PV SYSTEMS
REMOTE APPLICATIONS

REMOTE APPLICATIONS

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

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

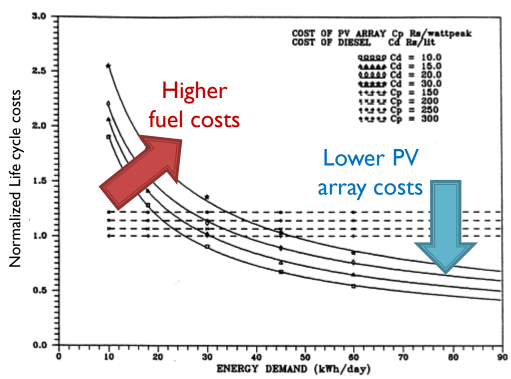


Fig. 3: PV and diesel system life-cycle cost comparisons for different PV array and diesel cost as a function of energy demand.

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

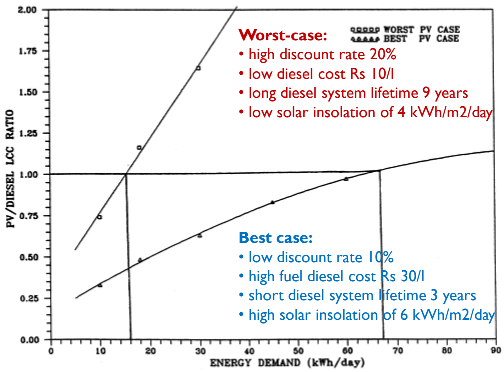


Fig. 4: Sensitivity to PV and diesel system life-cycle costs to the best and worst PV conditions as a function of energy demand.

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.

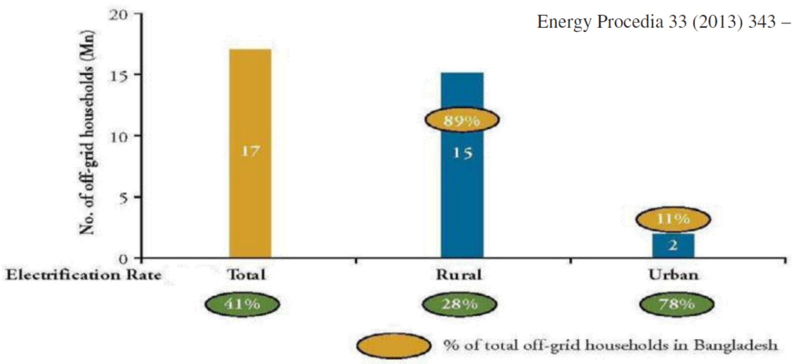
Parameter	Canada	Sub-Saharan Africa
Cost of energy (US$/Wh)	0.00013	–
Charge energy (Wh)	8 Wh	8 Wh
Charges per month	30	30
Cost per charge (US$)	0.001	0.20
Cost per month (US$)	0.03	6.00
Phone plan per month ($)	50.00	6.00
Charging costs as a percentage of total phone costs	0. 06%	50%

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

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

RURAL ELECTRIFICATION

Energy Procedia 33 (2013) 343 – 354



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

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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.

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

RURAL ELECTRIFICATION

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, [illegible]	N_H=16,853, [illegible]	N_H=20,900, N_M=18,149, N_F=16,517

