THESIS DEFENSE

A Search for the lowest cost electricity for rural India

Off grid SPV ? or Centralized Grid?

With a Village case study

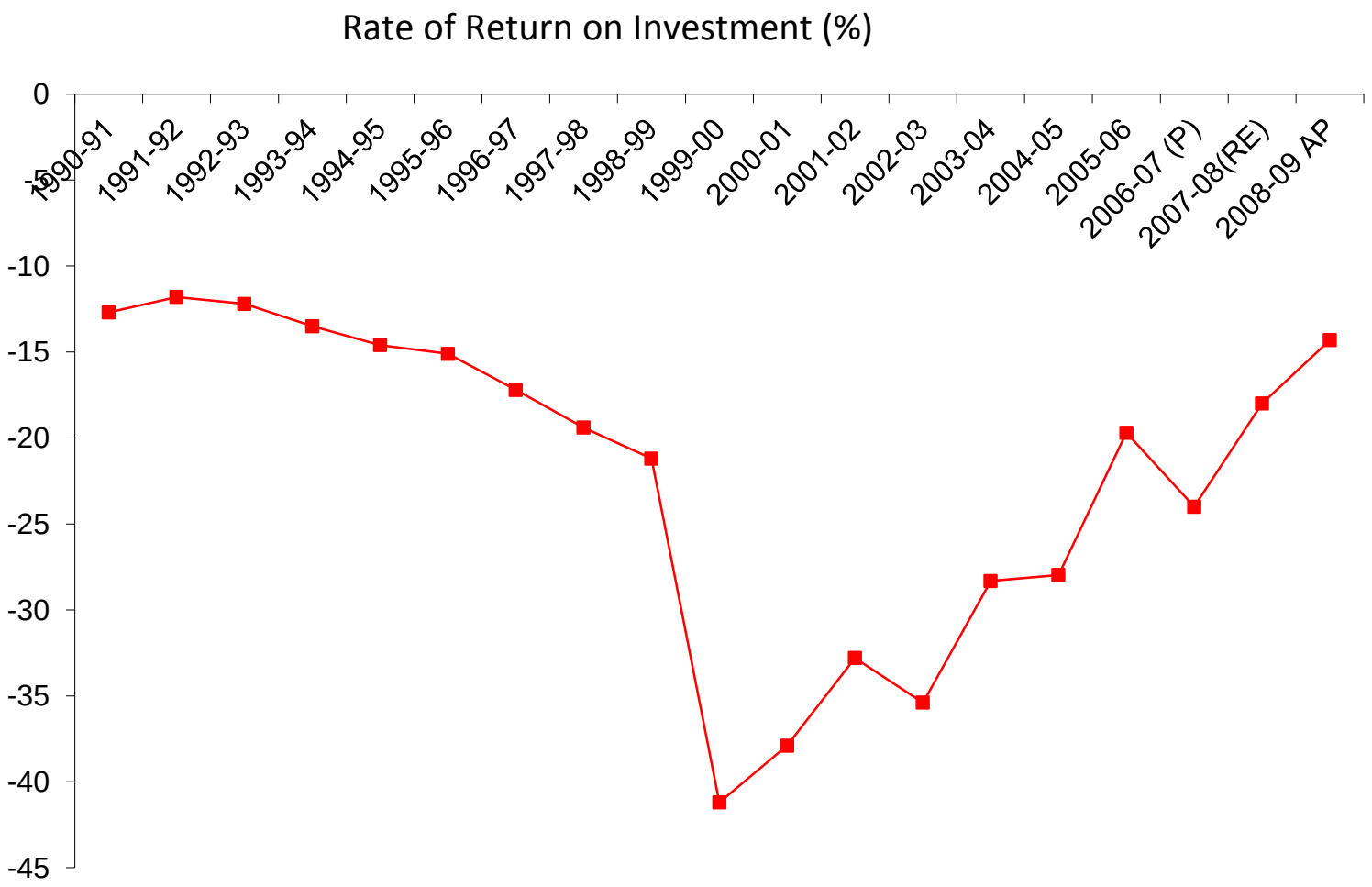
D.P Kar
Colorado School of Mines, Golden

Outline

- THREE Motivations
  - Half of Indian Homes Dark
  - Half gets unreliable power from bankrupt electric utilities
  - Ditto All Rural and Poor South Asia and Africa
- THREE Drivers from Literature Review
  - Rurality, Poverty, Inefficiency
- THREE Technologies with Demand Analysis
  - Fossil-grid, SPV-grid, Off-grid SPV
- FOUR Research Questions
  - Which is cheaper, subsidy free, threshold incomes today; and subsidy free by 2020?
- Village Case Study
  - THREE Phases of Case Study
  - THREE Methods of Funding

Off grid Kerosene Lighting in Rural Household

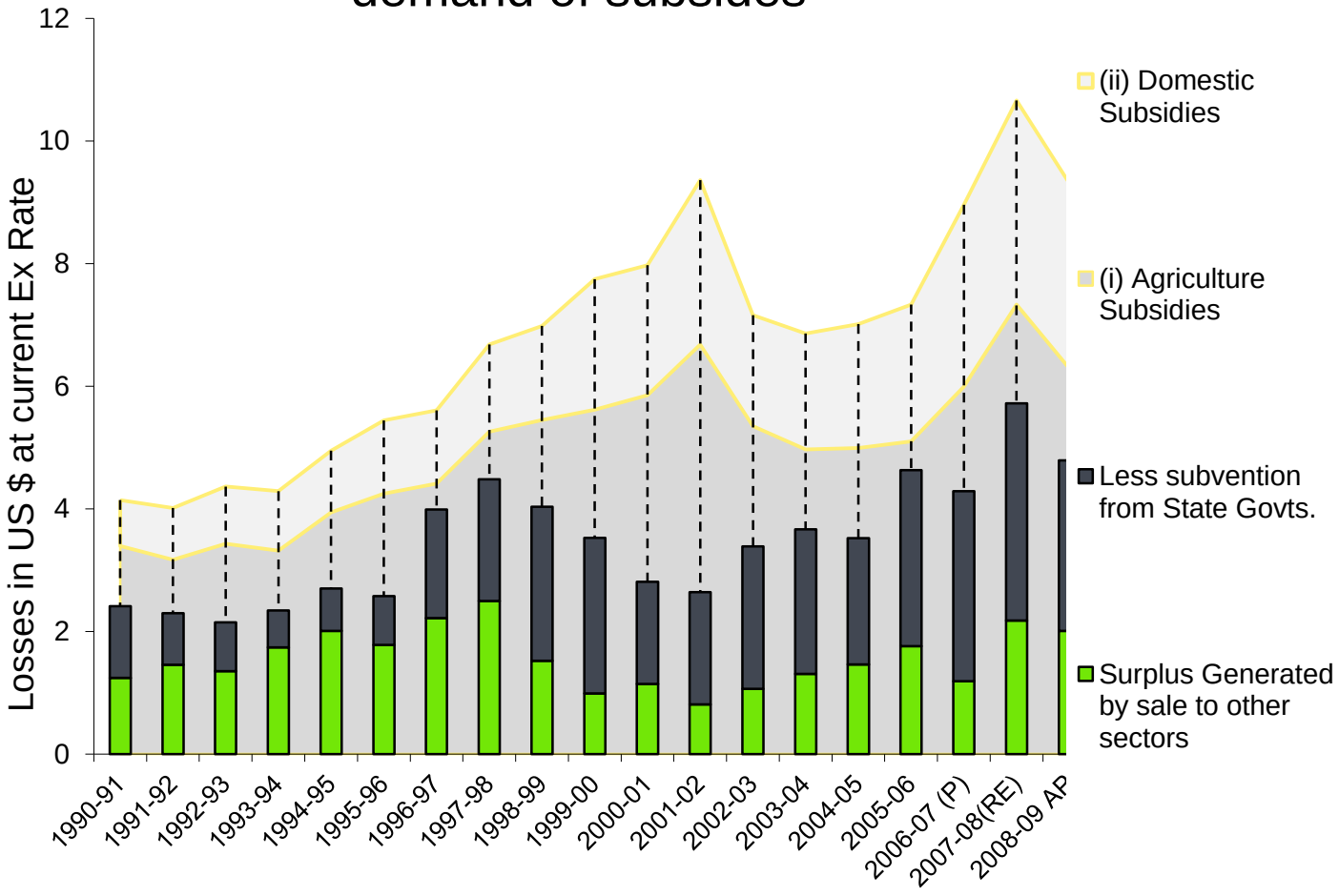
The Commercial Failure of Indian Utilities



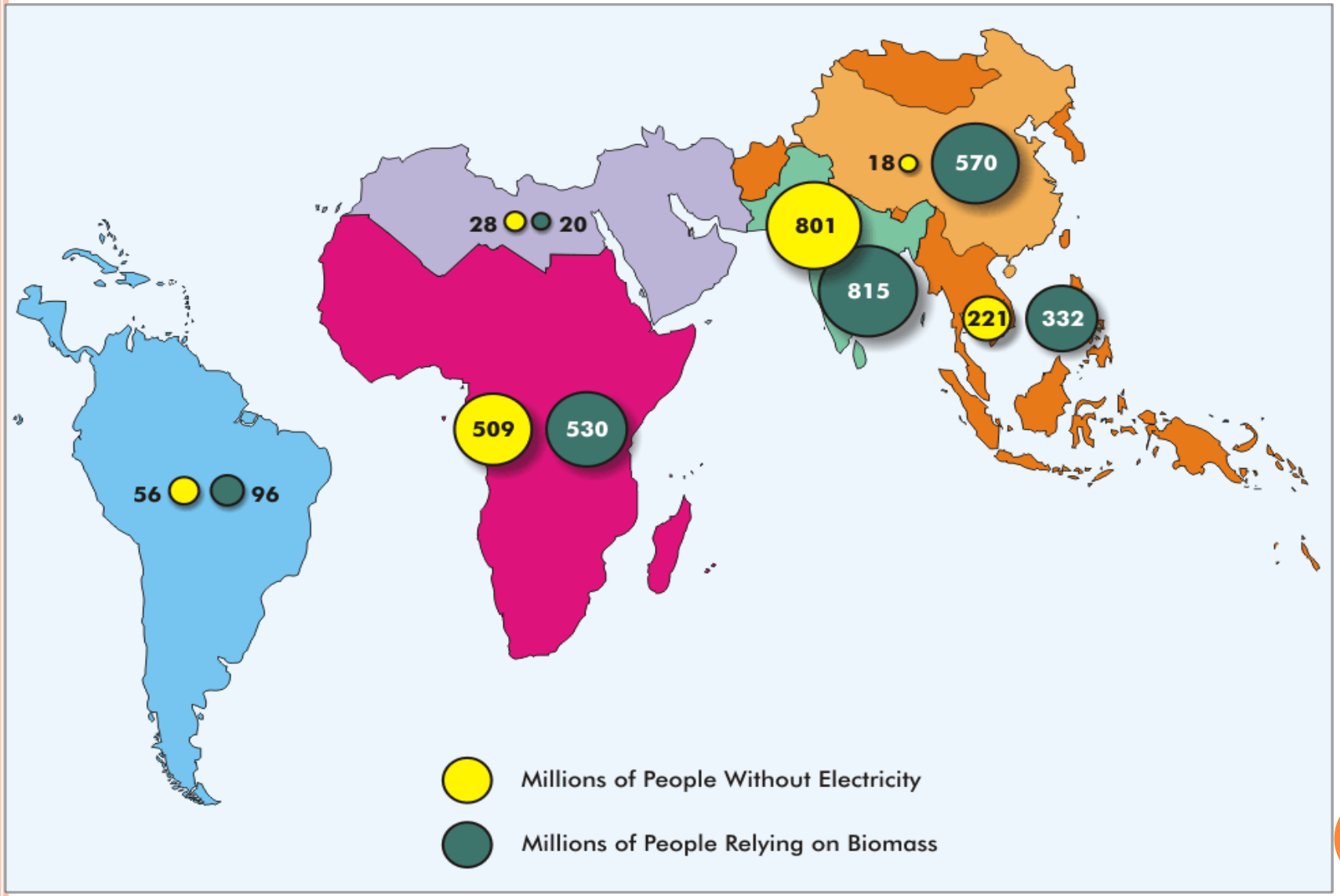
Fossil-Grid Electricity Crisis in India

- Low Access
  - Electricity - 55% of total and 80 million homes
- Technically Unstable
  - Low reliability, poor quality
- Financially Bankrupt
  - Bankrupt Utilities $6-10 Bn Losses annually (MOP, 2009)
- Economic Drag on the Nation
  - Economy-wide losses up to 6% GDP (Wartsila, 2009)

Supply of subsidies do not match the high demand of subsides



Poverty, Rurality and Lack of Electricity in India and Africa



Source: WEO 2002 , IEA

Drudgery of water lifting: Why Not Solar Pumping

Which is Cheaper, Subsidy Free, Dominant?

