
# PV SYSTEMS

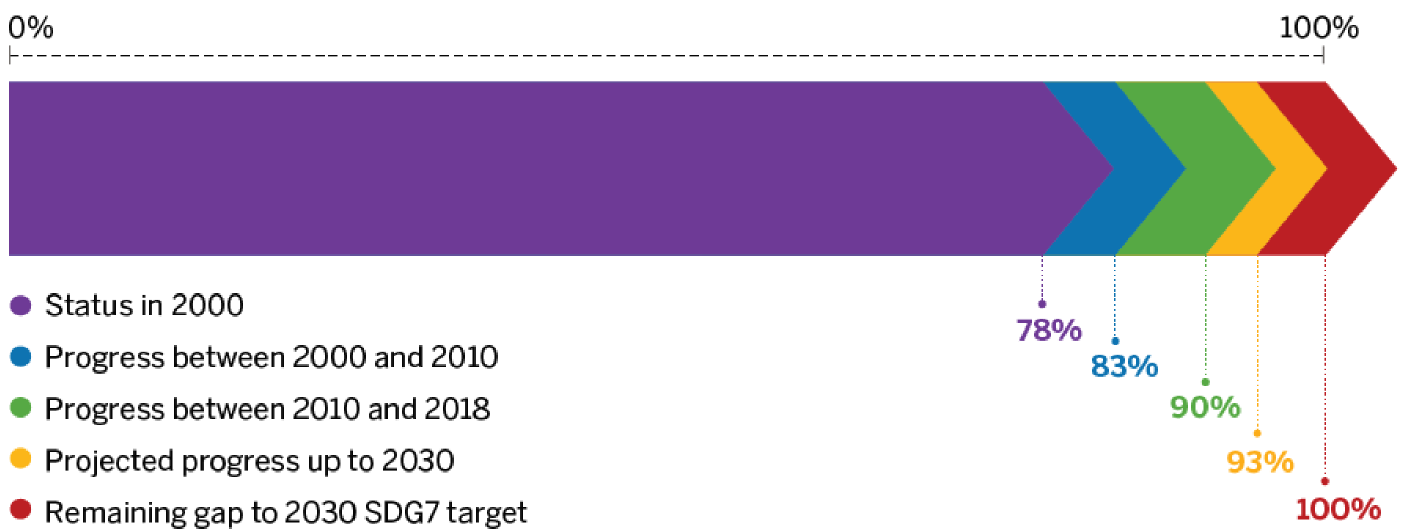
## REMOTE APPLICATIONS

# REMOTE APPLICATIONS

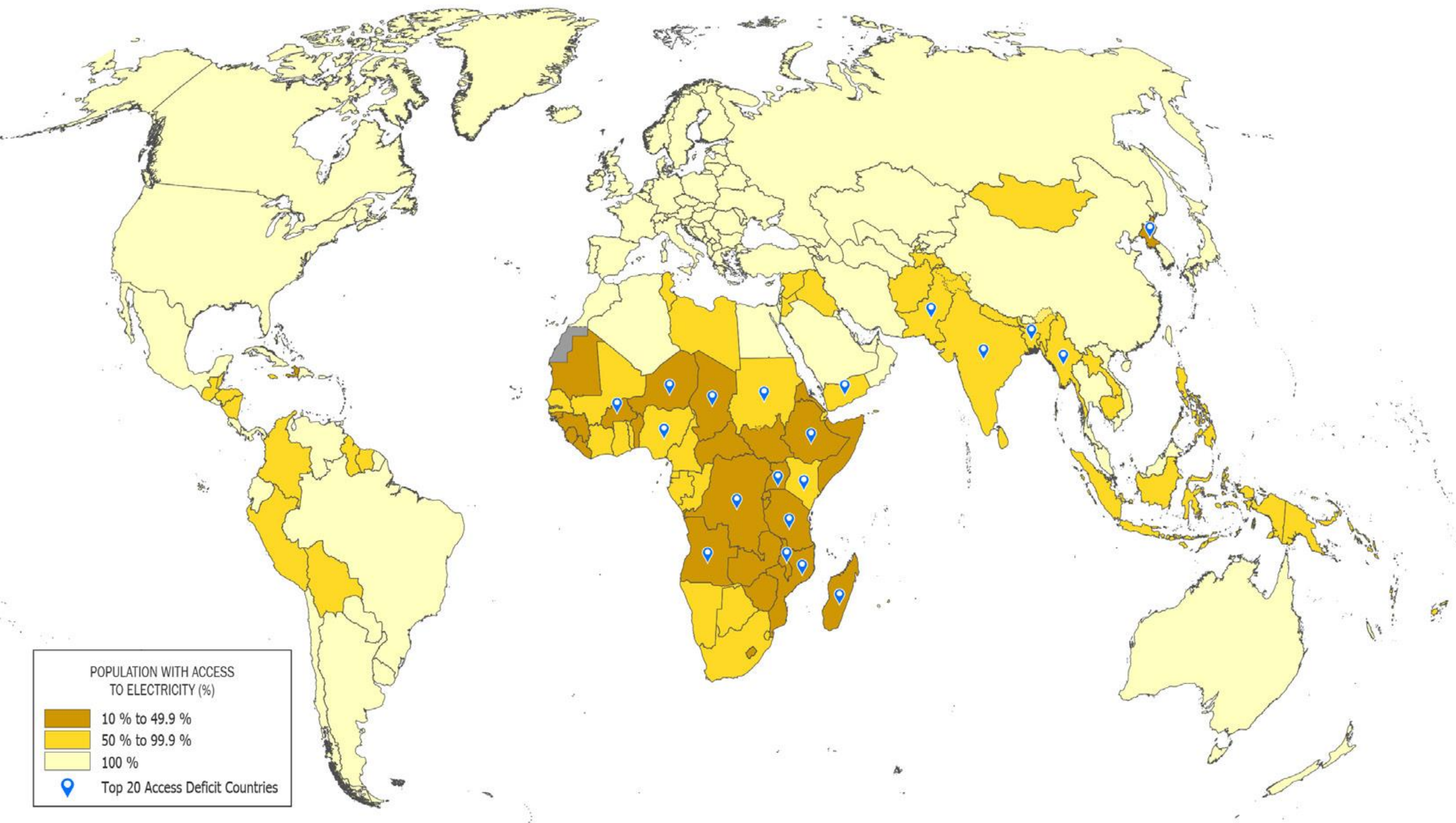
- Motivation
- PV economics
- Rural electrification
- Water pumping
- Health care systems
- Other remote applications