245%

131%

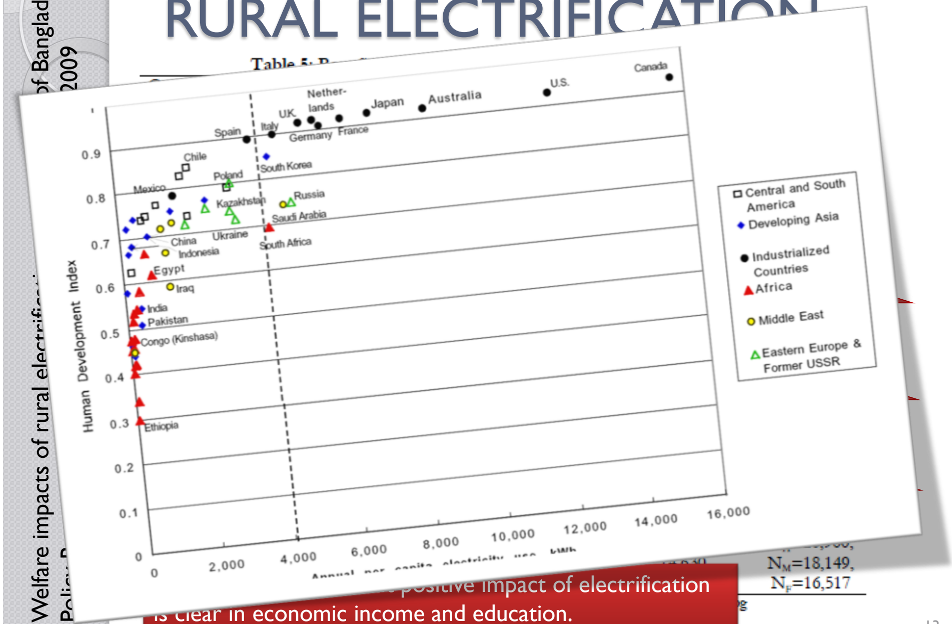
168%

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

RURAL ELECTRIFICATION

Welfare impacts of rural electrification: ... of Bangladesh, 2009

Table 5: R...



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

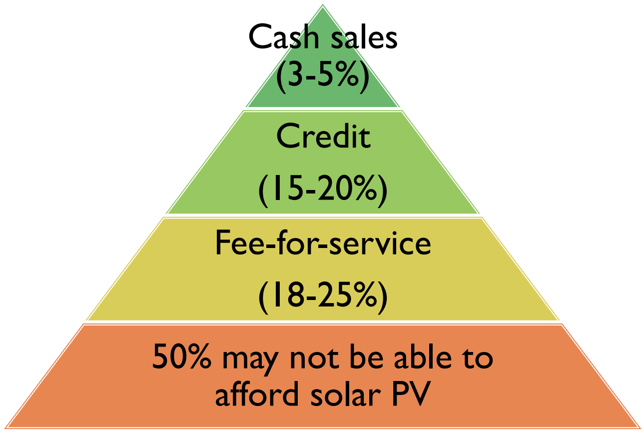
- **Donations**
  - ✓Low initial cost for user
  - ✓Economies of scale
  - ✓Rapid deployment
  - ✗Lack of user commitment
  - ✗No funding for maintenance/replacements

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

RURAL ELECTRIFICATION

- **Donations**
  - …
- **Cash sales**
  - …
- **Consumer credit**
  - Dealer extended credit or micro-credit
- **Fee-for-service**
  - 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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RURAL ELECTRIFICATION

- **Model deployment: 2 case studies**
  - Kenya – Cash sale
  - Zambia – Fee-for-service (ESCO)

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SHS: Solar Home Systems

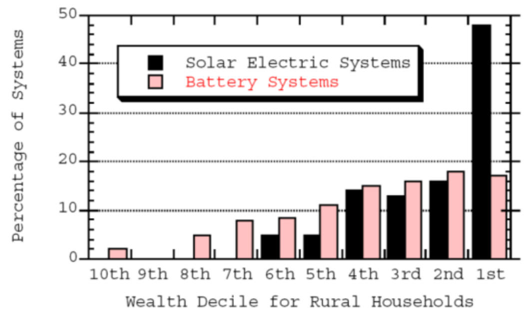
Cash sales deployment model

Technology type	Median wealth rank	Typical initial cost ($US)	Cost per kWh ($US/kWh)
Solar electric system	10%	200-600	0.25-1.0
Rural grid connection	17%	50-1500	0.08
Lead acid battery system	29%	50-100	1.0-1.5
Dry cell batteries	46%	5-30	50-100
Kerosene lighting	50%	2-20	n/a

A. Jacobson, *Connective Power: Solar Electrification and Social Change in Kenya*, PhD Thesis, University of California, Berkeley (2004)

SHS: Solar Home Systems

Cash sales deployment model



- Solar electrification market in Kenya is driven by the purchasing power of the rural middle class, in particular rural teachers (30%)
- 'Modular' deployment: one gets a battery before buying a small PV module

