PROVIDING ELECTRICITY ACCESS TO REMOTE AREAS IN INDIA – GRID EXTENSION VS. RENEWABLE ENERGY BASED DECENTRALIZED POWER OPTIONS

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Outline of Presentation

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Section-III	**Micro hydro projects for decentralized electricity supply**
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Contd.

Outline of the presentation (contd.)

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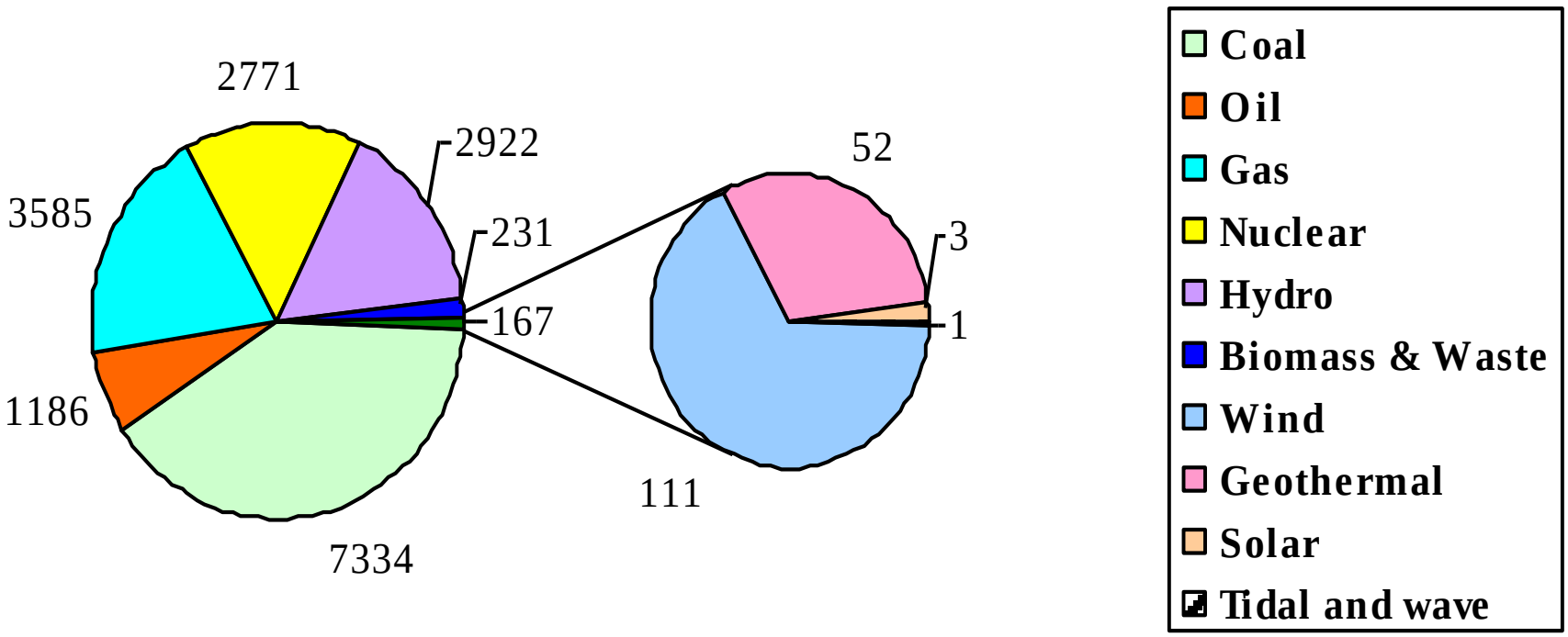
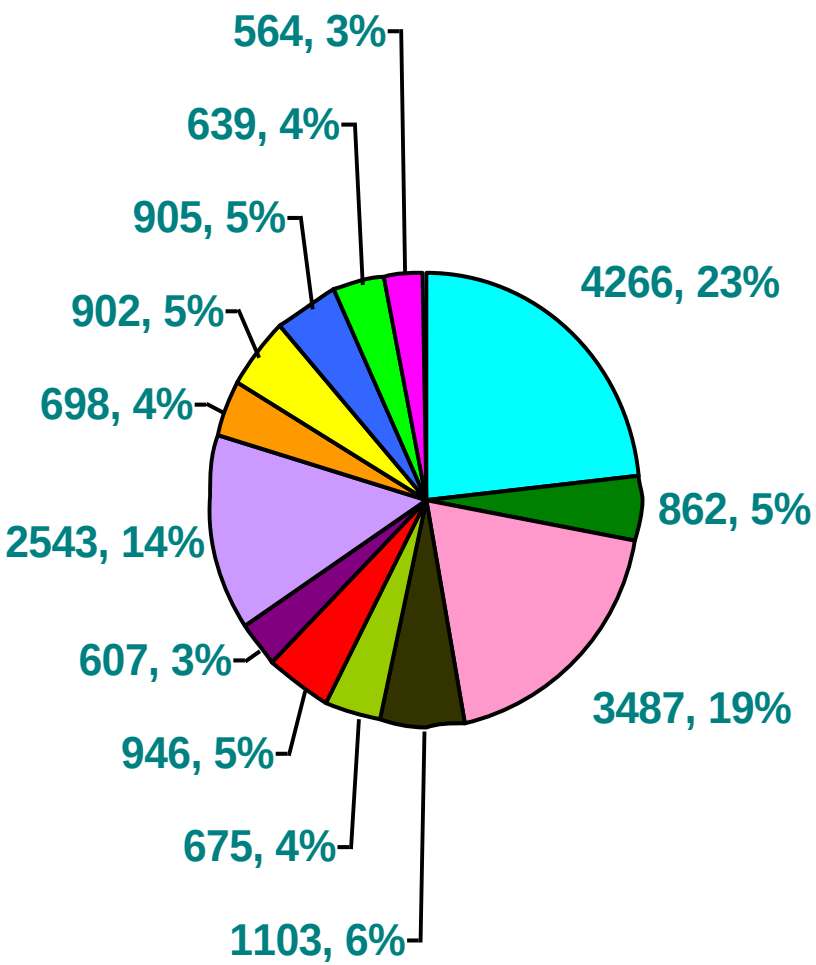
Introduction of Power Generation Scenario, Access to Electricity and Renewable Energy Technologies for Decentralized Power Generation

Energy source wise global electricity generation during 2005 (TWh)



Region wise generation of electricity in TWh during 2005

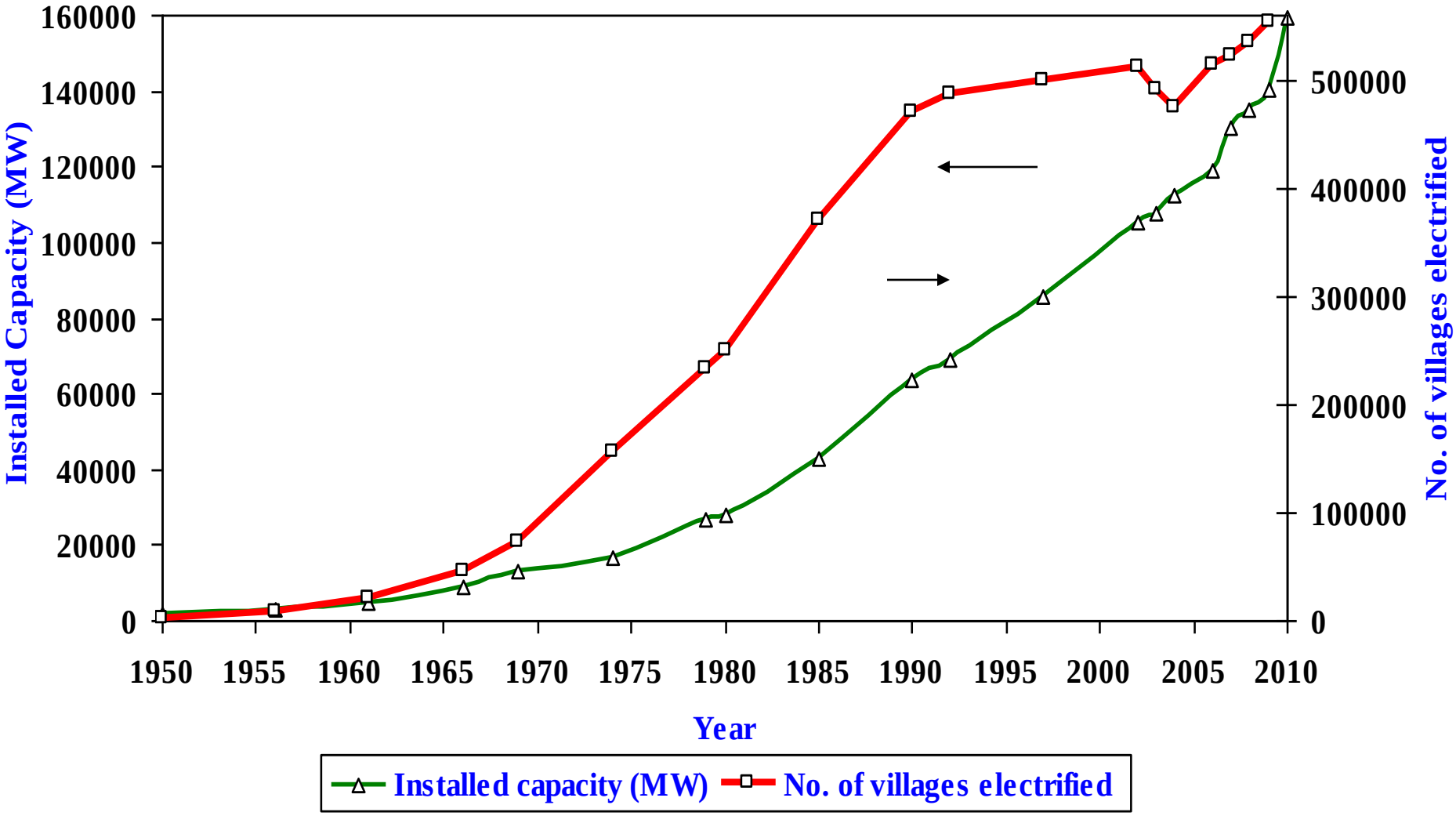


Countries with large population without access to electricity in the year 2008

Country	Total Population (million)	Population without access to electricity (million)	Electrification rate (%)	% of total world population without access to electricity
India	1139.44	404.50	64.50	27.78
Bangladesh	160.85	94.90	41.00	6.52
Indonesia	228.45	81.10	64.50	5.57
Nigeria	151.50	80.60	46.80	5.54
Pakistan	163.72	70.40	57.00	4.84
Ethiopia	81.11	68.70	15.30	4.72
D.R. of Congo	64.12	57.00	11.10	3.91
Myanmar	49.20	42.80	13.00	2.94
Tanzania	41.69	36.90	11.50	2.53
Kenya	38.59	32.80	15.00	2.25
Uganda	31.98	29.10	9.00	2.00
Sudan	39.36	27.00	31.40	1.85
Afghanistan	27.22	23.30	14.40	1.60
Mozambique	21.86	19.30	11.70	1.33
DPR Of Korea	23.92	17.70	26.00	1.22
Madagascar	20.25	16.40	19.00	1.13
Nepal	28.55	16.10	43.60	1.11
Yemen	22.98	14.20	38.20	0.98
Burkina Faso	15.33	13.80	10.00	0.95
Malawi	14.29	13.00	9.00	0.89
Total World	6678.90	1456.0	78.20	21.80

IEA – World Energy Outlook 2009

Growth of power sector and village electrification in India



Growth of power sector and village electrification in India

- **Electrification main infrastructural requirement for agriculture, industrial development and employment generation**
- **Power generating capacity : ~ 1,67,077 MW (as on 30.11.2010)**
  (Thermal-1,08,362 MW; Nuclear-4,560 MW; Hydro-37,367MW & Renewable-16,787 MW)
- **Total villages : 6,27,662**
- **Inhabited villages : 5,87,258 as per 1991 census (5,93,732 as per 2001 census)**
- **Villages having access to electricity : 5,08,992 as on 31.10.2010**
- **On an average, about 2300-2700 villages were electrified annually during the period 1990-2005. The pace picked up after 2005.**
- **Distance from existing grid, low peak load and poor load factors mainly responsible for slow rate of electrification of remote villages**

Why decentralized electricity generation?

- In the context of power supply mostly remote and inaccessible areas/villages in hilly, forest, island and desert areas are difficult to electrify

- Remote areas/villages can be characterised by:
  - Distance from the existing grid
  - Number of households in village
  - Electricity requirement for agriculture, industrial and commercial activities
  - Peak load
  - Load pattern
  - Load Factor

- Grid extension to remote villages not viable due to high cost of electricity transmission and distribution

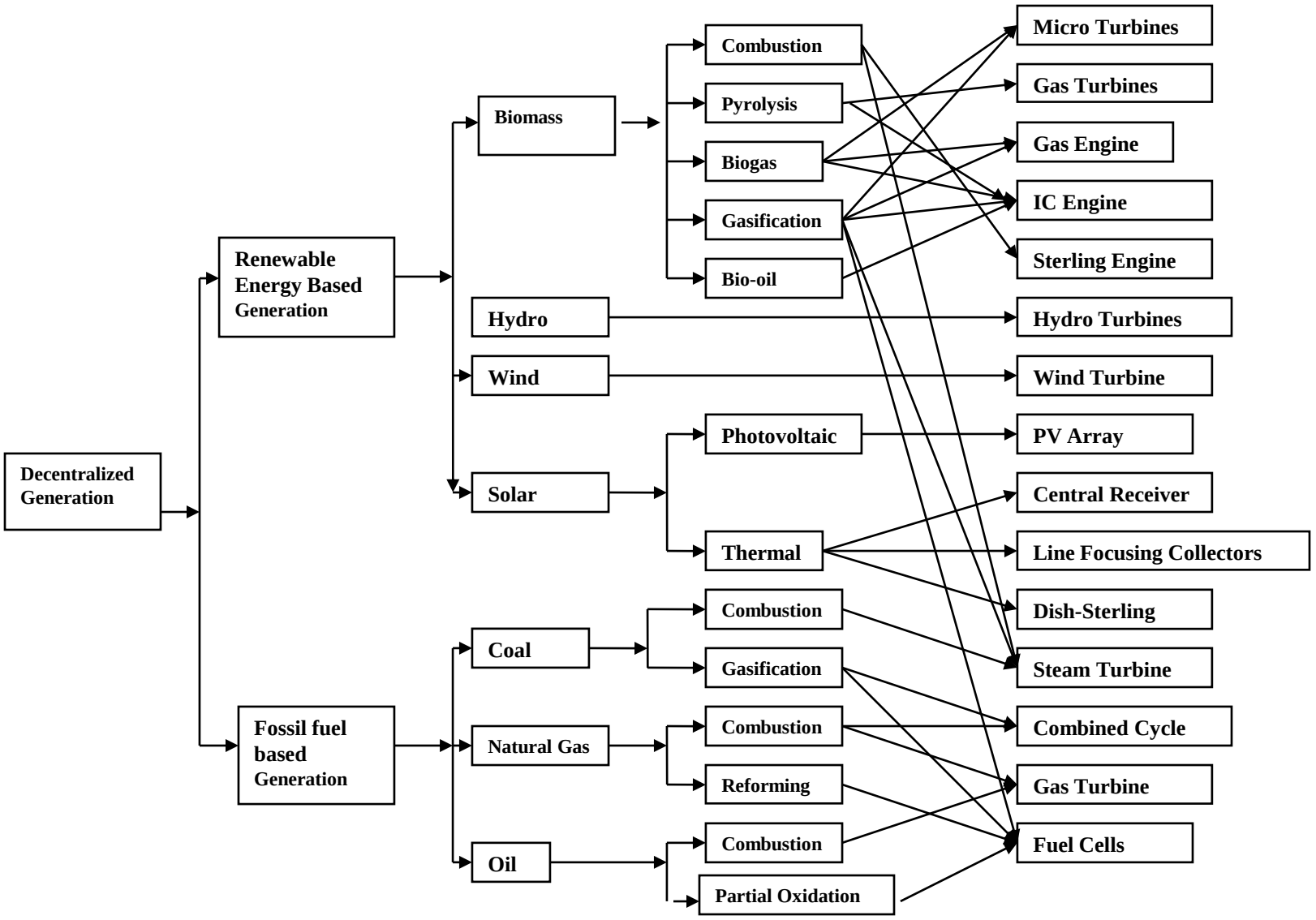
Why renewable energy options for decentralized electricity?

- Harnesses locally available resources
- India has a large renewable energy programme for decentralized as well as grid connected systems
- Grid interactive renewable power generating capacity of 17,174 MW & 420 MW off-grid capacity installed (as on 30.6.2010)
- 6867 remote villages and hamlets provided electricity through renewables as on 30.6.2010
- Generally modular and supply of electricity can be augmented depending on increase in demand

Power generating capacity based on renewables

Sl. No.	Type of power generation	Capacity installed (MW)
A. Grid interactive power based on renewables		
1.	Bagasse co-generation	1411.53
2.	Biomass power (agro-residue)	901.10
3.	Power from wastes	72.46
4.	Small hydro power (up to 25 MW)	2767.05
5.	Solar power	12.28
6.	Wind power	12009.48
B. Decentralized power based on renewables		
7.	Biomass gasifiers	125.44
8.	Biomass power /Co-gen (non-bagasse)	238.17
9.	Power from wastes	52.72
10.	Photovoltaic power plants	2.92
11.	Small wind electric generators and wind-PV systems	1.07
Total		17,594.22

Resource – Technology combinations for decentralized electricity generation



Status of village electrification in India as on 31.1.2010

Name of State/UT	No. of inhabited villages as per 2001 census	Total No. of electrified villages	Un-electrified villages	% of electrified villages
Andhra Pradesh	26,613	26,613	0	100.00
Arunachal Pradesh	3,863	2,195	1,668	56.82
Assam	25,124	19,741	5,383	78.57
Bihar	39,015	23,914	15,101	61.29
Delhi	158	158	0	100.00
Jharkhand	29,354	9,119	20,235	31.07
Goa	347	347	0	100.00
Gujrat	18,066	18,015	51	99.72
Haryana	6,764	6,764	0	100.00
Himachal Pradesh	17,495	17,183	312	98.22
Jammu & Kashmir	6,417	6,304	113	98.24
Karnatka	27,481	27,458	23	99.92
Kerala	1,364	1,364	0	100.00
Madhya Pradesh	5,2117	50,231	1,886	96.37
Chattishgarh	19,744	18,877	867	95.61
Maharastra	41,095	36,296	4,799	88.32
Manipur	2,315	1,989	326	85.92
Meghalaya	5,782	3,428	2,354	59.29
Mizoram	707	570	137	80.62
Nagaland	1,278	823	455	64.40
Orissa	47,529	29,735	17,794	62.56
Punjab	12,278	12,278	0	100.00
Rajasthan	39,753	28,018	11,735	69.90
Sikkim	450	425	25	94.44
Tamil Nadu	15,400	15,400	0	100.00
Tripura	858	491	367	57.23
Uttar Pradesh	97,942	86,450	11,492	88.27
Uttranchal	15,761	15,213	548	96.52
West Bengal	37,945	37,755	190	99.50
Total States	593,015	496,823	96,192	83.78
Total UTs	717	552	165	76.99
All India	593,732	497,157	95,858	83.80

Status of households having access to electricity in India

Name of State/UT	Rural Areas		Urban Areas	
	No. of Household (in '000)	% of households having access to electricity	No. of Household (in '000)	% of households having access to electricity
Andhra Pradesh	137707000	84.0	47318000	94.9
Arunachal Pradesh	1582000	59.1	264000	95.7
Assam	44428000	30.3	6061000	86.2
Bihar	126734000	10.1	13775000	73.8
Delhi	2025000	100	26739000	98.9
Jharkhand	39297000	26.0	8446000	87.1
Goa	1543000	99.9	892000	97.9
Gujrat	65950000	80.2	35445000	95.8
Haryana	30954000	89.7	12953000	95.5
Himachal Pradesh	11934000	97.6	1884000	87.7
Jammu & Kashmir	8961000	97.3	3427000	97.1
Karnatka	72557000	86.2	36195000	95.9
Kerala	54738000	79.4	17458000	93.0
Madhya Pradesh	87996000	69.2	27830000	96.4
Chattishgarh	36435000	61.9	7333000	93.2
Maharastra	119552000	76.2	84860000	95.7
Manipur	2862000	87.3	976000	95.1
Meghalaya	3707000	51.3	640000	98.5
Mizoram	835000	85.4	571000	99.7
Nagaland	1061000	97.4	488000	99.4
Orissa	67821000	31.5	11486000	81.3
Punjab	30936000	95.5	17078000	97.8
Rajasthan	78694000	47.2	25809000	89.5
Sikkim	1026000	94.1	166000	99.0
Tamil Nadu	91609000	84.6	59167	94.6
Tripura	6273000	69.1	1146000	91.7
Uttar Pradesh	232575000	24.0	63942000	84.4
Uttranchal	12598000	67.3	4428000	94.3
West Bengal	126886000	34.2	48819000	87.3
Total UTs	2320000	89.0	3943000	98.0
All India	1501596000	55.0	510431167	92.0

Need for Techno-Economic Evaluation

- **Renewable energy options for electricity supply have limitations compared to grid extension on account of:**
  - **- High capital cost**
  - **- Intermittent nature of resource**
  - **- Mismatch between generation and demand**
  - **- Need for storage**

- **In this presentation financial viability of renewable energy options is compared with grid extension and other options like DG set**

SECTION-II

Grid Extension Option for Power Supply in Remote Areas

Cost of delivered electricity

- **Cost of delivered electricity at point of consumption comprises of three components**

  - **Generation component**
    - **Thermal electricity**
    - **Hydroelectricity**
    - **Nuclear electricity**
    - **Electricity from grid connected renewables**

