# PV-hybrid microgrids for rural electrification: field experience

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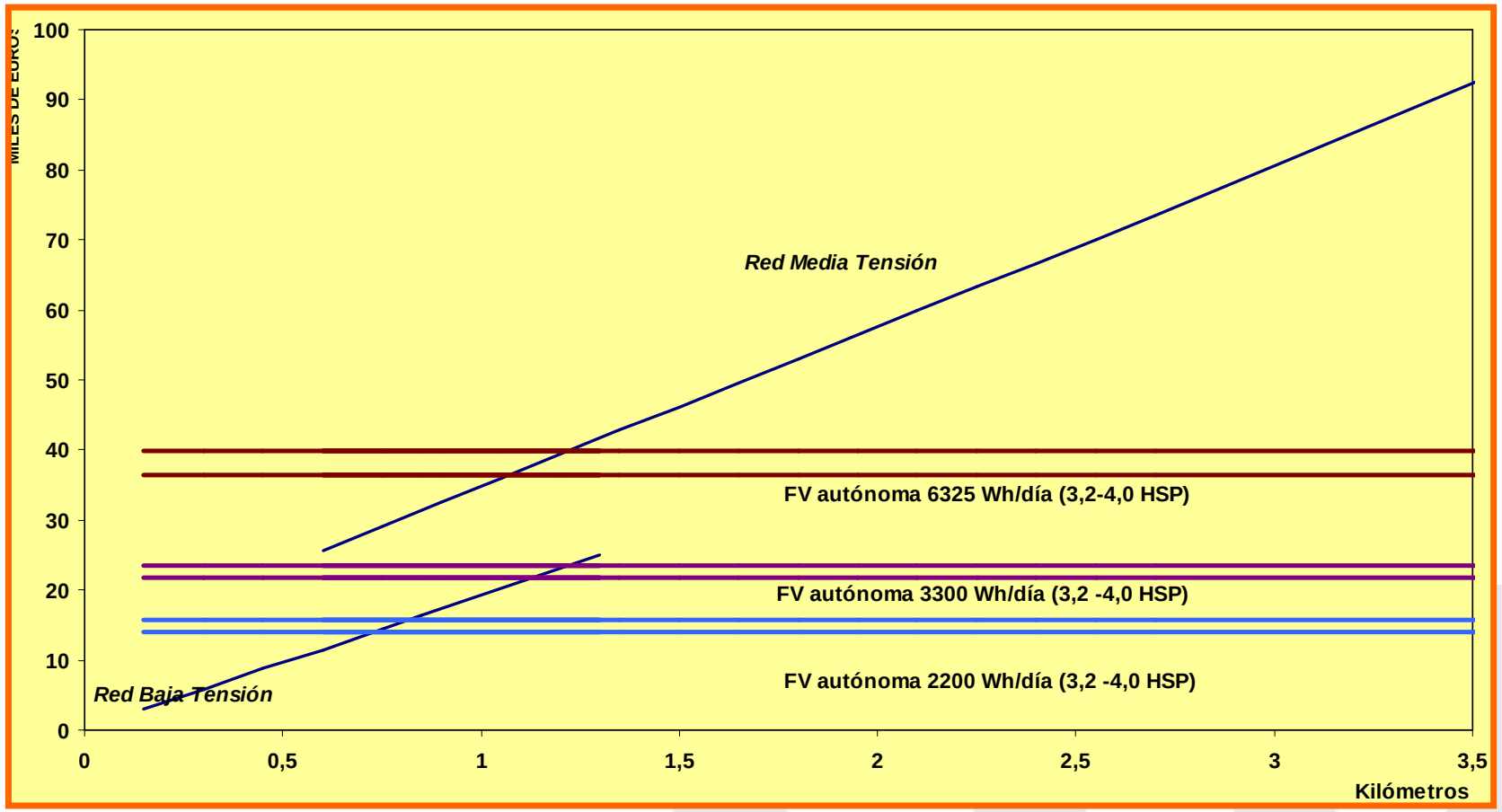
# Relevant aspects in rural electrification

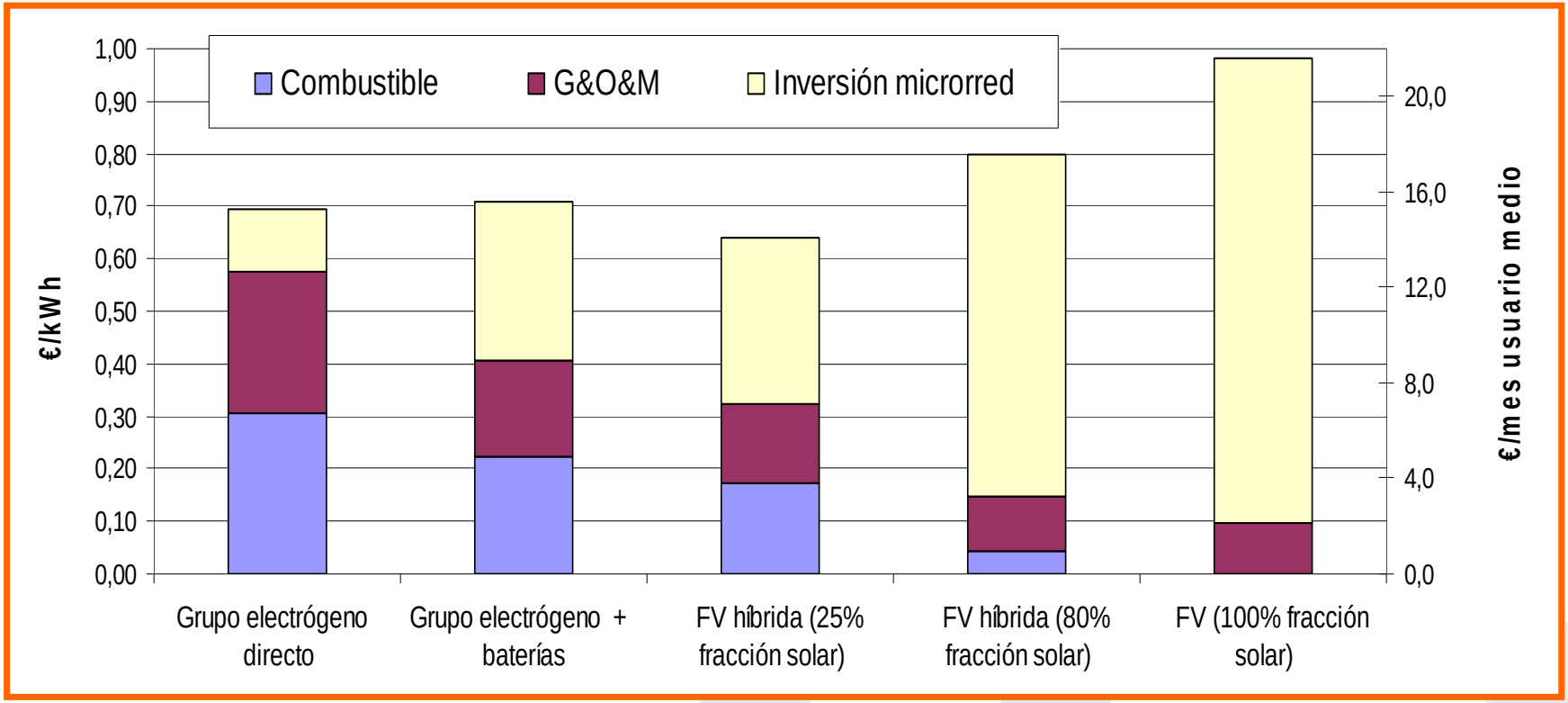
- **Cost-effectiveness**
- **The needs: demand analysis and segmentation**
- **The technologies and design practice**
- **Ownership, operational scheme and training**
- **Case studies**
- **Monitoring and performance assessment**