A. Jacobson, *Connective Power: Solar Electrification and Social Change in Kenya*, PhD Thesis, University of California, Berkeley (2004)

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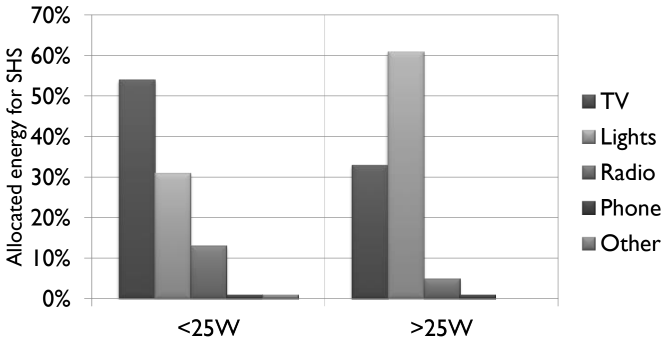
SHS: Solar Home Systems

Cash sales deployment model

- Main use of small SHS is TV! Light comes 2nd choice – only for ‘larger’ systems



A. Jacobson, *Connective Power: Solar Electrification and Social Change in Kenya*, PhD Thesis, University of California, Berkeley (2004)

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SHS: Solar Home Systems

Cash sales deployment model

- Low quality equipment

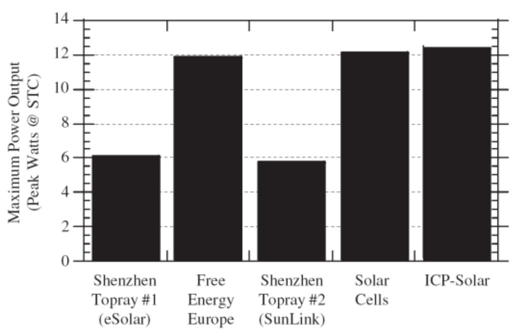


Fig. 5. Average stabilized maximum power output for five brands of 14 W rated amorphous silicon solar modules sold in Kenya. (Maximum Power at Standard Test Conditions, STC, of 1000 W/m^2 and 25 °C.)

A. Jacobson, D.M. Kammen, *Evaluating product quality in the Kenyan solar photovoltaics industry*, Energy Policy 35 (2007) 2960-2968

SHS: Solar Home Systems

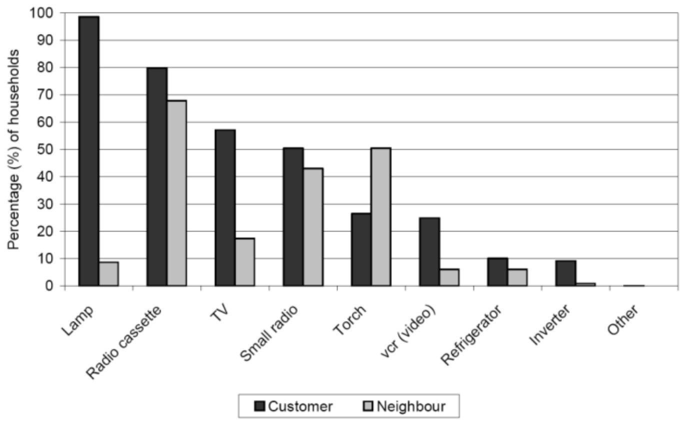
Fee-for-service deployment model

- **Access to SHS service**
  - 90% of households have 'formal income' (teachers, etc)
  - Better light quality but not cheaper
- **'Standard 'package':**
  - 50Wp module + battery + charge regulator
  - Equipment quality below specs (e.g. Siemens batteries)
- **Moderate/low rate of income-generation**
  - 13% willing to start a new activity enabled by SHS
  - most popular: shop
- **'Solar trap'**
  - Protests over long-term exclusion from grid connection

M. Gustavsson, *Solar Energy for a Brighter Life - A Case Study of Rural Electrification through Solar Photovoltaic Technology in the Eastern Province, Zambia*, PhD Thesis, University of Goteborg (2008)