  - **Transmission component**

  - **Distribution component**

Capital investment for pit head thermal power plants

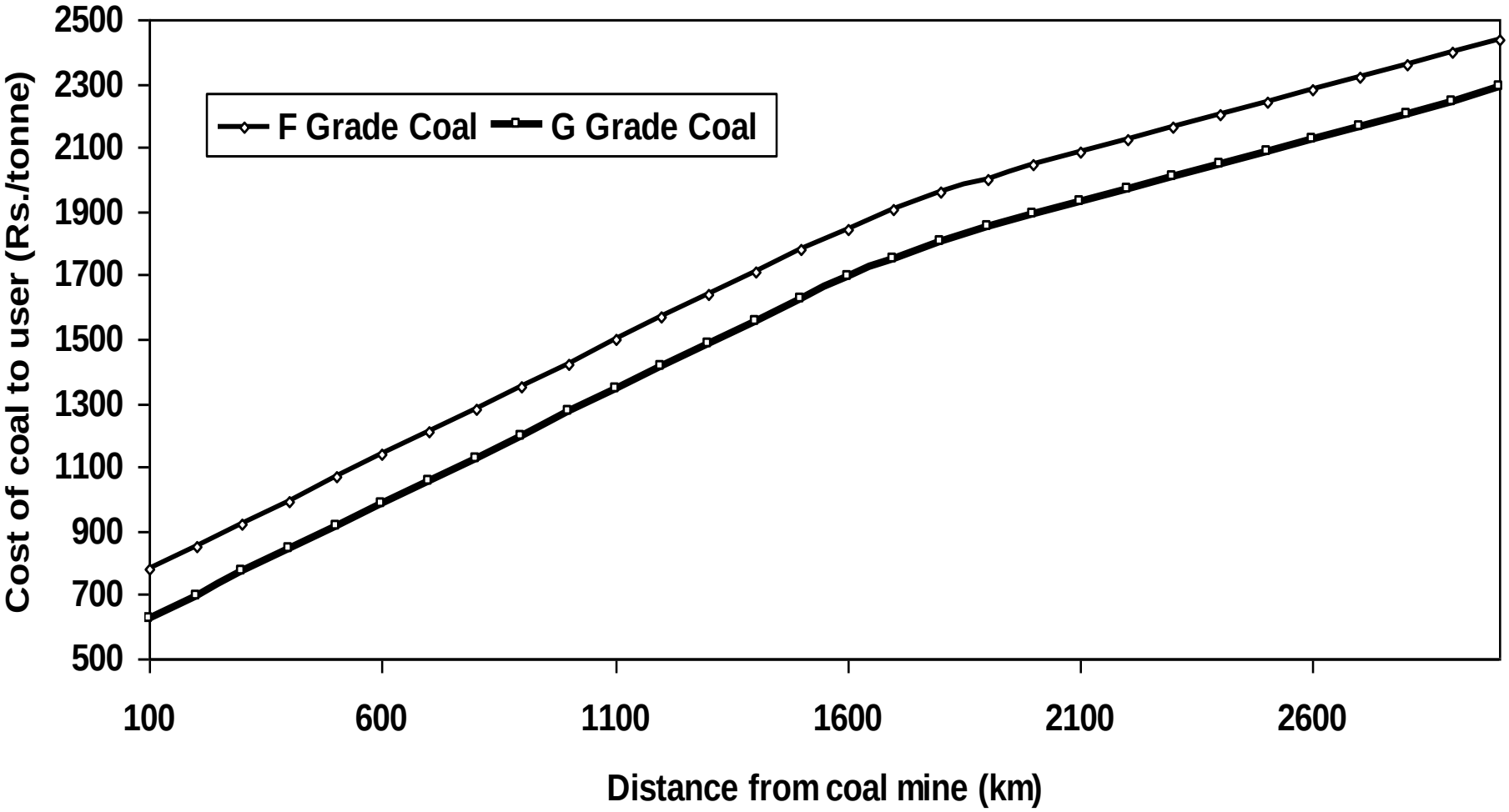
Name of Project	Capacity (MW)	Commercial Operation	Approved Cost (Rs. Cr.)	Cost/MW (Rs. Cr.)
Simhadri	1000	Nov. 02 & March 03	3650.79	3.65
Rihand Stage II	1000	2004-05	4049.49	4.05
Vindhyachal Stage III	1000	2006-07	4201.5	4.20
Ramagundam Stage III	500	2004-05	1818.46	3.64
Unchahar	210	2006-07	939.28	4.47
Sipat St-I	1980	2007-08, 2008-09	8323.39	4.20
Sipat St-II	1000	2007-08	4039.64	4.04

Cost of thermal electricity generation at pit head

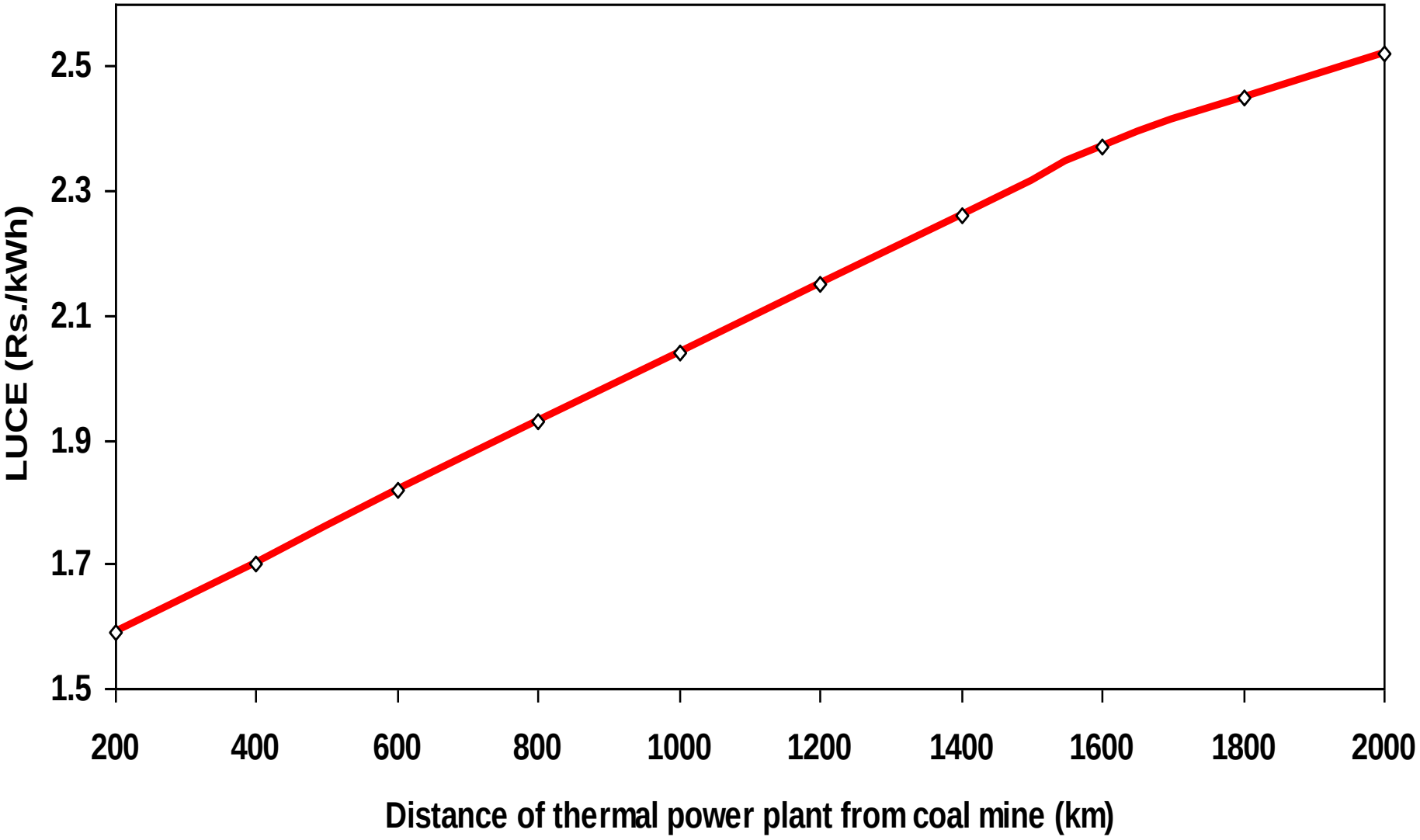
COST OF GENERATION FROM SIMHADRI 2 X 500 MW THERMAL PROJECT OF NTPC

SIZE OF PLANT CONSIDERED (kW)	1000
ESTIMATED CAPITAL COST (Rs.)	36500000
O&M COST AS FRACTION OF CAPITAL COST	0.04
AVERAGE COST OF FUEL OIL AT POWER PLANT (Rs./kL)	12916.97
GROSS STATION HEAT RATE (kCal/kwh)	2500
AVERAGE COST OF COAL AT POWER PLANT (Rs./Tonne)	1060.24
AVERAGE FUEL OIL CONSUMTION (ml/kWh)	3.5
CALORIFIC VALUE OF FUEL OIL (kCal/l)	9787
HEAT SUPPLIED BY OIL (kCal)	34.25
AVERAGE CALORIFIC VALUE OF GRADE G COAL (kCal/kg)	3508
HEAT TO BE SUPPLIED BY COAL (kCal)	2465.75
AVERAGE COAL CONSUMPTION (kg/kWh)	0.70
PLANT LOAD FACTOR	0.7482
AUXILIARY POWER CONSUMPTION (FRACTION OF GENERATION)	0.0882
AVERAGE COST OF GENERATION (Rs./kWh)	
DISCOUNT RATE	0.1
LIFE OF POWER PLANT (YEARS)	30
CRF	0.106079248
GENERATION FROM POWER PLANT (kWh)	6554232
AUXILIARY CONSUMPTION (kWh)	578083.2624
GENERATION AT BUS BAR (kWh)	5976149
ANNUAL CAPITAL COST (Rs.)	3871893
ANNUAL COAL COST (Rs.)	4884439
ANNUAL OIL COST (Rs.)	26135
O&M COST (Rs.)	1460000
TOTAL ANNUAL COST (Rs.)	10242466
UNIT COST OF GENERATION (Rs,/kWh)	1.71

Cost of delivered coal to load centre thermal power plants



Levelised unit cost of electricity from load centre thermal power plants



Cost of generation of hydroelectricity

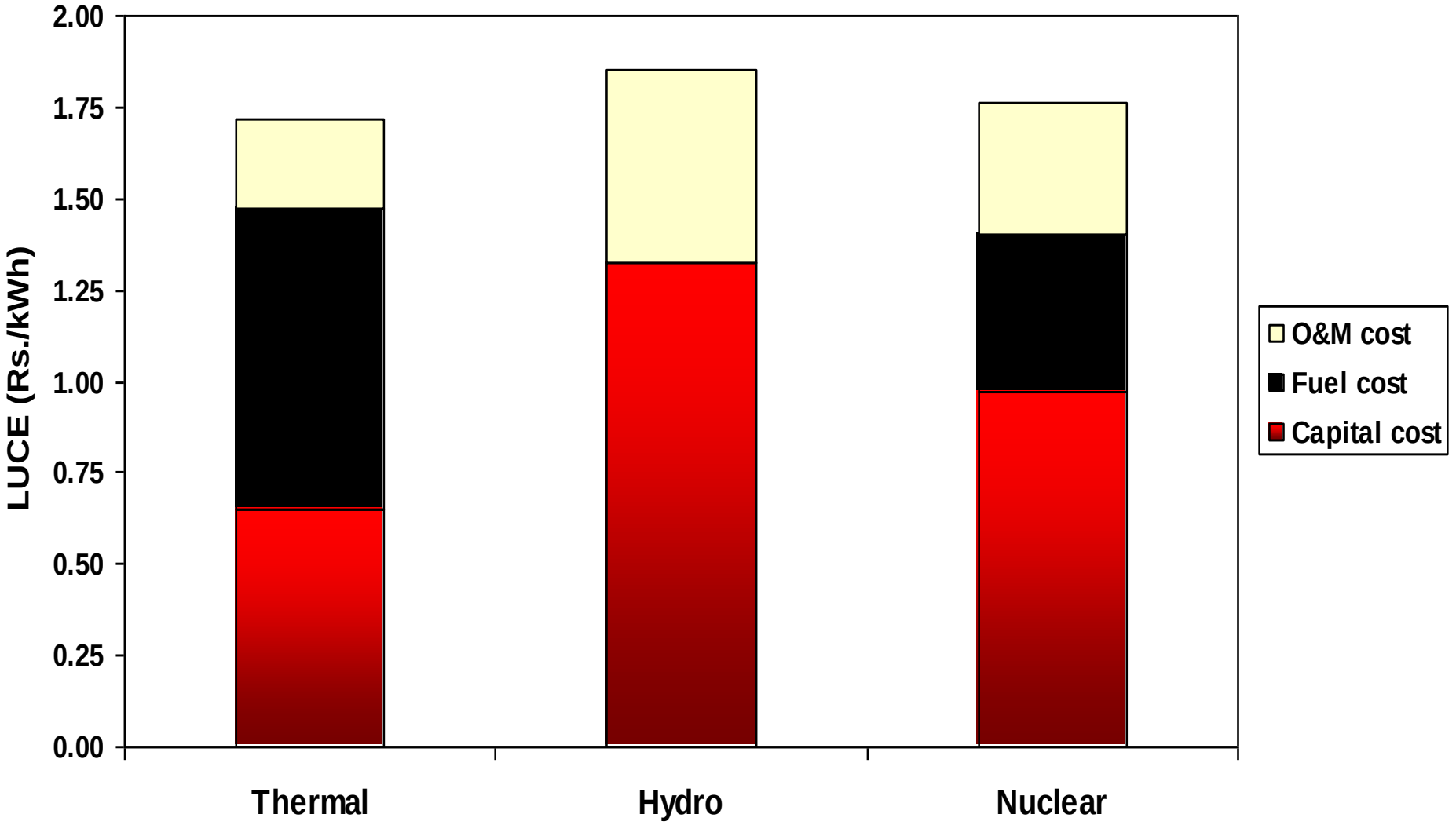
UNIT COST OF GENERATING ELECTRICITY FROM CHAMERA II HYDRO-ELECTRIC POWER PLANT (3 X 100 MW)

COMMISSIONING (MONTH/YEAR)	November 2003 to March 2004
APPROVED COST (Rs. Crores)	1956.06
AVERAGE O&M COST AS FRACTION OF CAPITAL COST	0.04
PLANT LOAD FACTOR (FRACTION)	0.57
CAPITAL COST/MW	6.5202
DISCOUNT RATE	0.1
LIFE OF POWER PLANT (YEARS)	50
CRF	0.100859174
ANNUAL CAPITAL COST (Rs.)	6576219
O&M COST (Rs.)	2608080
TOTAL ANNUAL COST (Rs.)	9184299
AUXILIARY POWER CONSUMPTION (FRACTION OF GENERATION)	0.0053
NET ELECTRICITY GENERATION (kWh)	4966736
UNIT COST OF GENERATION (Rs,/kWh)	1.84

Cost of electricity generation from nuclear plants

UNIT COST OF ELECTRICITY GENERATION FROM NUCLEAR POWER PLANT		
UNIT SIZE (MW)	220	500
SIZE OF PLANT CONSIDERED (kW)	1000	1000
ESTIMATED COST (Rs./MW)	65000000	52300000
PLANT LOAD FACTOR (FRACTION)	0.738	0.738
AUXILIARY POWER CONSUMPTION (FRACTION OF GENERATION)	0.1136	0.1136
DISCOUNT RATE	0.1	0.1
LIFE OF POWER PLANT (YEARS)	30	30
CRF	0.1060792	0.106079
GENERATION FROM POWER PLANT (kWh)	6464880	6464880
AUXILIARY CONSUMPTION (kWh)	734410.37	734410.4
NET GENERATION (kWh)	5730469.6	5730470
ANNUAL CAPITAL COST (Rs.)	6895151.1	5547945
ANNUAL FUEL AND O&M COST AS FRACTION OF CAPITAL COST	0.82	0.82
ANNUAL FUEL AND O&M COST	5654023.9	4549315
TOTAL ANNUAL COST (Rs.)	12549175	10097259
UNIT COST OF GENERATION (Rs,/kWh)	2.19	1.76

Comparison of LUCE for thermal hydro and nuclear electricity



Electricity transmission network

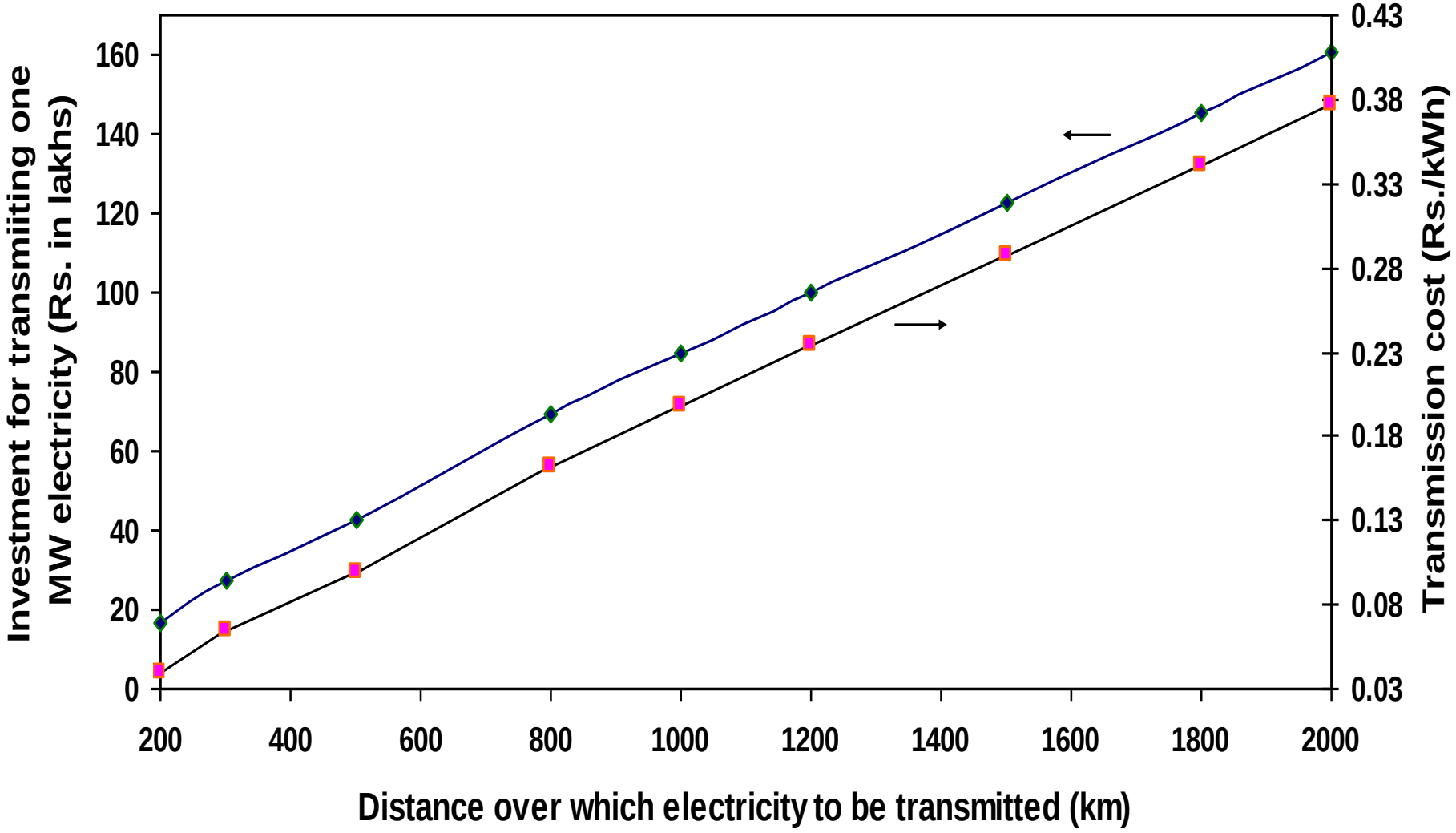
- **Extensive network for transmission of electricity exists but needs to be augmented with growth of power sector**

- **Depending on the quantum of electricity and distance involved, transmission lines of appropriate voltage are laid**
  - **500 kV HVDC**
  - **765 kV**
  - **400 kV**
  - **230/220 kV**
  - **110 kV**
  - **66 kV**

- **Transformers are also required to be set up**

- **Difficult to trace the transmission network used by electricity delivered to distribution network**

Investment requirement and cost of transmitting electricity



Cost details of electricity distribution network

COST DETAILS OF LT DISTRIBUTION			
DISTRIBUTION TRANSFORMERS 11 KV /440 V			
		PRICE	
RATING OF TRANSFORMER(kVA)	Unit	Plain	Hills
5	Rs.	-	33,765
25	Rs.	62,610	73,538
63	Rs.	90,554	1,06,360
100	Rs.	1,05,454	1,23,860
11 kV line with conductors	Rs./km	1,04,954	2,56,452
LT line 3 phase 4 wire with conductors	Rs./km	1,08,485	2,62,430
LT line single phase 2 wire with conductors	Rs./km	1,19,335	2,17,322
Discount rate	0.1		
Life of distribution system	25		
CRF	0.110168072		
Distance of 11 kV line as fraction of distribution network	0.50		
Distance of LT line 3 phase 4 wire as fraction of distribution network	0.25		
Distance of LT line single phase 2 wire as fraction of distribution network	0.25		

Cost of delivered electricity (Plain areas)

Cost of generation at bus bars (Rs./kWh)	:	1.71
T&D losses (%)	:	32.53#
Effective cost of generation (Rs./kWh)	:	2.53
Transmission cost (Rs./kWh)	:	0.50
Cost of electricity at distribution network (Rs./kWh)	:	3.03

Distance from 33 kV line (km)	Peak load (kW)	Delivered cost of electricity (Rs./kWh) with a load factor of					
		0.1	0.2	0.3	0.4	0.6	0.8
5	25	7.49	5.26	4.52	4.15	3.78	3.59
	63	4.89	3.96	3.65	3.50	3.34	3.27
	100	4.23	3.63	3.43	3.33	3.23	3.18
8	25	9.90	6.46	5.32	4.75	4.18	3.89
	63	5.84	4.44	3.97	3.74	3.50	3.38
	100	4.83	3.93	3.63	3.48	3.33	3.26
10	25	11.50	7.27	5.85	5.15	4.44	4.09
	63	6.47	4.75	4.18	3.89	3.61	3.46
	100	5.23	4.13	3.77	3.58	3.40	3.31
12	25	13.10	8.07	6.39	5.55	4.71	4.29
	63	7.11	5.07	4.39	4.05	3.71	3.54
	100	5.63	4.33	3.90	3.68	3.47	3.36
15	25	15.50	9.27	7.19	6.15	5.11	4.59
	63	8.06	5.55	4.71	4.29	3.87	3.66
	100	6.23	4.63	4.10	3.83	3.57	3.43
20	25	19.50	11.27	8.52	7.15	5.78	5.09
	63	9.65	6.34	5.24	4.69	4.14	3.86
	100	7.23	5.13	4.43	4.08	3.73	3.56
25	25	23.50	13.27	9.86	8.15	6.45	5.59
	63	11.24	7.14	5.77	5.09	4.40	4.06
	100	8.23	5.63	4.77	4.33	3.90	3.68