- **Conventional Rural Fossil-grid**
  - **Dominant** monopoly , preferred by the Indian Government
- **Alternative Solar Photovoltaic (Off-grid SPV)**
  - Advanced, modular, portable considered a **fringe technology**
- **Large SPVs connected to large grid (SPV-grid)**

Four Research Questions

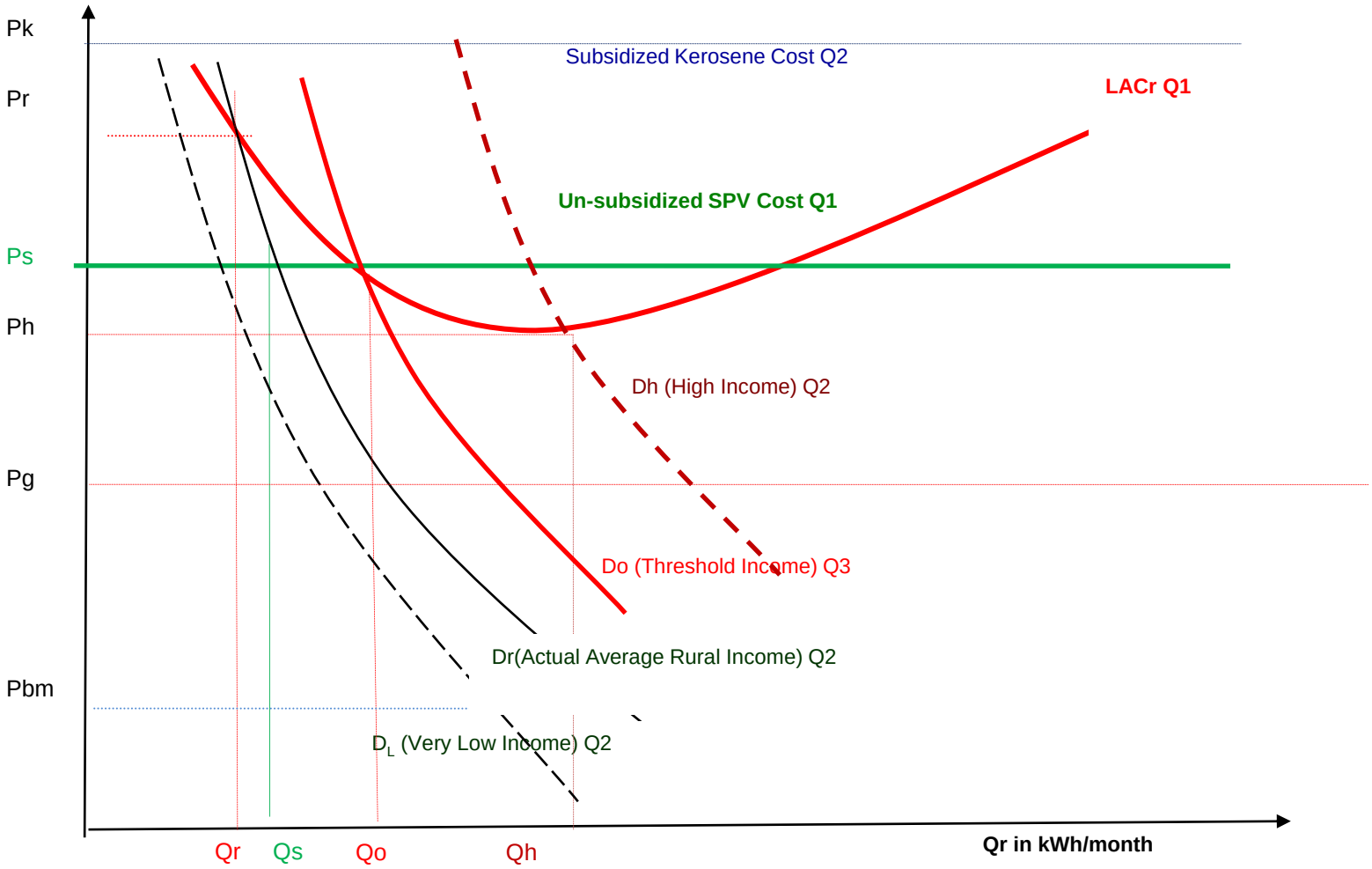
Q1. Is off-grid SPV electricity cheaper than grid electricity for the rural poor in India?

Q2. Can off-grid SPV electricity or grid electricity be subsidy free for the rural poor in India?

Q3. What are the break-even incomes for the grid to be cheaper than off-grid SPV?

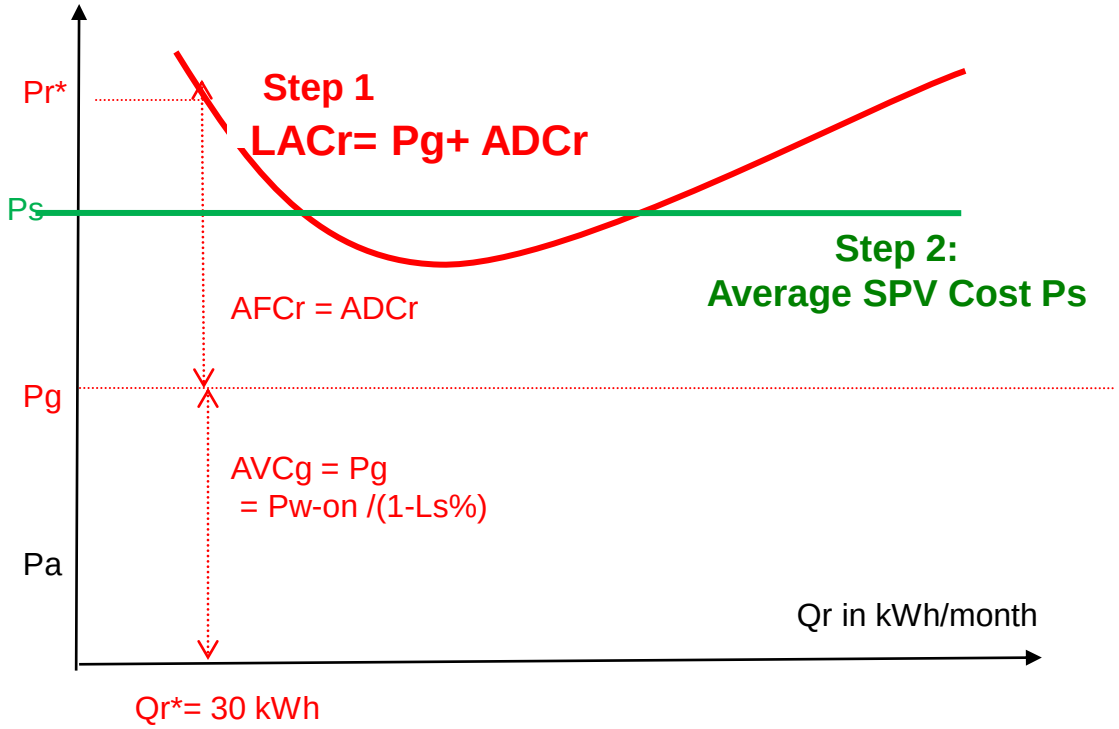
Q4. Can this break-even income and consumption be reached for the electricity grid to be competitive or subsidy free by 2020?

Cost and Demand Models Estimated



First Research Question

- **Q1.** Is off-grid SPV electricity cheaper than grid electricity for the rural poor in India? **Rurality and Cost**

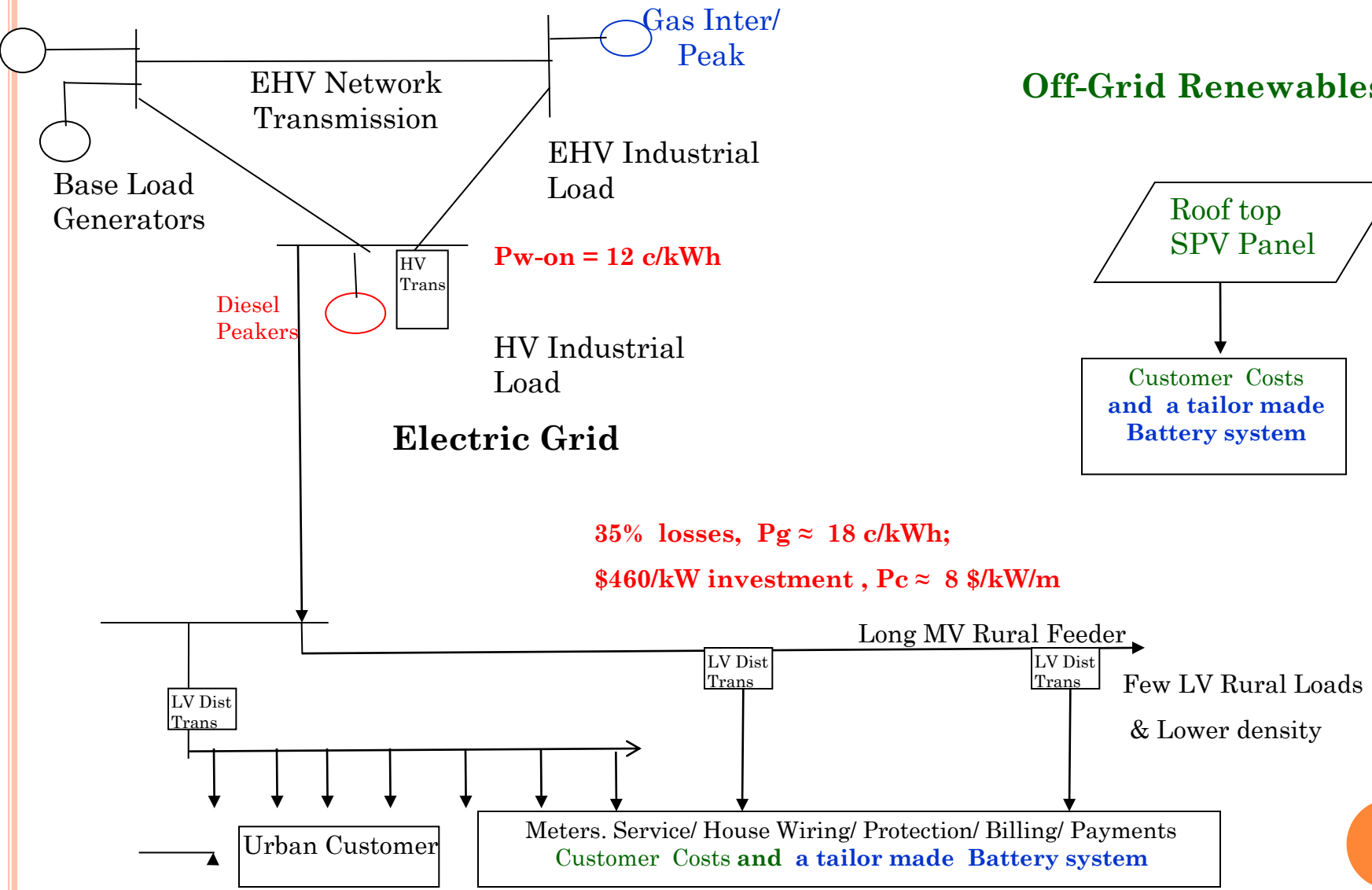


Wholesale Electricity Prices in India

Market energy prices in c/kWh		Utility Bilateral	Through Power Traders			Two Approved Power Exchanges		Pw-On in North-East-West (NEW) and South Regions	
Month	Source / Period	All Hours	Peak	Off-Peak	Total	IEX	PXIL	NEW Region	Southern Region
Average in **c/kWh**	13 months Aug 2008 to Aug 2009	15	18	15	16	16	17	12	16

Source: Central Electricity Regulatory Commission (CERC 2009) $**1=45 Indian Rupees (Rs.)**

Grid vs. SPV Technologies: Cost Drivers

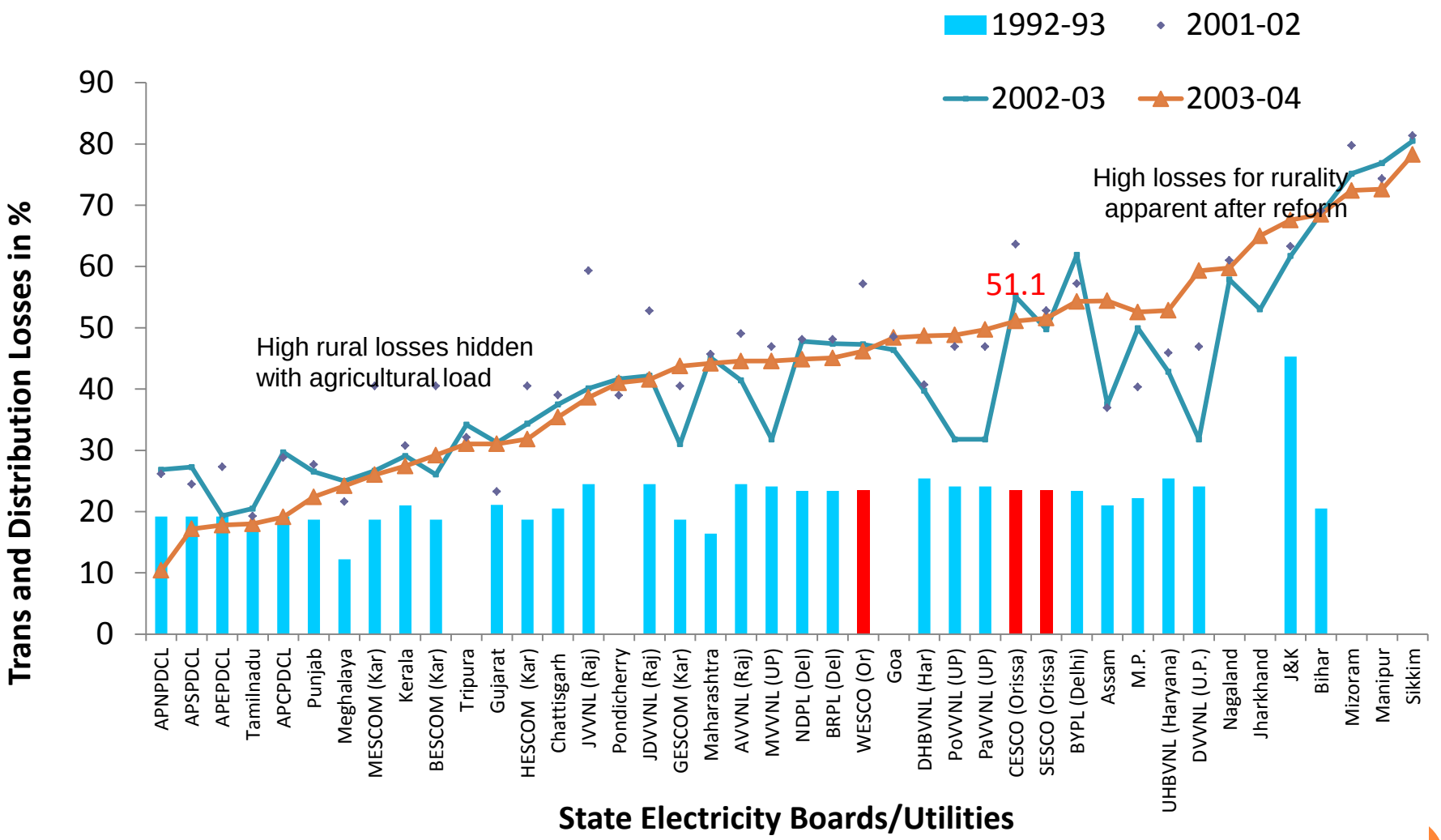


Off-Grid Renewables?