SHS: Solar Home Systems

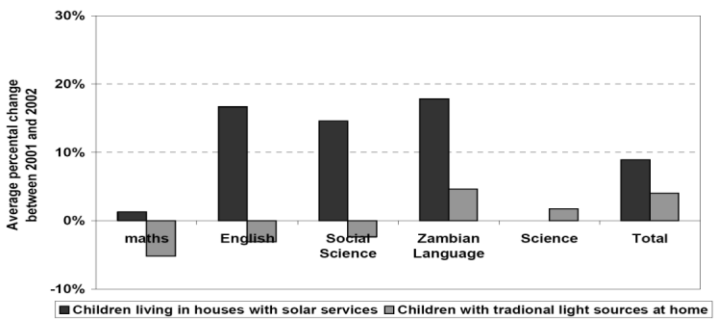
Fee-for-service deployment model



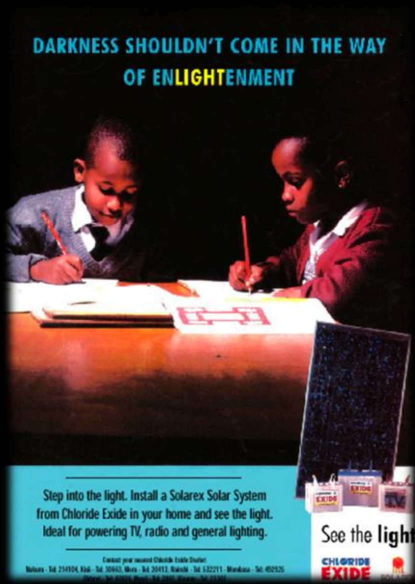
M. Gustavsson, *Solar Energy for a Brighter Life - A Case Study of Rural Electrification through Solar Photovoltaic Technology in the Eastern Province, Zambia*, PhD Thesis, University of Goteborg (2008)

SHS: Solar Home Systems

Fee-for-service deployment model



M. Gustavsson, *Solar Energy for a Brighter Life - A Case Study of Rural Electrification through Solar Photovoltaic Technology in the Eastern Province, Zambia*, PhD Thesis, University of Goteborg (2008)



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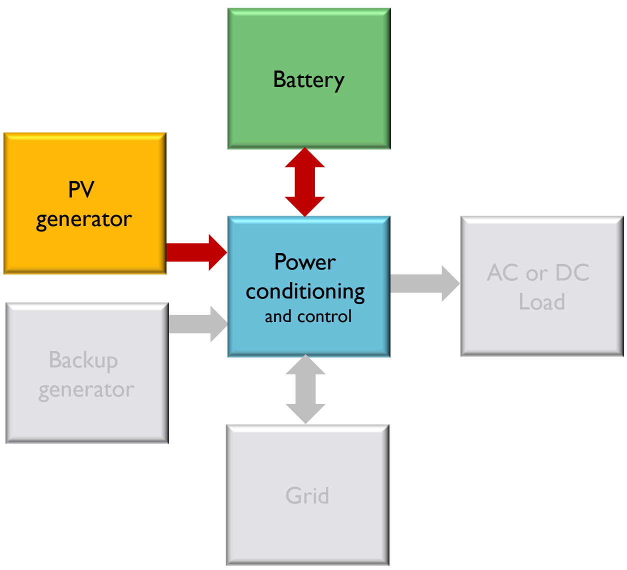
SOLAR HOME SYSTEMS



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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
- $n \times Load / Depth_{max} < C_B$

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)

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SOLAR HOME SYSTEMS

- Sizing:
  - PV generator capacity

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

    $CS = CU / L$

η – 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 ($3 < CS < 5$)

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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)

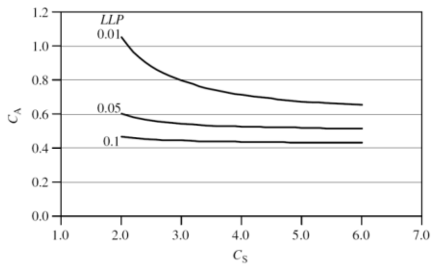

Figure 20.23 Reliability maps: Generator capacity C_A versus storage capacity C_S with the reliability *LLP* as parameter