Cost of delivered electricity (Hilly areas)

Cost of generation at bus bars (Rs./kWh)	: 1.71
T&D losses (%)	: 32.53#
Effective cost of generation (Rs./kWh)	: 2.53
Transmission cost (Rs./kWh)	: 0.50
Cost of electricity at distribution network (Rs./kWh)	: 3.03

Distance from 33 kV line (km)	Peak load (kW)	Delivered cost of electricity (Rs. /kWh) with a load factor of					
		0.1	0.2	0.3	0.4	0.6	0.8
5	5	49.64	26.34	18.57	14.69	10.80	8.86
	25	12.65	7.84	6.24	5.44	4.64	4.24
	63	6.94	4.99	4.34	4.01	3.69	3.52
	100	5.53	4.28	3.87	3.66	3.45	3.35
8	5	76.87	39.95	27.65	21.49	15.34	12.26
	25	18.09	10.56	8.05	6.80	5.54	4.92
	63	9.10	6.07	5.06	4.55	4.05	3.79
	100	6.89	4.96	4.32	4.00	3.68	3.52
10	5	95.02	49.03	33.70	26.03	18.37	14.53
	25	21.72	12.38	9.26	7.71	6.15	5.37
	63	10.55	6.79	5.54	4.91	4.29	3.97
	100	7.80	5.42	4.62	4.23	3.83	3.63
12	5	113.17	58.10	39.75	30.57	21.39	16.80
	25	25.35	14.19	10.47	8.61	6.75	5.82
	63	11.99	7.51	6.02	5.27	4.53	4.15
	100	8.71	5.87	4.92	4.45	3.98	3.74
15	5	140.39	71.71	48.82	37.37	25.93	20.20
	25	30.80	16.92	12.29	9.98	7.66	6.50
	63	14.15	8.59	6.74	5.81	4.89	4.42
	100	10.07	6.55	5.38	4.79	4.21	3.91
20	5	185.77	94.40	63.95	48.72	33.49	25.88
	25	39.87	21.45	15.31	12.24	9.17	7.64
	63	17.75	10.39	7.94	6.71	5.49	4.87
	100	12.34	7.69	6.13	5.36	4.58	4.20
25	5	231.14	117.09	79.07	60.06	41.05	31.55
	25	48.95	25.99	18.34	14.51	10.69	8.77
	63	21.35	12.19	9.14	7.61	6.09	5.32
	100	14.60	8.82	6.89	5.93	4.96	4.48

Conclusions emerging from Section-II

- **Cost of delivering electricity through grid extension could be prohibitively high for remote villages / hamlets in hilly areas having low peak loads and poor load factors**

- **Even in plain areas, for small villages with low peak loads and located at about 25 km from the existing grid, cost of delivering electricity mainly for lighting may also be very high**

Section-III

Micro Hydro Power (MHP) Projects for Decentralized Electricity Supply

Micro hydro power plant

MHP projects for decentralized electricity supply

- This case study considered 16 MHP projects (10 - 100 kW) capacity implemented in the states of Arunachal Pradesh and Uttaranchal

- Cost of MHP projects was found in the range of Rs. 124,310 to Rs. 233,335 per kW including the cost of power evacuation and distribution system.

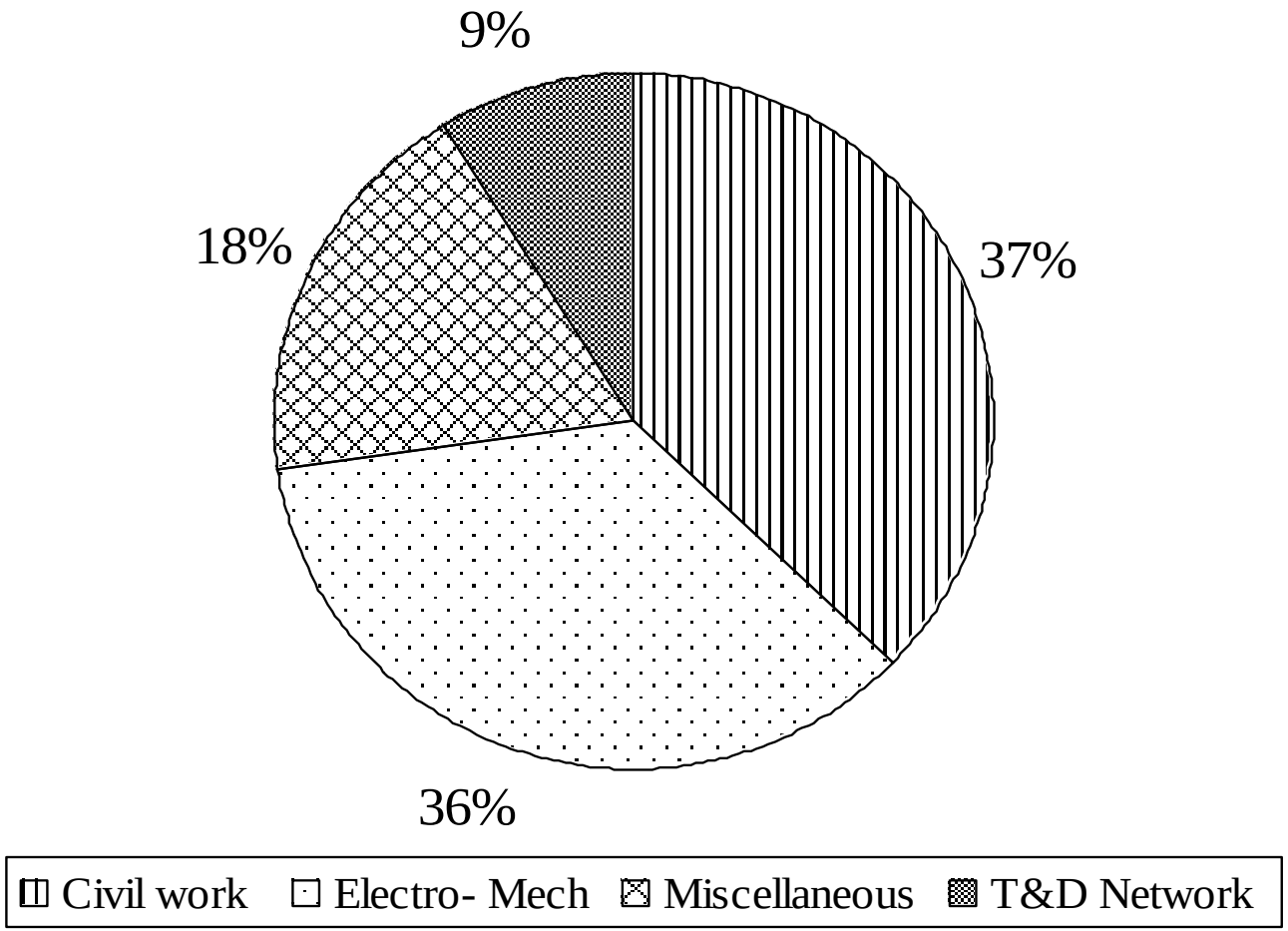
- There was substantial variation in the cost of civil works for the same capacity of MHP project. This may be owing to specific nature of civil work required.

- Cost of T&D network was found to vary considerably for different MHP projects (20 - 100 kW) in Uttarakhand owing to:
  - Need for step-up and step-down transformers
  - Number of benefited villages and distance between villages
  - Dispersed or closely packed nature of households within the village

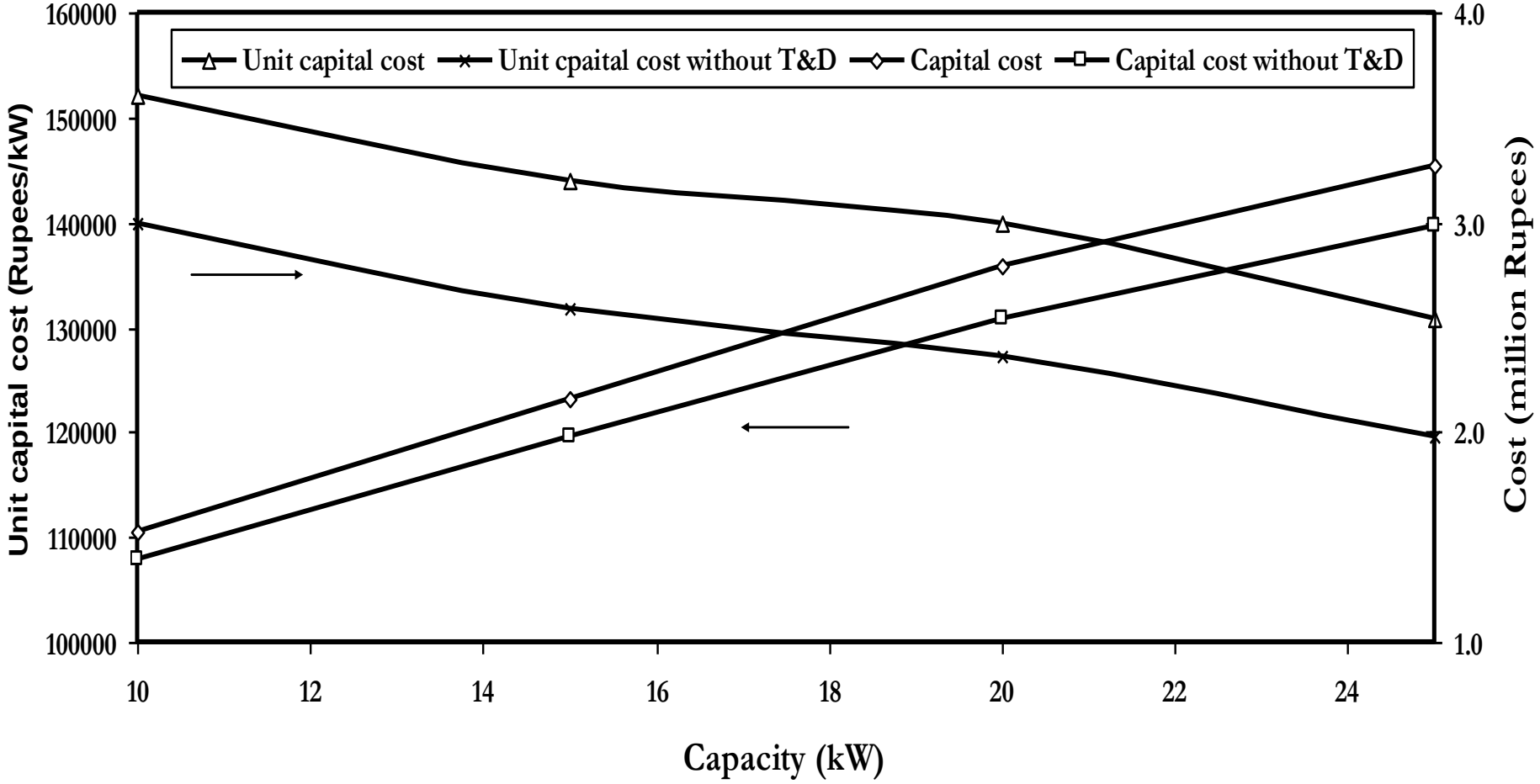
Cost details of MHP Projects

S. No	Name of MHP project	Rated capacity of the project (kW)	Total capital cost of the plant including T&D network (Rs.)	Cost of civil works (Rs.)	Cost of electro-mechanical equipment (Rs.)	Miscella-neous cost (Rs.)	Cost of T&D network (Rs.)	Cost per unit of rated capacity without T&D network (Rs./kW)	Cost per unit of rated capacity with T&D network (Rs./kW)
A :	**Arunachal Pradesh**								
1	Eya	10 (1x10)	1,520,000	450,000	480,000	395,000	120,000	142,000	152,000
2	Kibung	15 (1x15)	2,158,000	847,000	720,000	411,000	180,000	131,867	143,867
3	Poyom	20 (1x20)	2,797,000	1,038,000	1,000,000	509,000	250,000	127,350	139,850
4	Kayi	25 (1x25)	3,268,000	1,225,000	1,120,000	568,000	280,000	119,520	130,720
5	Nikte	30 (2x15)	4,195,800	1,312,500	1,500,000	783,300	375,000	127,360	139,860
6	Siki	40 (2x20)	5,266,000	1,875,000	2,000,000	766,000	500,000	119,150	131,650
B :	**Uttaranchal**								
7	Dokti Gaon	20 (1x20)	4,319,525	1,220,000	785,000	335,535	1,727,000	129,627	215,977
8	Lamchula	50 (2x25)	9,842,000	3,054,000	1,573,000	503,000	4,442,000	108,000	196,840
9	Rotan	50 (2x25)	9,562,000	2,684,000	1,573,000	473,000	4,562,000	100,000	191,240
10	Wan	50 (2x25)	10,389,000	2,608,000	1,600,000	372,000	5,539,000	97,000	207,780
11	Karmi II	50 (2x25)	10,054,101	2,176,891	4,182,750	622,430	2,818,800	144,706	201,082
12	Ratmoli	50 (2x25)	11,666,729	3,851,628	4,182,750	762,071	2,602,800	181,279	233,335
13	Ghes,	100 (2x50)	12,852,000	4,081,000	3,256,000	893,000	4,352,000	85,000	128,520
14	Tarula	100 (2x50)	13,265,000	4,054,000	3,131,000	1,045,000	4,765,000	85,000	132,650
15	Bank	100 (2x50)	12,431,000	3,712,000	3,228,000	790,000	4,431,000	80,000	124,310
16	Kanol Gad	100 (2x50)	19,761,862	9,263,684	7,107,750	920,448	2,106,000	176,559	197,619

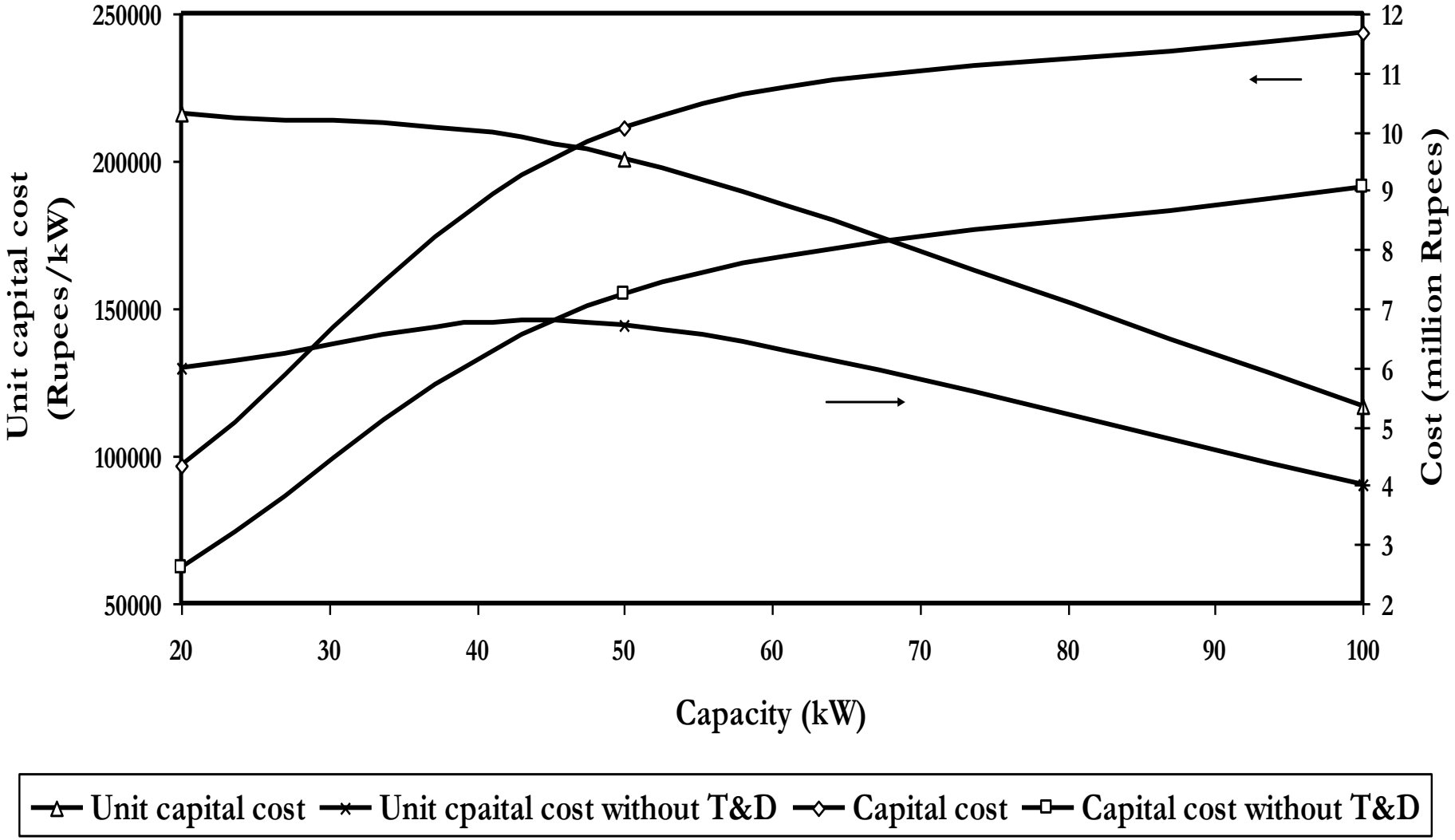
Relative contribution of cost of different sub-systems of a 20 kW MHP project



Variation of capital cost of MHP projects in Arunachal Pradesh



Variation of capital cost of MHP projects in Uttarakhand



Typical loads connected to a MHP project in Uttarakhand

Type of load	Number	Wattage of one load of its type
Domestic		
Number of incandescent lamps per household	3	40
Households having television in rural areas[1]	53	200
Households having radio in rural areas[1]	59	5
Households having electric iron[2]	8	750
Households having resistive heater for cooking[2]	8	1000
Households having resistive water heating system[2]	8	1000
Households having kitchen mixer[2]	8	750
Community		
Number of street lights[3]	84	40
Industrial		
Grain grinder	1	5000

Time variation of the peak load of a typical MHP project in Uttarakhand

Time of operation of the MHP project (hours)	Likely number of loads considered to be in operation							Estimated peak load (kW)
	Domestic lights per household	Television	Radio	Resistive heater for cooking	Resistive heater for water heating	Street lights	Grain grinder	
17 - 18	1	-	59	-	-	-	1	20.8
18 - 19	3	53	59	8	-	84	1	47.8
19 - 20	3	53	59	8	-	84	1	47.8
20 - 21	3	53	59	-	-	84	1	39.4
21 - 22	3	53	59	-	8	84	1	47.8
22 - 23	2	53	59	-	-	84	1	27.7
23 - 24	1	-	-	-	-	84	-	10.1
24 - 1	1	-	-	-	-	84	-	10.1
1 - 2	1	-	-	-	-	84	-	10.1
2 - 3	1	-	-	-	-	84	-	10.1
3 - 4	1	-	-	-	-	84	-	10.1
4 - 5	1	-	-	-	-	84	-	10.1
5 - 6	2	-	-	-	8	84	-	25.2
6 - 7	1	-	59	-	8	-	-	23.8

Estimated PLF for a typical MHP project in Uttarakhand

% of peak load connected to the MHP project	Estimated Plant Load Factor (%)
90	46.1
80	41.0
70	35.9
60	30.8
50	25.6

Measures of financial performance for MHP Project

$$LUCE = \frac{\{(R_{c,mhp} + m_{c,mhp}) * C_{c,mhp} + (R_{e,mhp} + m_{e,mhp}) * C_{e,mhp} + (R_{edn,mhp} + m_{edn,mhp}) * C_{edn,mhp} + R_{b,mhp} * C_{b,mhp} + m_{o,mhp} * C_{o,mhp}\}}{8760 * PLF * P * (1-l)}$$

$$R = \frac{d(1+d)^T}{(1+d)^T - 1}$$

$$DPP = \frac{\ln(B_i - C_i) - \ln[(B_i - C_i) - dC_{o,mhp}]}{\ln(1+d)}$$

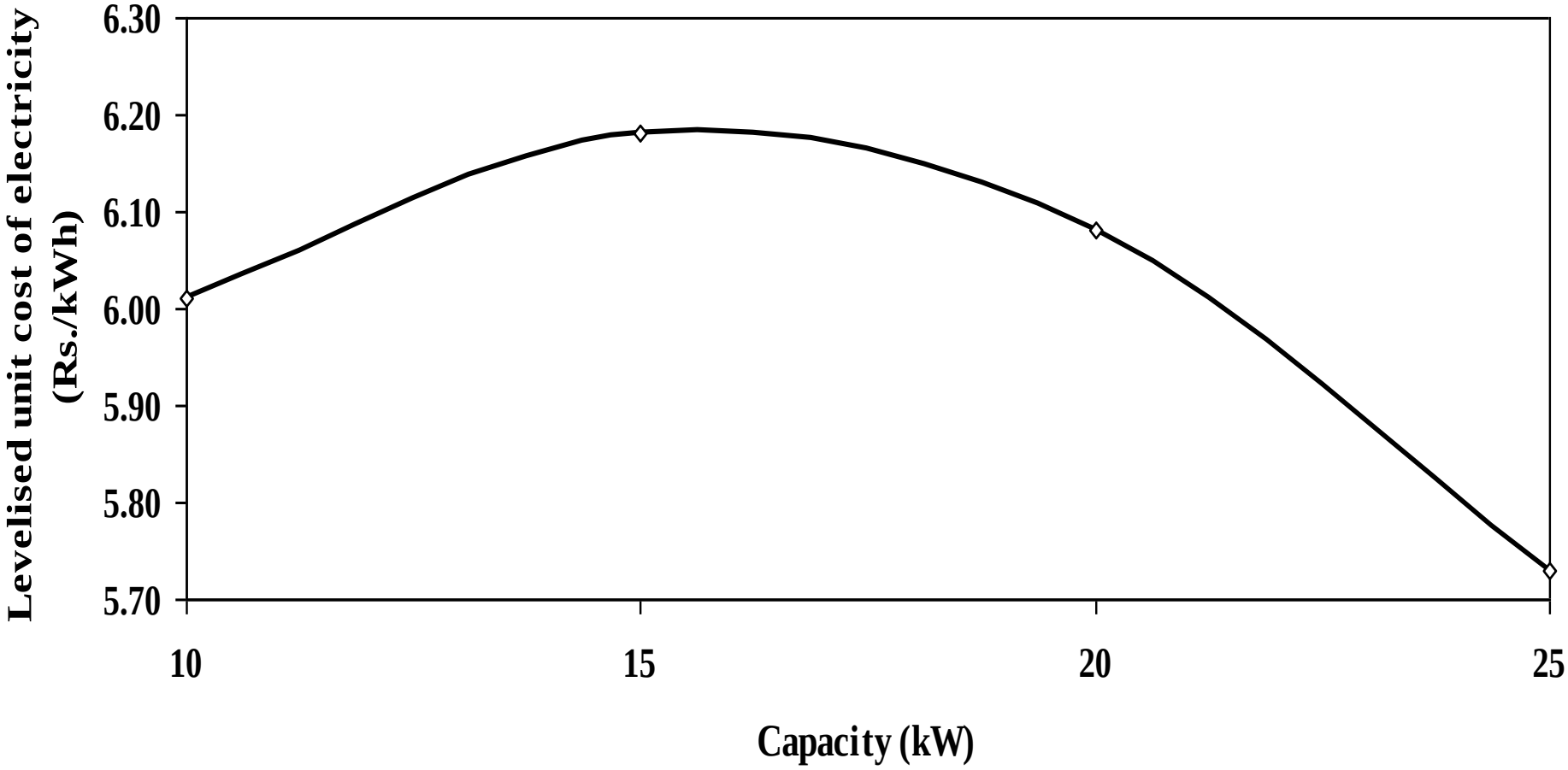
$$B_i = 8760 * p_e * PLF * P$$

$$C_i = m_{o,mhp} * C_{o,mhp} + m_{c,mhp} * C_{c,mhp} + m_{e,mhp} * C_{e,mhp} + m_{edn,mhp} * C_{edn,mhp}$$