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

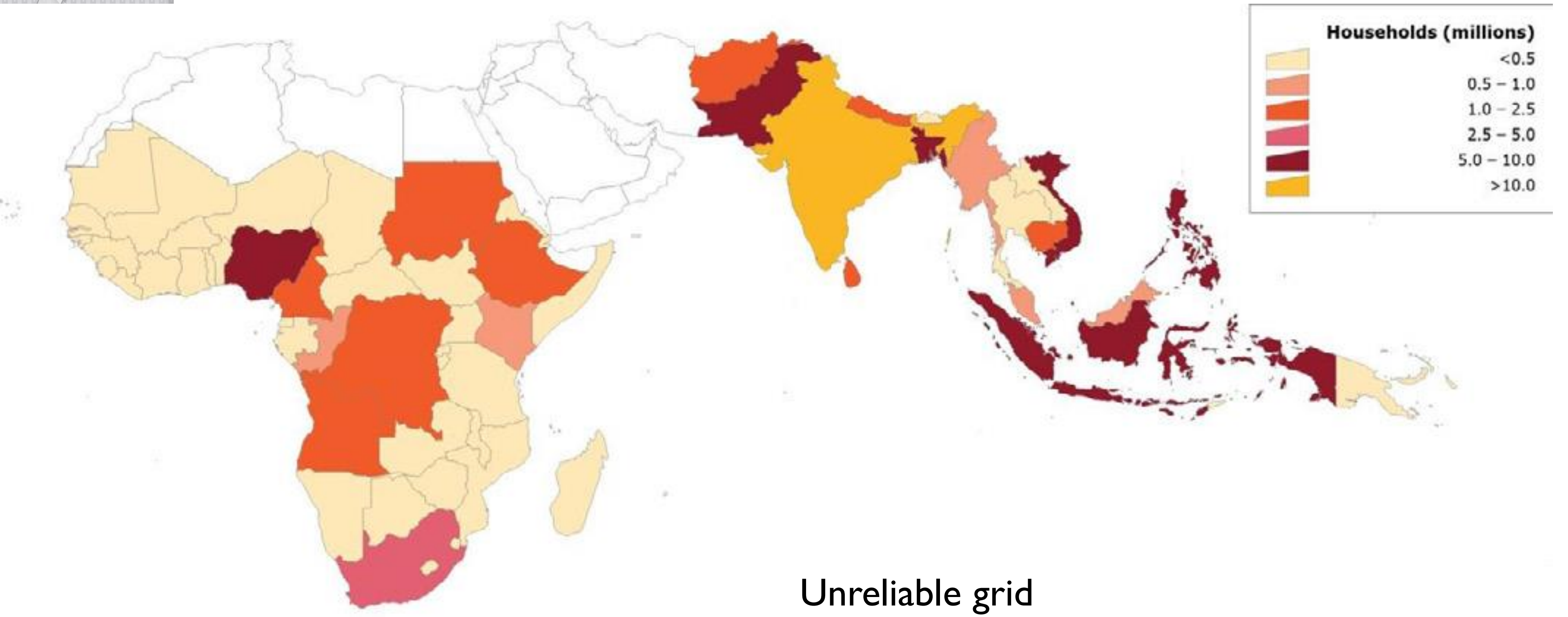
# SUSTAINABLE DEVELOPMENT GOALS

# Access to electricity



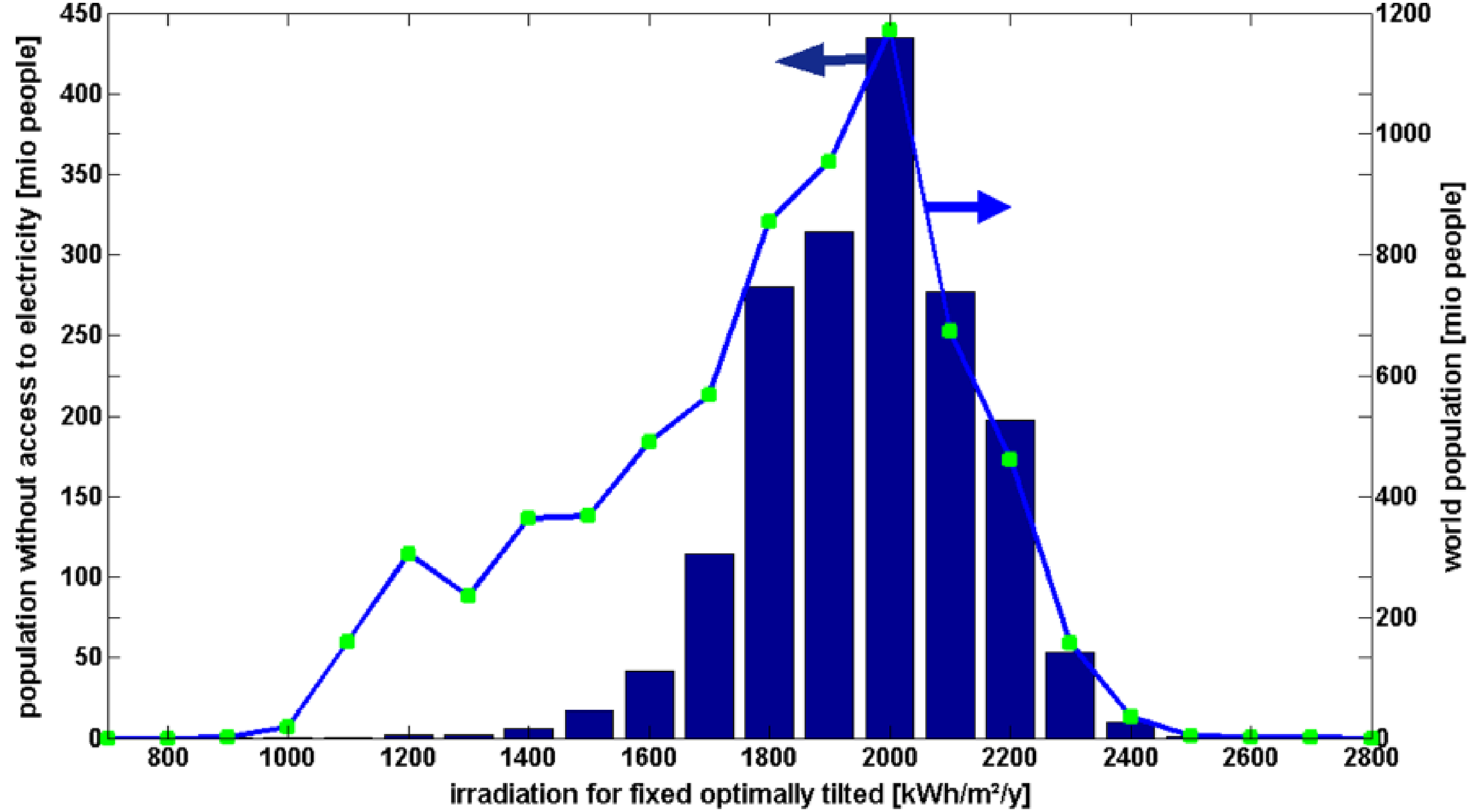
# Access to electricity




Unreliable grid

# Access to solar electricity

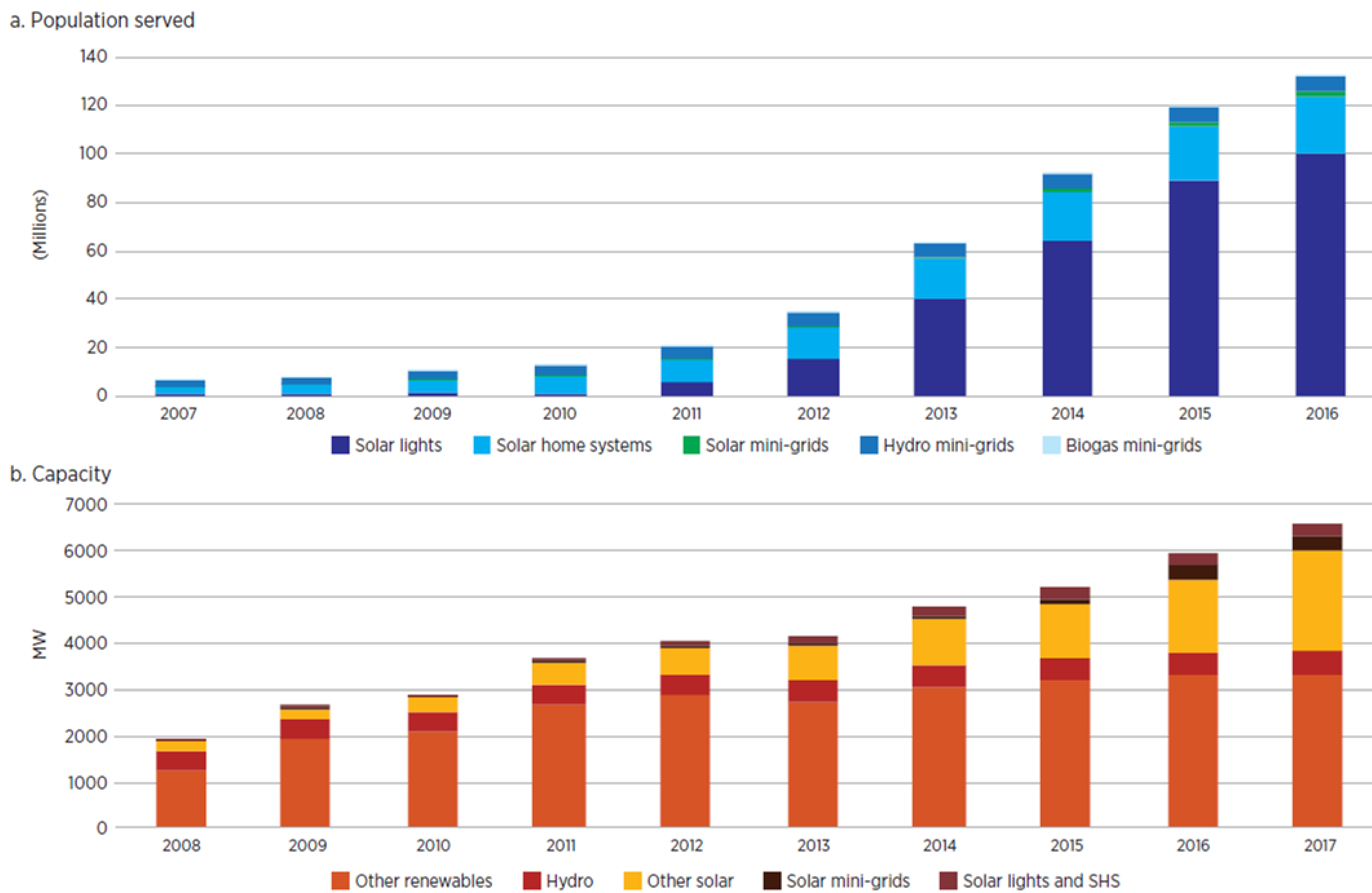
Population without access to electricity and local irradiation