Roof top
SPV Panel

Customer Costs
and a tailor made
Battery system

Transmission Distribution Losses Increasing

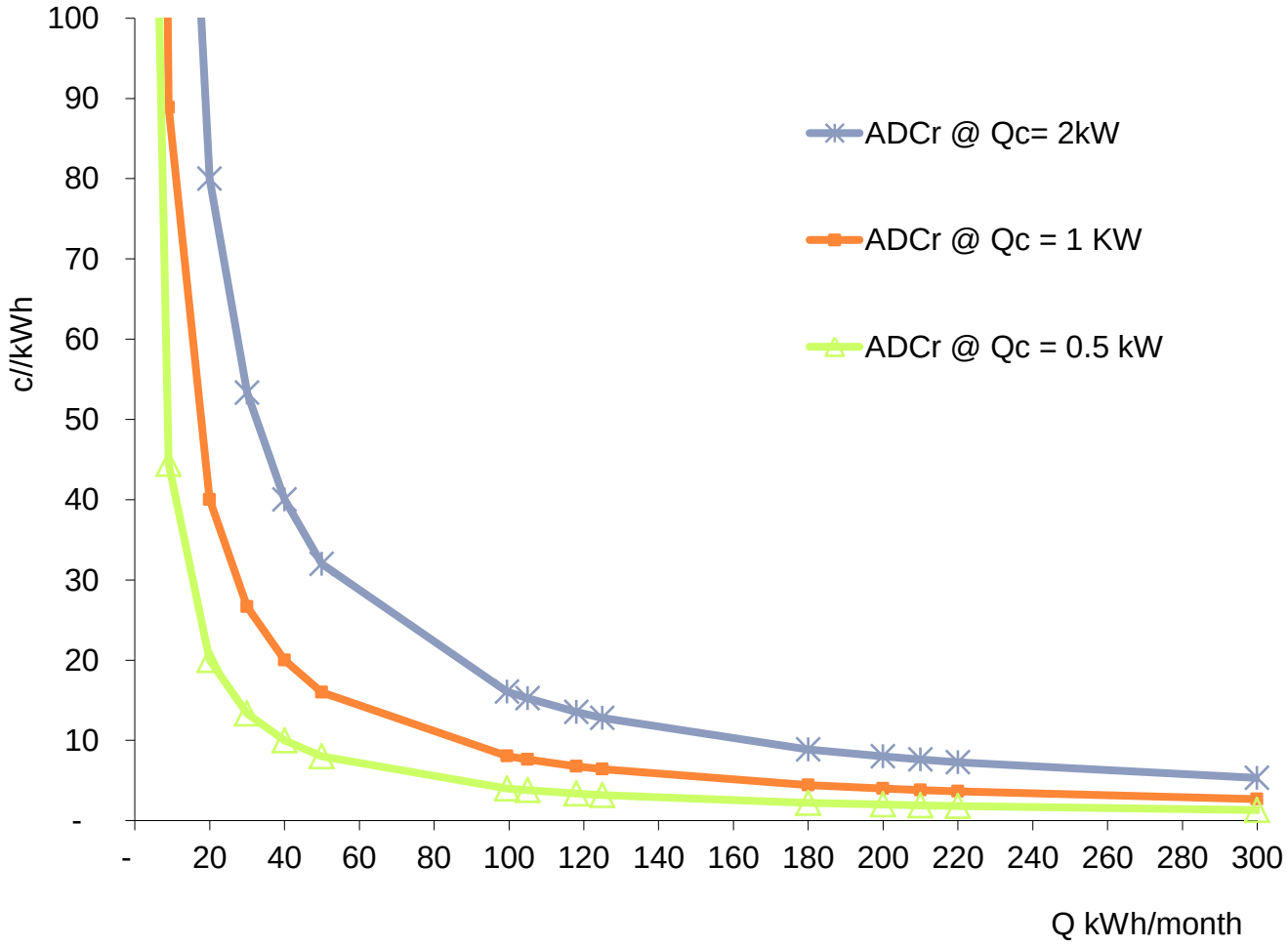


Assumptions in Q1

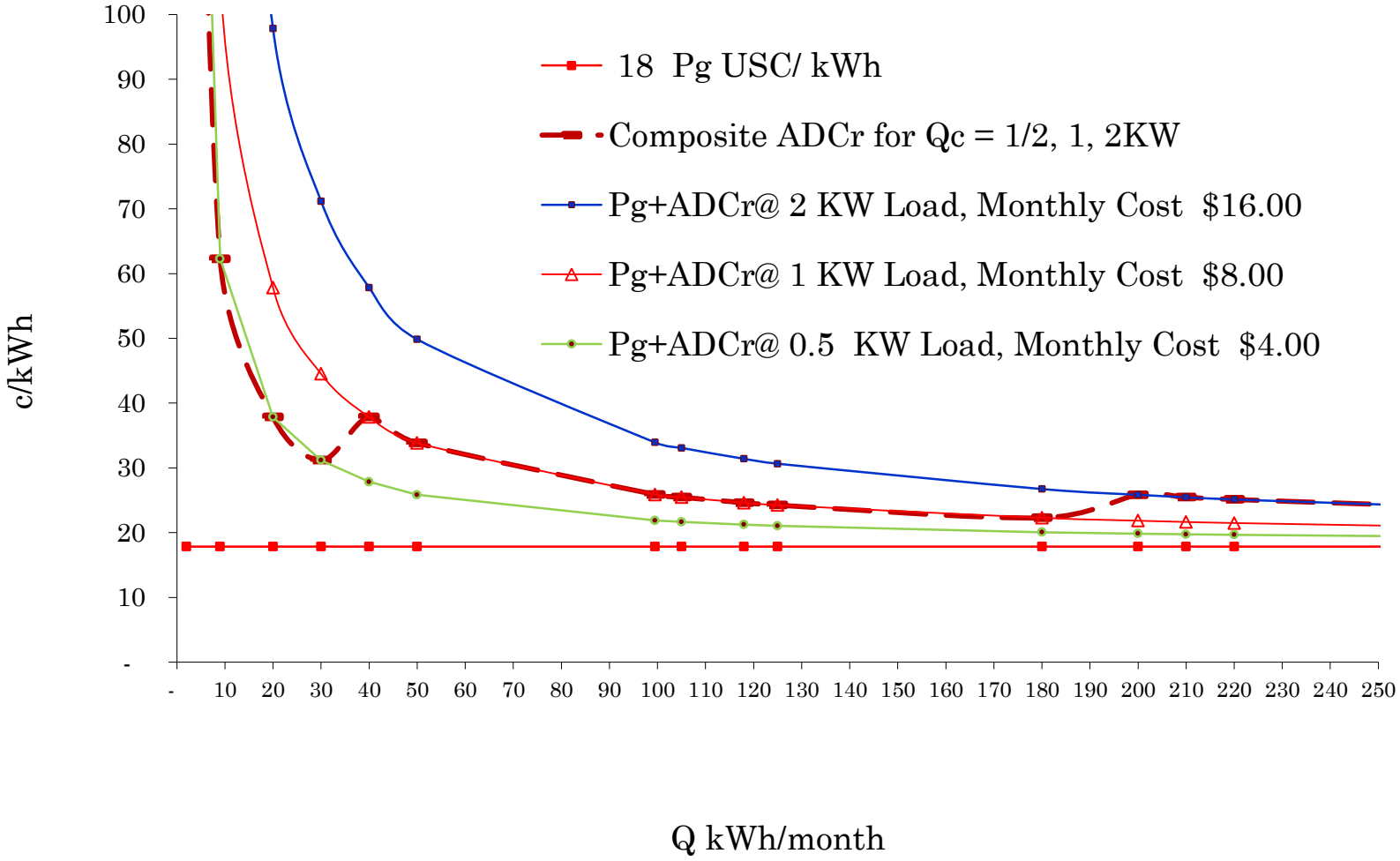
Q1. Cost Analysis: Is off-grid SPV electricity cheaper than grid electricity for the rural poor in India?

- Weighted Cost of Capital
  - Debt and Equity 14%
  - Discount Factor for Levelizing 14%
- Depreciation,Life
  - Grid 4% , 25 years
  - SPV 4%, 25 years
- O&M Expenses
  - 5% of capital investment for Grid and 5 % escalation
  - 0.5% for SPV, 5 % escalation
- Tax Rate 0%

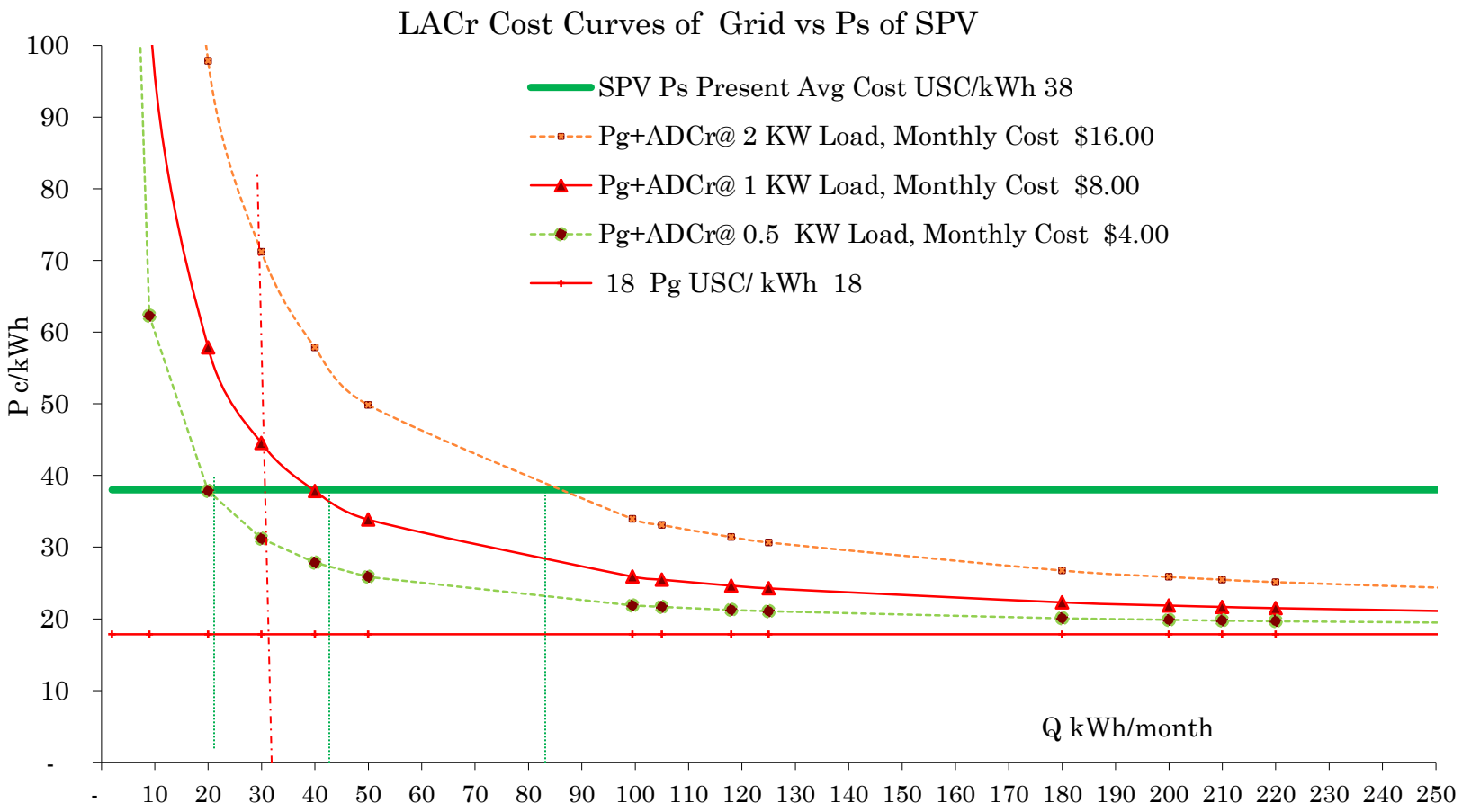
Average Distribution Cost (USC/KWH)