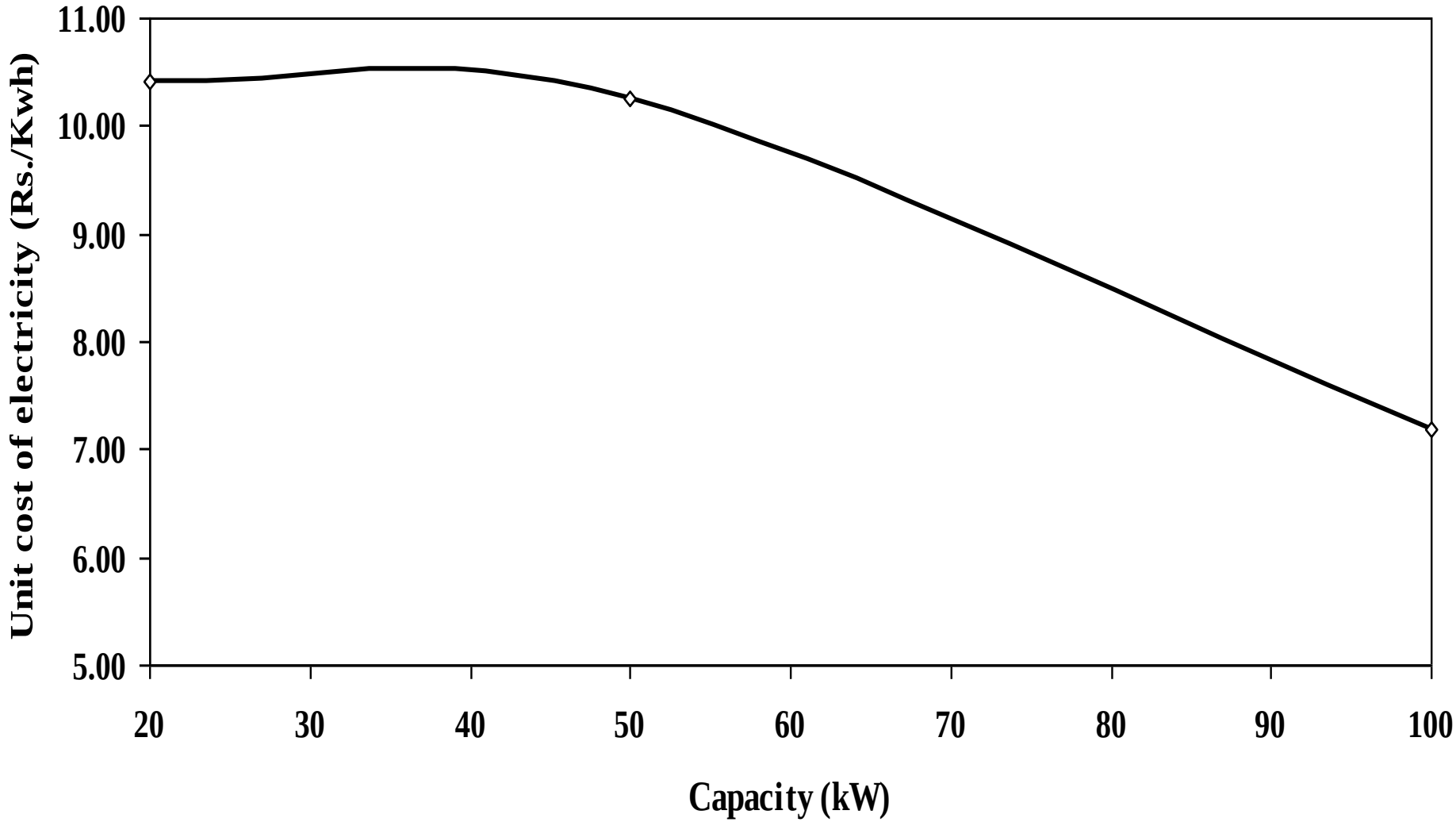
$$NPV = \sum_i^T \frac{B_i - C_i}{(1+d)^i} - C_o$$

$$B/C = \frac{(B-C)\left[\frac{(1+d)^T - 1}{d(1+d)^T}\right]}{C_{o,mhp}}$$

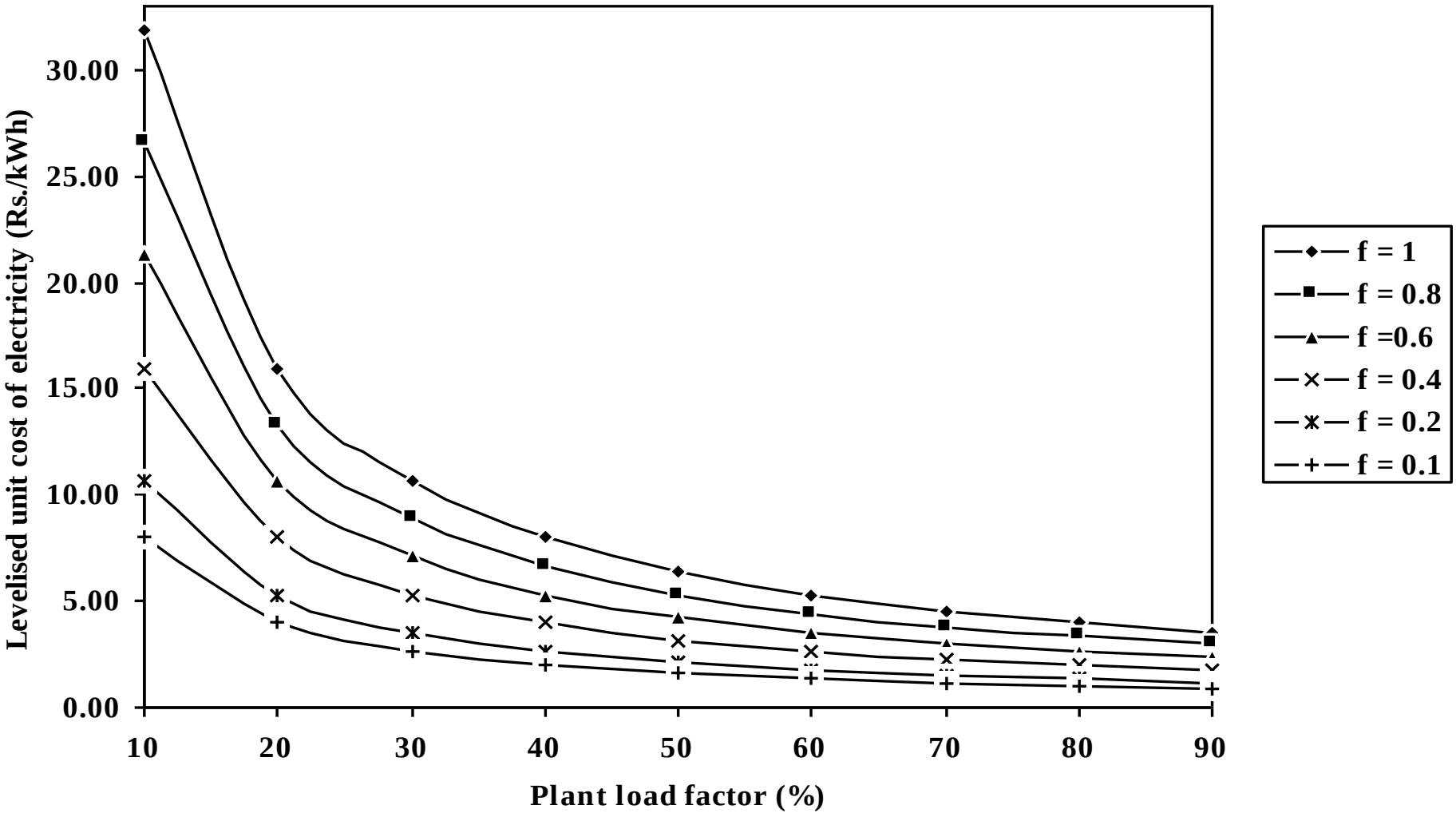
LUCE delivered by MHP projects in Arunachal Pradesh



LUCE delivered by MHP projects in Uttaranchal



Variation of LUCE delivered with PLF for a 50 kW MHP project in Uttarakhand



Effect of PLF on measures of financial performance for a 50 kW MHP project in Uttarakhand

PLF	DPP (years)	Benefit to Cost Ratio	NPV (Rs.)	IRR (%)
0.9	2.77	4.15	31,739,990	43.09
0.8	3.19	3.68	26,912,919	38.11
0.7	3.77	3.20	22,085,849	33.14
0.6	4.60	2.72	17,258,778	28.16
0.5	5.92	2.24	12,431,708	23.17
0.4	8.35	1.76	7,604,637	18.16
0.3	14.78	1.27	2,777,566	13.05
0.2	*	0.79	(-) 2,049,504	7.63
0.1	*	0.31	(-) 6,876,575	*

* Not possible

LUCE delivered by the Karmi II 50 kW MHP project for different fractions of capital cost borne and breakeven PLF

Fraction of cost borne by the project implementer	Levelised unit cost of delivered electricity (Rs./kWh)
1	14.23
0.9	13.08
0.8	11.93
0.7	10.78
0.6	9.63
0.5	8.47
0.4	7.32
0.3	6.17
0.2	5.02
0.1	3.87

Conclusions emerging from Section-III

- **Even with PLF of 30% MHP option appears to be attractive to PV based option in terms of delivered LUCE. Even, in most of the cases it would be a financially better than diesel engine/ biomass-diesel dual fuel engine based options.**

- **Break-even PLF for a particular project was ~24%.**

- **Capital subsidy to an extent of at least about 90% is essential for making decentralized power supply system based on MHP projects located in remote areas for providing electricity to the users at more or less same average price of electricity as paid by the consumers in the domestic sector in 2000-01 i.e. Rs. 1.73/kWh.**

Section-IV

Biomass Gasifier Based Power Projects (BGPP) for Decentralized Power Generation

Biomass Gasifier Power Projects (BGPP) for Decentralized Power Supply

- **Biomass gasification is a thermo-chemical process for conversion of biomass into a combustible gas mixture called 'producer gas' through partial combustion process.**

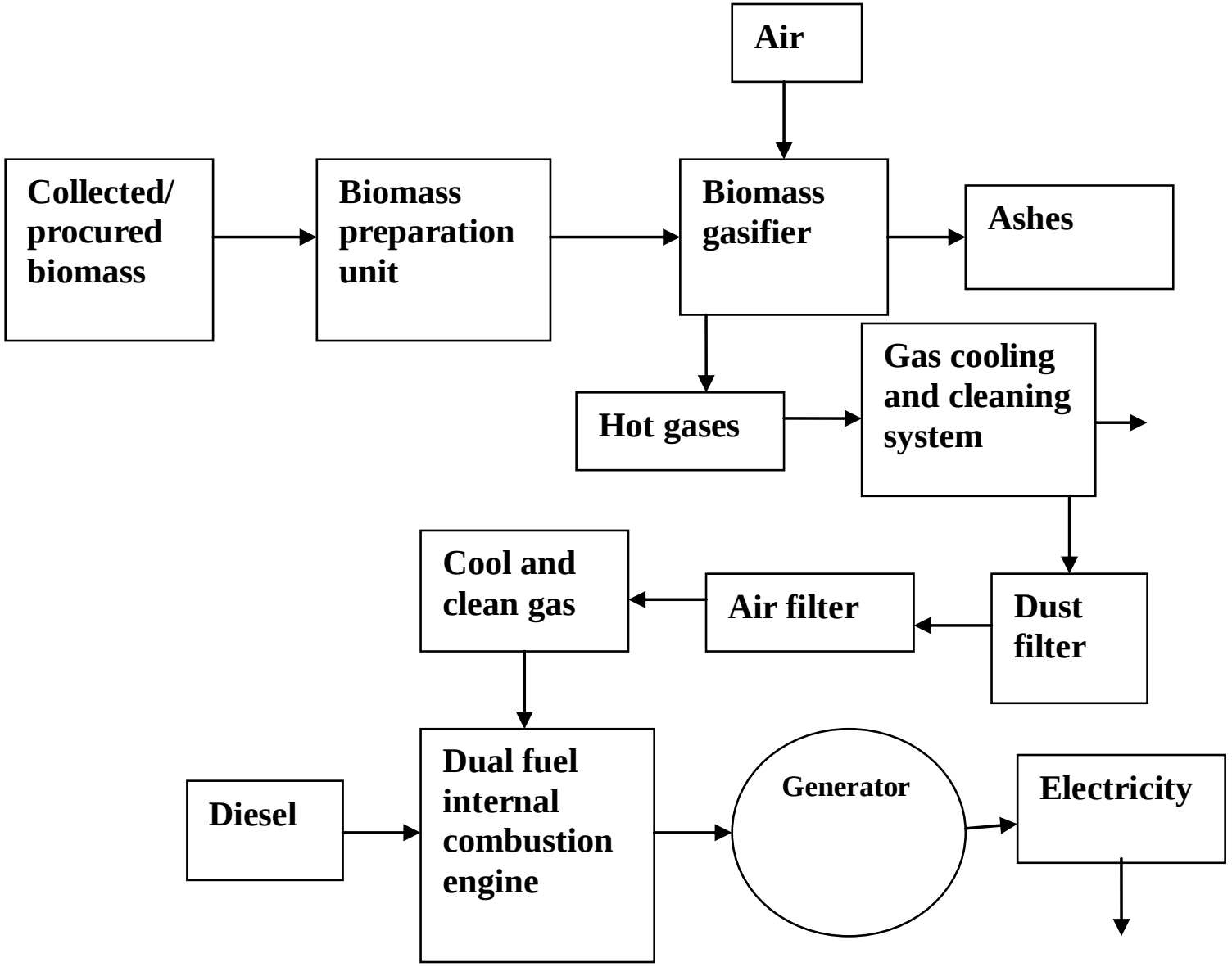
- **Producer gas typically contains 15-30% CO, 10-20% H_2, 2-4% CH_4, 5-10% CO_2, 6-8% H_20 and remaining N_2.**

- **Dual Fuel (DF) and 100% Producer Gas (HPG) engine-generator systems for power generation are in use.**

- **In this study capital cost details of DF BGPP (5 – 40 kW) and HPG BGPP (9/10 kW and 40 kW) capacities for two manufacturers were analyzed.**

- **Cost of local electricity distribution network considered:**
  - **2 km for BGPP of capacity up to 20 kW**
  - **3 km for BGPP of capacity of 30 kW and higher capacity BGPPs**

Biomass gasifier based power plant



Levelised Unit Cost of Electricity

Electricity Generation by BGPP

$$E_O = P(8760 * CUF)(1-a)(1-l)$$

a **: fraction of generated power consumed by the auxiliaries of the BGPP**

l **: fraction of electrical losses in the local distribution network**

Cost of BGPP

$$C_{bgpp} = C_g + C_{eg} + C_{cw} + C_{dn}$$

Levelised Unit Cost of Electricity from a BGPP

$$LUCE = \frac{\begin{array}{l} C_g(R_g + m_g) + C_{eg}(R_{eg} + m_{eg}) + C_{cw}(R_{cw} + m_{cw}) + C_{dn}(R_{dn} + m_{dn}) \\ + 8760CUF(m_l n + c_{pf} s_{spfc} P + c_{bm} s_{sbmc} P) \end{array}}{E_O}$$

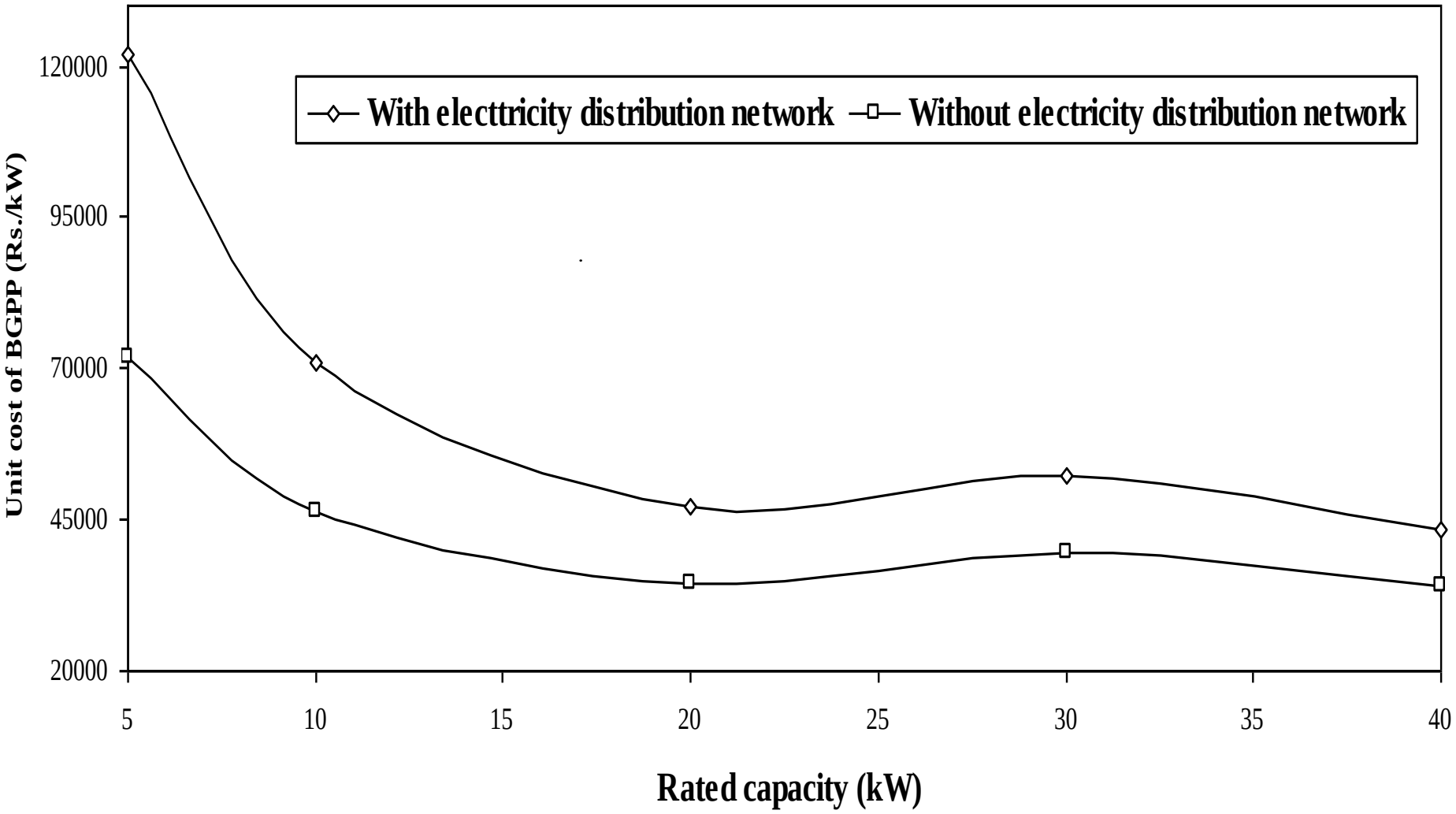
Cost of Biomass Gasifier Power Projects for Decentralized Electricity Supply