Christian Breyer and Alexander Gerlach, *Global overview on grid-parity,* Prog. Photovolt: Res. Appl. (2012) DOI: 10.1002/pip.1254

# Access to solar electricity

**Figure 3:** Population served by, and capacity of, off-grid renewable energy solutions



# PV ECONOMICS

- High capital cost
- No fuel cost
- Low maintenance cost
- High reliability (= low replacement cost)
- System output depends on location

# PV ECONOMICS

- **Life cycle cost**: sum of all costs over lifetime, at today's money
- **Payback time:** time it takes for total cost to be paid for by system benefits/revenues
- **Rate of return:** magnitude of benefits expressed as a percentage on initial investment

# PV ECONOMICS

- **Period of analysis:** lifetime of longest lived system under comparison
- **Excess inflation (i):** rate of price increase above (or below) general inflation
- **Discount rate (d):** rate (relative to inflation) at which money would increase in value if invested
- **Capital cost:** total initial cost
- **Operation and maintenance:** amount spend yearly in keeping system operational
- **Fuel costs:** annual fuel bill
- **Replacements costs:** cost of replacing each component at the end of its lifetime.

# PV ECONOMICS

M. Kolhe, S. Kolhe, J. C. Joshi, *Economic viability of stand-alone solar photovoltaic system in comparison with diesel-powered system for India* , Energy Economics, **24**:2 (2002)155-165

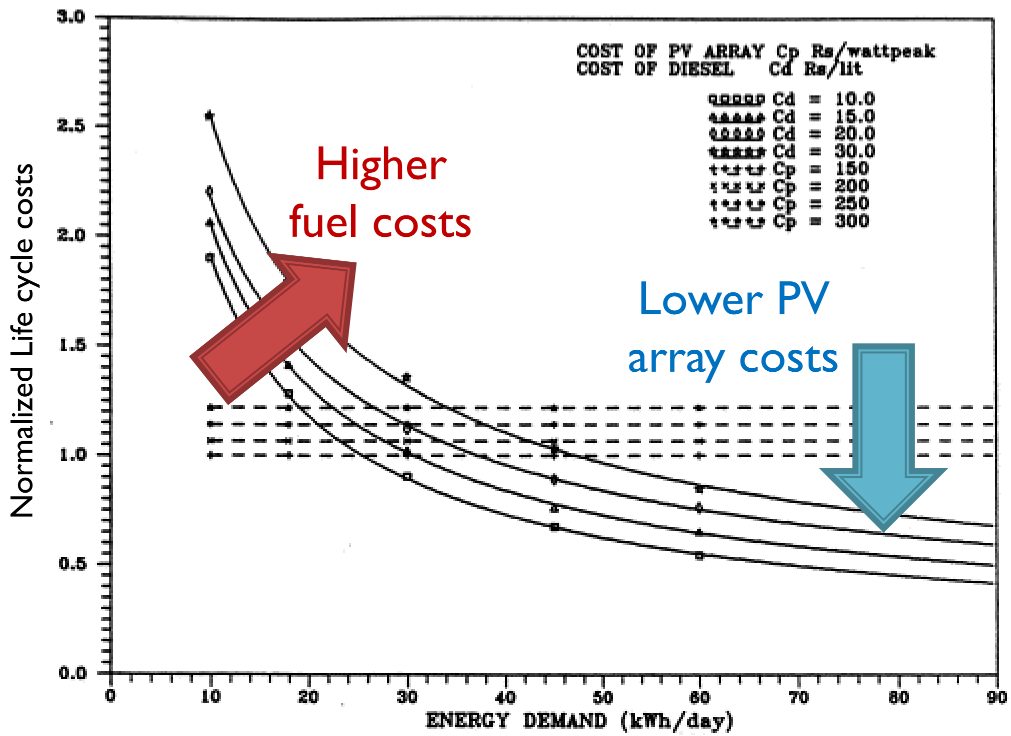



Fig. 3: PV and diesel system life-cycle cost comparisons for different PV array and diesel cost as a function of energy demand.

# PV ECONOMICS

M. Kolhe, S. Kolhe, J. C. Joshi, *Economic viability of stand-alone solar photovoltaic system in comparison with diesel-powered system for India* , Energy Economics, **24**:2 (2002)155-165

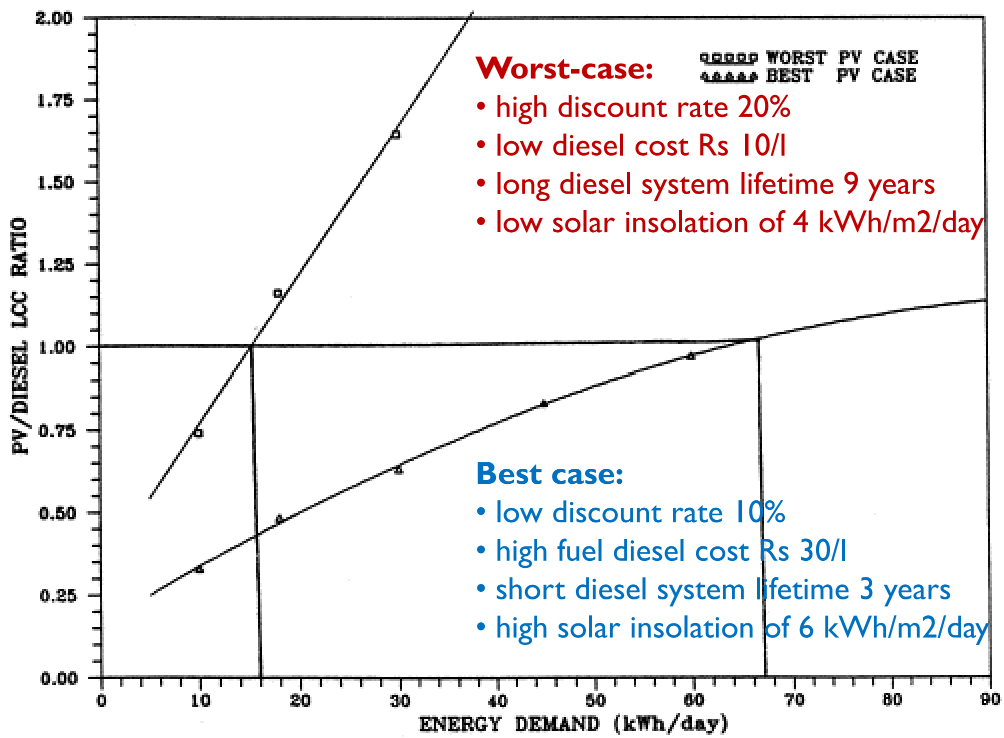



Fig. 4: Sensitivity to PV and diesel system life-cycle costs to the best and worst PV conditions as a function of energy demand.