# PV cheaper than grid extension for remote areas




**Comparison of investment costs between grid extension and off-grid PV in Spain**

# PV more sustainable than fossil fueled Gensets

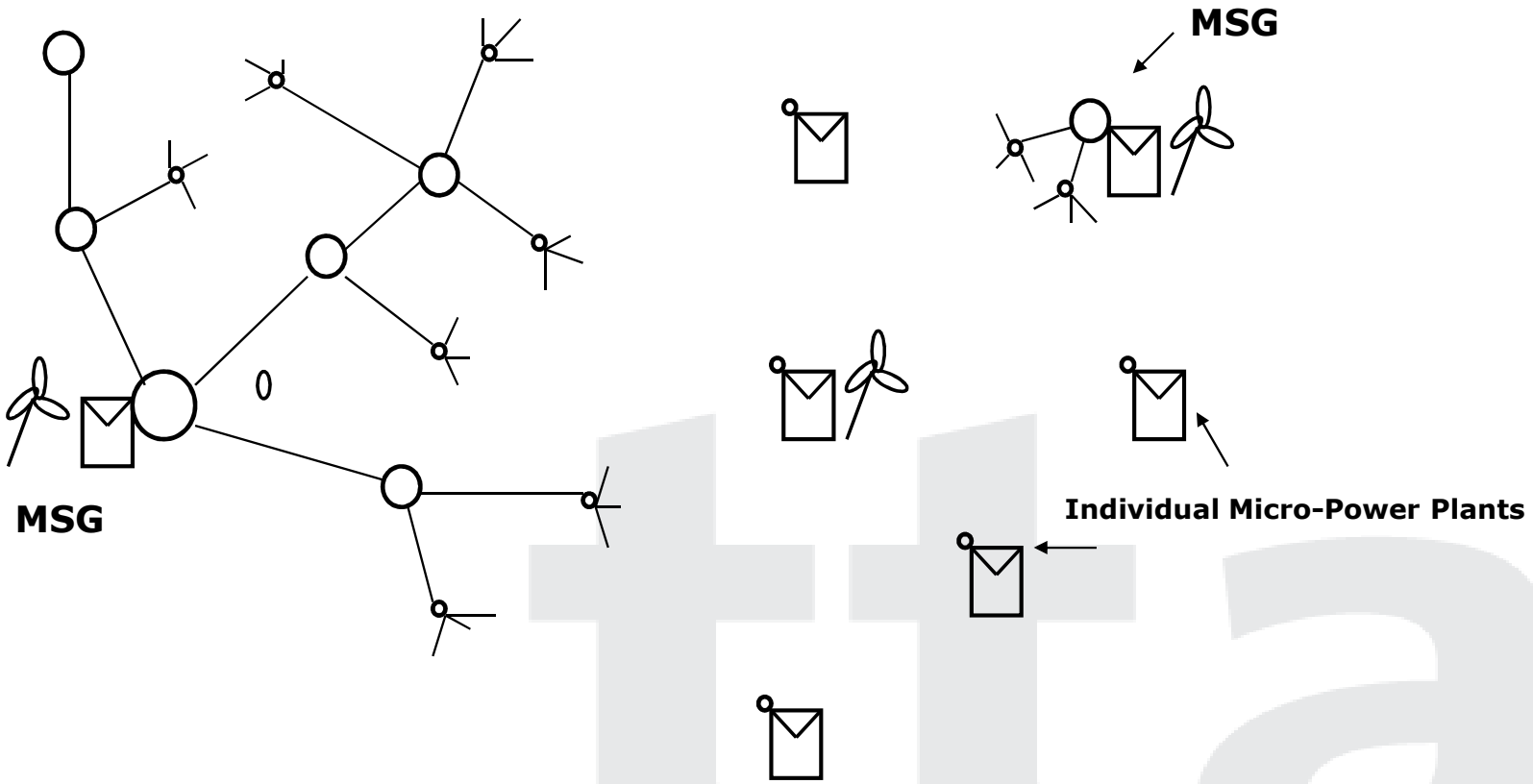



**Levelized costs for PV and Diesel technologies in microgrid for 340 users in Peru**

**(D.R. 5%, Diesel: 0,57 €/l)**

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

# VISION: Universal electrification-individual plants and microgrids under one operational scheme



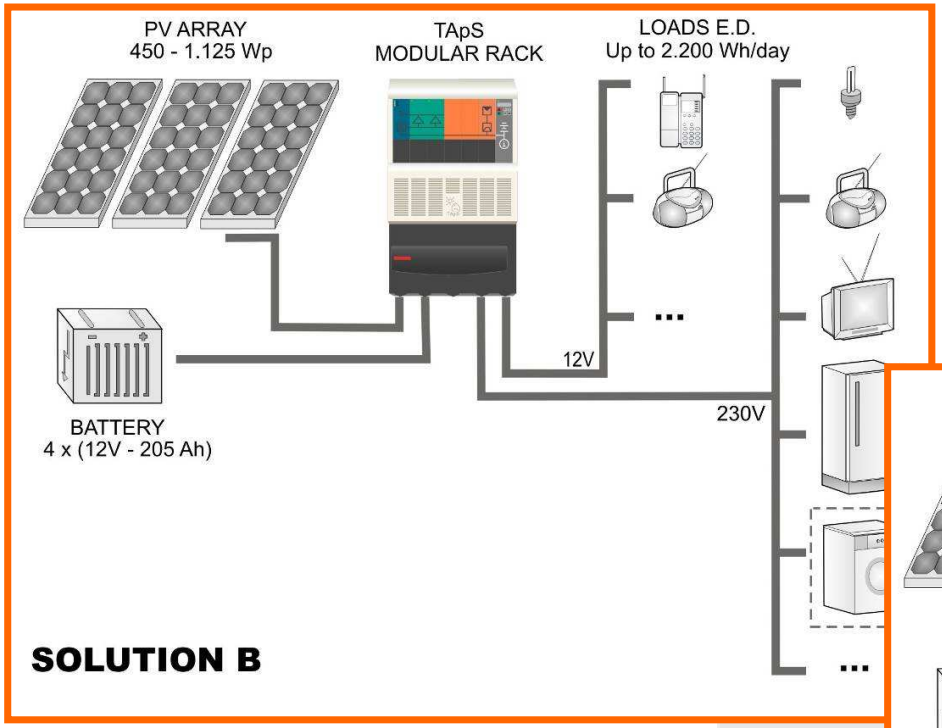
# BACKGROUND: Typical Design approach

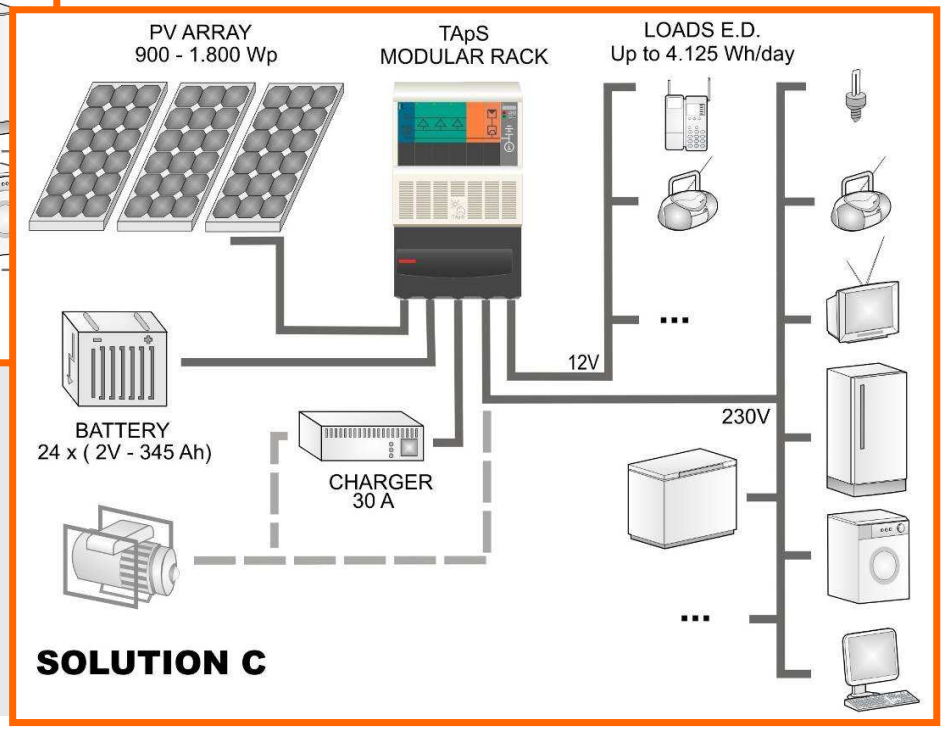
- **Experience in Design and Project management of PV-hybrid micro-power plants in rural areas of southern Europe, Africa, Latin America, Pacific …**
- **Technical specification for PV-hybrid micro-power plants (<100 kW, LV) partially adapted from IEC 62257 TS series**
- **Demand analysis and segmentation**
- **Standardized technical solutions with high PV penetration**
- **10 yr. Service horizon with local operator and local capacity building**
- **Monitoring of  systems to validate technology and the service**

# BACKGROUND: Typical Technical Specification

- **DC coupled topology, high fraction of Renewable Energy generation**
- **System bus-bar voltage: < 75V DC (SELV)**
- **Battery: Pb-tubular, vented, $DOD_{max}$=75%, A>3 days, 48V**
- **PV Charge controller: MPPT**
- **Inverter: sinusoidal $\eta$> 85% +25W pilot inverter**
- **PV modules: crystalline CEI 61215**
- **Data logging: based on CEI 61724 (JRC guidelines)**
- **Load electrical supply: Mainly standard AC quality single phase**
- **Load Management: user interface, automatic load disconnect**
- **Etc.**