LACr Cost Curves Grid



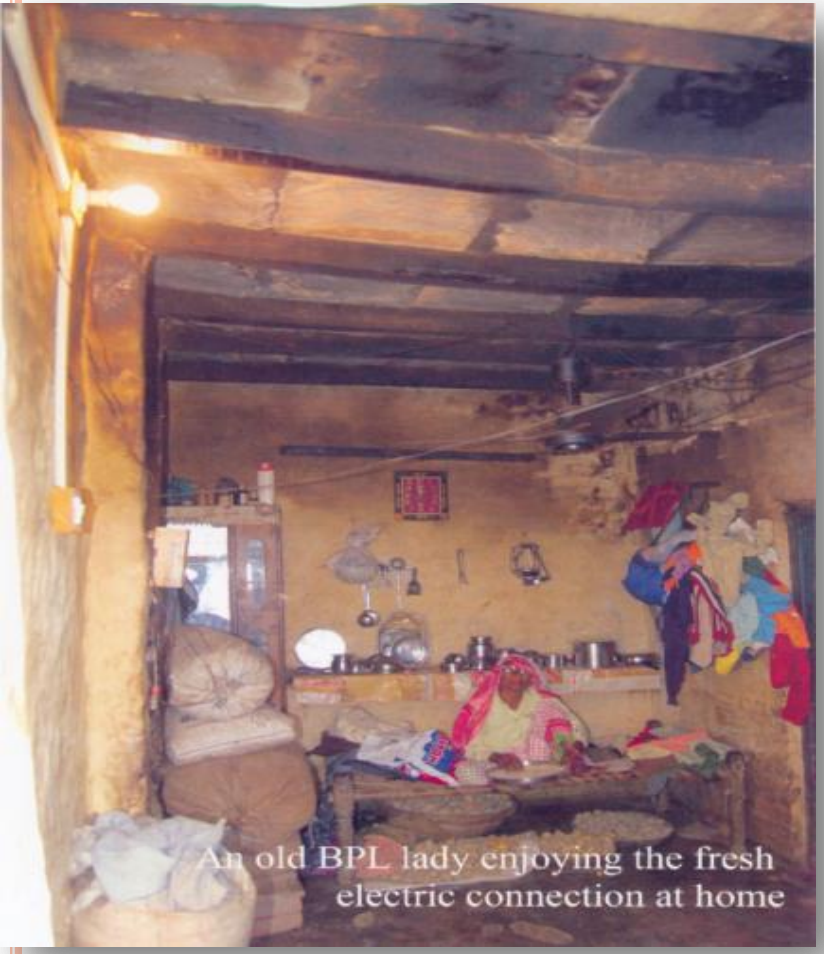
LACr (Grid Cost) and Ps (SPV Cost)



Average Electricity Cost of Inefficient rural lighting

Grid peak load capacity Qc	Average Cost $/kWh		Total Qty kWh/month	Total Cost in $/month	
	Grid LACr	**SPV Ps**	**Qs=Qr =Qr***	**Rural Grid TCr= Qr*LACr**	**SPV TCs = Qs*Ps**
½ kW	0.31	0.38	30	**9.3**	11.4
1 kW	0.45	0.38	30	**13.5**	11.4
2 kW	0.72	0.38	30	**21.5**	11.4

Grid Electricity India Vs. Modern Solar Power



Indian Government Target for all 23 million poor by 2012 1 kWh/day (2*100W*5hrs)

Source: Website of the Ministry of Power, Government of India

Modern Solar lantern, LED, TV and fan can use 1/3 kWh/day

Source: JABA case study (Kar 2010)

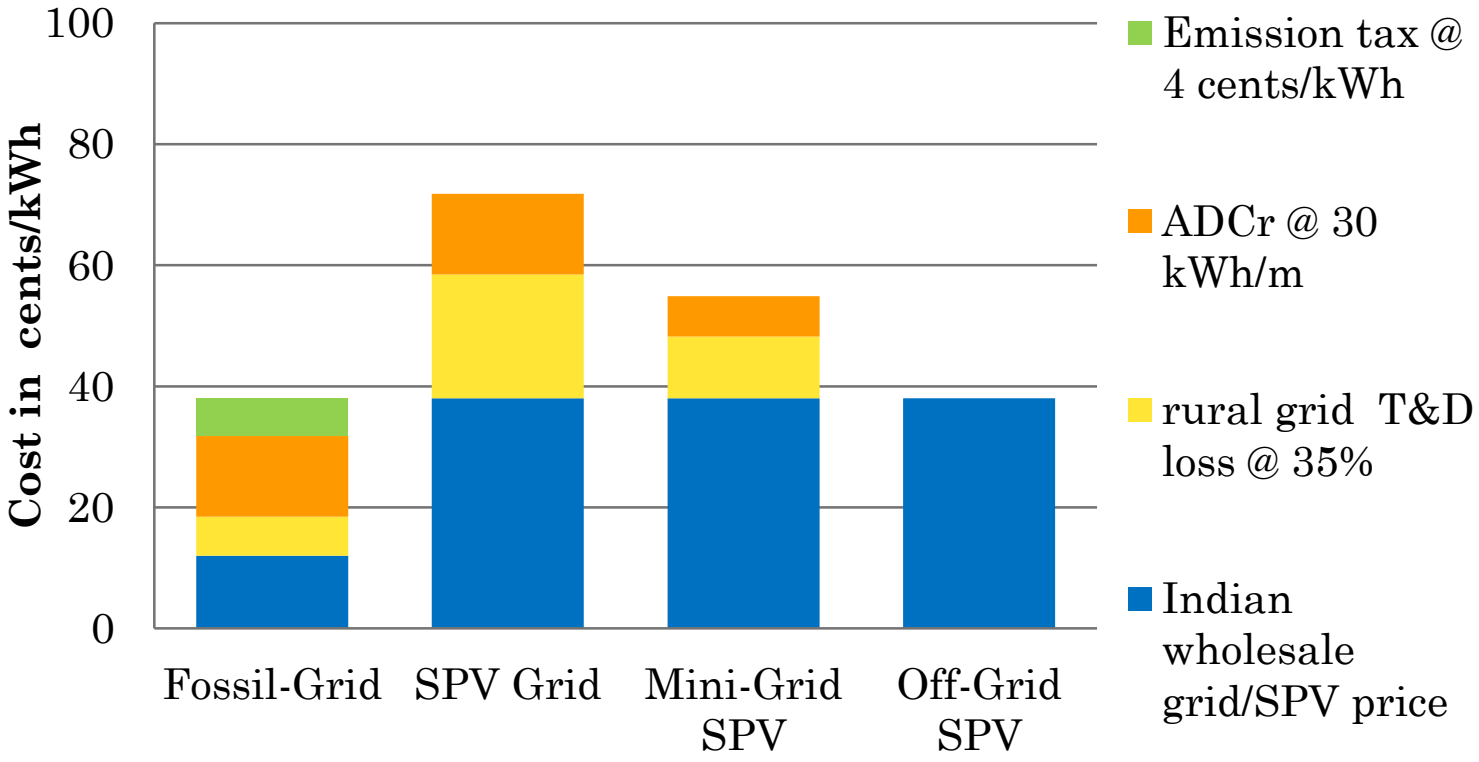
Efficient Appliances for Minimum Rural Domestic Needs

Appliances	Power ratings (Watt)	Number of devices	Total Power (Watt)	Hours/day	Total kWh/day	Equivalent inefficient kWh/day
CFL	10	2	20	5	0.100	2*40W *5h= 0.4
Cell phone	3	1	3	2	0.006	0.006
Small TV and Fan	40	1	40	5	0.200	2*60W*5h=0.6
Total Power and Energy			61		0.306	1.006
Monthly electricity need Qs/Qr			9.18 kWh			30.18 kWh
SPV capacity required with 20% capacity factor			0.306/24/20% = 0.062 kW= 62Wp			1.006/24/20%= 210Wp

Average Cost of Electricity for Rural Use

Uses per month →		Inefficient appliances 30 kWh/month (1)	Efficient appliances 9 kWh/month (2)	Monthly Efficient Costs TCs or TCr
Technology Capacity / Formula used →		18 +800 Qc/30 c/kWh	18+800*Qc/9 c/kWh	LACr * 9 Ps * 9 $/month
Rural grid LACr	½ kW	31	62	62*9=5.6
	1 kW	45	106	106*9= 9.5
Off-grid SPV Ps		38	38	38*9 =3.4

Total Average Costs of Fossil-grid, SPV-grid, and Off-grid SPV



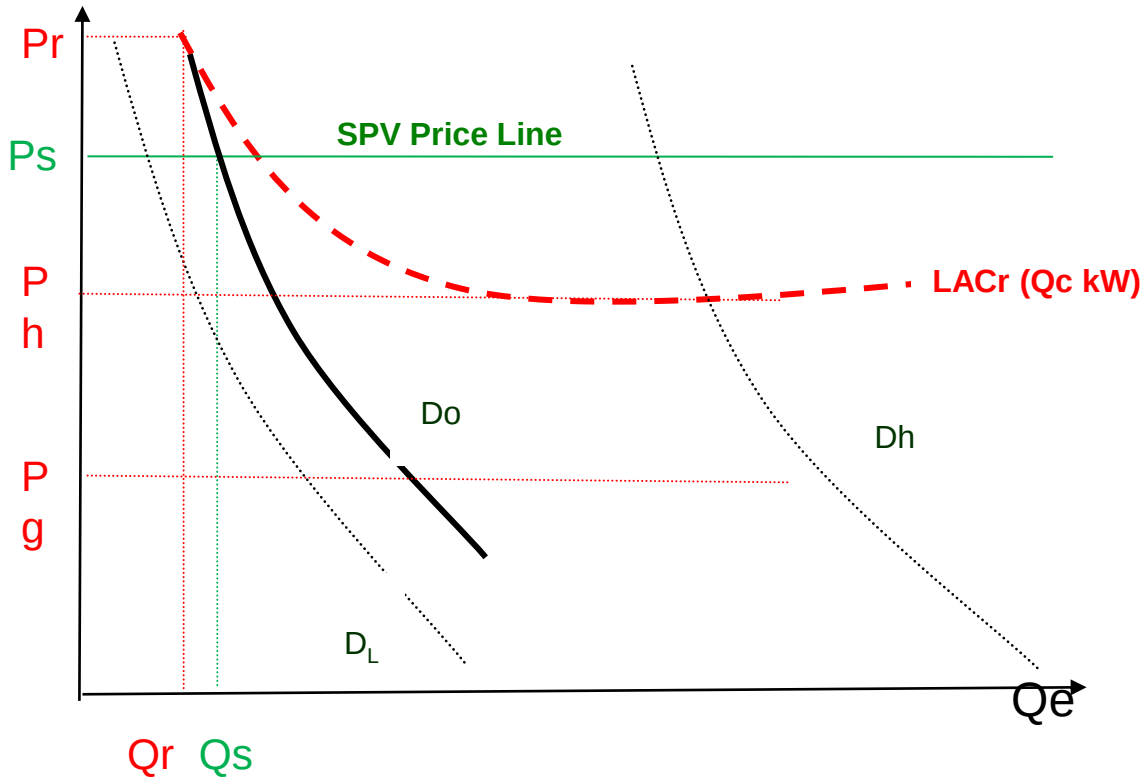
Cost is One side of the Market

- Rural grid cost is high and may or may /not be cheaper than SPV depending on efficiency.
- **Less efficient -cheap grid, more efficient - expensive grid.**
- Off grid renewables might fit well with rural low income and conservative lifestyle as we will see next.
- Need demand equation to answer these questions.

Second Research Question

- **Q2.** Can off-grid SPV electricity or grid electricity be subsidy free for the rural poor in India?

- **Q3.** What is the Threshold Income

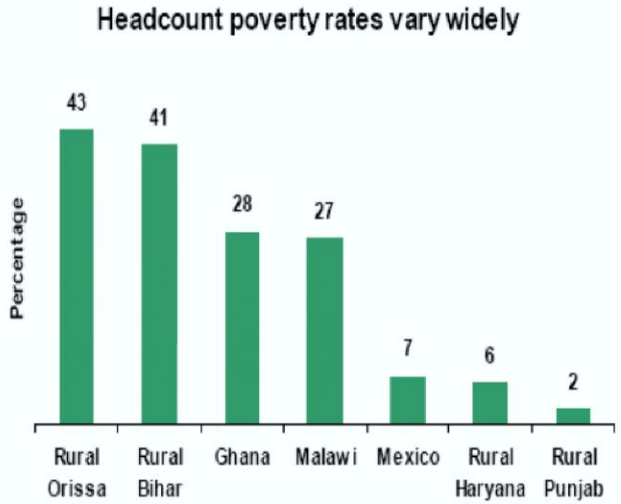


Using Indian village data representing rural and poor economies

Assumption and Data of the Sample Village

- The JABA villages in Orissa: rural poverty in Indian electrified villages
- Average income in 2008 same as rural Indian average of close to $90/month.
- Electrified in mid 1970s while 50% Orissa villages, 80% population in Orissa, and 70% eastern India have no electricity.
- All use kerosene as a lighting fuel.
- The electricity equivalent of kerosene is computed based on the lumen output of a 5W incandescent bulb.

igure 3. ***Lagging States****:* While India's prosperous states have poverty rates that are comparable with the richer Latin American countries, India's poorest states are mired at Sub-Saharan African levels of poverty. And, the gap is growing.