# RURAL ELECTRIFICATION

- Lighting and power supply for remote buildings (mosques, farms, schools, mountain huts, etc.)
- Remote villages
- Battery charging stations
- Portable power for nomads

# RURAL ELECTRIFICATION

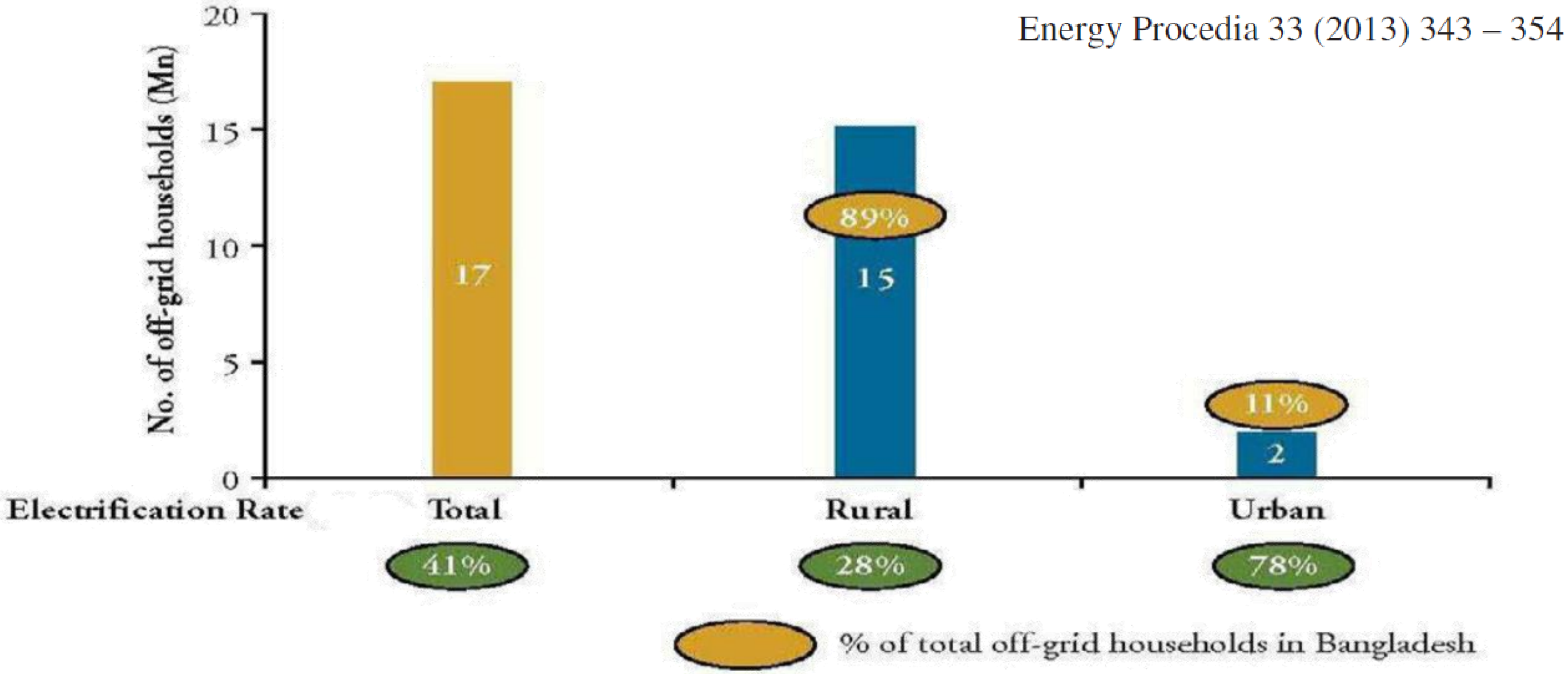
**Table 1**
Expenses related to charging MP in developed and developing areas.

| Parameter | Canada | Sub-Saharan Africa |
|---|---|---|
| Cost of energy (US$/Wh) | 0.00013 | – |
| Charge energy (Wh) | 8 Wh | 8 Wh |
| Charges per month | 30 | 30 |
| Cost per charge (US$) | 0.001 | 0.20 |
| Cost per month (US$) | 0.03 | 6.00 |
| Phone plan per month ($) | 50.00 | 6.00 |
| Charging costs as a percentage of total phone costs | 0. 06% | 50% |

Even if an MP user was to charge their phone once a month (and not daily!) they would still be paying nearly seven times the price for it.

And remember: there are 500,000,000 mobile phones in off grid regions around the globe

# RURAL ELECTRIFICATION




| | | | |
|---|---|---|---|
| **1. Rural Electrification Board (REB)**<br>Started from 1993<br>Number of Installation: Solar electricity provided to 4220 rural houses by June 2007. | **2. Local Government Engineering Department (LGED)**<br>Started from 1998 to 2006<br>Number of Installation: 4500 direct and about 50,000 indirect beneficiaries. | **3. Infrastructure Development Company Limited (IDCOL)**<br>From 2003 until present<br>Partner Organisation: 30<br>Number of Installation: A total of 1,655,832 (Aug 2012). | **4. Grameen Shakti (GS)**<br>From 1996 until present<br>Collaboration: Partner Organisation of IDCOL<br>Number of Installation: 5, 18,210. |

# RURAL ELECTRIFICATION

Energy Policy 63 (2013) 348–354

## Solar Home System (SHS) in rural Bangladesh: Ornamentation or fact of development?

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### HIGHLIGHTS

- No specific proof is there to conclude that SHS has contributed to development.
- SHS's contribution to income generation and employment is not significant.
- SHS is mostly used for entertainment and to uplift the so called 'social status'.

### ARTICLE INFO

*Article history:*
Received 23 April 2013
Accepted 8 August 2013
Available online 30 August 2013

*Keywords:*
Solar Home System (SHS)
Rural development
Bangladesh

### ABSTRACT

Energy requirement has been growing every day due to higher population growth, and consequently higher consumption. About one third of rural households of Bangladesh are connected to the grid. To meet the gap, solar energy has been treated as a feasible option for people in rural areas where grid connections are not available. A good number of organizations have been working together to provide Solar Home System (SHS) in rural Bangladesh. There is little evidence that supply of small scale energy supports significant rural development. This paper aims at understanding how increased energy access through SHS in rural Bangladesh contributes towards rural development. Recent published literatures on SHS in Bangladesh have been studied to get insight into the technical, financial, and operational as well as economic and social issues. Later the findings have been critically analyzed with respect to selected indicators of rural development. The study identified that increased access to energy through SHS in rural Bangladesh provides mostly recreational and leisure benefits with the so called 'social status'; income generation is negligible while support for education is average.

# RURAL ELECTRIFICATION

Welfare impacts of rural electrification – a case study of Bangladesh, Policy Research Working Paper 4859, The World Bank 2009

Table 5: Benefits of household electrification (single difference)

| Outcome variables | Comparison of electrified households with households without electricity in | | |
|---|---|---|---|
| | In villages with electricity | In villages without electricity | All villages |
| **Economic outcomes** | | | |
| Yearly per capita expenditure (Tk.) | 0.234 | 0.112 | 0.155 |
| | (35.76) | (17.99) | (26.61) |
| Yearly farm income (Tk.) | 1.227 | -0.733 | -0.037 |
| | (14.05) | (-9.51) | (-0.50) |
| Yearly non-farm income (Tk.) | 0.993 | 1.322 | 1.205 |
| | (15.64) | (21.18) | [illegible] |
| Yearly total income (Tk.) | 0.433 | 0.177 | [illegible] |
| | (45.44) | (18.89) | (30.92) |
| **Education outcomes (age 5-18)** | | | |
| Boys' completed schooling years | 1.134 | 0.725 | 0.867 |
| | (18.91) | (12.97) | [illegible] |
| Girls' completed schooling years | 1.068 | 1.015 | [illegible] |
| | (16.72) | (17.47) | (18.99) |
| Boys' study time (minutes/day) | 33.4 | 17.7 | 23.1 |
| | (14.32) | (8.24) | [illegible] |
| Girls' study time (minutes/day) | 36.2 | 24.6 | [illegible] |
| | (15.10) | (11.17) | (14.04) |
| Observations | $N_H$=13,829, $N_M$=11,806 | $N_H$=16,853, $N_M$=14,630 | $N_H$=20,900, $N_M$=18,149, $N_F$=16,517 |