# Individual PV micro power plant layouts

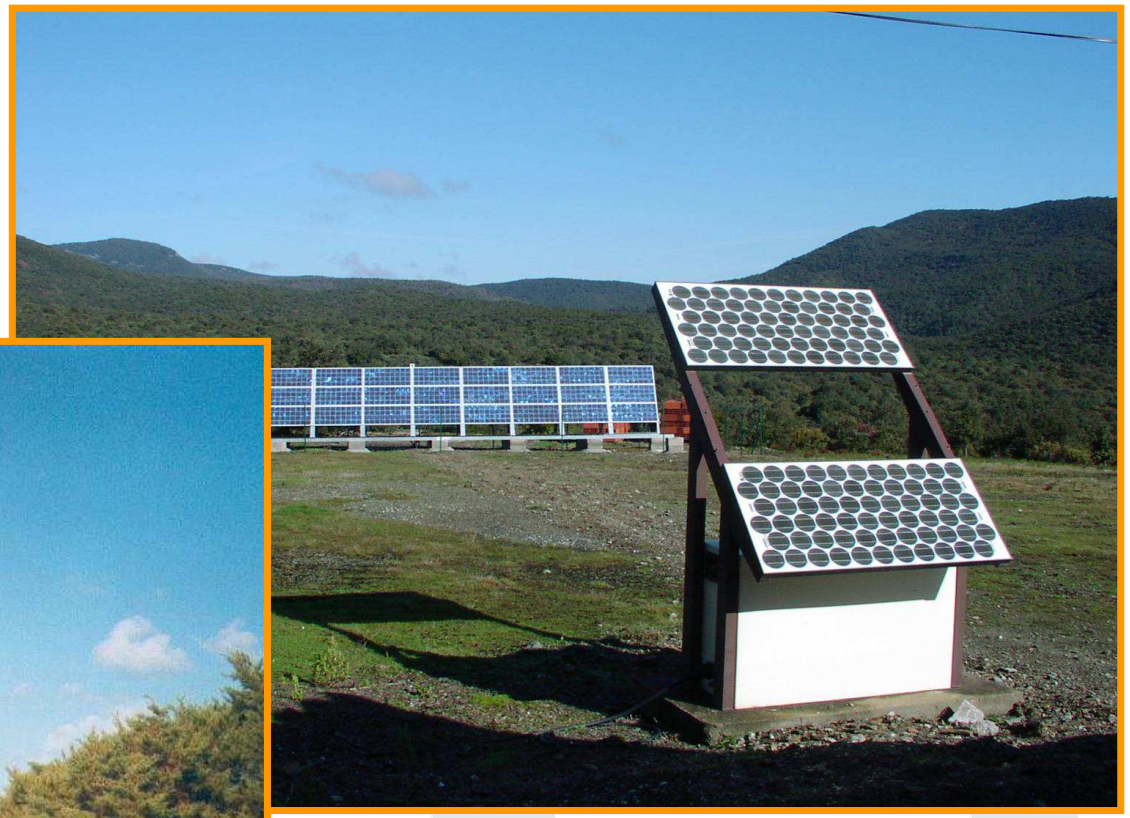


# Example Solution C

Pyrenees, Spain

# From interim to permanent solutions



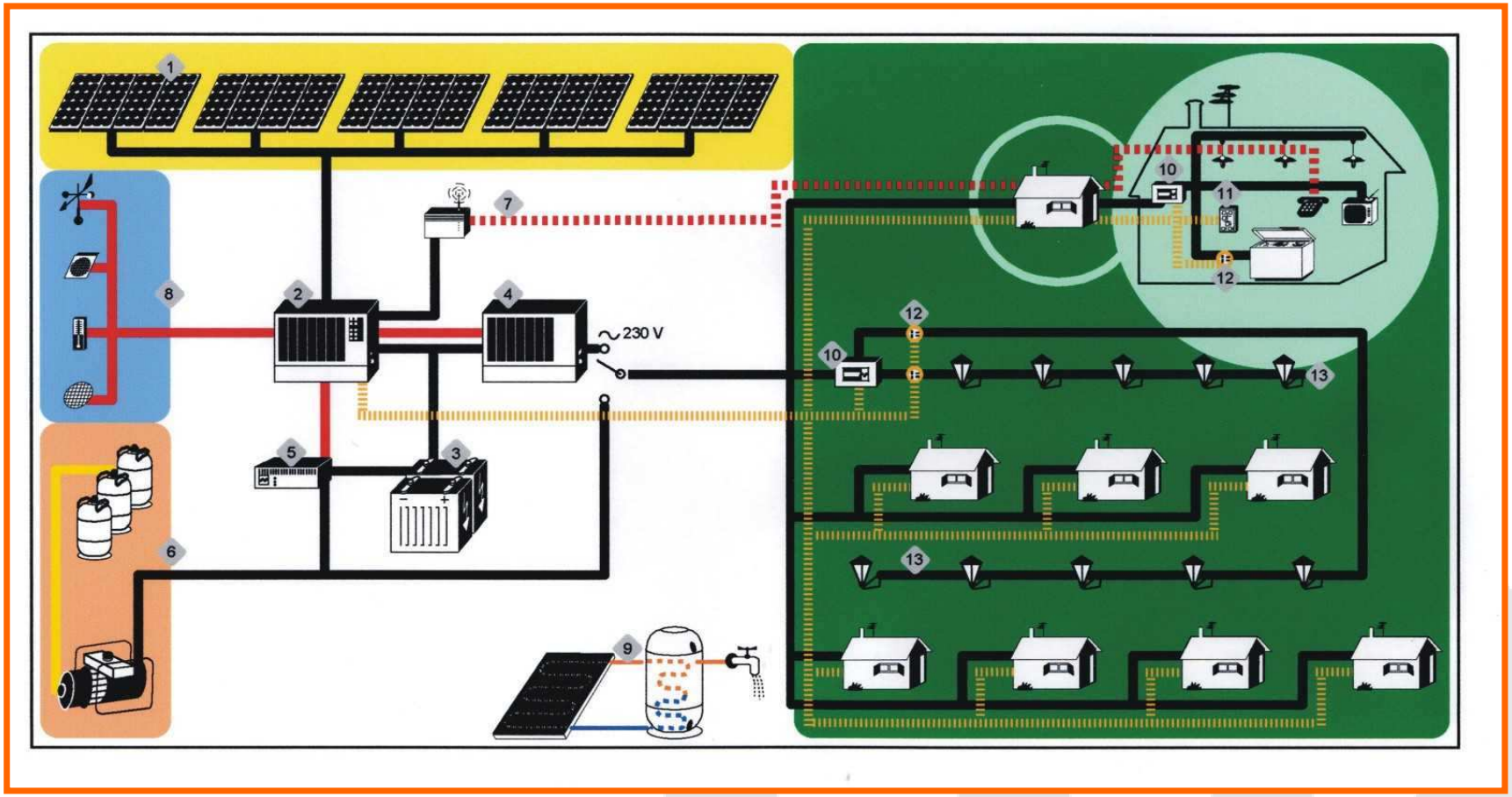
# From individual PV autonomous power plants to microgrids

| Application types | Types of uses |
|---|---|
| Home applications | Lighting<br>Audio/video<br>Refrigerator(s)<br>Small household appliances<br>Washing machine<br>Irons<br>Freezer(s)<br>Odd jobs |
| Public areas applications (places of collective life: worship halls, community centre, health centre, etc.) | The same appliances as above are used, but more and more powerful.<br><br>Public lighting.<br><br>Village water pumping. |
| Economic activities applications | Process equipment supply (mainly motors) |

Individual PV micro plants in Spain

Multi-user microgrids in Developping Countries

# From single user to villages: MSG (Multi user Solar Grid) up to 150 kW.h/day




**Typical layout (DC bus-bar micro power plant+AC single phase grid )**

# Comparison Individual and Microgrids

| | Advantages | Disadvantages |
|---|---|---|
| Individual Electrification Micro plants | •Consumption is user managed and determined from one day to another.<br>•System black outs affect just one user.<br>•Systems can be easily moved to a new location. | •Inadequate power (current) management will self impair the user.<br>• Monitoring individual systems can be expensive and difficult.<br>• Maintenance and repair service complex to organize in rural areas especially in developing countries. |
| Multiuser Solar Grids (MSG) | •Improved quality (surge power, load shedding, etc).<br>•Lower investment for compact villages.<br>•Energy saving can be practiced using improved management tools.<br>•Lower maintenance costs.<br>•Telemetry can be economic for monitoring system status. | •If the power plant fails, everybody is cut off.<br>•Social rules required to distribute energy availability.<br>•Local management required.<br>•Systems generally need to be serviced on site. |

- **Challenge: sharing the energy available without conflicts**

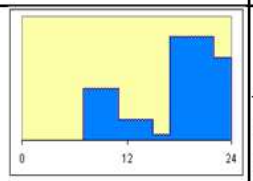
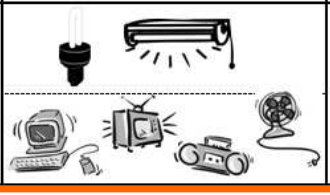
➔ **Energy distribution and metering problem!**