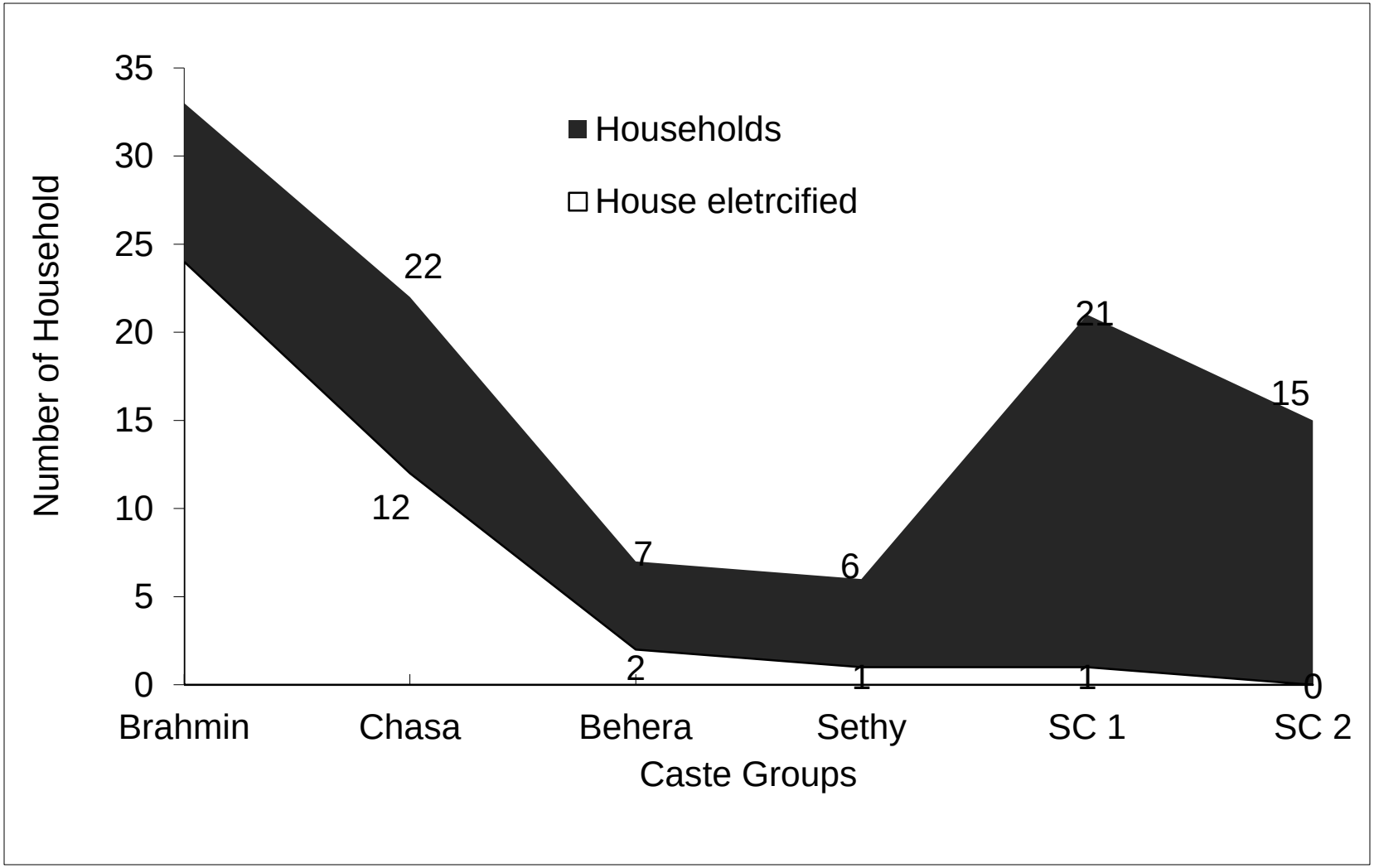
Source: For Indian states Deaton and Dreze (2002), for comparisons, author's calculations from World Bank Poverty Database.

JABA villages in Orissa

Number and types of appliances used by the electrified Households (HHs)

	Bulbs	Fan	TV	Tube-light	Water Pump	Refrigerat-or	Water heater	Washer/ Drier
Total numbers	184	78	32	17	8	4	2	1
HHs have	40	32	32	14	8	4	2	1
HHs do not have	64	72	72	90	96	100	102	103
% HH don't have	62%	69%	69%	87%	92%	96%	98%	99%

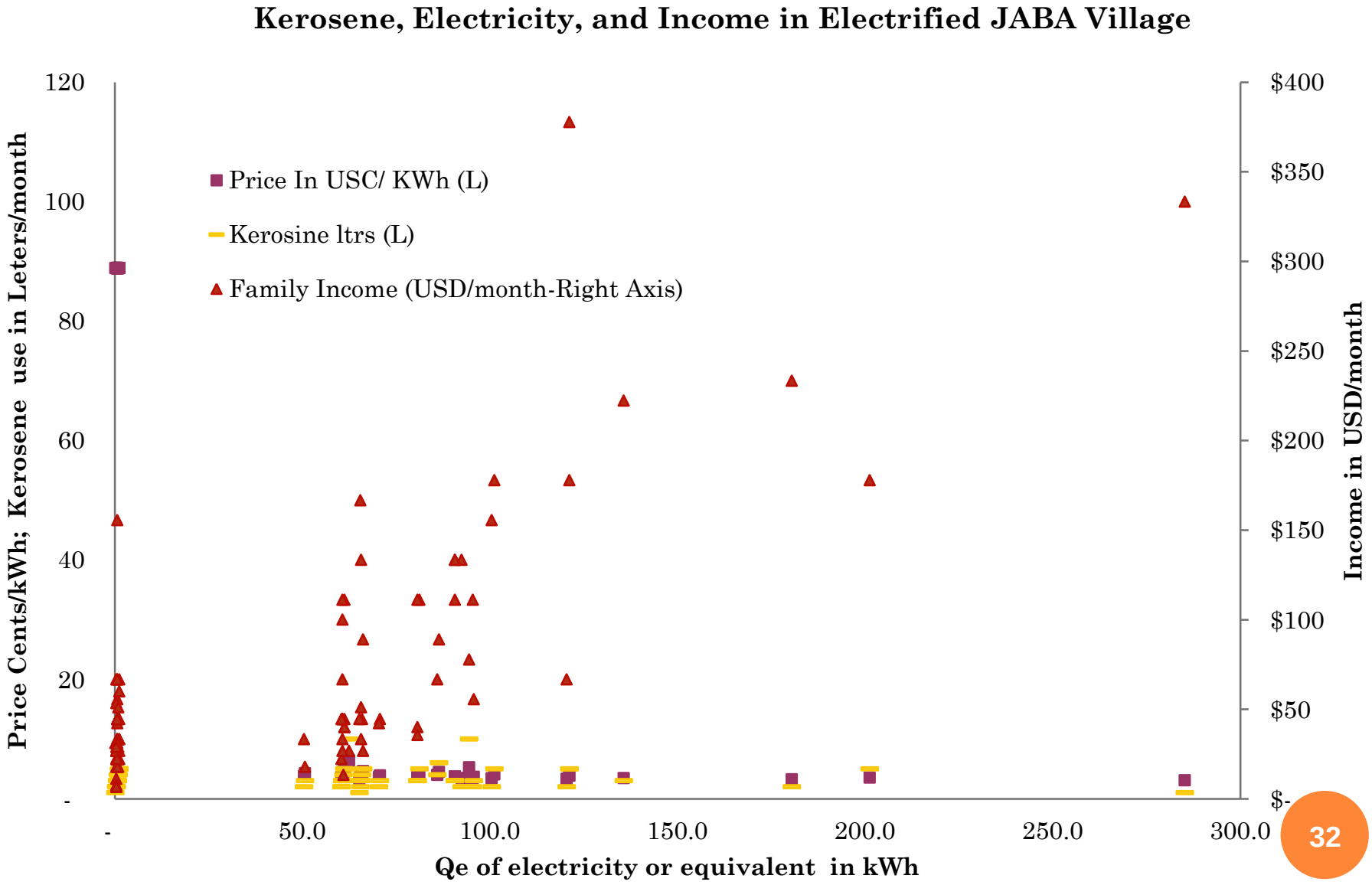
Present Lighting in JABA village by Caste Group



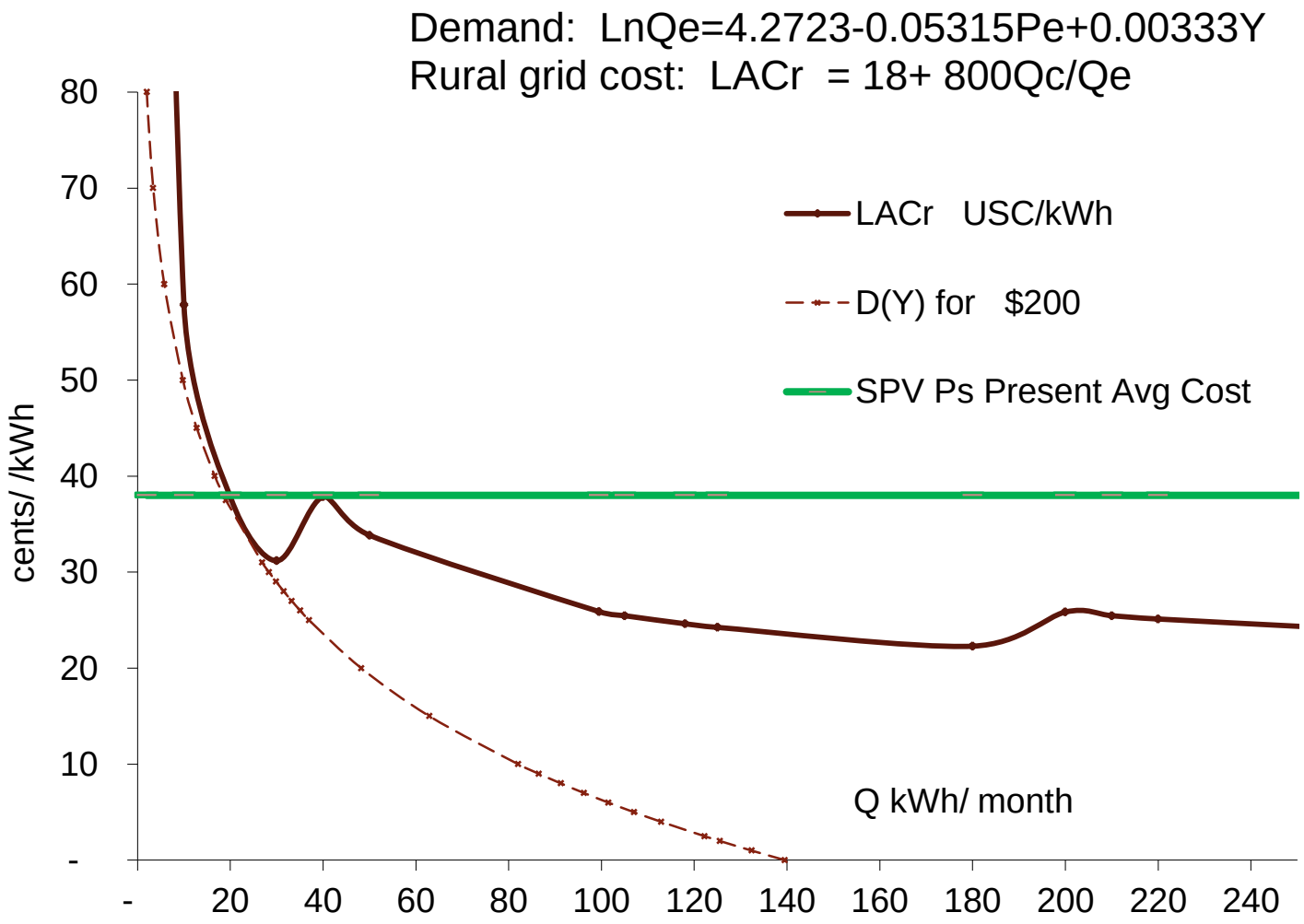
JABA VILLAGE AVERAGE HOUSEHOLD ELECTRICITY AND KEROSENE FOR LIGHTING

Group	Primary Income Sources	Fuel Sources	Number of households	Consumption kWh/month (Q)	Price c/kWh (P)	Income $/month (Y)
Electrified Poor	Labor	Electricity	36	70	3	53
Non-electrified Poor	Labor	Kerosene	58	1	90	55
Electrified not so Poor	Some Skill, Capital, Land	Electricity	4	200	3	240