Manufacturer of BGPP	Manufacturer I							Manufacturer II			
Type of engine	Dual fuel engine					100% producer gas engine		Dual fuel engine		100% producer gas engine	
Rated capacity of BGPP (kW)	5	10	20	30	40	9	40	10	40	10	40
Gasifier with accessories	76,000	95,000	145,000	300,000	380,000	145,000	700,000	230,000	510,000	250,000	600,000
Biomass cutter	12,000	12,000	12,000	20,000	20,000	12,000	20,000	7,500	7,500	7,500	7,500
Biomass dryer	9,000	9,000	9,000	40,000	40,000	9,000	50,000	10,000	35,000	10,000	35,000
Moisture meter	3,000	3,000	3,000	3,000	3,000	3,000	3,000	5,000	5,000	5,000	5,000
Chain pulley block	0	0	0	10,000	10,000	0	10,000	3,000	6,500	3,000	6,500
Water cooling system	10,000	10,000	15,000	15,000	15,000	10,000	25,000	0	30,000	0	30,000
Other accessories	0	0	0	0	0	0	0	50,000	90,000	50,000	90,000
Taxes and duties	29,700	34,830	49,680	104,760	126,360	48,330	218,160	82,485	184,680	87,885	208,980
Total cost of biomass gasifier	139,700	163,830	233,680	492,760	594,360	227,330	1,026,160	387,985	868,680	413,385	982,980
Engine-generator set	94,000	140,000	245,000	375,000	405,000	200,000	814,000	60,000	400,000	80,000	725,000
Accessories	0	0	0	0	0	0	100,000	0	0	0	0
Taxes and duties	25,380	37,800	66,150	101,250	109,350	54,000	273,780	16,200	108,000	21,600	195,750
Total cost of engine-generator set	119,380	163,830	311,150	476,250	514,350	254,000	1,287,780	76,200	508,000	101,600	920,750
Earthing materials	10,000	10,000	15,000	20,000	30,000	10,000	30,000	15,000	30,000	15,000	30,000
Civil work	60,000	80,000	100,000	150,000	175,000	80,000	200,000	125,000	400,000	125,000	400,000
Erection, commissioning and training	30,000	30,000	30,000	50,000	50,000	30,000	50,000	80,000	100,000	80,000	100,000
Cost of site related work	100,000	120,000	145,000	220,000	255,000	120,000	280,000	220,000	530,000	220,000	530,000
Total installed cost of BGPP	359,080	461,630	689,830	1,189,010	1,363,710	601,330	2,593,940	684,185	1,906,680	734,985	2,433,730
LT electricity distribution network	250,000	250,000	250,000	375,000	375,000	250,000	375,000	250,000	375,000	250,000	375,000
Total cost including distribution network	609,080	711,630	939,830	1,564,010	1,738,710	851,330	2,968,940	934,185	2,281,680	984,985	2,808,730
Cost of BGPP per kW of rated capacity	121,816	71,163	46,992	52,134	43,468	94,592	74,224	93,419	57,042	98,499	70,218

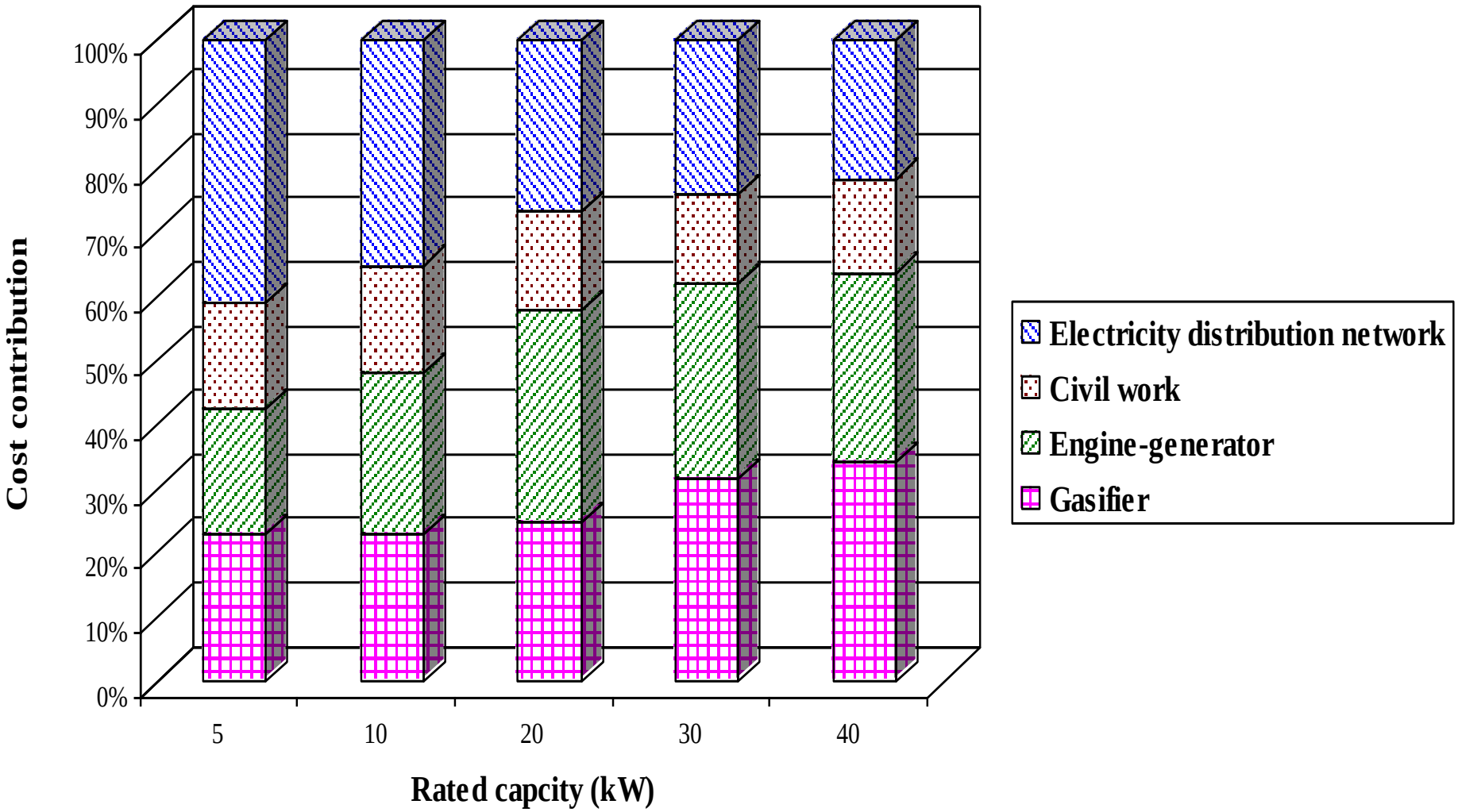
Input parameters

Input parameter	Unit	Value
Annual maintenance cost of gasifier as a fraction of its capital cost	fraction	0.05
Annual maintenance cost of engine-generator as a fraction of its capital cost	fraction	0.10
Annual maintenance cost of LT electricity distribution network as a fraction of its capital cost	fraction	0.03
Annual maintenance cost of civil work as a fraction of its capital cost	fraction	0.02
Auxiliary power consumption by BGPP	fraction	0.10
Capacity utilization factor	fraction	0.25
Discount rate	fraction	0.10
Excise duty	fraction	0.16
Manpower cost	Rs./man-hour	15.00
Price of biomass	Rs./kg	1.50
Price of diesel	Rs./liter	30.45
Specific biomass consumption in a typical DF engine BGPP at rated capacity	kg/kWh	1.10
Specific biomass consumption in a typical 100% PG engine BGPP at rated capacity	kg/kWh	1.40
Specific diesel consumption in a typical DF engine BGPP at rated capacity	liter/kWh	0.11
Specific diesel consumption in a typical diesel engine at rated capacity	liter/kWh	0.30
Unit cost of LT electricity distribution network	Rs./km	125,000
Useful life of civil work	years	20
Useful life of engine-generator set with diesel as pilot or main fuel	hours	20,000
Useful life of biomass gasifier	hours	10,000
Useful life of LT electricity distribution network	years	20

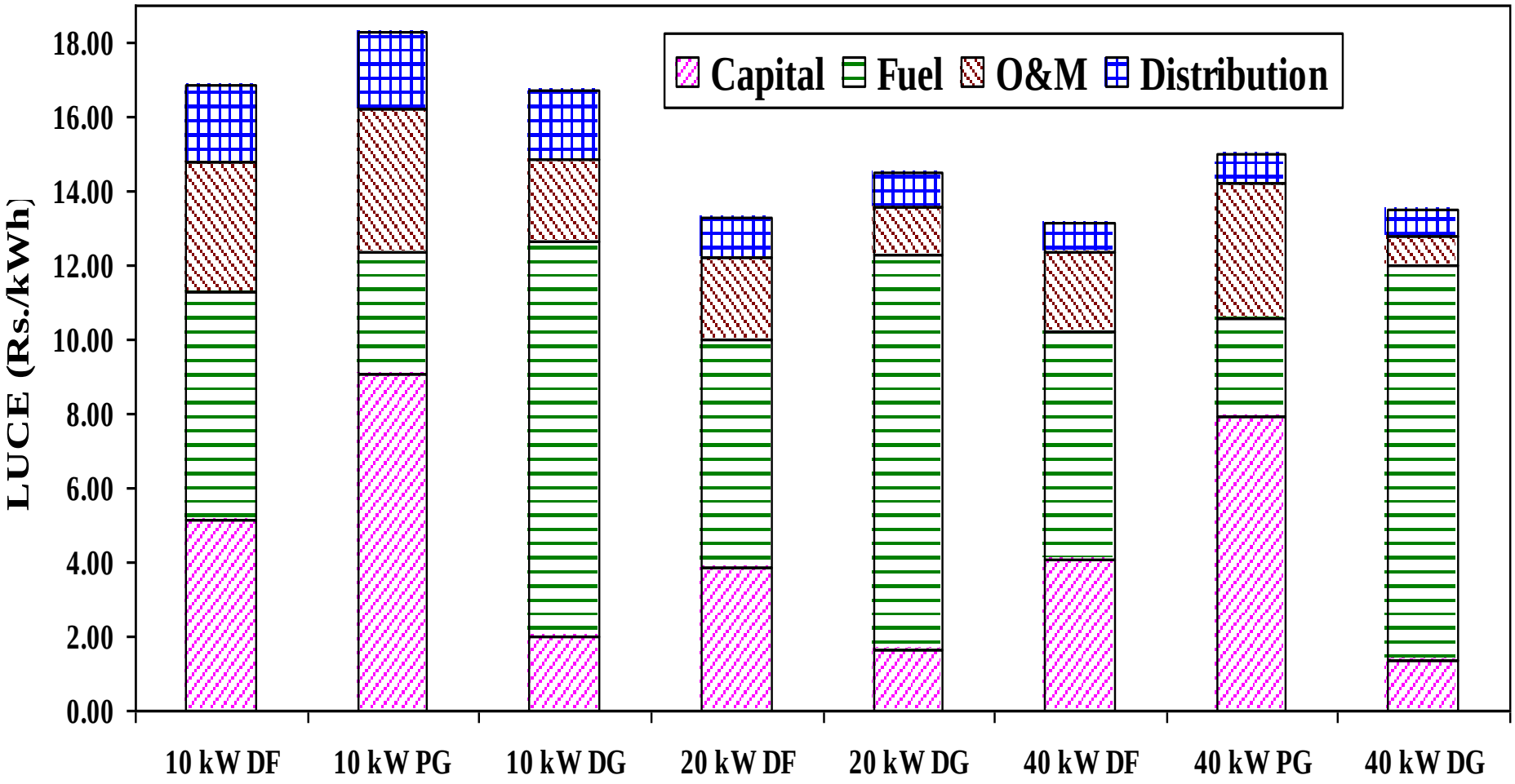
Cost per unit capacity of DF BGPP



Relative cost contributions of different components of Biomass Gasifier Power Projects



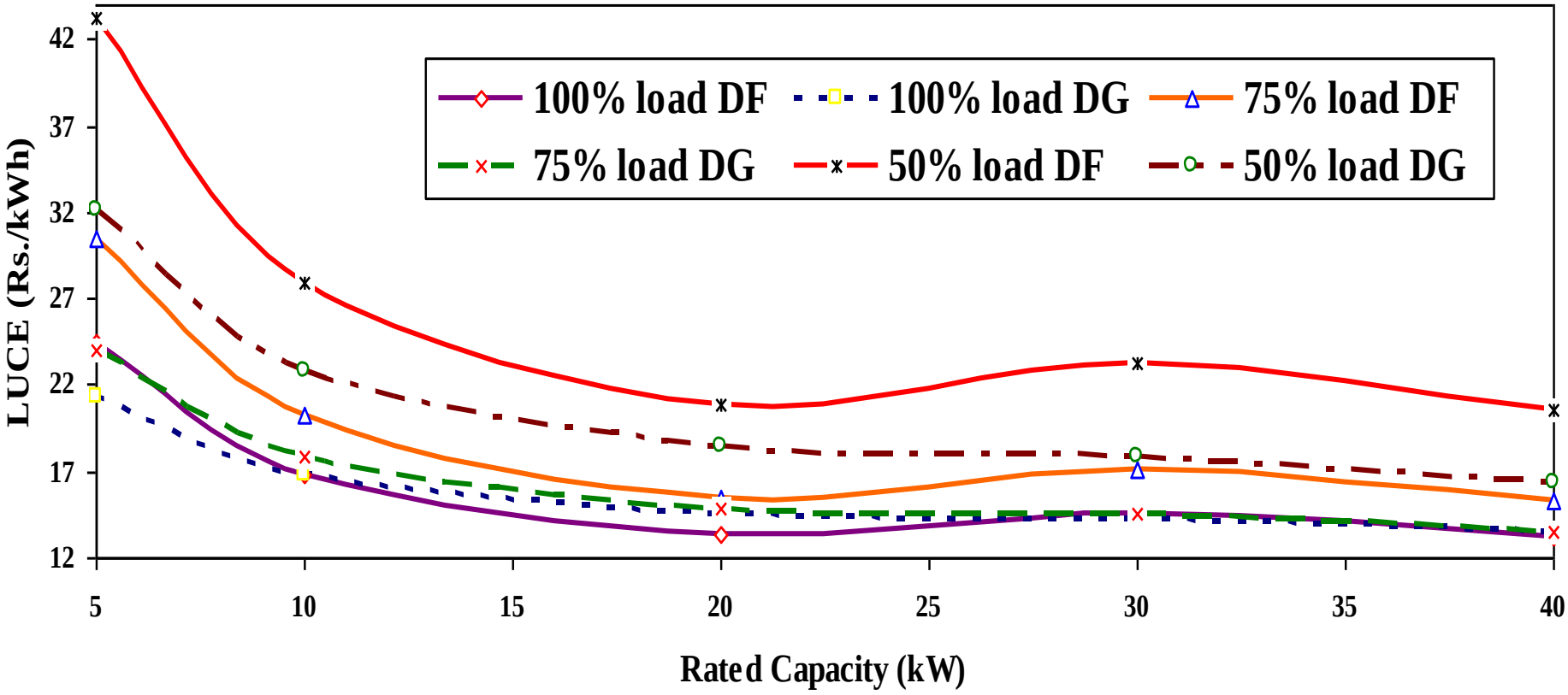
Comparison of components of LUCE for DF, HPG and DG set based power projects



LUCE for DF, PG and DG set for different operating loads

Type of power generating system	Rated capacity (kW)	LUCE (Rs./kWh) for different operating load as percentage of rated capacity		
		100%	75%	50%
DF BGPP	5	24.49	30.43	43.23
	10	16.84	20.22	27.91
	20	13.28	15.48	20.80
	30	14.54	17.15	23.21
	40	13.14	15.29	20.51
100% producer gas BGPP	9	18.53	23.26	33.68
	40	15.02	18.06	25.92
Diesel generating set	5	21.38	23.99	32.13
	10	16.75	17.82	22.86
	20	14.51	14.84	18.39
	30	14.26	14.51	17.89
	40	13.51	13.50	16.39

Comparison of LUCE for DF and DG set based power projects



Comparison of two smaller vs. one larger Biomass Gasifier Power Projects

Attribute of BGPP	Rated Capacity of BGPP (kW)					
	10		20		40	
	One 10 kW system	Two 5 kW systems	One 20 kW system	Two 10 kW systems	One 40 kW system	Two 20 kW systems
Unit cost (Rs./kW)	46,163	73,728	34,492	49,973	34,093	36,778
LUCE (Rs./kWh)	18.87	18.90	14.45	13.83	13.66	11.48

Levelised unit cost of electricity of a 40 kW DF BGPP for different fractions of capital cost borne by the owner of the project

Fraction of capital cost borne by the user	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
LUCE (Rs./kWh)	7.26	7.84	8.43	9.02	9.61	10.20	10.78	11.37	11.96	12.55

Conclusions emerging from Section-IV

- **In terms of initial capital cost and unit capital cost, DF BGPP and HPG BGPP were costlier to equivalent capacity DG set based power generating options.**

- **Capital cost of HPG BGPP was almost twice that of DF BGPP based on the prevailing prices of these options.**

- **The prevailing market prices of HPG based engines were high either due to very low demand for such engines and/or due to a pricing strategy of the suppliers of these engines.**

Conclusions emerging from Section-IV (contd.)

- **HPG based BGPPs were not competitive with either DF based BGPP or DG set based power projects**

- **DG set based power projects were found to be financially more attractive as compared to DF based BGPP for projects of 5 kW and 10 kW capacities.**

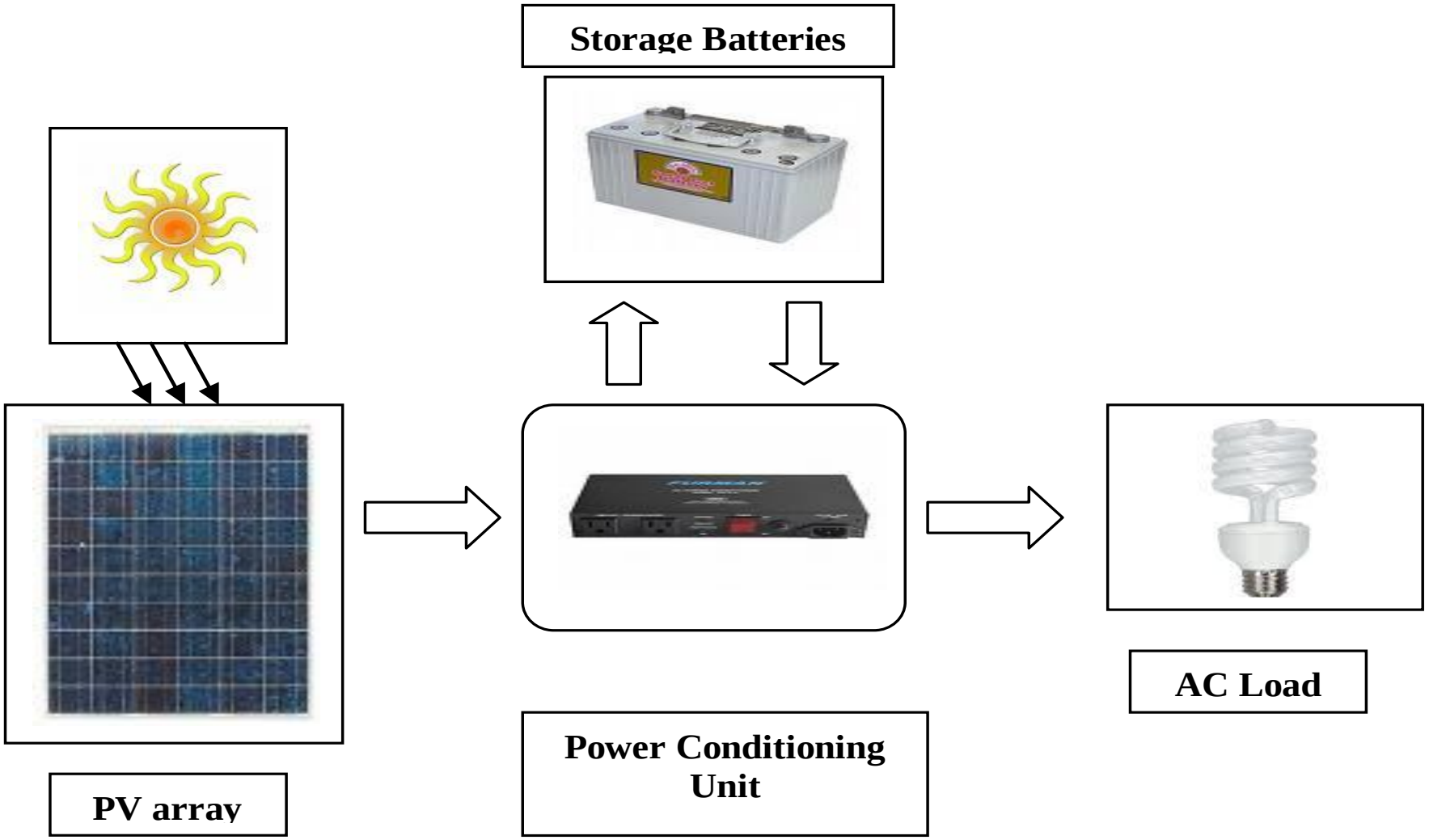
- **On prevailing prices, LUCE from DF BGPP of capacity greater than 10 kW were competitive to DG based power projects**

- **Instead of installing a single large capacity BGPP often operating at part loads for long durations, it may be financially more attractive to install two smaller BGPP with each having a capacity equal to one half of the larger capacity BGPP. However, such an option necessitates higher initial capital investment.**

Section-V

Photovoltaic Power Projects for Decentralized Power Supply

Solar Photovoltaic power generating system



PV power projects for decentralized electricity supply

- **18 locations in different geographical regions of India with annual average daily global solar radiation ranging from 4.45 – 6.4 kWh/m^2 were identified for detailed analysis**

- **To estimate total solar radiation on tilted surface of PV array two different approaches were used**

  - **For Sagar Island, only values of monthly average daily global solar radiation on a horizontal surface are available**

  - **For other locations monthly average daily values of direct and diffuse solar radiation are available**

PV power projects for decentralized electricity supply

$$E_m = h_{eq} * [1 - \frac{\alpha}{100}(T_{co} - 25)] * z * (1 - l_{pv})$$

Capital cost of a PV project (C_{spp})

$$C_{pvp} = C_a + C_{sb} + C_{pcu} + C_{bos}$$

LUCE delivered by the PV project

$$LUCE = \frac{R_a * C_a + R_{sb} * C_{sb} + R_{pcu} * C_{pcu} + R_{bos} * C_{bos} + m_{o,pvp} * C_{pvp}}{E_o}$$

Locations of eighteen sites considered for PV projects in this study on the map of India

Monthly average daily solar radiation and ambient temperature at eighteen select locations in India