# Load Categories

| | Category A | Category B | Category C | Category MSG |
|---|---|---|---|---|
| Type of use | Individual basic (lighting and audio/video)<br>Or community "low energy consumption" services. | Individual services (same as category 1 + freezer or refrigerator and appliances)<br>Or community services (health care centre: lighting and freezer, etc.) | Individual services<br>(same as category 2<br>+ washing machine, vacuum cleaner, odd jobs, etc.)<br>Or public lighting | Multi-user microgrid with aggregate of individual and community loads of category A, B and C |
| Essential consumption characteristics | • Low number of receivers<br>• Low power of receivers<br>• Slim rigid load profile (P1) | • Medium number of receivers<br>• Receivers more powerful<br>• Slim rigid and base load profiles (P1+P2+P3)<br>• or Multiple basic users (P1+P1+ .. n) | • High number of receivers<br>• Some receivers are powerful<br>• High instantaneous power inrush<br>• "Variable" load profile (P1+P2+P4+P5)<br>• or Multiple users (P1+P1+P2+ .. n) | • Powerful receivers<br>• High instantaneous power inrush<br>• Many users some with "Variable" load profile (P1+P2+P4+P5) |
| Probable needed power | $P \leq 100$ W | 0,1 kW < $P$ < 0,5 kW | 0,5 kW ≤ $P$ < 2 kW | 2 kW ≤ $P$ |
| Average energy over 24h | $E \leq 550$Wh/d | $E \leq 1{,}5$ kWh/d | $E < 4$ kWh/d | $E < 150$ kWh/d |

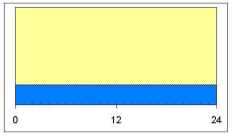
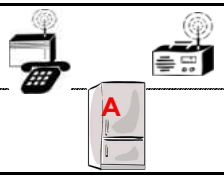
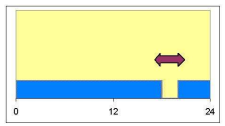
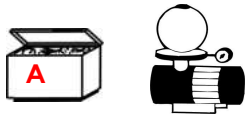
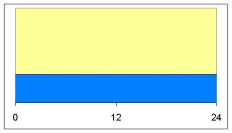
# Typical load profiles

**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 |

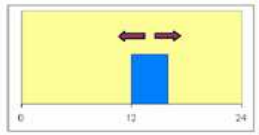
**Profile 2- Base Load**

**2a-Base Load** **2b- Base Load Interruptible** **2c- Base Load- Stand-by**

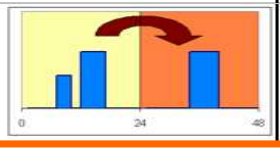
| PROFILE | LOAD | AVOIDABLE | DEFERABLE | INTERRUPT. | MODULABLE | TYPICAL DAILY RANGE (Wh/day) | |
|---|---|---|---|---|---|---|---|
| 2a  |  | NO | NO | NO | NO | 275 | 275 |
| | | | | | | 550 | 1100 |
| 2b  |  | NO | NO | YES | NO | 550 | 1100 |
| 2c  |  | YES | NO | YES | YES | 0 | 1100 |

# Typical load profiles

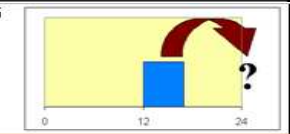
**Profile 3- Daily Deferrable load**

| 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 |

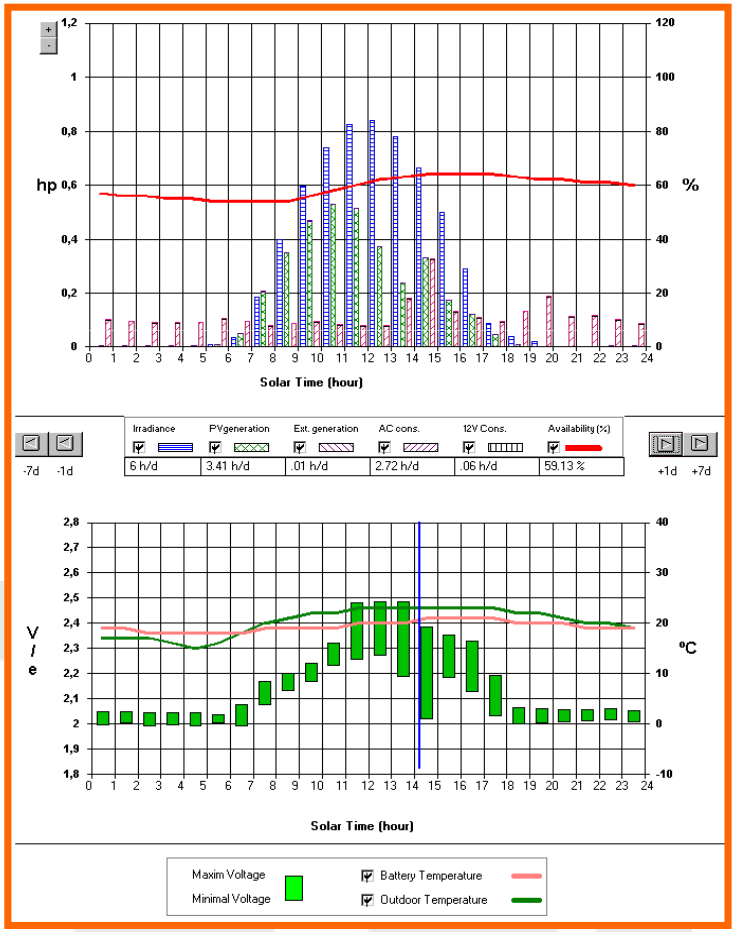
**Profile 5- " Dump or ballast" load**

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

# Interest for load management in PV powered micro-grids

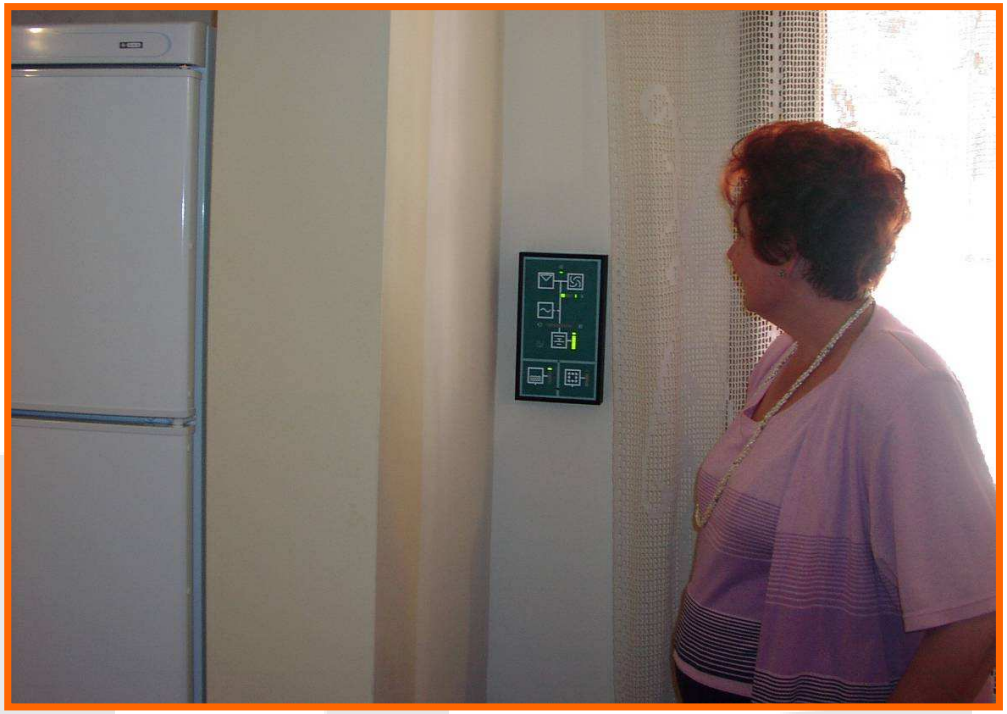
Strategies of load management:

- Disconnect loads to protect the battery: traditionally based on battery voltage. But this does not provide adequate information to user
- Find and try to eliminate parasitic stand by loads: the most important and difficult ! Undetected by performance indicators !
- Time shift deferrable loads to only sunny days: SoC is higher… battery could be smaller
- Time shift deferrable and ballast loads to battery float status: PR is higher… Array size could be smaller; HBI is higher… longer battery life, better autonomy



# Load management tools

- User information interface + training
- Automatic total load disconnect
- Automatic selective load switching
- Individual Energy limitation (multi user system)

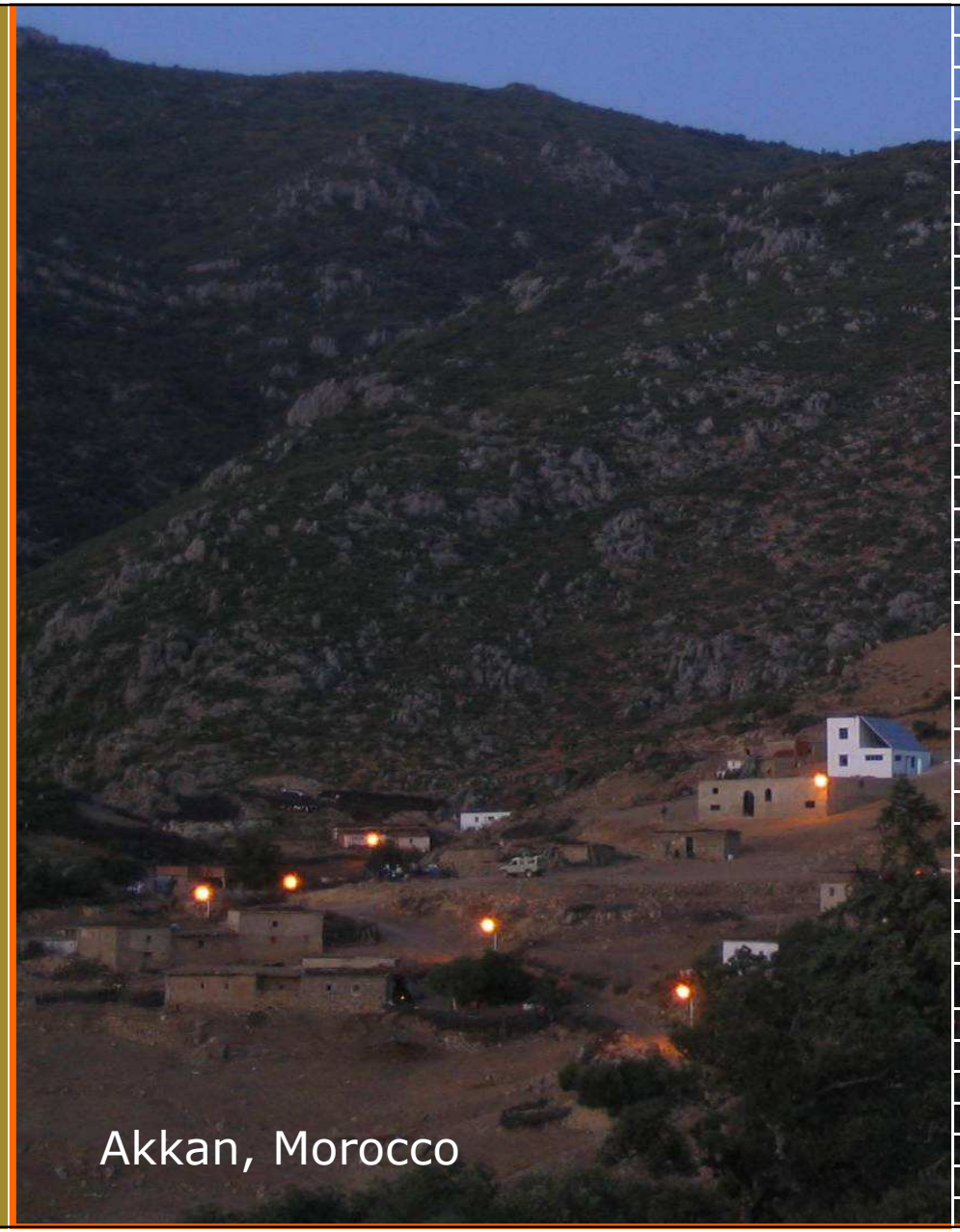


# Electricity Dispenser / meter

- Metering and invoicing interface
- Energy and power limitation and guidance according to tariff contracted and generation status
- User pays for availability of energy, not for the consumed energy

# Examples MSG

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% |
| **DATA LOGGER** | |
| Memory / log frequency | 300 kbyte / hourly |
| Type of data | Energy, voltage, radiation, etc. |
| **ELECTRICITY DISPENSER – METER** | |
| Input | 230 V AC 50 Hz |
| Maximum current | 10 A |
| Algorithm | Configurable Daily Energy Deliverability |
| **STREET LIGHTING** | |
| Number of lamps | 13 |
| Type | 70 W hp sodium / 2 level electronic ballast |
| Total power - high | 910 W |
| Total power - low | 683 W |
| **INDIVIDUAL LOADS** | |
| Households 275 Wh/day | 23 |
| Households 550 Wh/day | 3 |
| School 550 Wh/day | 1 |
| Mosque 550 Wh/day | 1 |