DATA FROM THE VILLAGE CASE STUDY USED FOR REGRESSION STUDY



THRESHOLD INCOME >$200/MONTH



Fourth Research Question

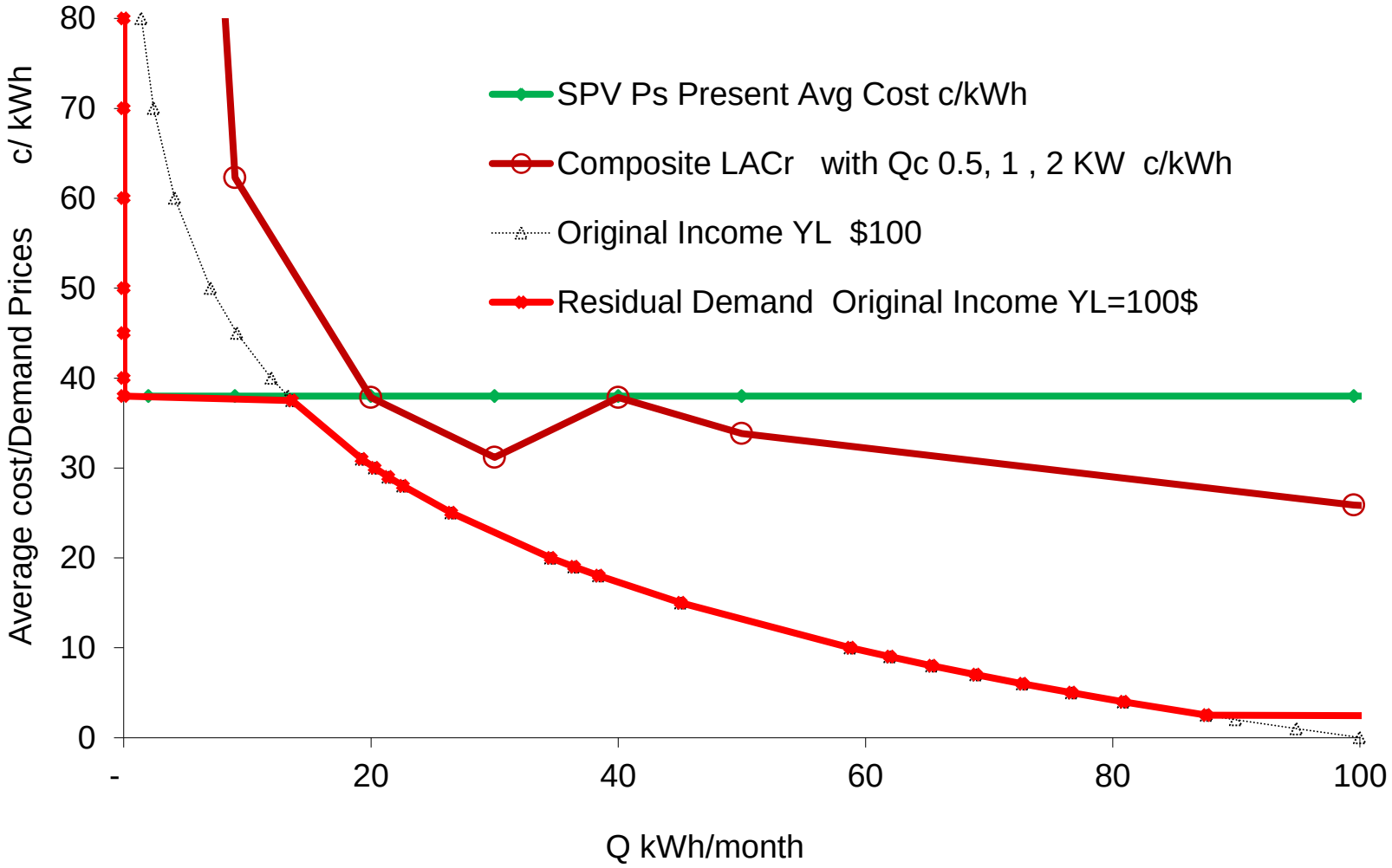
- **Q4.** Can this break-even income and consumption be reached for the electricity grid to be competitive or subsidy free by 2020? **Dominant Firm in a Dynamic Setting**

- **Assumptions:**

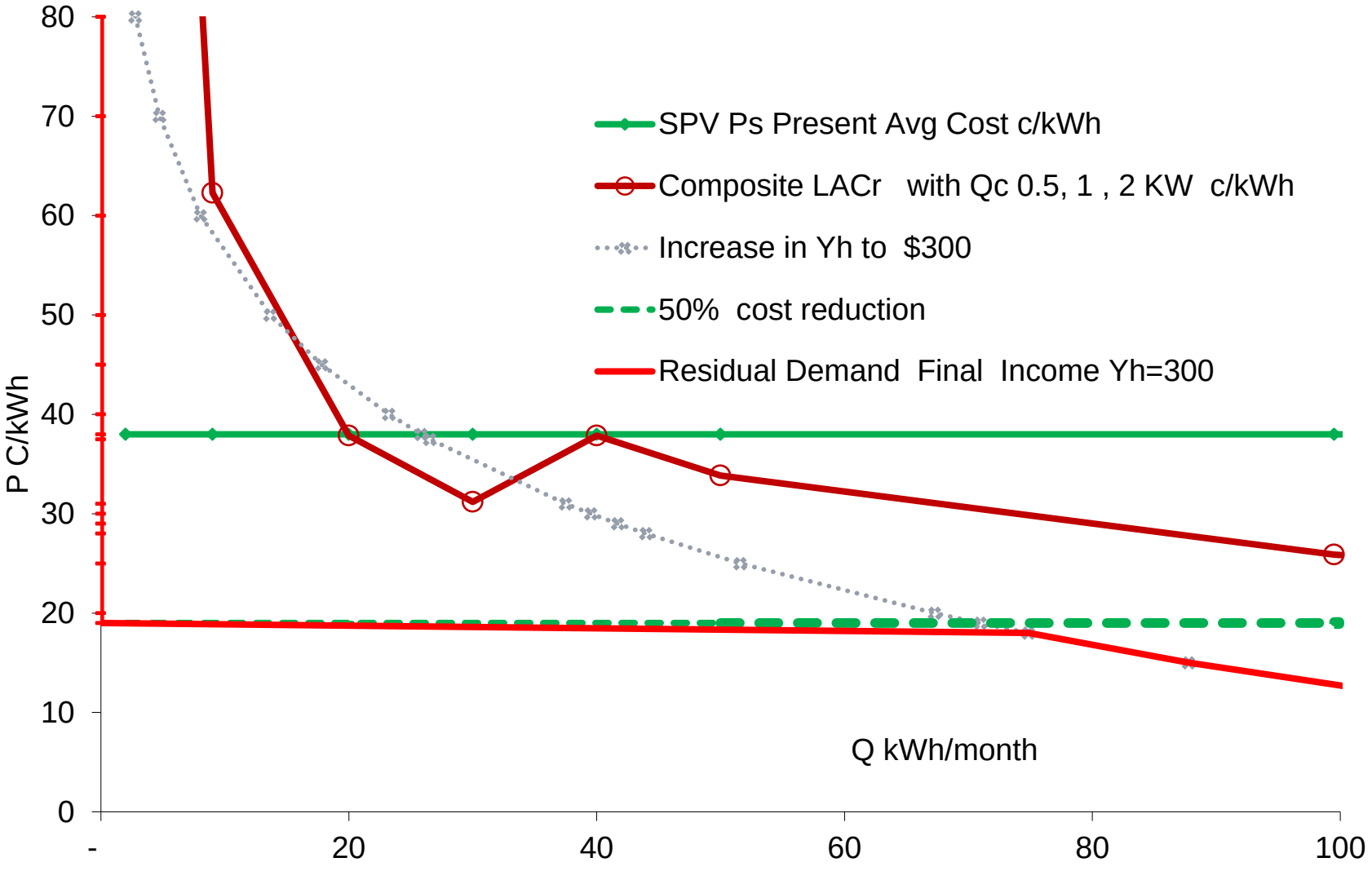
Income grows annually	10%
Learning Rate for SPV	10%

Price ratio (PR) = 90% for each doubling of quantity or Quantity Ratio QR =2

Current village income compared with the SPV and the Grid Cost



Reduced SPV Cost and Triple income moves residual rural demand further against the grid by 2020



Summary Results of Data Analysis

Data		Source	period
Grid Fixed Costs per Peak demand Qc (Pc)	$8 /kW/month	RGGVY (Govt. of India)	2005 /2008
Grid Variable Costs (AVC= MCr= Pg)	18 c/kWh	CERC, Power Exchange	Average Aug 2008 – Sept 2009 adjusted for 35% loss
SPV Costs (Ps)	38 c/kWh	CERC and Local Market Data	2008-09
Kerosene Costs (Pk)	90-200 c/kWh	Village Ration Shop – Market Price	2003-2008
Demand Curve	Ln Qe=4.2723-0.05315Pe+0.00333Y	Village Case Study ADB methodology	2003-2008

Off-Grid SPV? Are Issues Real?

- Too little?
  - Poor can only afford a little (Kerosene Vs. Solar Lamp)
- Too Intermittent and unreliable?
  - Grid Unavailable or Unreliable too
- Cannot be stored?
  - Easy to store at sub-kWh level: Conservation, Efficient Design and Flexible Use (Solar LED Lamp, cell phone, radio; TV & Laptop,)
  - Batteries-inverter used anyway in urban areas and have more value for portable rural applications

Summary of the Results

- Rurality and High Costs
  - Grid costs come down with high consumption
  - SPV costs constant for very low consumption level
- Poverty and Subsidy
  - Demand below grid cost for average villagers income level
  - Grid cannot be subsidy free but SPV can
- Modified Dominant Firm Model shows SPV dominant
  - Grid Residual Demand below the LACr and SPV is the backstop marginal cost
  - No Grid Equilibrium even with Increase in Income as SPV Price also decreases

Renewable Grid No Better for Rural Poor India

- Add Costs of Transmission from Rural to Urban
- Add Costs of lack of reliability, scarcity, battery back up during peak shortage
- Does not help conservation by selling a “Hope of Plenty”
- Add more emission with back up diesel generators or migration to cities

Programs And Presence

Eco Econ Empowerment with ADIRE

WHY ADI-RE?

- **600,000 villages (700 million people) are all green but poor;** not polluting and not developing also.
- **Engaging few of these green villages in a novel experiment of clean development** without any pollution and risks of creating additional scarcity of fuel, water, urban space, roads, transit, law and order so important for all urban dwellers.
- **Developing villages to keep them in the villages with urban-like lifestyle but use local renewable energy:** Bring HELP to them instead of they searching for HELP in cities and overcrowded slums!