City	Jan		Feb		March		April		May		June		July		Aug		Sept		Oct		Nov		Dec	
	H	T_m	H	T_m	H	T_m	H	T_m	H	T_m	H	T_m	H	T_m	H	T_m	H	T_m	H	T_m	H	T_m	H	T_m
Agra	4.293	22.5	5.202	26.5	6.120	32.2	6.782	38.0	6.904	41.5	6.230	42.4	5.472	35.6	5.178	32.8	5.697	33.1	5.537	33.2	4.769	29.1	4.104	24.5
Barmer	4.693	25.6	5.615	30.1	6.658	34.9	7.474	38.9	8.063	42.3	7.886	40.5	6.548	36.8	6.264	35.6	6.617	35.4	6.069	37.0	5.074	31.9	4.476	27.0
Bikaner	4.456	23.3	5.369	27.4	6.382	32.3	7.487	37.6	8.122	41.5	8.147	41.7	7.290	38.2	6.831	36.7	6.791	36.3	5.963	36.0	4.802	30.2	4.208	24.2
Bhuj	4.956	26.9	5.815	30.7	6.196	34.6	6.924	37.9	7.436	39.7	6.544	36.6	5.308	33.4	5.192	32.4	5.880	33.1	5.931	35.7	5.279	32.1	4.766	27.6
Dibrugarh	3.658	21.7	4.099	22.5	4.972	26.3	4.775	27.2	5.091	27.4	4.626	29.3	4.786	29.9	5.215	29.8	4.457	29.5	4.597	27.8	4.233	25.1	3.740	22.4
Guahati	4.081	34.0	4.972	25.0	5.363	29.1	5.939	30.5	5.934	29.6	4.901	29.5	4.984	30.4	5.073	30.3	4.843	30.3	4.981	28.9	4.517	26.3	4.018	23.3
Imphal	4.590	20.1	5.322	22.3	6.085	25.4	6.630	26.8	5.857	27.1	4.901	26.6	4.690	27.5	4.805	27.2	4.776	27.5	4.848	26.3	4.660	24.0	4.363	20.7
Jaisalmer	4.608	24.3	5.559	28.1	6.488	33.2	7.479	37.5	8.114	41.8	8.243	40.9	7.440	37.9	7.084	36.4	6.809	36.2	6.061	36.5	4.996	30.9	4.361	24.8
Jammu	3.446	20.1	4.257	23.2	5.384	27.2	6.360	32.9	7.697	38.0	7.958	40.6	6.277	35.7	6.192	33.8	6.119	33.1	5.266	32.2	3.870	27.7	3.258	21.6
Jharsuguda	4.706	26.1	5.893	29.4	5.934	34.3	6.700	37.9	7.001	40.0	5.146	34.9	4.746	29.1	4.491	32.3	5.224	29.9	5.730	29.7	4.922	28.2	4.503	26.1
Kottayam	6.211	32.0	6.578	32.2	6.910	33.2	6.481	33.1	5.849	31.9	5.015	29.9	4.514	28.9	5.052	28.9	5.661	29.4	5.165	30.2	5.426	30.9	5.358	31.5
Leh	3.329	-2.1	4.289	1.4	5.347	6.4	6.706	12.2	7.605	15.5	8.385	21.3	7.991	25.2	7.174	25.2	6.796	21.8	5.444	15.3	4.259	7.3	3.251	2.2
Ootacmund	5.938	20.7	6.474	20.9	6.810	21.9	6.538	22.9	5.926	21.6	4.905	18.8	4.211	16.6	4.729	17.8	5.032	18.5	5.092	18.8	5.148	19.2	5.264	19.3
Pune	5.317	20.5	6.098	22.0	6.531	25.6	6.915	28.8	6.990	29.7	5.743	27.4	4.575	25.3	4.679	24.5	5.195	25.1	5.603	25.0	5.345	22.3	5.030	20.2
Ranchi	4.935	22.9	5.875	26.1	6.535	31.0	7.069	35.3	7.140	37.6	6.044	34.2	4.818	29.1	4.953	28.7	5.143	28.6	5.386	27.8	5.329	25.6	4.891	23.0
Tiruchirapalli	5.683	29.0	6.431	31.6	6.677	34.1	6.717	35.3	6.353	36.0	5.879	35.3	5.379	34.0	5.769	33.9	6.020	33.3	5.448	30.8	5.150	28.5	4.949	28.1
Titabar	3.758	24.1	4.389	25.2	4.795	28.7	5.032	30.5	4.971	30.2	4.660	31.9	4.660	32.8	4.789	32.5	4.640	32.1	4.409	30.1	3.974	27.3	3.536	24.8
Sagar	4.790	*	5.440	*	6.290	*	6.470	*	6.160	*	4.210	*	3.730	*	3.940	*	4.260	*	4.750	*	4.550	*	4.510	*

H - Monthly average daily global solar radiation ($kWh/m^2/day$)

T_m - Maximum values of ambient temperature in the month (°C)

* - Values not available. Assumed to be same as Titabar

Source: Mani and Rangarajan, 1982.

Estimated electricity output of 1 kW_p PV Power Projects at select locations

Estimated electricity output of a 1 kW_p PV array at select locations in India

City	Latitude & Tilt of PV array (degrees)	H (kWh/m^2)	O (kWh)	O_d (kWh)
Agra	27.17	5.52	1976	1374
Barmer	25.75	6.29	2199	1529
Bikaner	28.00	6.32	2238	1556
Bhuj	23.25	5.85	2040	1418
Dibrugarh	27.48	4.52	1593	1108
Gauhati	26.10	4.97	1761	1225
Imphal	24.77	5.12	1855	1290
Jaisalmer	26.90	6.44	2275	1582
Jammu	32.67	5.51	1951	1357
Jharsuguda	21.92	5.41	1878	1306
Kottayam	9.53	5.68	1868	1299
Leh	34.15	5.89	2278	1584
Ootacmund	11.40	5.50	1909	1327
Pune	18.53	5.66	1998	1389
Ranchi	23.42	5.67	2026	1409
Tiruchirapalli	10.77	5.87	1927	1340
Titabar	26.58	4.47	1562	1086
Sagar Island	22.15	4.92	1747	1215

H – Annual average daily global solar radiation
O - Annual output of unit array
O_d - Annual delivered output of unit array

Base values of input parameters for PV power projects for decentralized electricity supply

Base values of input parameters used for techno-economic evaluation of PV power projects for decentralized power supply in India

Input parameter	Unit	Value
Annual maintenance cost as a fraction of capital cost	fraction	0.03
Cable losses	fraction	0.03
Cell power degradation co-efficient	fraction	0.0035
Discount rate	fraction	0.10
Inverter efficiency	fraction	0.90
Useful life of BOS	years	20
Useful life of power conditioning unit	years	10
Useful life of PV array	years	20
Useful life of storage batteries	years	7
Module output de-rating due to array mismatch	fraction	0.02
Module output de-rating due to dust	fraction	0.03
Module output de-rating due to shadow	fraction	0.02
Module output de-rating due to gradual ageing	fraction	0.05
Reflectance of ground	fraction	0.20
Charging efficiency of Storage battery	fraction	0.90

Cost details of some PV power projects deployed in Sagar Island for decentralized electricity supply

Cost details of some PV power projects installed/under installation/planned for decentralized application in Sagar Island in West Bengal

Name of site	Year of installation	Capacity (kW)	Total Project cost in nominal Rupees (Rs.)	Total Project cost in real Rupees (1996) (Rs.)	Cost of PV array		Cost of storage batteries		Cost of power conditioning unit		Cost of balance of system		Installed cost per unit capacity (Rs./kW_p)
					Amount nominal Rupees (Rs.)	% of total project cost	Amount nominal Rupees (Rs.)	% of total project cost	Amount nominal Rupees (Rs.)	% of total project cost	Amount nominal Rupees (Rs.)	% of total project cost	
I. Projects already implemented													
Kamalpur	1996	25	7,325,000	7,325,000	4,617,000	63.0	850,000	11.6	1,050,000	14.3	808,000	11.0	293,000
Mrityunjay	1998	25	9,218,000	6,727,485	4,631,000	50.2	975,000	10.6	1,375,000	14.9	2,237,000	24.3	368,720
Khasmahal	1999	25	7,968,000	6,009,503	4,317,000	54.2	1,025,000	12.9	1,650,000	20.7	976,000	12.2	318,720
Gayenbazar	1999	25	7,968,000	6,009,503	4,317,000	54.2	1,025,000	12.9	1,650,000	20.7	976,000	12.2	318,720
Mahendra	1999	25	7,968,000	5,910,541	4,317,000	54.2	1,025,000	12.9	1,650,000	20.7	976,000	12.2	318,720
Natendrapur	2000	25	7,098,000	5,063,129	3,375,000	47.5	675,000	9.5	1,750,000	24.7	1,298,000	18.3	283,920
Hardhanpur	2000	25	7,098,000	4,984,201	3,375,000	47.5	675,000	9.5	1,750,000	24.7	1,298,000	18.3	283,920
Mandirtalte	2000	25	7,098,000	5,029,049	3,375,000	47.5	675,000	9.5	1,750,000	24.7	1,298,000	18.3	283,920
Mean value for 25 kW_p projects			7,717,625	5,882,301	4,040,500	52.4	865,625	11.2	1,578,125	20.4	1,233,375	16.0	308,705
Mousini-I	2001	55	15,379,000	10,921,034	8,175,000	53.2	2,035,000	13.2	2,970,000	19.3	2,199,000	14.3	279,618
Mousini-II	2003	110	30,758,000	19,715,403	16,350,000	53.2	4,070,000	13.2	5,940,000	19.3	4,398,000	14.3	279,618
Parth Pratin	2004	110	34,873,000	21,865,321	16,110,000	46.2	4,070,000	12.6	6,710,000	19.2	7,653,000	21.9	317,027
II. Project under implementation/planned													
Tushkhali	2004	55	20,523,438	12,945,274	8,600,000	41.9	2,300,000	11.2	5,600,000	27.3	4,023,438	19.6	373,153
Jogeshganj	2004	55	20,523,438	12,945,274	8,600,000	41.9	2,300,000	11.2	5,600,000	27.3	4,023,438	19.6	373,153
Pathankhali	2004	55	20,523,438	12,945,274	8,600,000	41.9	2,300,000	11.2	5,600,000	27.3	4,023,438	19.6	373,153
Hardhanpur	2004	110	36,611,574	23,092,957	17,390,000	47.5	4,600,000	12.6	7,800,000	21.3	6,821,574	18.6	332,832

* Base year 1996

Estimates of costs of PV power projects for remote areas

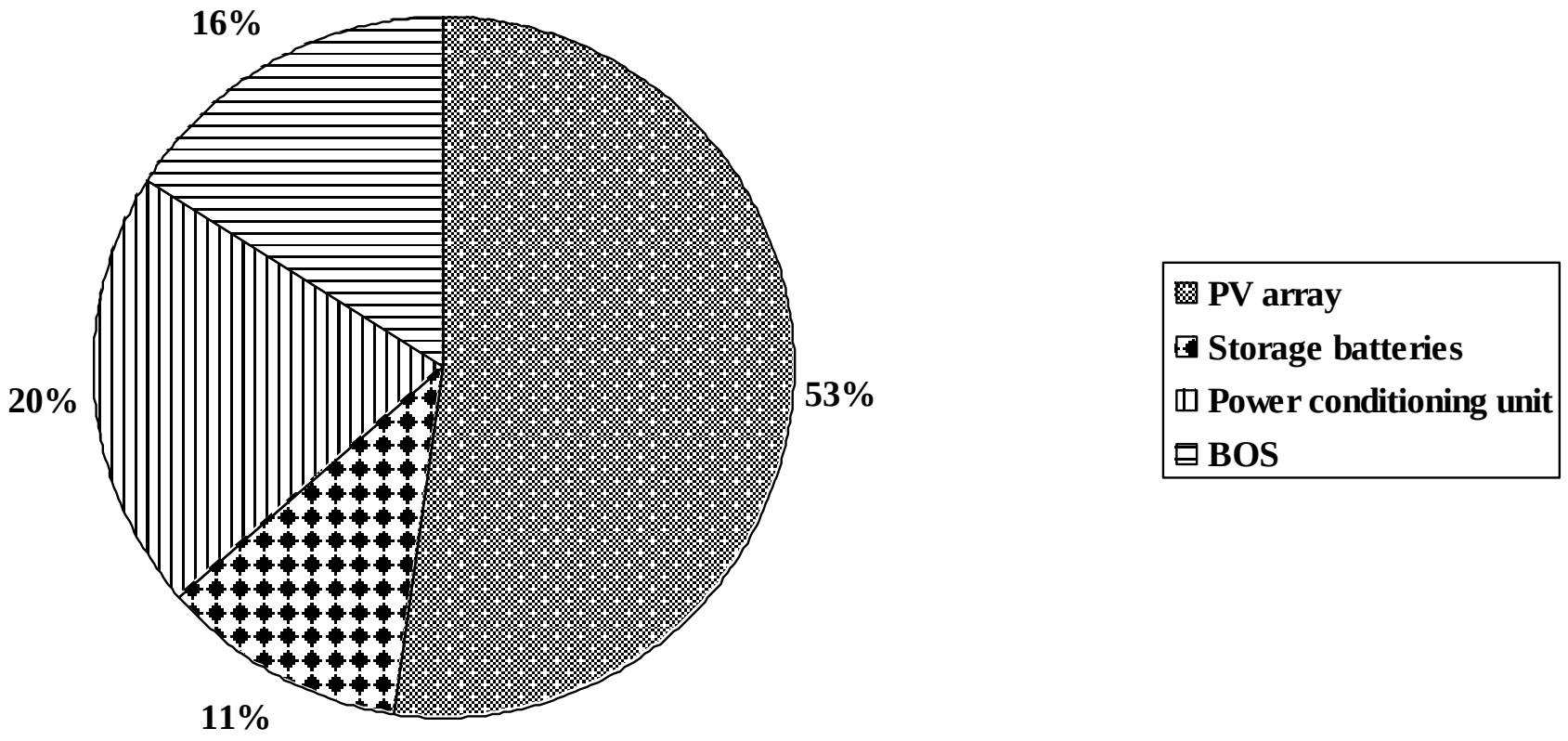
Capacity of PV Power Project (kW_p)	Installed cost	
	Total (Rs.)	Cost per unit capacity (Rs./kW)
2.5	700,000	308,000
5	1,254,000	269,800
10	2,660,000	292,500
25	6,485,000	278,840

LUCE from PV power projects at select locations

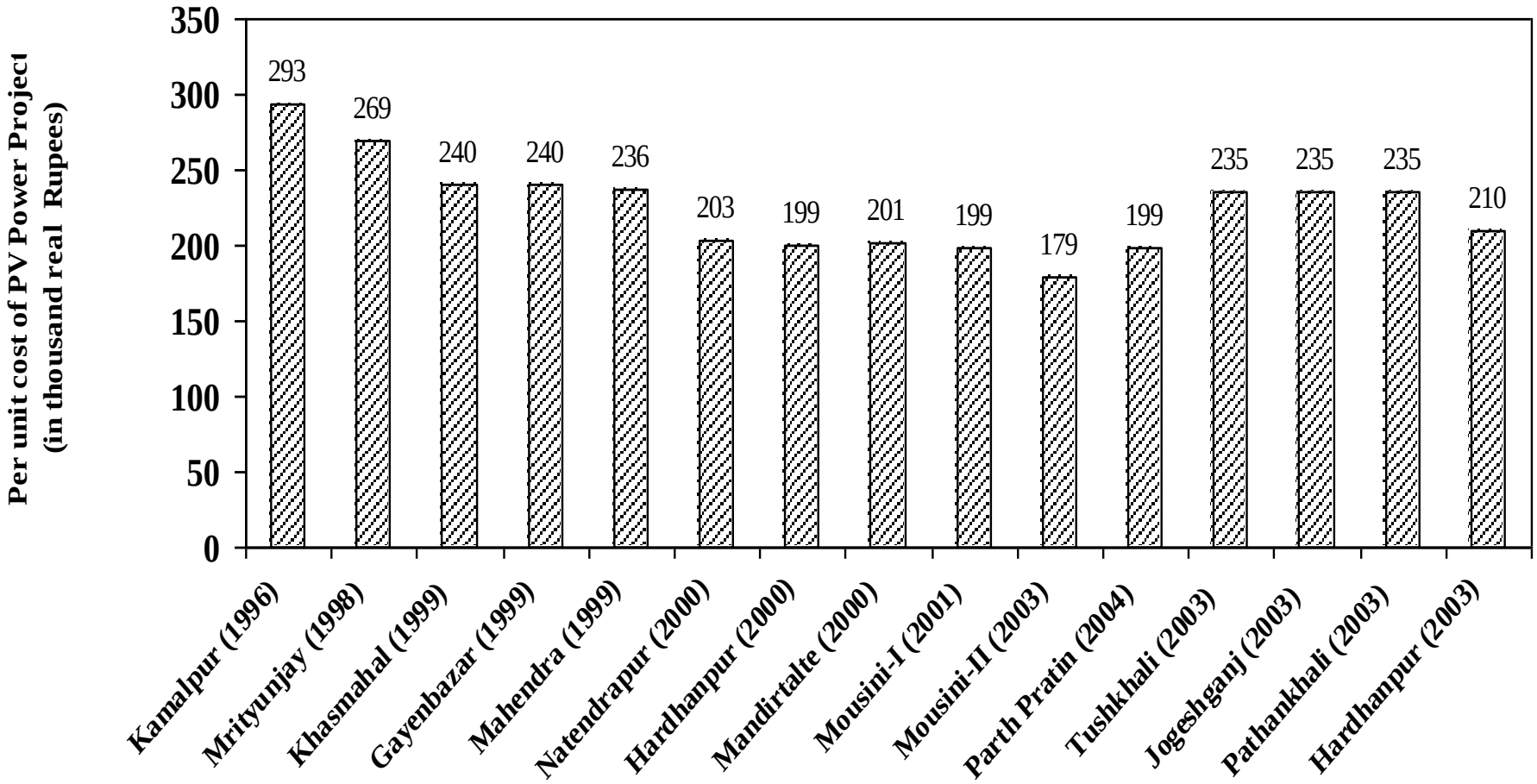
Levelised unit cost of electricity from PV power projects at select locations

City	Levelised unit cost of electricity (Rs./kWh)				
	1 kW	2.5 kW	5 kW	10 kW	25 kW
Agra	46.76	37.26	32.64	35.38	33.73
Barmer	42.01	33.47	29.32	31.79	30.31
Bikaner	41.28	32.89	28.81	31.24	29.77
Bhuj	45.30	36.09	31.61	34.27	32.67
Dibrugarh	58.00	46.21	40.49	43.89	41.84
Gauhati	52.46	41.80	36.61	39.70	37.84
Imphal	49.79	39.67	34.75	37.68	35.92
Jaisalmer	40.60	32.35	28.34	30.72	29.28
Jammu	47.35	37.73	33.05	35.83	34.16
Jharsugud	49.19	39.19	34.33	37.22	35.48
Kottayam	49.45	39.40	34.52	37.42	35.67
Leh	40.56	32.32	28.31	30.69	29.26
Ootacmun	48.40	38.57	33.78	36.62	34.92
Pune	46.25	36.85	32.28	34.99	33.36
Ranchi	45.60	36.34	31.83	34.51	32.90
Tiruchirap	47.94	38.20	33.46	36.28	34.58
Titabar	59.16	47.14	41.29	44.76	42.67
Sagar	52.88	42.13	36.91	40.02	38.15

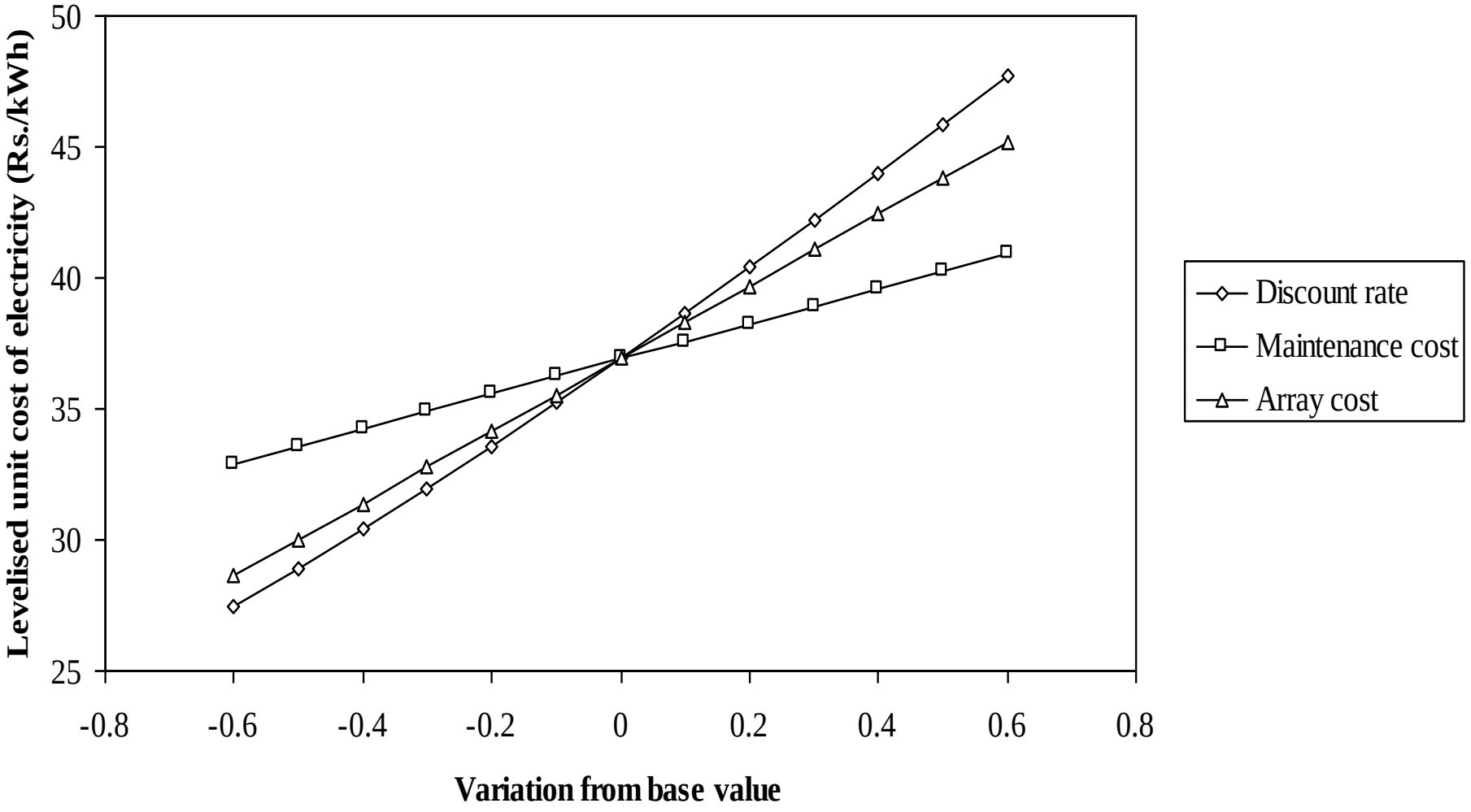
Cost break up of a 25 kWp PV project



Cost of PV projects (Rs./kWp)



Sensitivity of LUCE for a 5 kWp PV project in Sagar island



Conclusions emerging from Section-V

- **Annual delivered electrical power output of a 1 kWp PV project varies in the range of 1075 – 1600 kWh depending on the region**

- **Remote locations in Rajasthan, Gujarat and Jammu and Kashmir have advantage over other remote locations in terms of annual delivered electrical power output of PV projects**

- **Remote locations in the eastern and the north-eastern part of the country the least attractive on this count**

- **A trend of declining unit cost of PV projects is noted considering PV projects implemented in Sagar Island during 1998-2003 (Rs. 369/Wp to Rs. 280/Wp)**

Conclusions emerging from Section-V (contd.)