# Technology-PV hybrid power plant



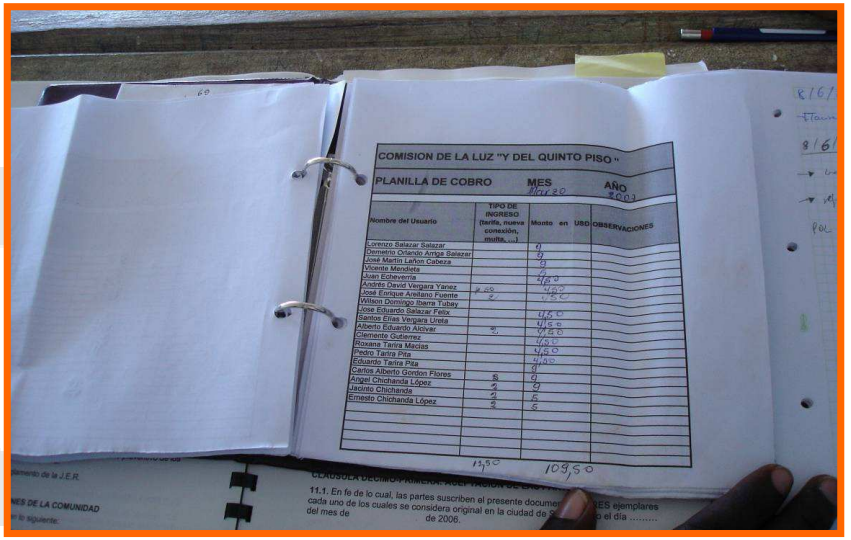
# Technology-distribution microgrid


San Lorenzo, Ecuador (LA)

# User interface and loads

San Lorenzo, Ecuador (LA)

# Ownership and Operation




San Lorenzo, Ecuador (LA)

Civil works of multiple use building

Agreements with users

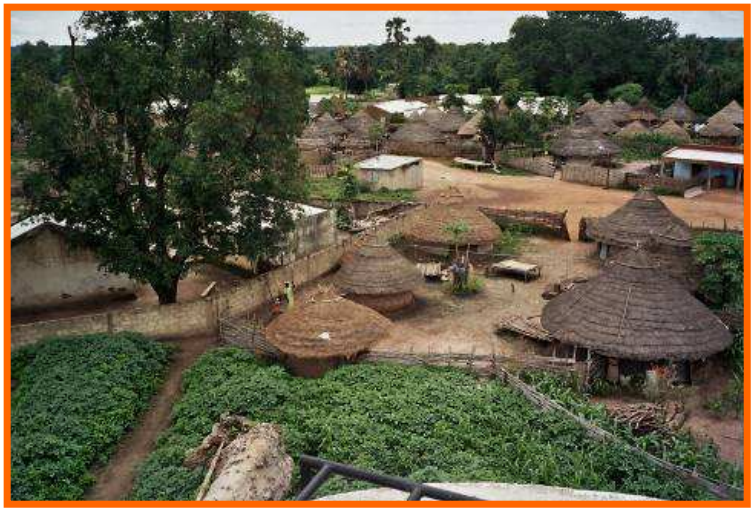
Local kick-off meeting

Floreana, Ecuador (LA)




Floreana, Ecuador (LA)

# Diakha Madina, Senegal



Diakha Madina, Senegal

| | |
|---|---|
| **PV ARRAY** | |
| PV installed power | 3.150 Wp |
| PV Module model | PW750 75 Wp 12V |
| Nº PV modules | 42 |
| Orientation/Inclination | 0º S / 10º S |
| PV Area | 46 $m^2$ |
| **AVAILABLE ENERGY** | |
| Available Energy (Wh/day) | 4.803 |
| Irradiation (GpHp) | 5 HPS |
| Month of design | December |
| **BATTERY** | |
| Nº elements | 24 |
| Battery type | Tudor 6 OPzS 420 |
| Capacity (C100) | 672 Ah |
| Day of 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% |
| **DATA LOGGING** | |
| Memory / freq. of logging | 300 kbyte / hourly |
| **PUBLIC LIGHTING** | |
| Number | 2 |
| Type of lamp | 70 W / electronic ballast |
| **PUMPING SYSTEM** | |
| Power of the pump | 1.100 W |
| Flow | 5$m^3$/h |
| Deep | 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 |

# Monitoring

**Combination of user questionnaires and data logger**

- **User records:**
  - **Satisfaction ??**
  - **Electrolyte level in battery**
  - **Black outs ?**