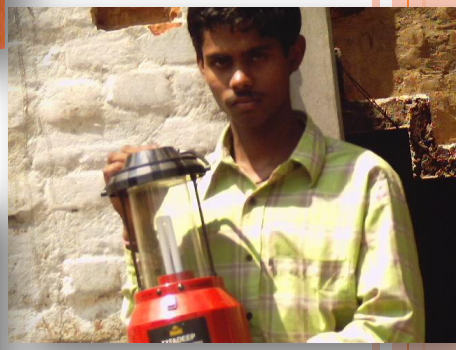
Phase I ADI-RE

From Open Toilet To Playground , Clean Water

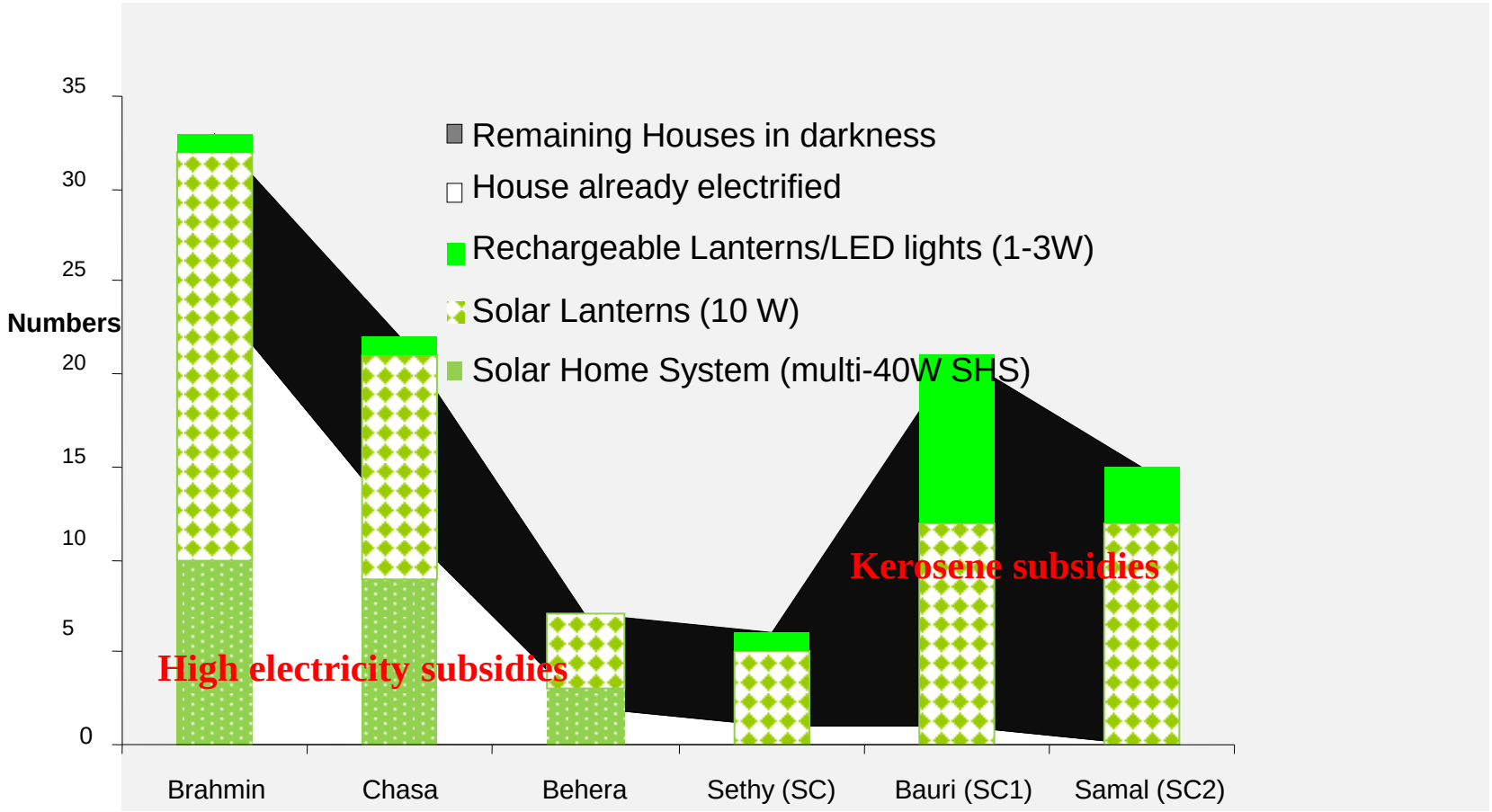
Phase I: ADI-RE

Energy

Handy Solar Lanterns

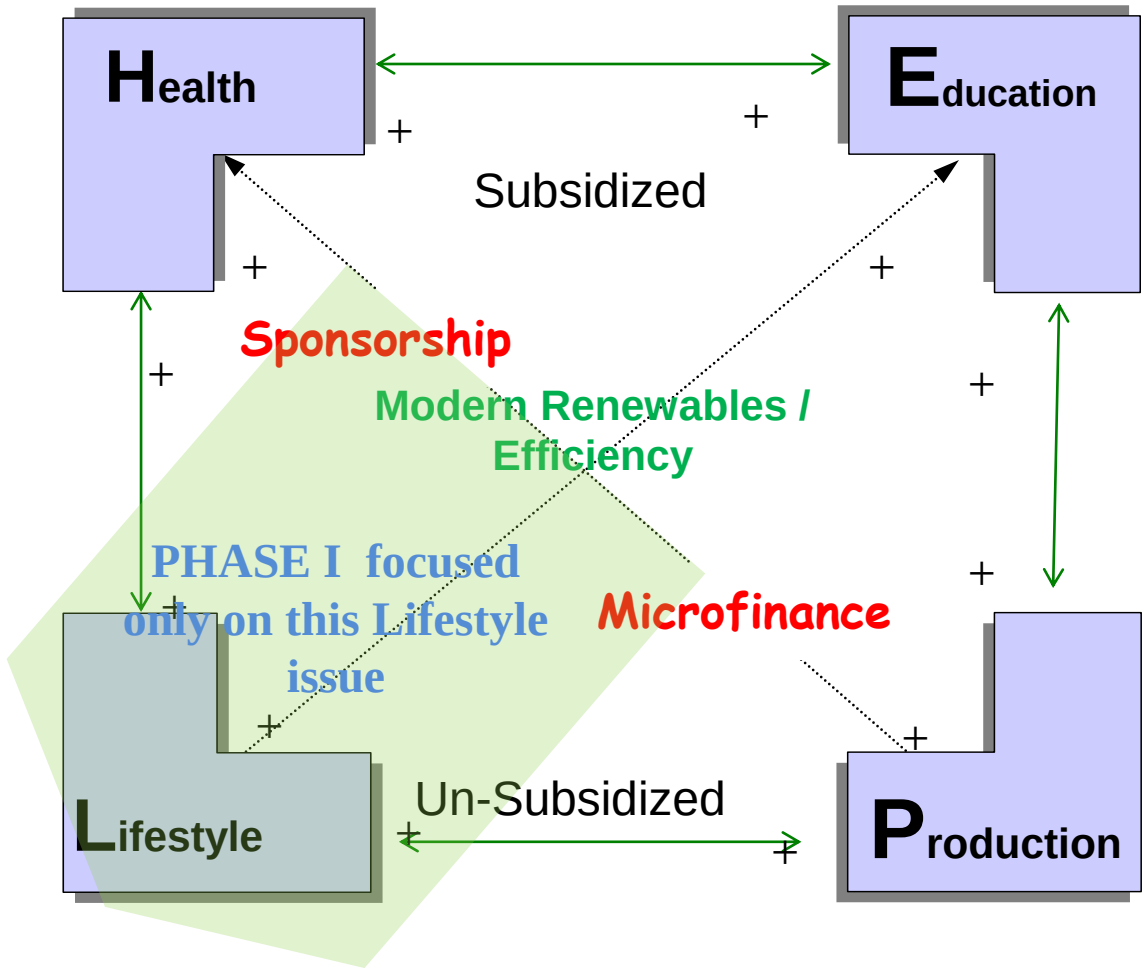


JABA village electrified in 1970s:
Grid availability vs. solar electricity potential in 2003-05



Social segregation and energy use

ADI-RE-HELP (PHASE II)



ENERGY

Solar Applications in JABA village

HEALTH

SHAMA's donation for Mosquito net for Malaria prevention and LED lights for study

HEALTH CAMPS

Energy

Renewable power lighting up lives

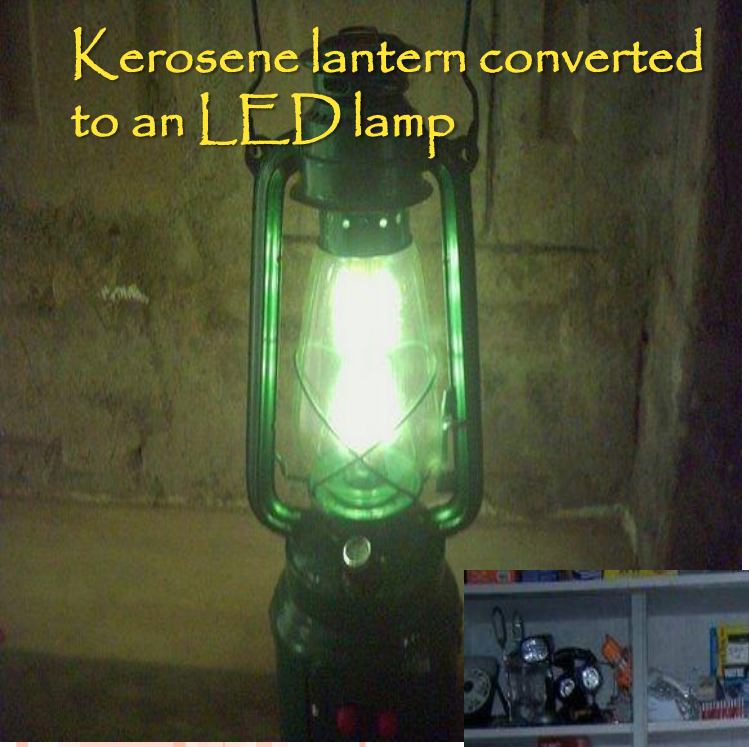
Energy

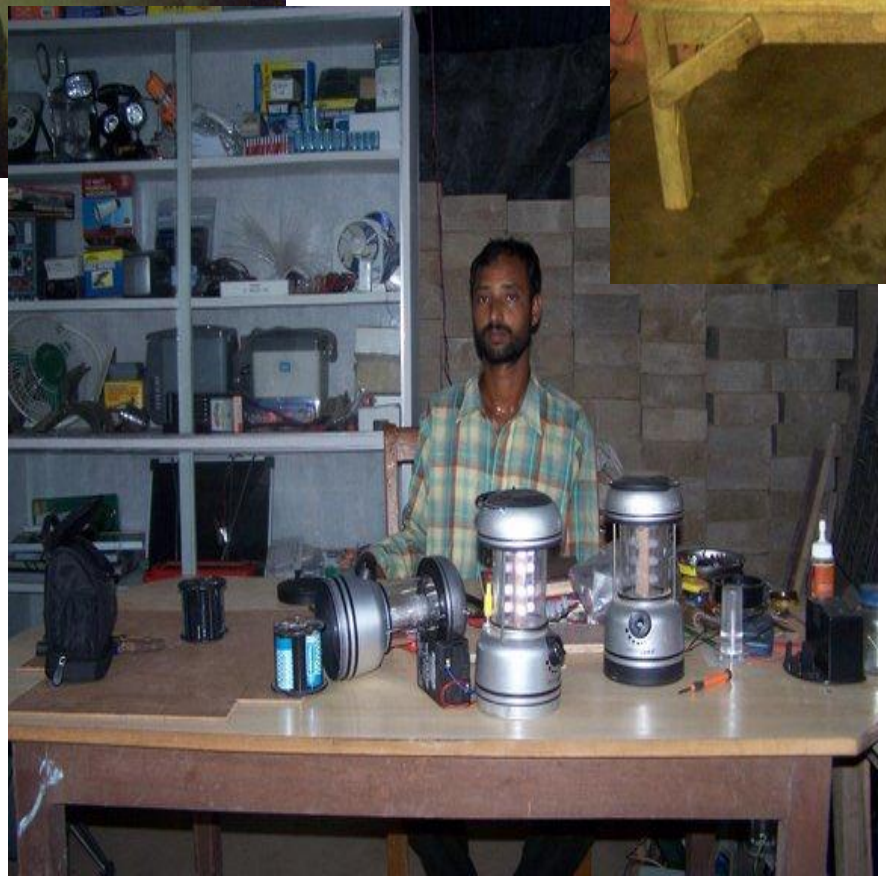
Solar Streetlights removed physical and mental darkness

The Learning Center

Energy and Education

Solar powered Adividya Elementary School





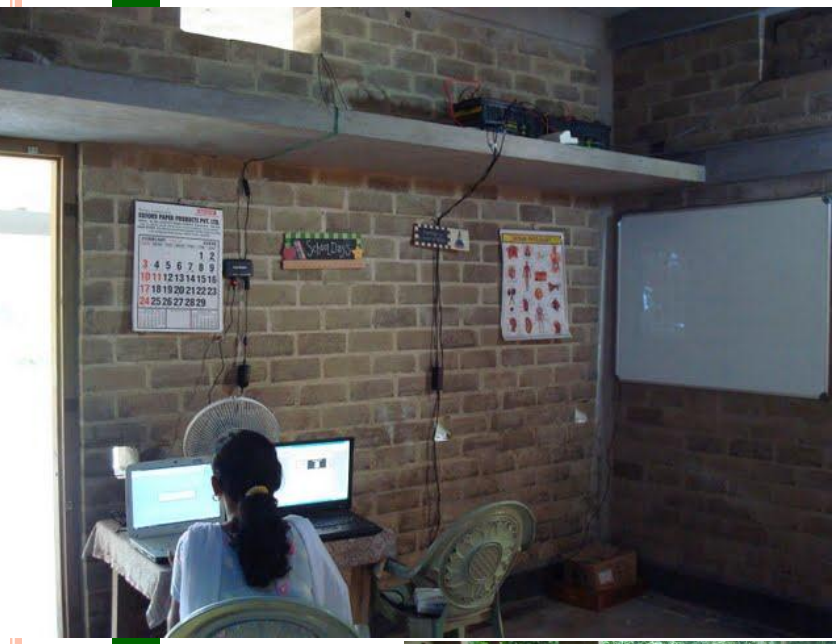
Solar Workshop
In the village

Local Innovations with
Solar PV & LEDs

Comparing a kerosene lamp(left) and locally made low cost LED lamp (Right)