- **Unit cost of PV power projects in India is in the same range as projects in international market**

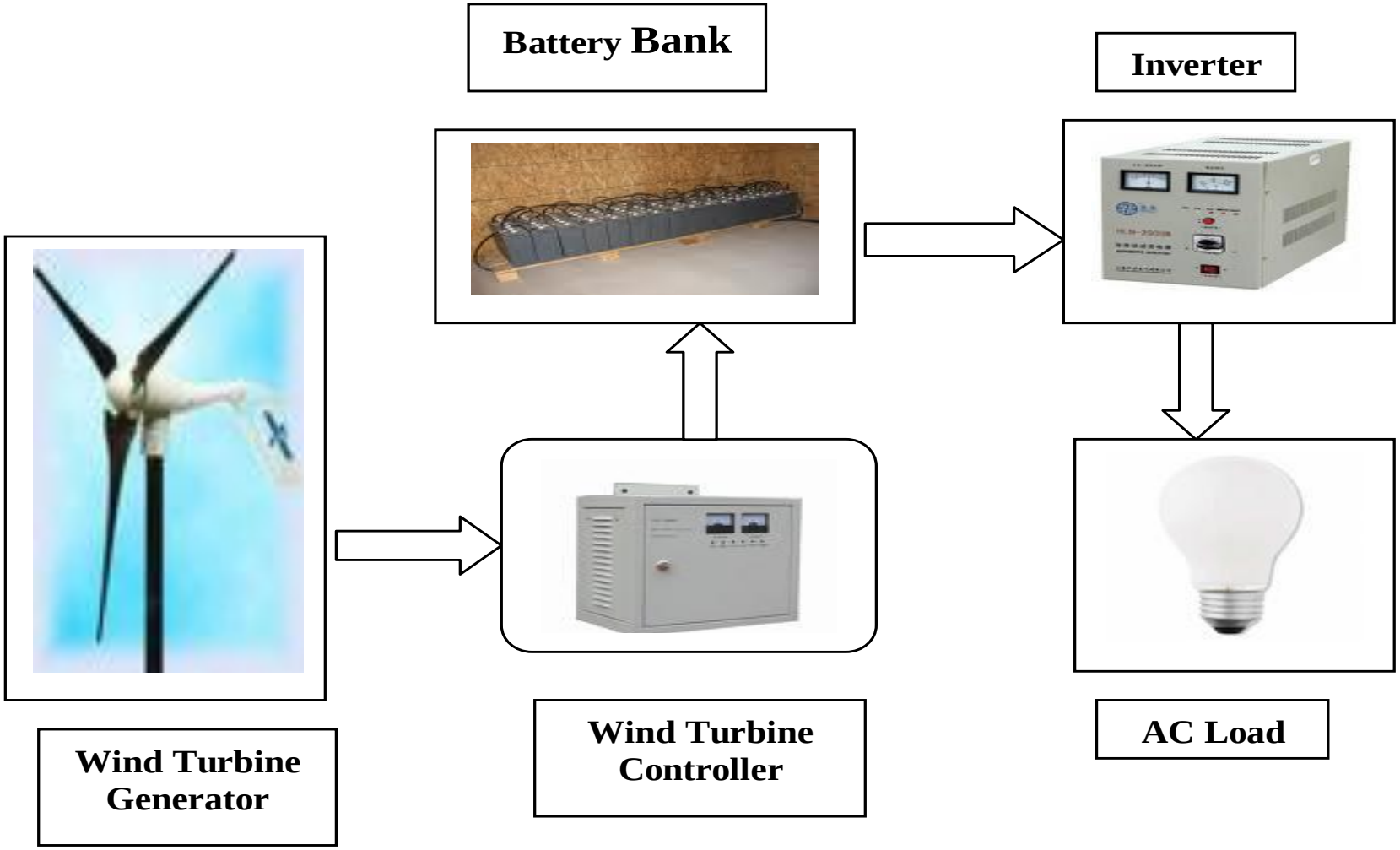
- **LUCE from PV projects of 5 kWp capacity in Rajasthan, Gujarat and Jammu and Kashmir estimated in range of Rs. 28.31 – 31.61/kWh and are close to the upper end of the reported value of US$ 0.2 - 0.6 /kWh for international projects**

- **Even in remote locations, PV projects can be financially attractive as compared to DG sets only if a capital subsidy of about 80% is provided, clearly demonstrating the un-viability of the present generation PV systems for decentralized power supply**

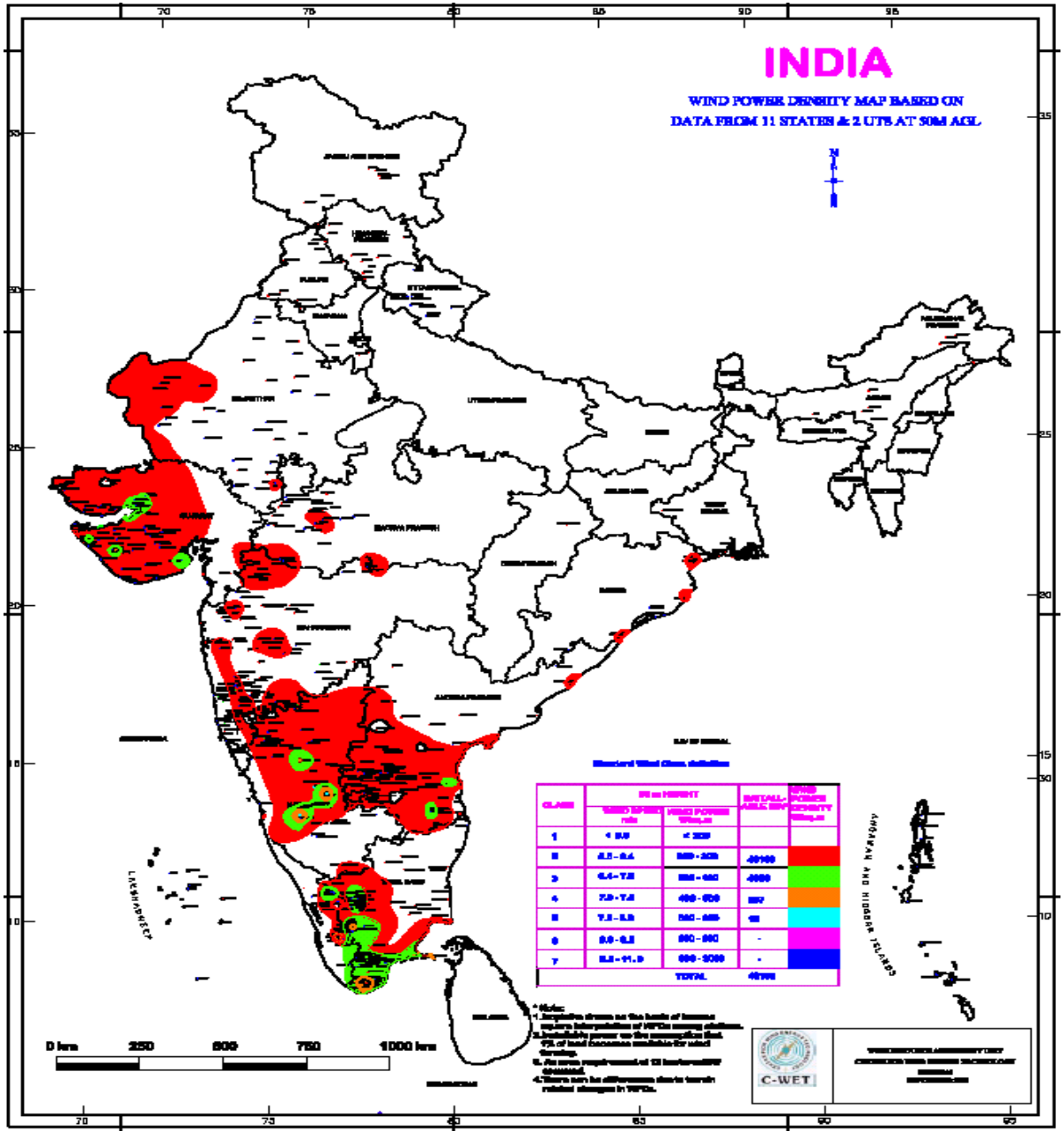
Section-VI

Small Wind Electric Generator (SWEG) Projects for Decentralized Power Supply

Small wind electricity generator system



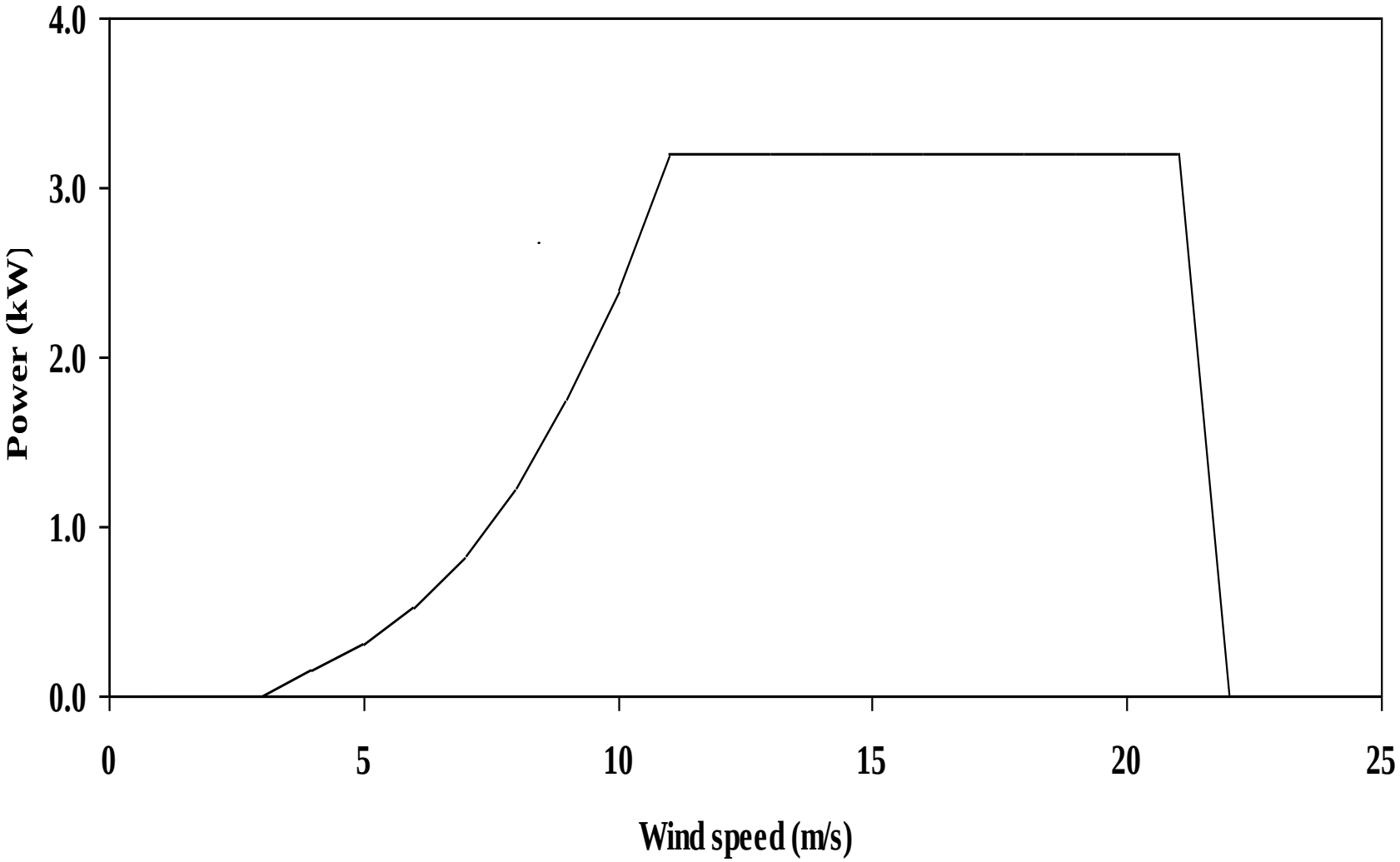
Wind energy resource in India



Small wind electric generator projects for decentralized electricity supply

- **The co-efficient of performance C_p of SWEGs is significantly lower as compared to large wind turbines due to their aerodynamic performance**
- **Most SWEGs are direct-driven, variable speed systems with permanent magnet generators**
- **Speed regulation in SWEGs is mechanical as against electronic regulation in large wind turbines. Vertical or horizontal furling is used for power control at wind speeds higher than rated wind speed**
- **SWEGs are more expansive as compared to large wind turbines in terms of cost per kW**
- **Back up power supply is essential for an SWEG to be used as a reliable decentralized power supply source**

A typical power curve of the 3.2 kW rated SWEG



Small Wind Electric Generator Projects for Decentralized Electricity Supply

- **19 locations in the country with annual mean wind speeds ranging from 3.35 m/s to 7.08 m/s considered for detailed analysis**

- **For these locations, values of annual mean wind speed, altitude above the mean sea level, density of air, values of shape factor (k) and scale factor (c) are available**

- **Capital cost details of SWEGs in the capacity range 0.4 – 50 kW installed at sixteen project sites for decentralized power supply in Maharashtra and in Sagar Island, West Bengal during the period 2003 – 2004 analyzed**

Small Wind Electric Generator Projects for Decentralized Electricity Supply

Mechanical power output of the rotor of a wind electric generator

$$P = \rho A C_p V^3 / 2$$

Annual electrical energy delivered by an SWEG

$$E_d = \sum_{v_{cut-in}}^{V_{cut-out}} PNH_v$$

Capital cost of SWEG project

$$C_{swp} = C_{weg} + C_b + C_i + C_{misc}$$

LUCE delivered by an SWEG project

$$LUCE = \frac{R_{weg}C_{weg} + R_bC_b + R_iC_i + R_{misc}C_{misc} + m_oC_{swp}}{E_d}$$

Specifications of small wind electric generators deployed in India

Information/ Relevant characteristic	Model							
	Air X400	H80	H80	W175	BWC/XL1	BWC Excel-R	E5.5 - 5	AEP AOC 15/50
Indian supplier(s)	Exide, Machinocraft, Tata-BP, Unitron	Exide, Machinocraft, Tata-BP, Unitron	Exide, Machinocraft, Tata-BP, Unitron	Exide, Machinocraft, Tata-BP, Unitron	Machinocraft, AEP	Machinocraft, AEP	Square Engg.	AEP
Principal	South West Windpower, USA	South West Windpower, USA	South West Windpower, USA	South West Windpower, USA	Bergey Windpower, USA	Bergey Windpower, USA	EOLTEC, France	Atlantic Orient, Canada
Rotor diameter (m)	1.15	3	3	4.65	2.5	7	5.5	15
Rotor swept area (m^2)	1.04	7.07	7.07	16.98	4.91	38.48	23.76	176.71
Cut-in wind speed (m/s)	3.1	3.1	3.1	2.5	2.5	3.6	2.8	4.6
Rated wind speed (m/s)	12.5	11	12	11	11	12.5	11	12
Cut-out wind speed (m/s)	13.5	21	21	21	23	23	23	22.4
Rated power (kW)	0.4	1	1.3	3.2	1	7.5	5	50

Base values of input parameters

Base values of input parameters used for techno-economic evaluation of small wind electric generators for decentralized power supply in India

Input parameter	Unit	Value
Annual maintenance cost of wind turbine system as a fraction of its capital cost	fraction	0.02
Discount rate	fraction	0.10
Efficiency of generator	fraction	0.90
Efficiency of inverter	fraction	0.90
Forced outage of wind electric generator	fraction	0.05
Losses in battery bank	fraction	0.10
Losses in LT distribution network	fraction	0.10
Unit cost of LT electricity distribution network	Rs./km	125,000
Useful life of battery bank	years	7
Useful life of civil work	years	20
Useful life of wind turbine controller and inverter	years	10
Useful life of LT electricity distribution network	years	20
Useful life of small wind electric generator	years	20

Locations of nineteen sites considered for SWEG Projects in this study on the map of India

Electricity delivered by a SWEG of 1 kW capacity at select locations

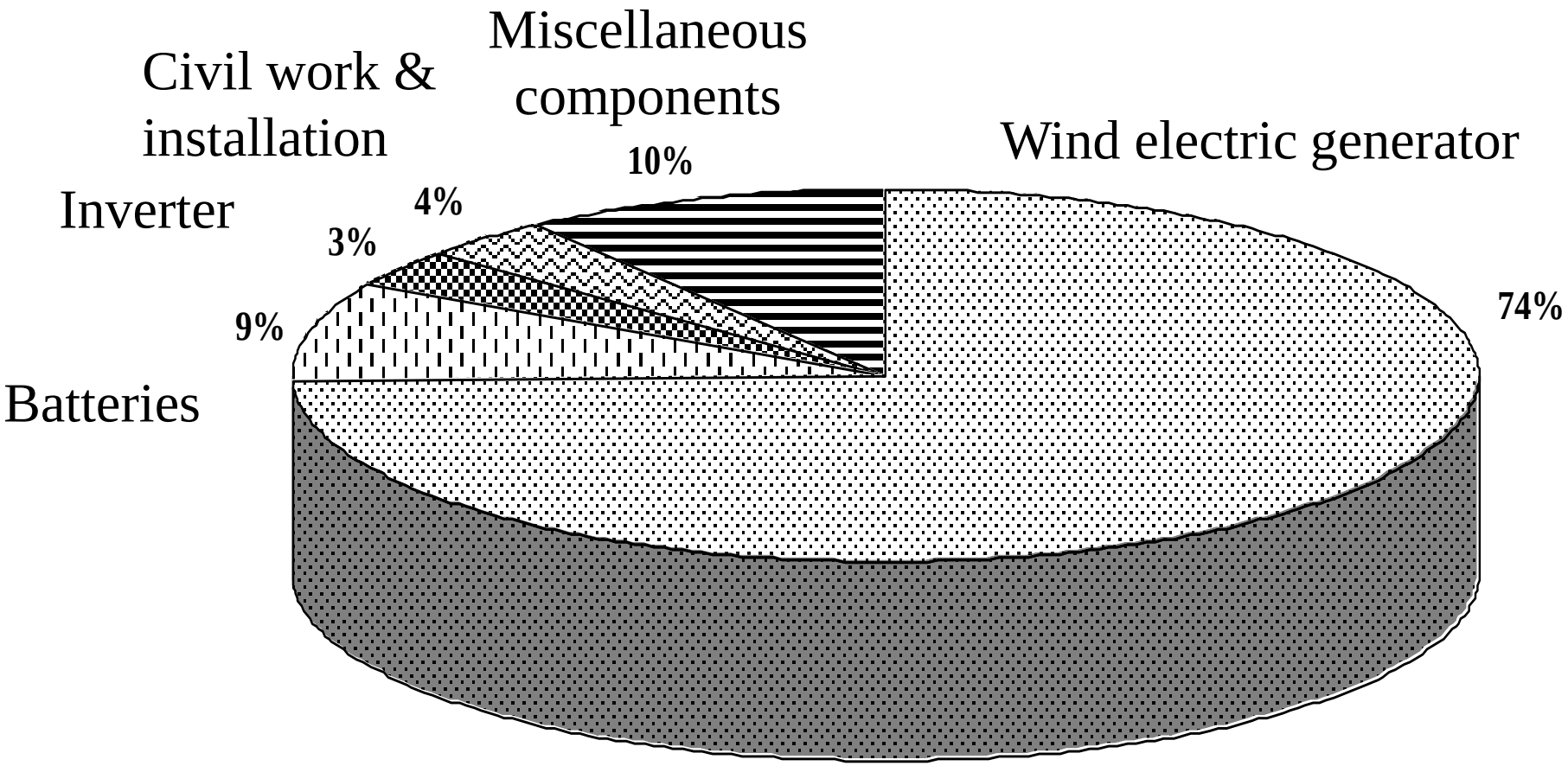
Name of location	Annual mean wind speed (m/s)	Energy delivered by SWEG* of 1 kW capacity (kWh)	LUCE from a 1 kW SWEG (Rs./kWh)
Ayikudy	5.95	1300	38.87
Bhadka	4.19	530	95.42
Bhimnupatnam	5.31	946	53.45
Chalkewadi	5.53	1093	46.24
Dahod	4.58	570	88.70
Dandi	4.03	362	139.66
Harshad	5.56	928	54.43
Jaisalmer	4.93	819	61.69
Kaipdar	4.30	604	83.64
Kakulkonda	6.67	1319	38.33
Kattadimlai	6.64	1460	34.63
Lonavla	4.31	599	84.36
Malwan	3.72	297	170.37
Muppandal	7.08	1769	28.57
Pachpadra	3.35	379	133.42
Panchgani	5.06	765	66.10
Ramanaidukandrika	4.37	474	106.65
Tirumala	5.68	993	50.90
Tuticorin	4.89	740	68.31