245%

131%

168%

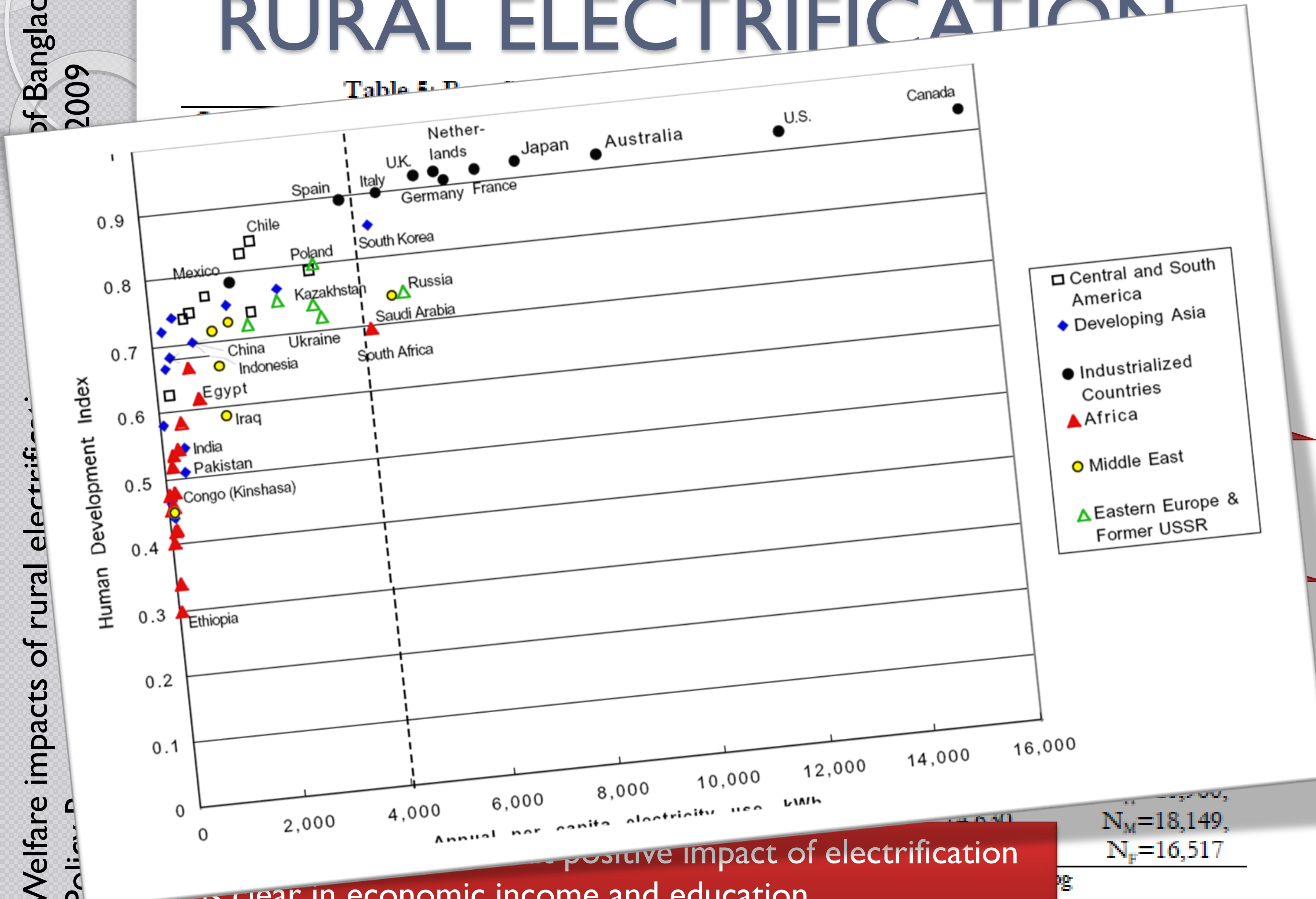
More boys than girls, but positive impact of electrification is clear in economic income and education.

# RURAL ELECTRIFICATION

Welfare impacts of rural electrifi... of Bangladesh, 2009

Policy R...

Table 5: P...




$N_M$=18,149,

$N_F$=16,517

...positive impact of electrification is clear in economic income and education.

# RURAL ELECTRIFICATION

Different **deployment strategies**

- Donations
- Cash sales
- Consumer credit
- Fee-for-service

# RURAL ELECTRIFICATION

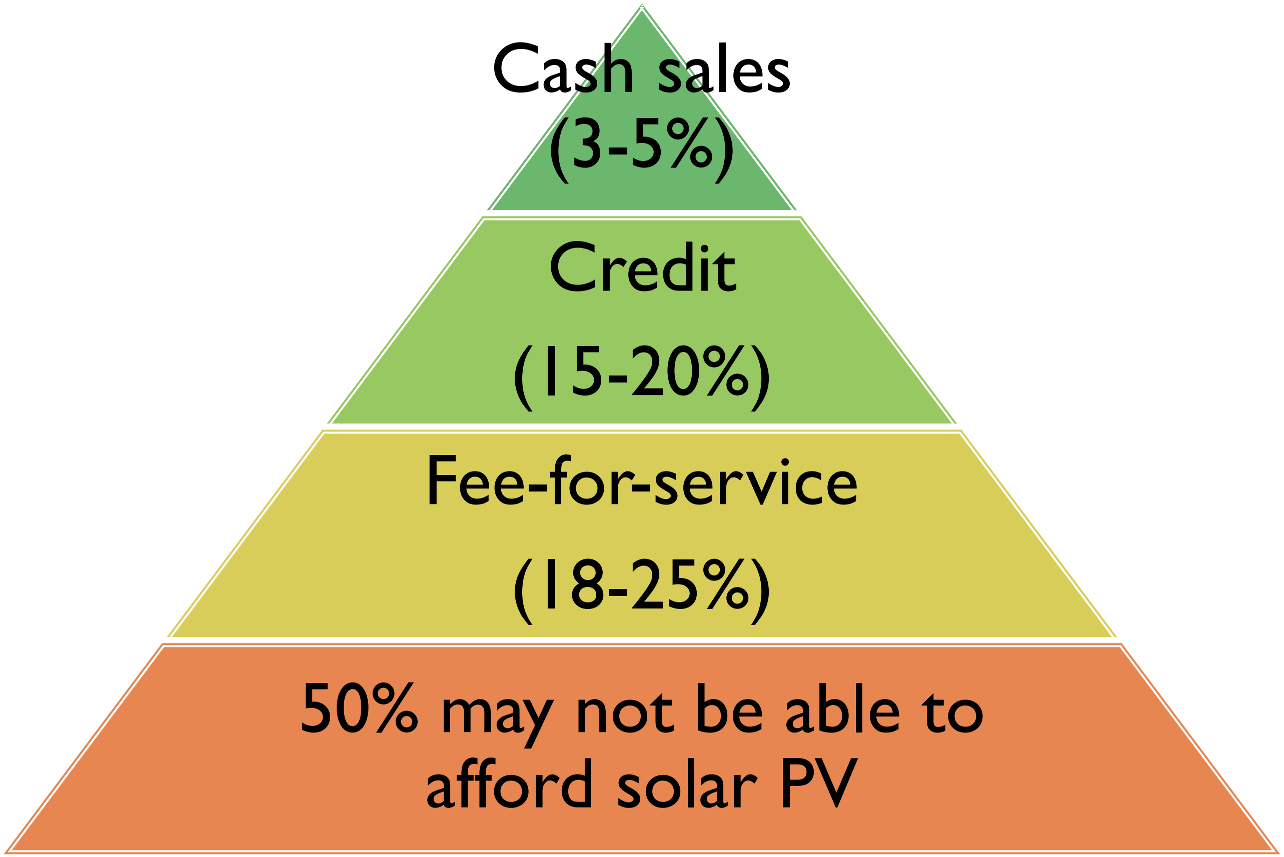
- **Donations**
  - ✓Low initial cost for user
  - ✓Economies of scale
  - ✓Rapid deployment
  - ✘Lack of user commitment
  - ✘No funding for maintenance/replacements

- **Cash sales**
  - ✓User choice
  - ✓User commitment
  - ✓'Modular' purchasing
  - ✘Cheap/low quality/undersized components
  - ✘High- and middle class access only

# RURAL ELECTRIFICATION

- **Consumer credit**
  - As 'cash sales'
  - Dealer extended credit or micro-credit
- **Fee-for-service**
  - As 'cash sales'
  - Economies of scale