ADIRE founder, D.P Kar fixing a solar panel in a village building roof top

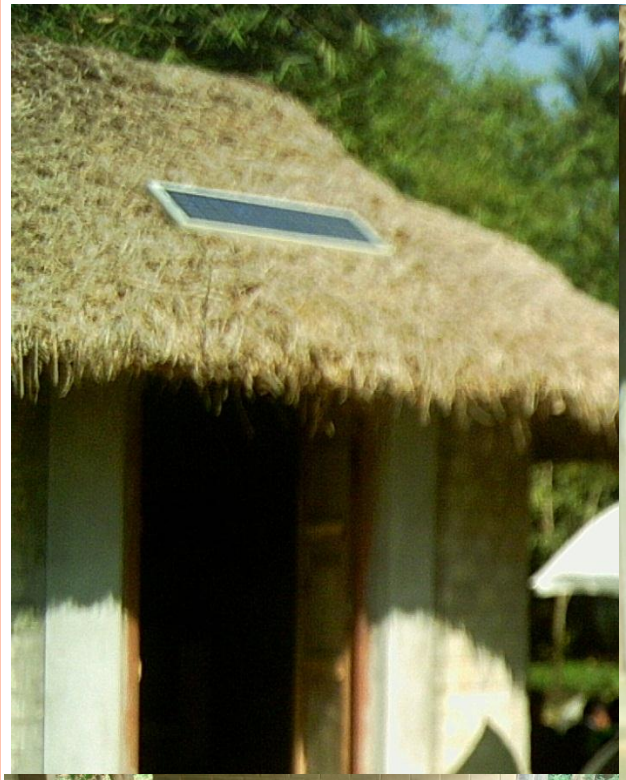
ADIRE/SHAMA
ADIVIDYA MANDIR SCHOOL



Solar water pumping during building construction

LEARNING

Adividya School -Mid day Meal from Bio-Cafe

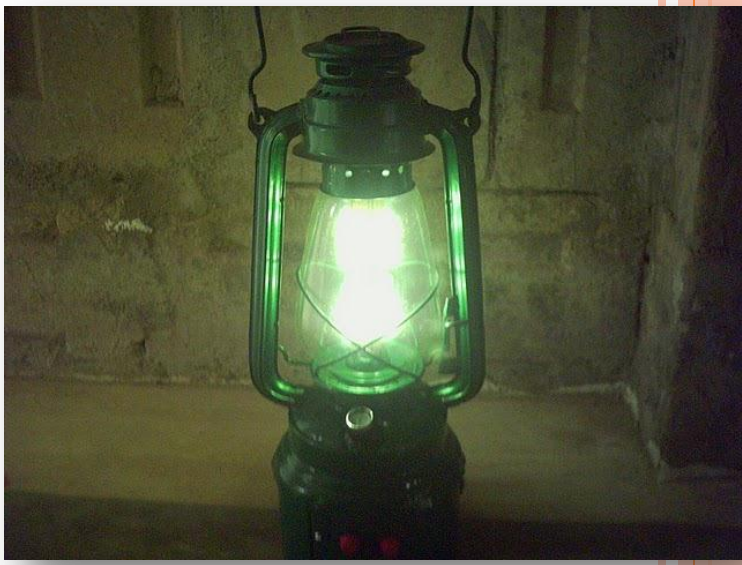


Adult Education

Adividya School kids teaching their parents

Educating parents through street plays

PRODUCTION



Energy Workshop – Solar & LED applications

Production

CSEB Brick making
(Compressed Stabilized Earth Block)

Production

Buildings with CSEB Bricks

Production

Solar water pumping removes drudgery of water lifting

ADIRE-SKILL-HELP

- HELP alone is not sustainable on its own

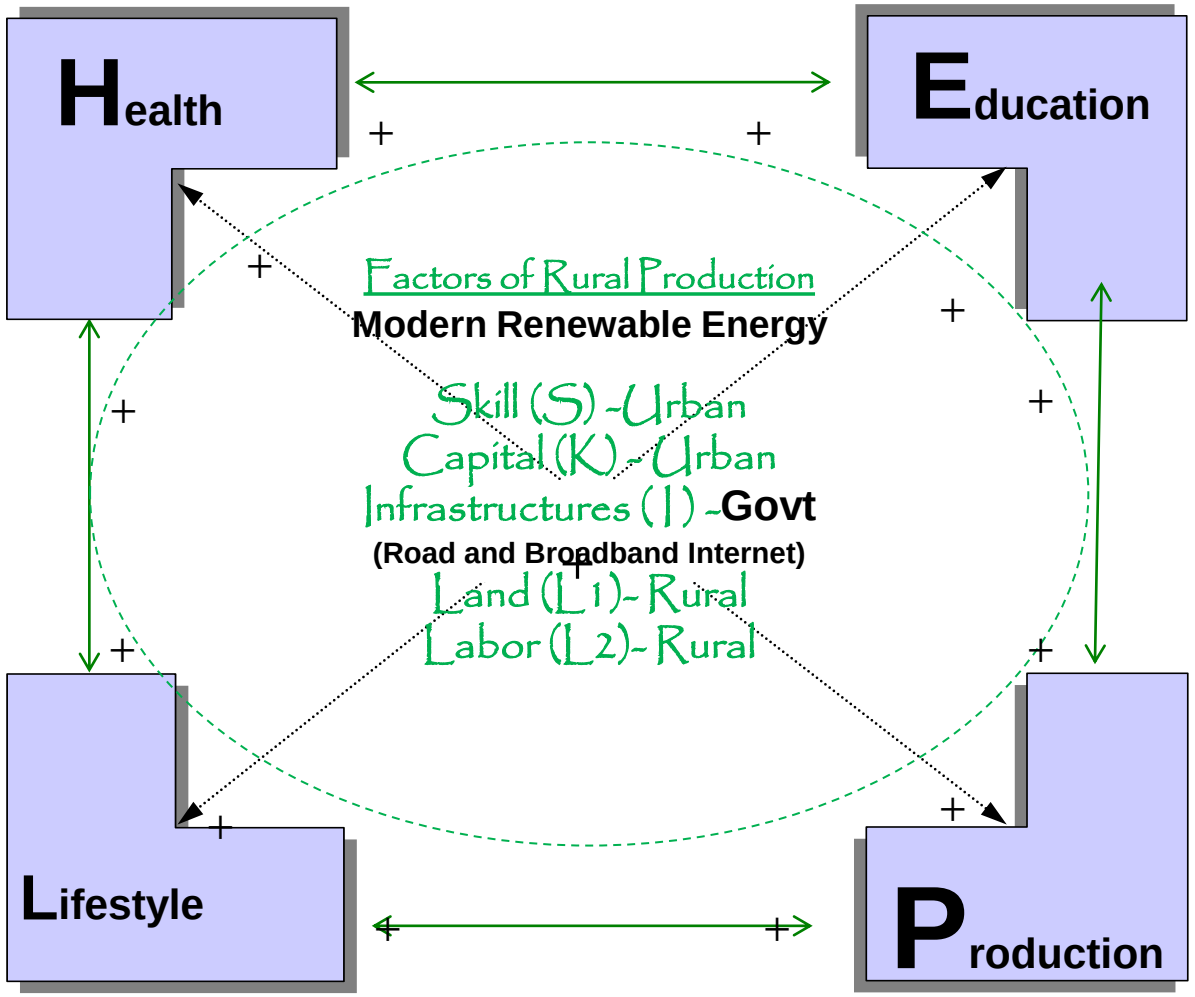
  We need their commercial sustainability

  we do not have to provide money year after year.

- Next stage now is to provide SKILL

  they build clean developed villages ground up.

Next Phase ADIRE-SKILL-HELP



How do We HELP Transition?

NOT THROUGH MIGRATION (Conventional)

- Rural people will not migrate to resource intensive *overburdened* cities
- Too much pollution and emission
  - 3-10 Ton CO_2 per capita emission
  - My family owe @30$/Ton = $300-$1200/year
- Not really a solution
  - Rural Indian Population is more than *twice* the size of entire USA

MODERNIZED VILLAGES (Alternative)

- Information, Communication, Clean Energy Technologies (ICET)
- We are building solar electrician, teachers, plumbers, accountant, managers, computer operators, drivers, mason
- Transition to Off-grid Solar/Biomass/Biogas)
- No CO, CO2, SO2, NOx, Mercury; Hence less Cancer, Asthma, Birth defects,…
- Way to go!!!

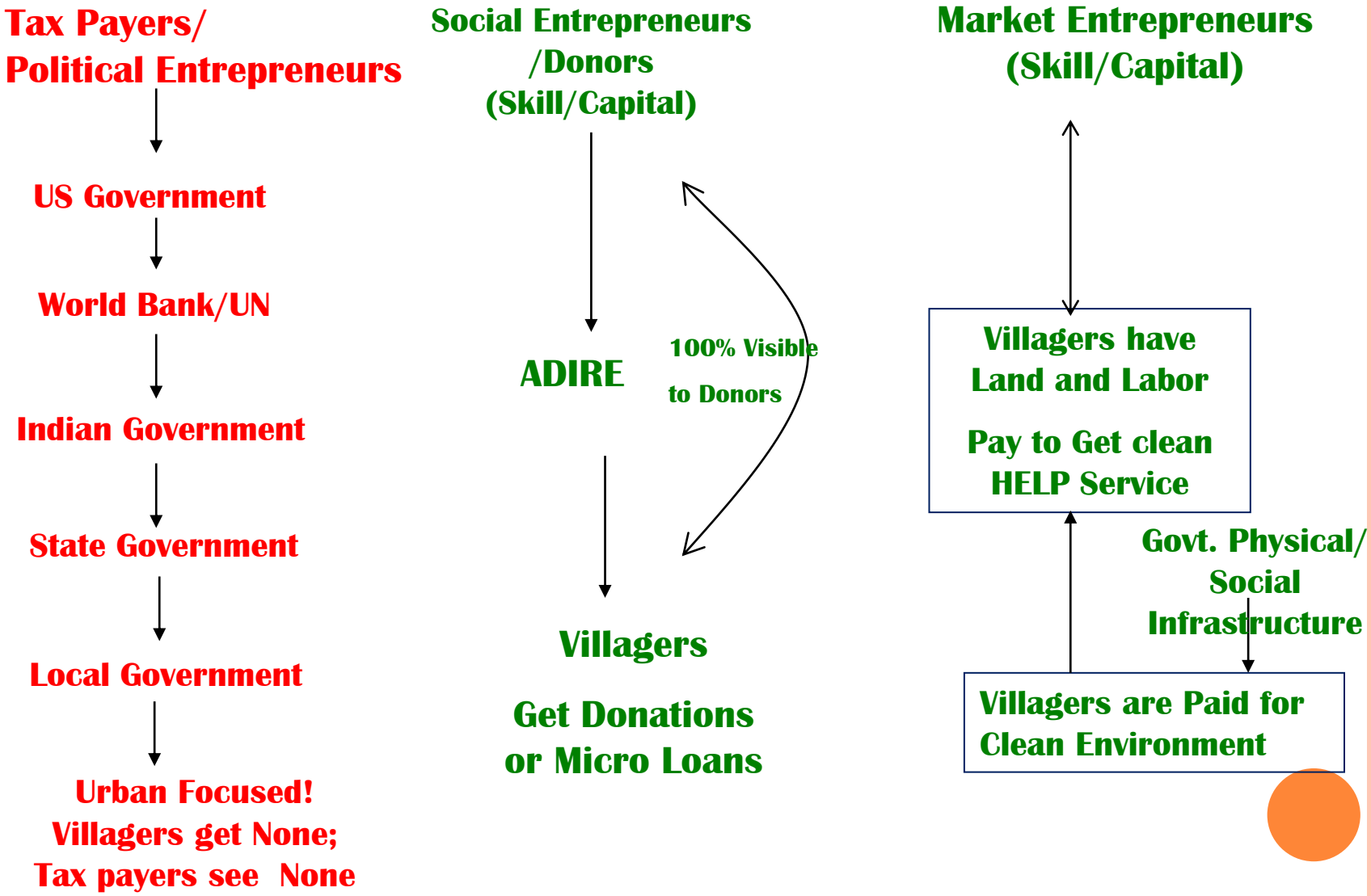
The Projects to Achieve RE-SKILL:

- **Green Transportation**
- **Solar Water Pumping**
- **Organic Farming**
- **Bio café feeding school and community workers**

All will be fueled by the energy from sun, trees, cows, and voluntary muscle power available in the village

Three Methods of Market Funding			Method 1		Method 2		Method 3	
			Current rural-grid subsidies as loan for off-grid energy		Emission Tax (ET) on each MWh for rural HELP		International Carbon Credit can RE-SKILL	
R1	Data description	Units	Rural poor	Future expectation	Low ET	High ET	Low CC	High CC
	Energy data to be used							
1	Peak grid capacity investment	kW/family	0.5	1.5				
2	Monthly consumption	kWh/family	30	100				
3	Fossil electricity produced	billion kWh			700	700		
4	Carbon saved by off-grid homes	MT /capita					3	10
	Price data							
5	Capacity charges	$/kW/month	8	8				
6	Energy charges	c/kWh	18	18				
7	Emission tax /cross subsidies	c/kWh			1	4		
8	Emission credit for carbon	$/MT					10	40
	Population data							
9	Number of off-grid households	million	80	80	80	80		
10	Number of members 4/family	million					320	320
11	Source and disbursement							
12	Revenue available	$ billion			7	28	9.6	128
13	Payment per family	$/Year			88	350	120	1,600

Alternative Development Channels



Future Work:

- Is Renewables-Grid Better for than Off-grid Renewables? Add non-SPV/Wind/Biomass
  - Add Costs of Transmission/Ancillary services
  - Add Costs of lack of reliability, scarcity, battery back up during peak shortage
- Can Poor Villages Help Solve Global Warming
  - How much CO2 will be saved?
  - How can they be rewarded?
- How Grid Subsidies/Taxes can be channeled for Clean Sustainable Development

QUESTIONS?

THANK YOU

Demography and Lifestyle

- Population 417
- Households 100 (Income < 100$/m)
  4 (Income > 200$/m)

- Farm Earners 87 (21%) 135 Acres
- Cash Earners 48 (12%) Jobs/Business

- Toilets 30 +30 from 2003
- Water Pump 10 +10 from 2003

- Energy in households
  - Wood/ Dung All 80Kg Non-commercial
  - Kerosene All 3 liters Subsidized
  - Electricity 40 from 1970 Subsidized
  - LPG 6 from 1995 Subsidized
  - **Biogas 10 from 2003 Unsubsidized economically**
  - **Solar Lantern 22 from 2003 Unsubsidized financially**
  - **LEDs 20 from 2005 Low cost multi task**

Energy Use in JABA village

	Quantity/ month	Price per unit In cents	Total spending In $	% Income spent
Electricity	70 kWh	3	2.1	2.1%
Biomass	80 kg	2	1.6	1.6%
Cattle dung	300 kg	0	0	0
Kerosene	3 liters	22	0.66	0.66%