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

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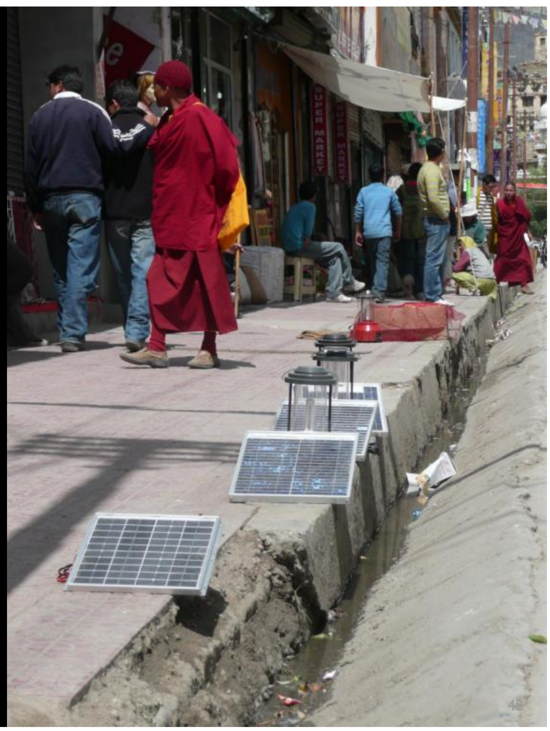

WATER PUMPING

- 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 x 10^{-3} x volume required (m^3/day) x head (m)

  - Solar array required (kWp) =

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

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

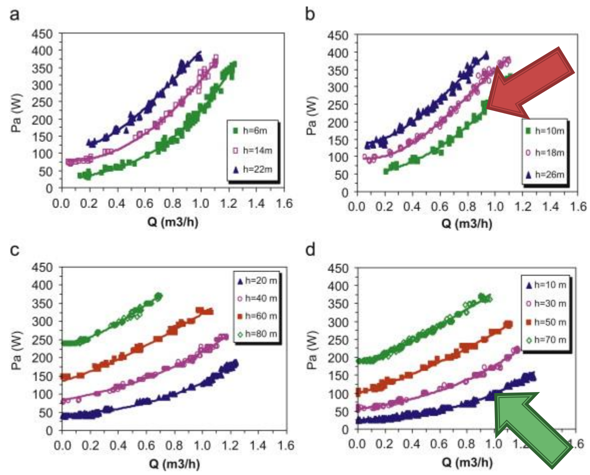

Fig. 3. Electrical power versus flow rate: (a) and (b) centrifugal pump, and (c) and (d) displacement pump.

WATER PUMPING

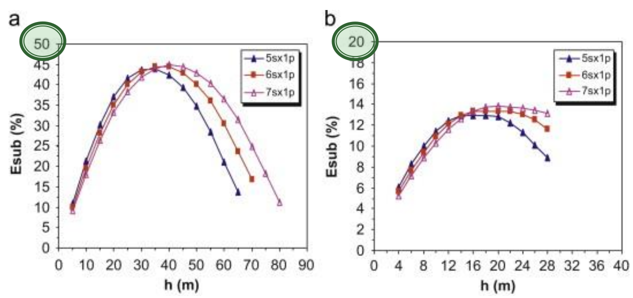

Fig. 4. The subsystem efficiency, the peak power of the photovoltaic array:
(a) DC motor with a positive displacement pump and (b) AC motor with a centrifugal pump.

WATER PUMPING

- Maximum point tracker:

  DC/DC converter to track pump input I/V

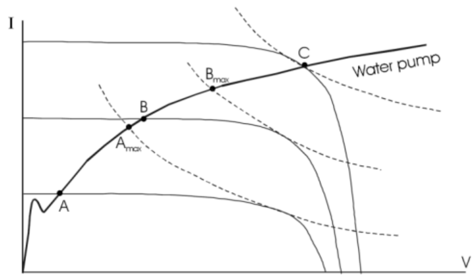

Figure 3.27 Pump and PV I-V characteristics, showing the need for use of MPT.

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