# RURAL ELECTRIFICATION




Data from: M.T. Eckhartet al *Financing PV growth*, Chpt 24 in *Handbook* …, Ed. A. Luque, S. Hegedus, John Wiley & Sons, USA (2003)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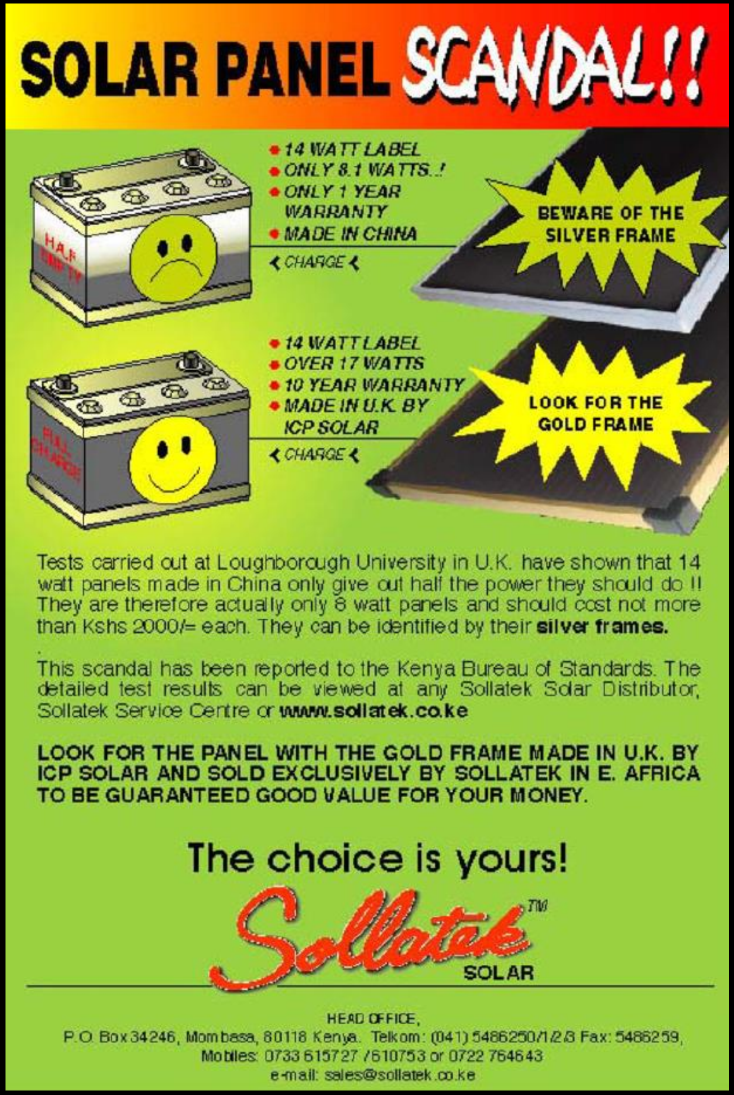
EMBU: Kenyatta Highway Te:l 0727 608696 0733 850085
MERU: Moi Avenue (Opp. Kobil) Te:l 20366 KISUMU: OPENING SOON



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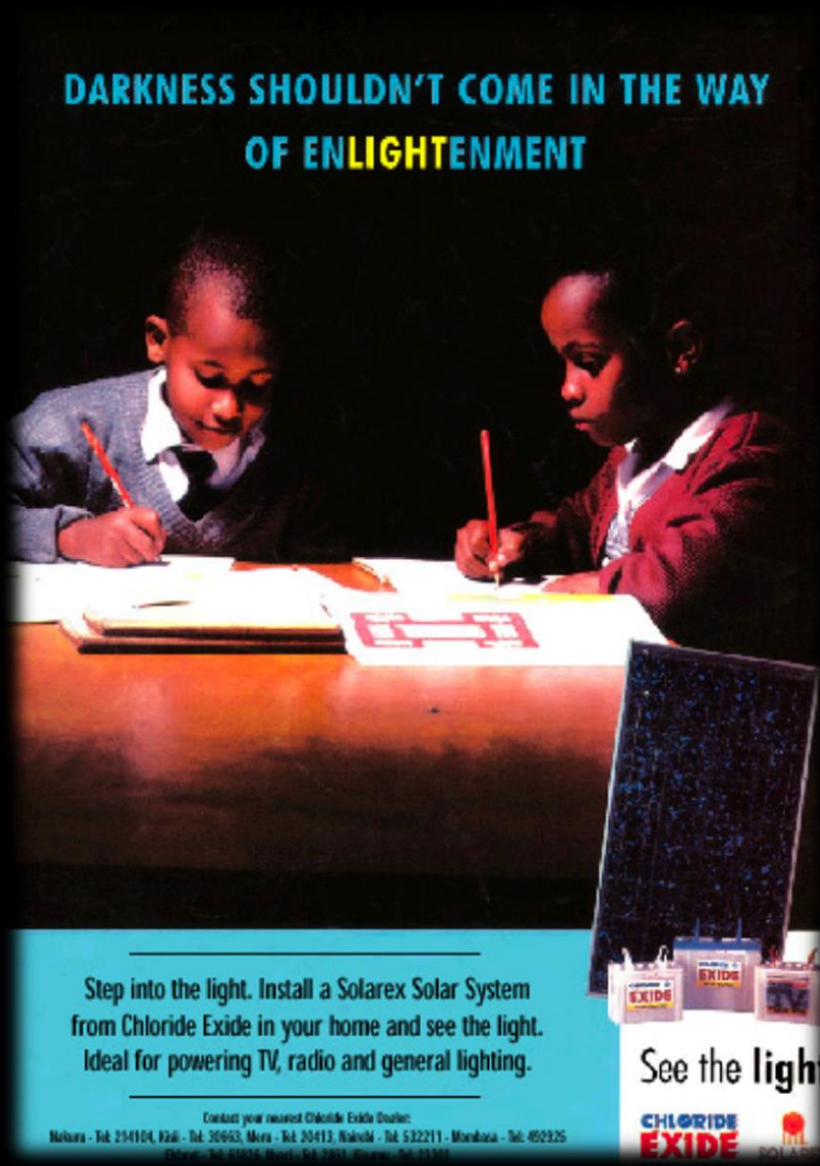
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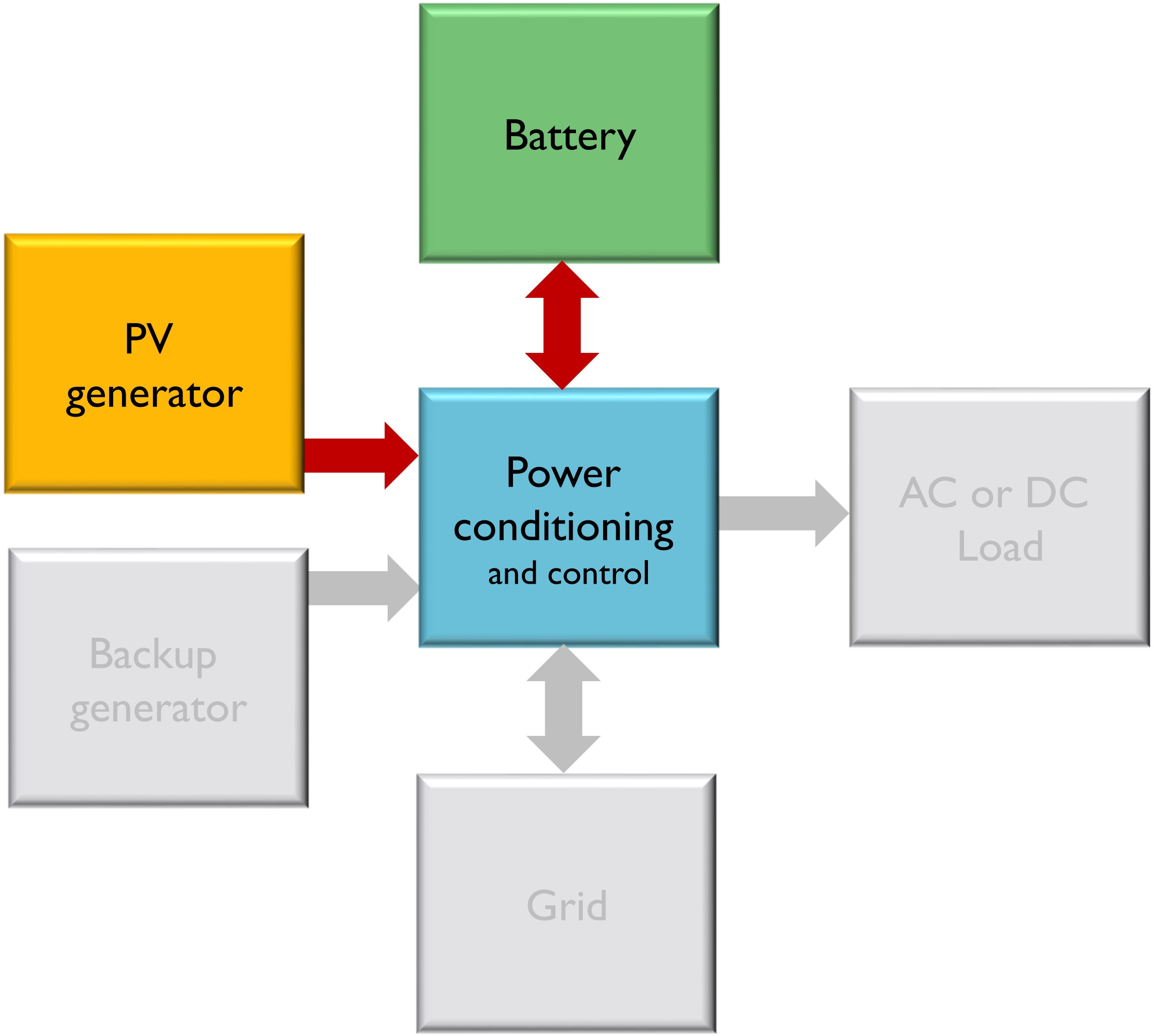
# SOLAR HOME SYSTEMS



