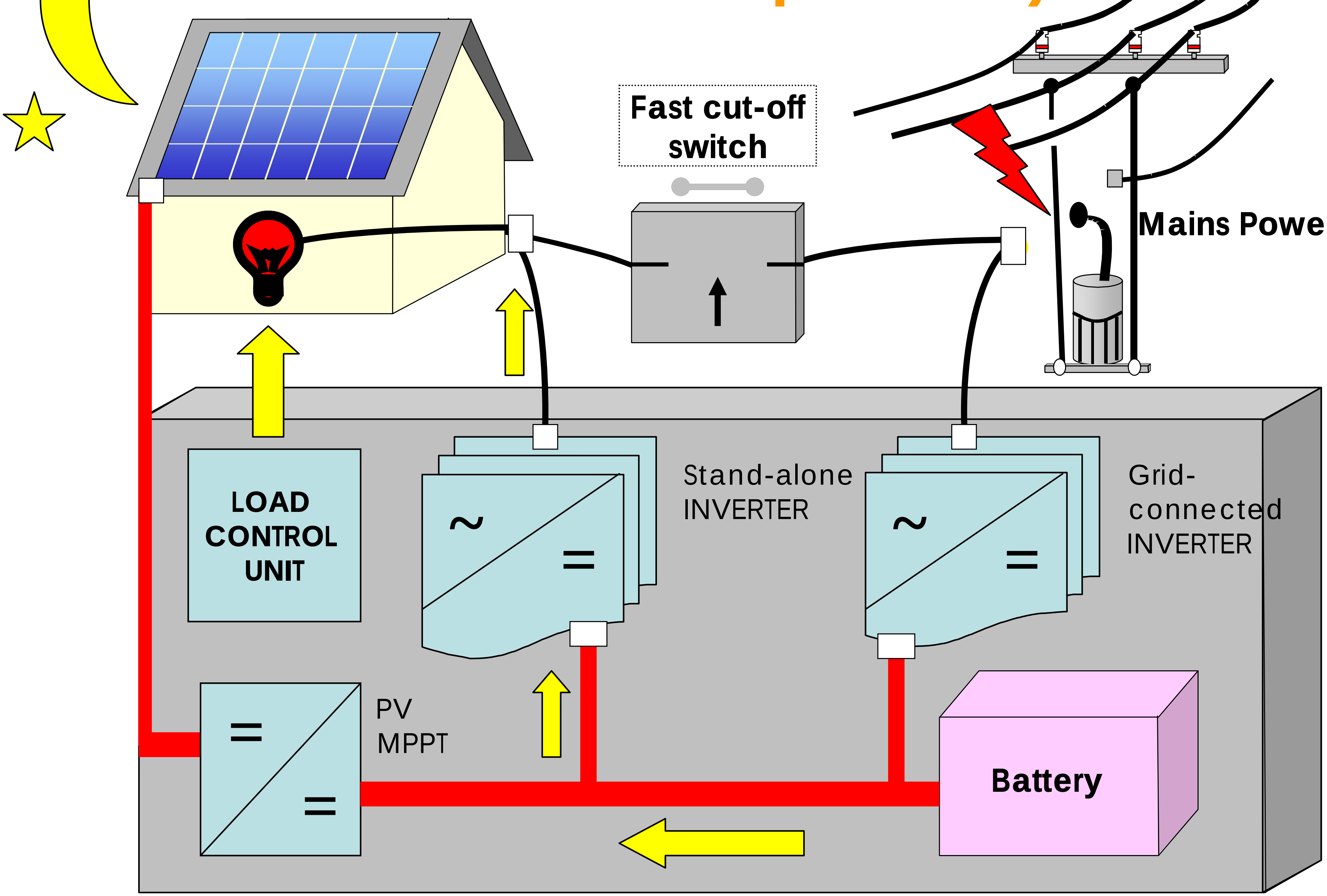


Mains Power
LOAD CONTROL UNIT
Stand-alone INVERTER
Grid-connected INVERTER
PV MPPT
Battery

Grid interruption: e)



Grid interruption : f)



Example PV back up (Multimode)

Demonstration PV back up facilities in a school in Lebanon (UNDP-CEDRO project)

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Demonstration PV back up installations in Lebanon (CEDRO project)

Example PV back up (Multimode)

Demonstration PV back up facilities in a school in Lebanon (UNDP-CEDRO project)