## Data logger:

**built-in device in power conditioner**

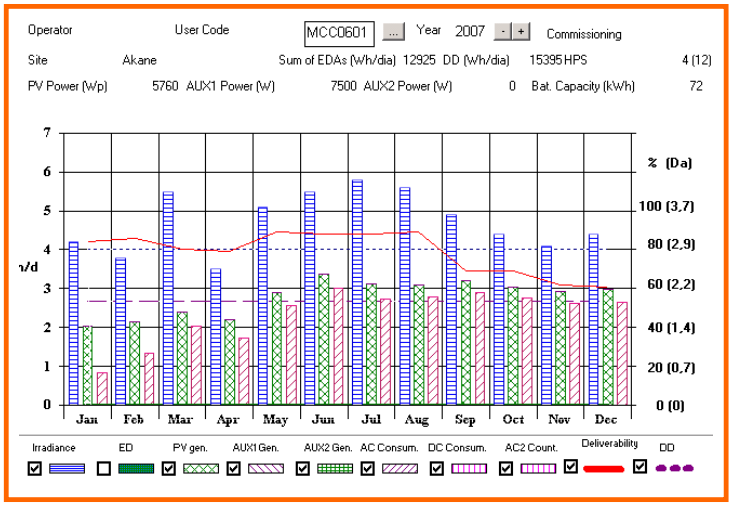
**Hourly Data Storage (1 year):**

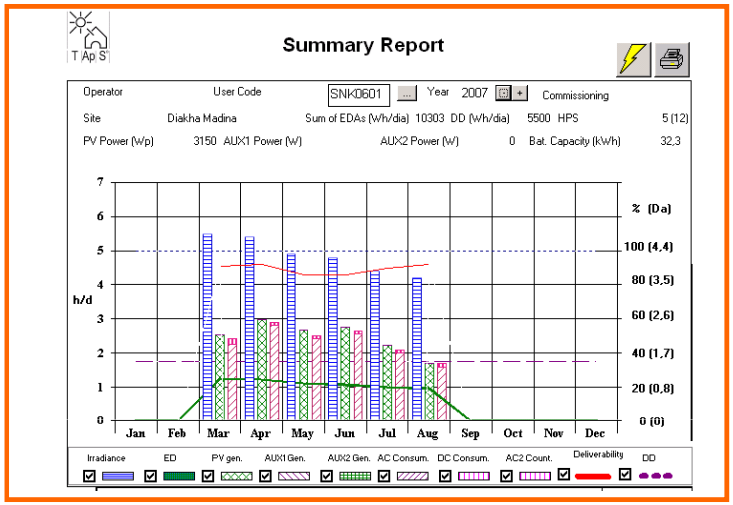
Average and total hourly values

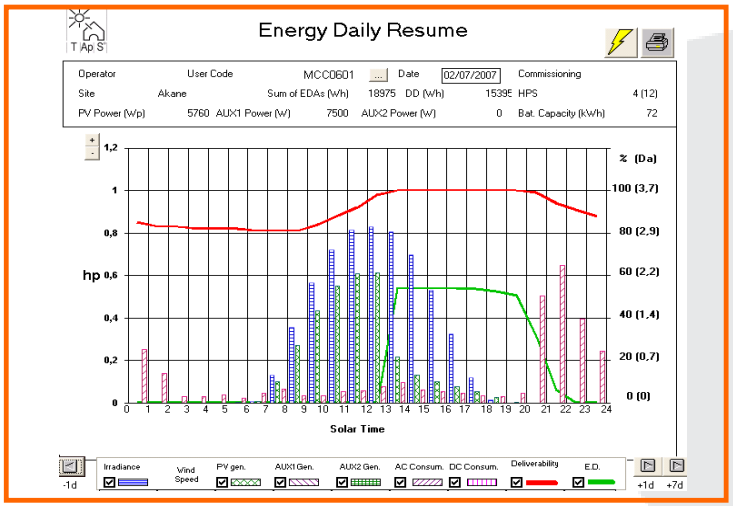
**Parameters:**

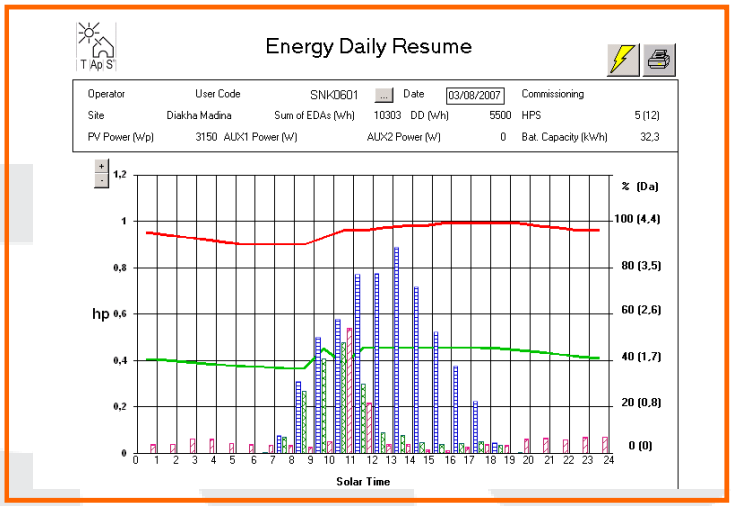
all relevant energy flows
solar irradiance
information on battery (voltage, SOC, etc.)
others

# Typical monitoring data

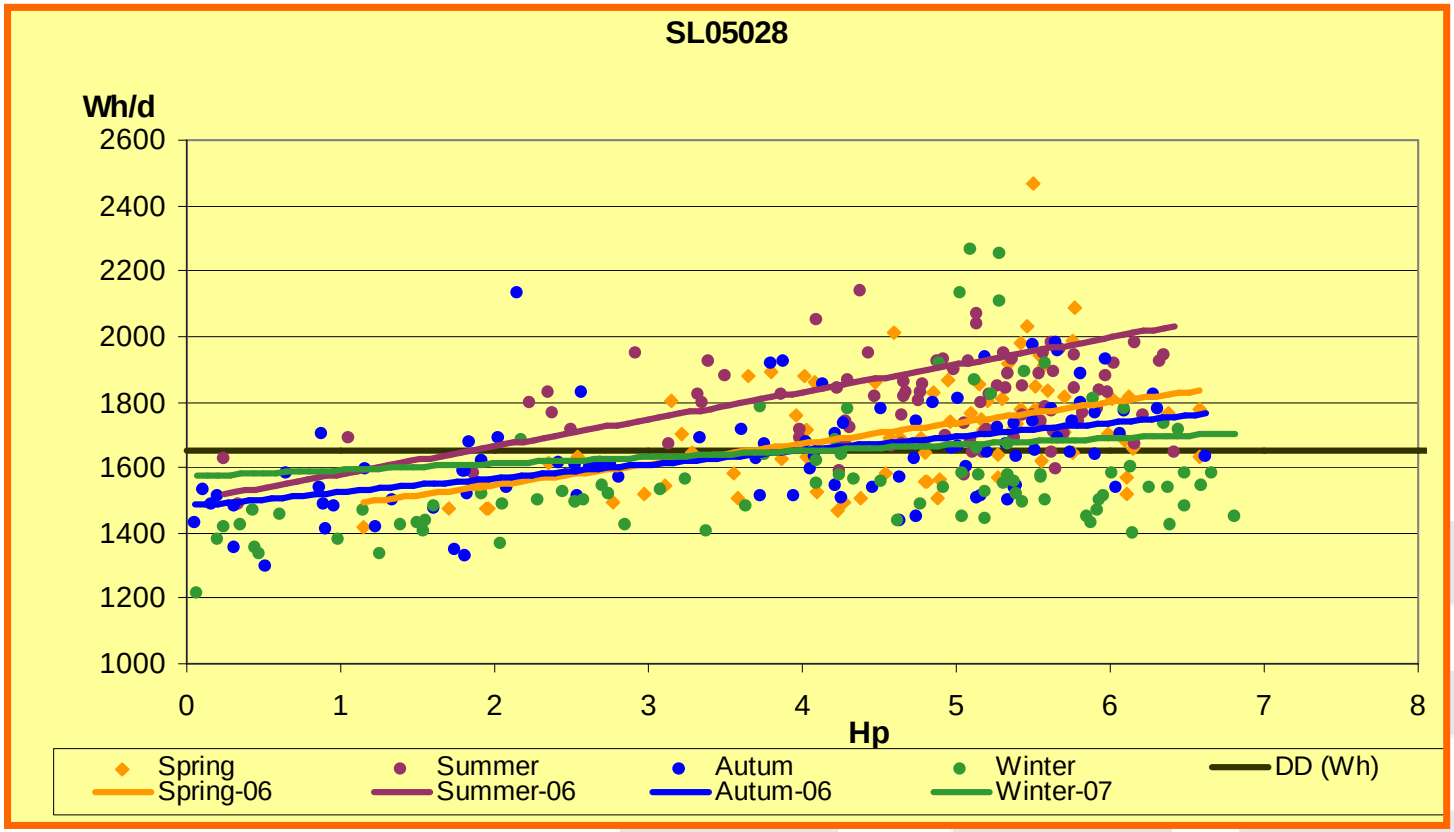


# RESULTS OF INDIVIDUAL LOAD SENSITIVITY ANALYSIS (careful user: good operator)



# LESSONS LEARNED in 15 years of practice

- **Modular solutions evolved from individual applications are good to meet requirements but new developments in microgrid technology open new possibilities**
- **PV-hybrid microgrids are an acceptable long term option and expanding market**
- **Public subsidies in rural electrification must be technology neutral**
- **Typical average energy consumption is low but very valuable to users**
- **Demand limitation not a problem if EE appliances available**
- **Generation technology more and more reliable and adequate but…**
  - **Load management is an important issue**
  - **Stand-by loads in appliances dramatically increasing !!**
- **Operator recommended for long term security. Fixed user fees better**
- **User interface is critical !**

Trama TecnoAmbiental

# Thanks for your attention!