# SOLAR HOME SYSTEMS

- Certified PV modules (no need for bypass diode)

- Support structures
  - at least 10 years of outdoor exposure
  - withstand winds of 120 km/h

- Tilt angle: latitude ± 10°

- Manual tracking: 2-3 positions/day, moving from East to West)
  - ✓ (Slight) performance improvement
  - ✓ Promotes user participation
  - ✘ Risk of damage
  - ✘ Risk of energy loss due to poor or no adjustment

"Universal technical standard for solar home systems" Thermie B SUP 995-96, EC-DGXVII, 1998

# SOLAR HOME SYSTEMS

- Automotive batteries (SLI)
  - ✓ Cheap
  - ✓ Widely available
  - ✓ Locally produced
    - Economic & socially convenient
    - Recycle
  - ✘ Short lifetime
    - use larger capacity
    - use lower electrolyte density (1.24 instead of 1.28g/cl)
    - replace thin electrodes (>2mm)

# SOLAR HOME SYSTEMS

- Maximum **depth of discharge**:

  $0.3 < Depth_{max} < 0.6$

- **Useful capacity** ($C_U$) < Nominal capacity ($C_B$)

  $C_U = C_B \times Depth_{max}$

- $C_U$ = 3-to-5 days x daily energy consumption

  *Depth of discharge in **daily cycle**:*

  $0.06 < Depth < 0.2$

# SOLAR HOME SYSTEMS

- $Depth_{max}$ = 0.3-0.5
- n x Load / $Depth_{max}$ < $C_B$

Load = 12 Ah
Dry place: n = 3 days
Isc = 3.3 A
C: 72 Ah < $C_B$
R: 120 Ah < $C_B$

Load = 12 Ah
Wet place: n = 5 days
Isc = 3.3 A
C: 120 Ah < $C_B$
R: 200 Ah < $C_B$

- NOC (number of cycles before residual capacity less than 80% CB) > 200
- Self discharge < 6%/month

# SOLAR HOME SYSTEMS

- Voltage losses:
  - PV modules → charge regulator < 3%
  - Battery → charge regulator < 1%
  - Charge regulator → load < 5%
- Minimum section of copper cable (12V)

  $S(mm^2) = 0.3 \times length\ (m) \times I_M(A)\ /\ \Delta V(\%)$

# SOLAR HOME SYSTEMS

- Energy performance
  - Loss of load probability (LLP)
  - Performance ratio(= useful energy / max theoretical energy)

    *includes losses in module (temperature, mismatch), self consumption of charge regulator, battery efficiency, etc.*

- Energy requirement (typical)
  - 40-50Wp
  - 120-160Wh/day

  *Lighting, radio, TV*

  *(for refrigerator, fans, etc, larger systems required)*

# SOLAR HOME SYSTEMS

- Sizing:
  - PV generator capacity

    $CA = \eta A \, Gd / L$
  - Storage capacity (days)

    $CS = CU / L$

$\eta$ – efficiency
A – Area
Gd – daily irradiation
L – (load) daily consumption
CU – useful battery capacity

- Rules of thumb
  - Energy produced during worst month can, at least, equal demand of the load (CA = 1)
  - Battery useful capacity should allow 3-to-5 days of autonomy ($3 < CS < 5$)

# SOLAR HOME SYSTEMS

Proper sizing using Loss-of-load-probability method (LLP)

- R. Posadillo, R. López Luque, *Approaches for developing a sizing method for stand-alone PV systems with variable demand,* Renewable Energy 33:5 (2008)1037-1048
- E. Lorenzo, *Energy collected and delivered by PV modules,* in Handbook of Photovoltaic Science and Engineering, ed. A. Luque , S. Hegedus (2003)

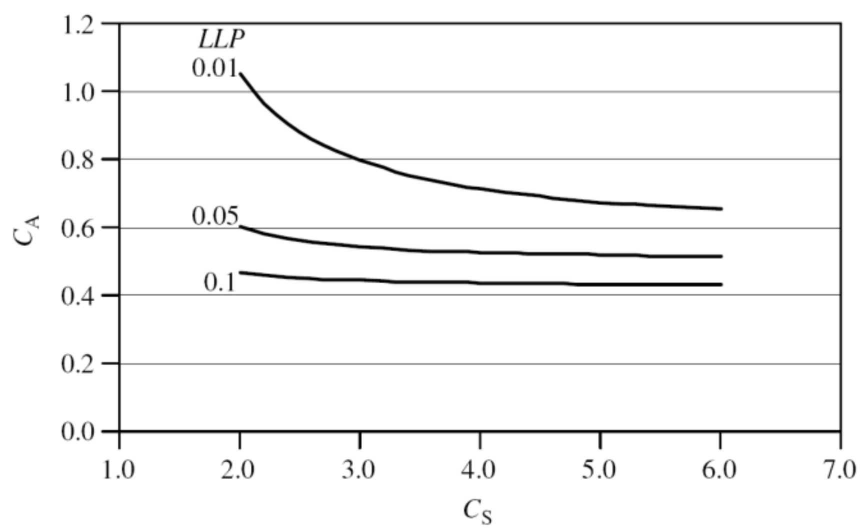



**Figure 20.23** Reliability maps: Generator capacity $C_A$ versus storage capacity $C_S$ with the reliability *LLP* as parameter

# SOLAR HOME SYSTEMS

- No shadows on modules, at least 8h/day, centred at noon, all year
- Pedestal mounting preferable
- If on roof: 5cm gap for air circulation
- Battery locked but accessible
- And…
  - Avoid different bolts/screws to minimise tools
  - Use fluorescent tubes available locally
  - All materials (screws, connectors, etc) in SHS kit
  - etc.

# SOLAR HOME SYSTEMS

**Flexibility:**

- Any component may be substituted by similar component (even from different supplier)
- Increasing system size:
  - PV modules in parallel (check wiring sizes and regulator maximum current)
  - Batteries in parallel?
    - Not more than 2 identical batteries
    - Old and new batteries OR 2 non-identical batteries may not be connected in parallel


SUPER MARKET
SUPER MARKET

# WATER PUMPING

- Pumping for drinking water
- Pumping for irrigation
- De-watering and drainage
- Ice production
- Saltwater dessalination
- Water purification
- Water circulation in fish farms

# WATER PUMPING

- Solar pumps
  - Hydraulic energy (kWh/day) =

    = volume required ($m^3$/day) x head (m) x water density x gravity

    = $2.725 \times 10^{-3}$ x volume required ($m^3$/day) x head (m)

  - Solar array required (kWp) =

$$\frac{\text{Hydraulic energy (kWh/day)}}{\text{Average daily solar irradiation (kWh/m}^2\text{/day)} \times F \times E}$$

F (mismatch factor) = 0.85

E (subsystem efficiency) = 0.25 – 0.4

**Example**
$25m^3$/day
20m head
requires 800Wp
at Sahel

Sizing example: W. Stuart, *Applied Photovoltaics.*, London, Earthscan Publications (2006) Appendix H

# WATER PUMPING

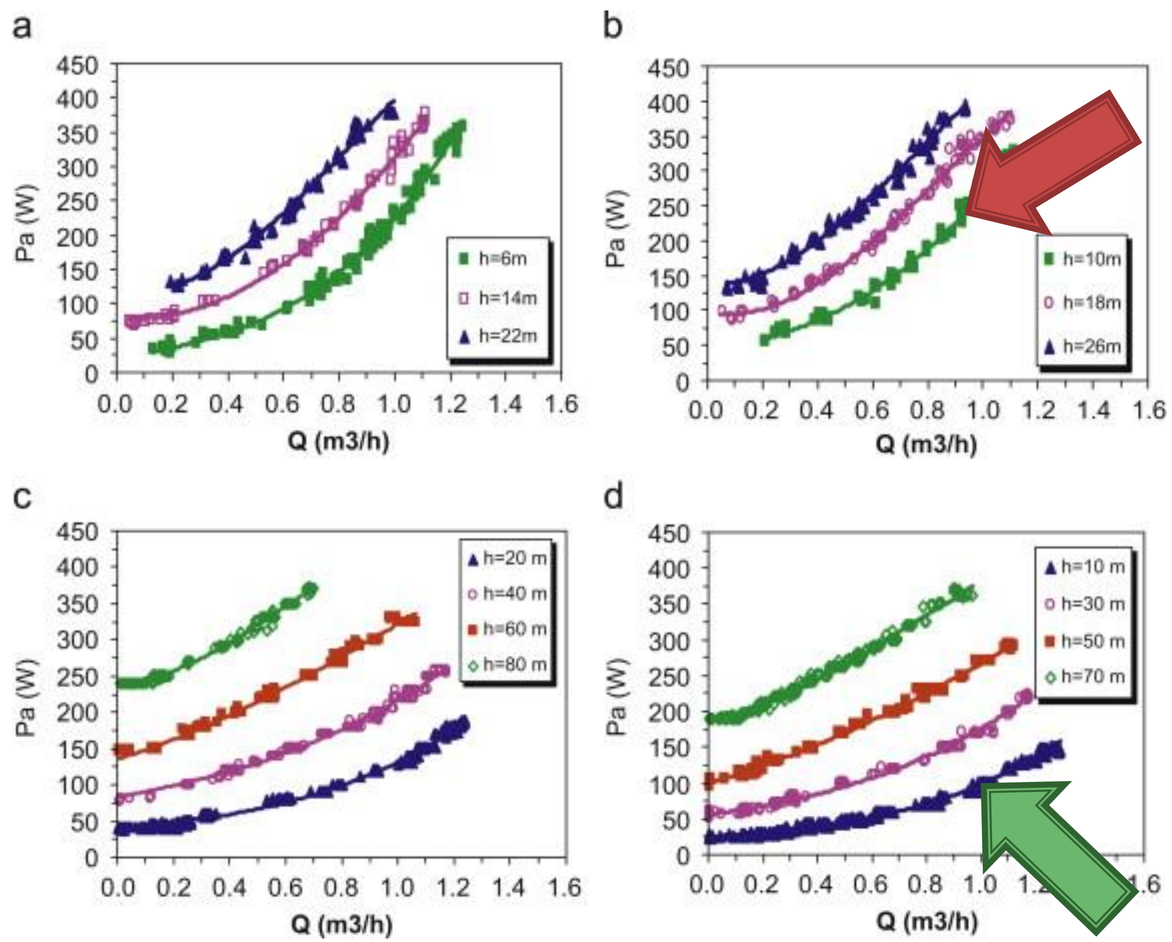



**Fig. 3.** Electrical power versus flow rate: (a) and (b) centrifugal pump, and (c) and (d) displacement pump.

A. Hamidat and B. Benyoucef, *Systematic procedures for sizing photovoltaic pumping system using water tank storage*, Energy Policy 37:4 (2009) 1489-1501

# WATER PUMPING

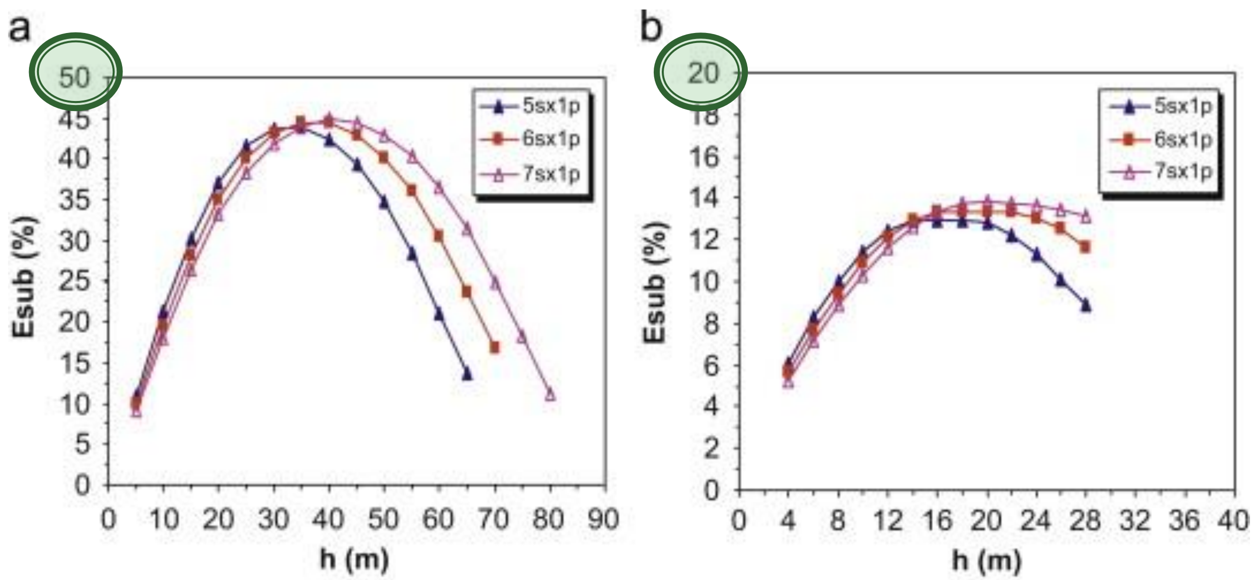



**Fig. 4.** The subsystem efficiency, the peak power of the photovoltaic array:
(a) DC motor with a positive displacement pump and (b) AC motor with a centrifugal pump.

A. Hamidat and B. Benyoucef, *Systematic procedures for sizing photovoltaic pumping system using water tank storage*, Energy Policy 37:4 (2009) 1489-1501

# WATER PUMPING

- Maximum point tracker:

  DC/DC converter to track pump input I/V

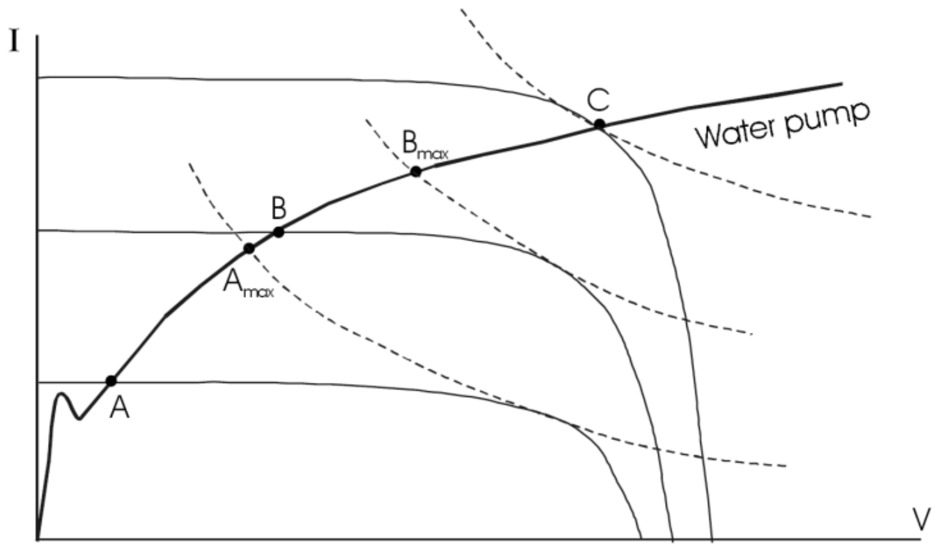



**Figure 3.27** Pump and PV I-V characteristics, showing the need for use of MPT.

R. Messeger *Photovoltaic System Engineering,* 2nd Ed. (2003) CRC Press, Washington

# HEALTH CARE SYSTEMS

- Lighting in rural remote clinics
- UHF transreceivers between health centres
- Vaccine refrigeration
- Ice pack freezing for vaccine carriers
- Sterilisers
- Blood storage refrigerators

# OTHER REMOTE APPLICATIONS

- Remote communications: Radio repeaters, Remote TV & radio receivers, Mobile radios, Emergency phones
- Remote weather measuring
- Earthquake monitoring
- Road sign lighting
- Navigations buoys
- Boat power supply
- Corrosion protection systems
- Calculators


Sunny Boy