* For H80 model SWEG manufactured by Unitron

Cost details of SWEGs deployed in India

Site	Year of installation	Capacity of wind turbine (kW)	Numbers of wind turbines	Cost of wind turbine and tower (Rs.)	Cost of inverter (Rs.)	Cost of battery bank (Rs.)	Cost of misc. Components (Rs.)	Cost of civil work and installation (Rs.)	Total cost (Rs.)
Nikam & Nikam, Kolhapur	2003	0.4	1	60,000	9,408	24,800	18,800	8,400	121,408
Sinhagad Road, Dharyi, Pune	2004	0.4	1	49,637	9,408	25,200	11,900	5,000	101,145
Shri Gurudev Atmanusandhan B.A.T., Chandrapur	2004	1.0	1	203,000	9,408	50,400	5,600	10,500	278,908
Vasant Smruti, Thane	2004	1.0	1	210,000	10,000	30,000	40,000	30,000	320,000
PHC Pimpalkhuta, Nandurbar	2003	1.3	1	210,000	29,770	39,780	29,250	32,500	341,300
District Rural Development , Osmanabad	2003	1.3	1	260,000	19,500	19,500	52,000	39,000	390,000
Gram Panchayat, Gaughar, Ratnagiri	2004	1.3	1	226,000	16,250	39,000	42,500	26,000	349,750
Ashwini Hospital, Solapur	2003	3.2	1	463,000	113,500	160,000	132,000	62,000	930,500
Sai Children's Home, Saswad, Dist. Pune	2003	3.2	1	522,000	27,500	77,600	56,700	45,700	729,500
Shri Chaitanya Adhyatmik Dhyan Prasar Sanstha, Pune	2003	3.2	2	1,006,000	61,440	245,760	89,600	35,200	1,438,000
Shri Siddhivinayak temple, Ahmednagar	2004	3.2	1	565,000	55,000	128,780	83,000	15,600	847,380
Ulhas Nagar Municipal Corporation, Thane	2003	3.2	2	926,000	115,200	316,160	168,960	76,800	1,603,120
Zilla Parishad Office Building, Kolhapur	2003	3.2	2	695,640	194,500	207,000	78,540	110,700	1,286,380
Shri Shetra Bhagavangad, Ahmednagar	2004	5.0	2	1,956,000	84,000	225,000	260,000	100,000	2,625,000
J.G. Malhotra Development Trust, Dist. Pune	2003	7.5	1	1,230,000	116,250	356,250	165,000	300,000	2,167,500
Sagar Island	2003	50	8	26,838,800	Nil	Nil	2,408,136	6,146,000	35,392,936

Cost break up of a 5 kW SWEG project



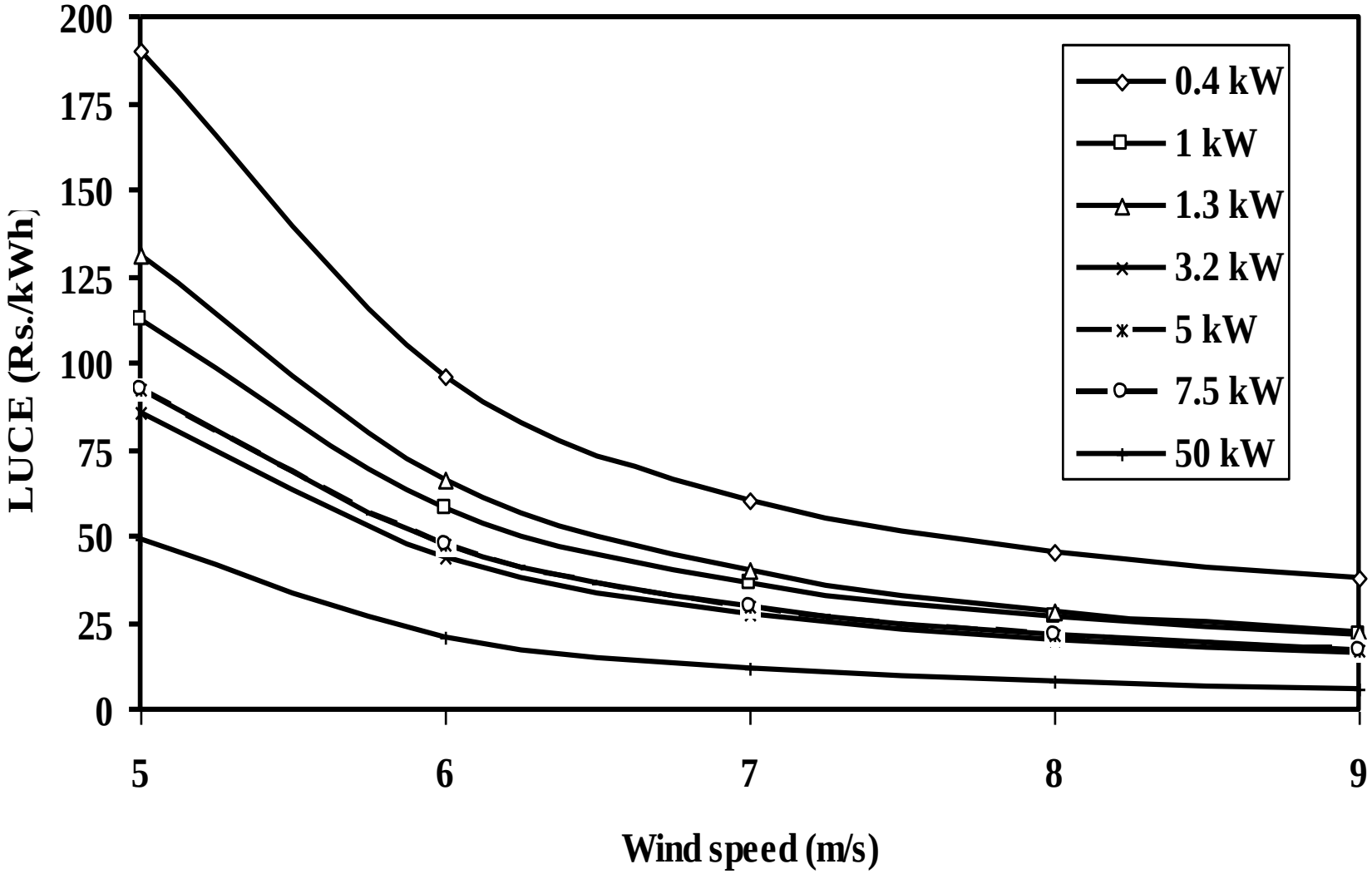
LUCE delivered by SWEGs at different annual mean wind speeds

Annual mean wind speed (m/s)	LUCE (Rs./kWh) for SWEG of capacity			
	3.2 kW	5 kW	7.5 kW	50 kW
4	85.68	92.21	176.38	49.27
5	44.17	47.53	83.02	20.91
6	27.96	30.09	49.04	11.97
7	20.37	21.91	33.69	8.19
8	16.36	17.53	25.72	6.30
9	14.09	14.99	21.19	5.27
10	12.77	13.45	18.49	4.67

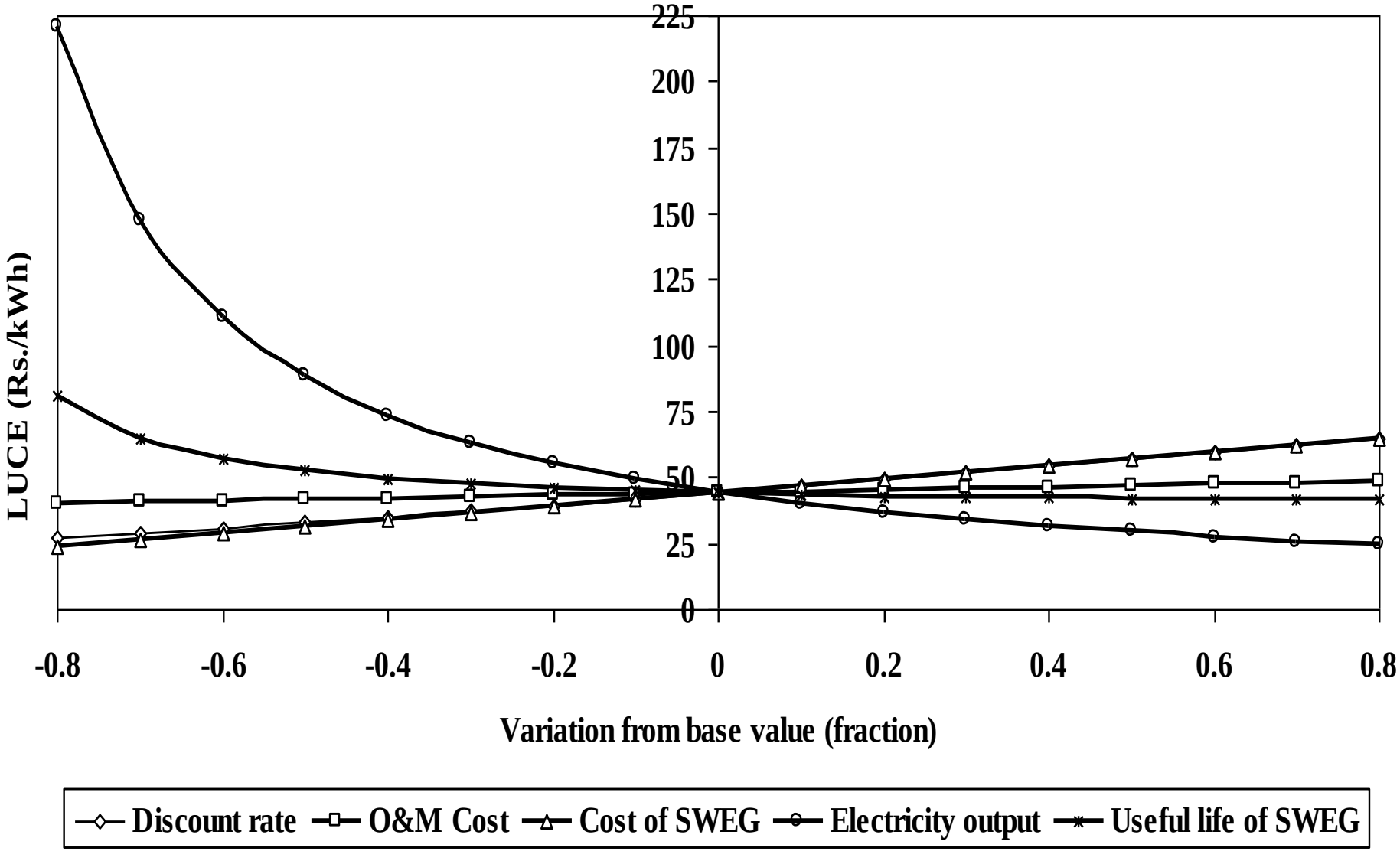
Effect of capital subsidy on LUCE for a 3.2 kW SWEG

Fraction of capital cost borne by the user	Annual mean wind speed (m/s)			% reduction in LUCE
	5	6	7	
	LUCE	LUCE	LUCE	
1.0	44.17	27.96	20.37	-
0.9	40.27	25.49	18.58	8.82
0.8	36.38	23.03	16.78	17.63
0.7	32.49	20.57	14.99	26.44
0.6	28.59	18.10	13.19	35.27
0.5	24.70	15.64	11.40	44.08
0.4	20.81	13.17	9.60	52.88
0.3	16.92	10.71	7.80	61.69
0.2	13.02	8.24	6.01	70.52
0.1	9.13	5.78	4.21	79.33
0	5.24	3.32	2.42	88.14

Effect of annual mean wind speed on LUCE of SWEG



Sensitivity of LUCE for a 3.2 kW SWEG project (annual mean wind speed of 6 m/s)



Conclusions emerging from Section-VI

- **Annual delivered electrical power output of 1 kW SWEG project found to vary in the range of 765 – 1770 kWh for locations having the annual mean wind speed of more than 5 m/s**

- **SWEG project may not be viable at locations having annual mean wind speed of about 5 m/s or less**

- **1 kW SWEG project at Panchgani (with annual mean wind speed of about 5 m/s), Ayikudy (about 6 m/s) and Muppandal (7 m/s) is expected to have capacity utilization factors of about 8.73%, 14.84% and 20.19% respectively.**

Conclusions emerging from Section –VI (contd.)

- **Average installed unit cost of the SWEG projects (1 kW to 7.5 kW) including storage batteries is in the range of Rs. 164,000 to Rs. 206,500 (US$ 3600 to US$ 4535) which is higher as compared to international unit costs**

- **LUCE from the SWEG projects of the 3.2 kW capacity at locations having the annual mean wind speed of 6 m/s to 10 m/s is in the range of Rs. 27.96/kWh to Rs. 12.77/kWh**

Section-VII

Comparison of Options for Decentralized Electricity Supply in India and Identification of Niche Areas

Estimated Average Electrical Load of Households in Remote Areas

Load	No. of units	Wattage (W)	Coverage (fraction)	Connected load (W)
Domestic lighting	3	40	1	120
Street lights	1	40	0.5	20
Fans for cooling	1	100	0.5	50
Refrigeration	1	250	0.15	37.5
Television	1	200	0.316	63.2
Transistor	1	5	0.351	1.755
Water pumping	1	3730	0.1	373
Other loads	1	100	0.1	10
Estimated average electrical load of household (kW)				0.675

Unelectrified villages in undivided UP with connected electric load of less than 100 kW

NAME OF DISTRICT	Up to 10	10 - 20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
UTTARKASHI	32	37	28	19	11	5	5	2	2	1
CHAMOLI	237	91	84	56	38	21	17	13	6	10
TEHRI GARHWAL	234	184	118	103	61	53	25	26	8	7
DEHRADUN	31	25	11	5	2	2	1	0	0	0
GARHWAL	755	418	209	128	80	48	36	16	8	8
PITHORAGARH	391	249	148	105	53	58	24	25	14	7
ALMORA	380	221	158	101	62	47	30	16	8	9
NAINITAL	74	38	22	22	13	15	3	4	4	1
BIJNOR	741	27	17	26	19	14	9	11	11	9
MORADABAD	486	22	15	36	28	35	27	34	22	26
RAMPUR	55	8	13	27	23	18	16	16	10	10
SAHARANPUR	262	7	13	3	8	9	12	7	7	6
HARDWAR	135	3	7	3	5	4	2	3	2	3
MUZAFFARNAGAR	146	3	7	4	1	4	1	1	3	0
MEERUT	94	0	1	0	1	3	0	2	1	2
GHAZIABAD	0	0	0	0	0	0	0	0	0	0
BULANDSHAHR	0	0	0	0	0	0	0	0	0	0
ALIGARH	9	4	4	2	2	3	8	4	4	2
MATHURA	160	11	8	11	14	12	10	14	9	2
AGRA	37	8	10	19	18	12	13	19	20	11
FIROZABAD	24	13	9	9	13	14	9	9	6	5
ETAH	92	18	21	34	36	39	24	33	21	20
MAINPURI	40	14	20	21	18	20	14	10	10	9
BUDAUN	313	24	42	46	43	63	49	45	40	45
BAREILLY	256	48	73	81	58	85	51	45	24	35
PILIBHIT	182	25	25	44	44	44	46	37	29	29
SHAHJAHANPUR	356	89	92	131	111	123	96	86	69	50
KHERI	104	29	26	44	50	49	44	33	28	32
SITAPUR	53	60	59	115	105	96	94	94	82	72
HARDOI	119	48	53	85	86	83	76	68	68	60
UNNAO	122	27	42	66	75	72	68	76	61	62
LUCKNOW	9	3	7	10	11	8	6	4	8	2

Unelectrified villages in undivided UP with connected electric load of less than 100 kW (contd.)

NAME OF DISTRICT	Up to 10	10 - 20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
FARRUKHABAD	198	35	40	34	50	37	53	35	22	25
ETAWAH	92	29	36	54	51	34	40	51	29	41
KANPUR (DEHAT)	147	27	40	52	65	60	58	67	67	41
KANPUR (NAGAR)	31	1	6	3	3	6	3	8	2	4
JALAUN	226	43	25	44	30	30	33	42	13	18
JHANSI	92	14	22	26	23	25	12	121	21	14
LALITPUR	99	29	32	43	27	34	37	29	25	16
HAMIRPUR	249	28	40	33	27	27	18	23	19	25
BANDA	183	46	32	48	29	33	18	38	21	25
FATEHPUR	174	32	43	48	41	31	34	32	18	21
PRATAPGARH	60	52	54	74	59	59	63	50	31	25
ALLAHABAD	492	69	62	64	55	48	39	44	46	30
BAHRAICH	65	39	37	48	49	33	56	56	46	32
GONDA	51	65	75	84	89	92	71	74	68	62
BARABANKI	52	45	45	69	103	94	58	68	70	54
FAIZABAD	157	36	52	38	38	34	26	23	18	16
SULTANPUR	38	9	6	5	11	6	7	1	3	2
SIDDHARTHNAGAR	321	141	169	231	179	157	117	107	82	80
MAHARAJGANJ	76	25	16	24	35	24	21	26	28	24
BASTI	669	311	336	286	217	198	163	107	59	49
GORAKHPUR	596	145	87	101	77	73	55	34	31	22
DEORIA	329	94	72	98	110	80	76	60	53	45
MAU	45	2	1	6	2	1	1	2	0	1
AZAMGARH	495	109	66	47	40	34	20	18	14	11
JAUNPUR	164	54	60	31	33	32	28	26	27	16
BALLIA	599	45	30	25	18	14	8	11	6	6
GHAZIPUR	765	32	27	13	13	8	5	5	4	3
VARANASI	536	71	49	46	47	33	19	36	23	13
MIRZAPUR	353	98	73	85	55	55	49	37	34	33
SONBHADRA	218	98	110	112	75	59	44	38	24	18
TOTAL	13564	3585	3092	3228	2748	2519	2050	2026	1491	1310
Fraction of total with load up to 100	0.38	0.10	0.09	0.09	0.08	0.07	0.06	0.06	0.04	0.04

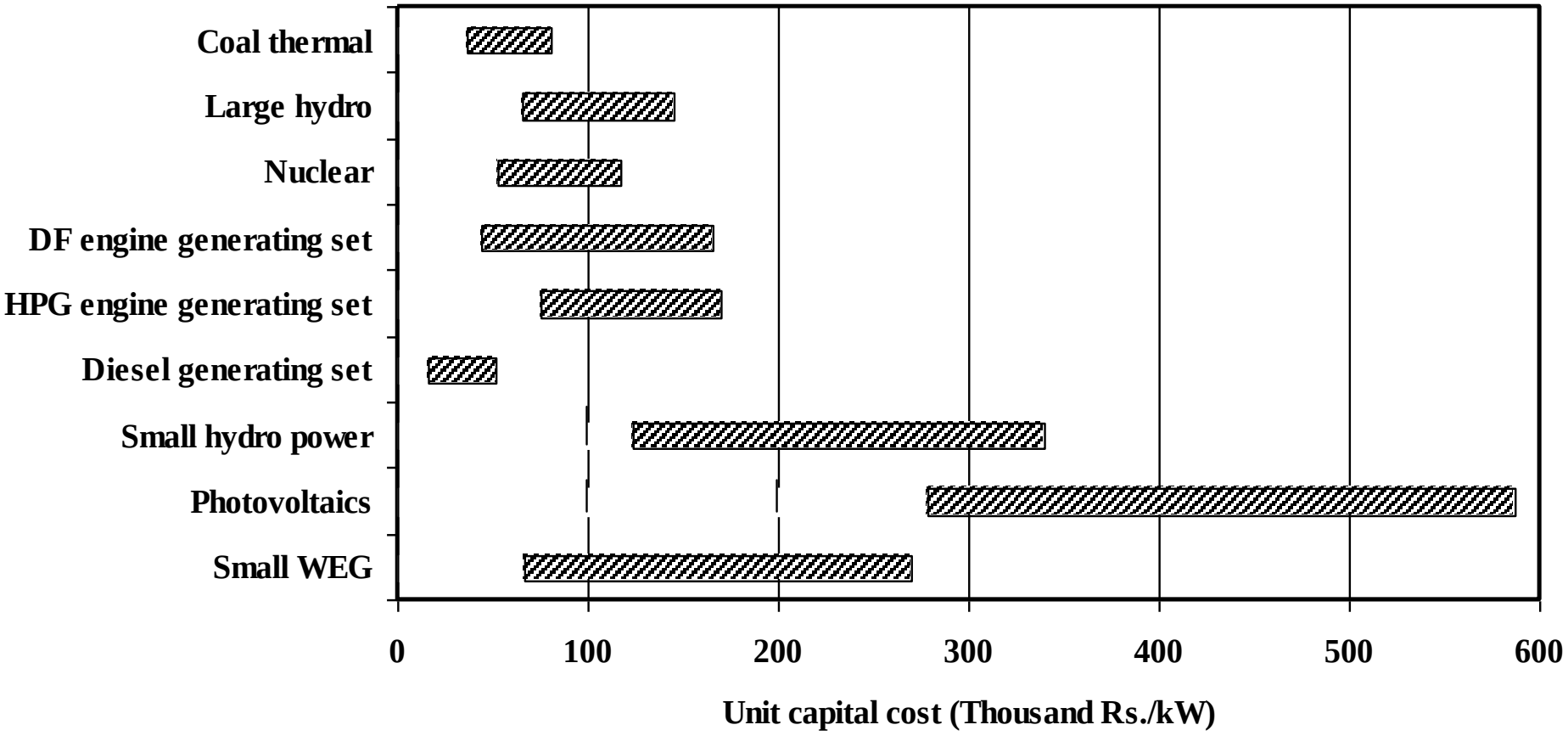
Unelectrified villages in undivided Bihar with connected electric load of less than 100 kW

Name of District	up to 10	10 to 20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
PATNA	1	6	12	17	10	17	11	19	12	7
NALANDA	1	5	7	7	11	14	7	6	6	4
BHOJPUR	51	81	71	81	71	68	59	55	34	37
ROHTAS	125	158	147	146	144	109	89	92	65	48
AURANGABAD	44	67	108	94	67	67	51	39	28	18
JEHANABAD	7	11	20	28	16	14	15	17	9	11
GAYA	96	132	126	154	131	102	87	66	55	47
NAWADA	11	18	24	24	19	21	14	16	9	8
SARAN	5	77	44	54	48	59	48	62	54	60
SIWAN	45	45	64	81	74	74	66	65	57	46
GOPALGANJ	54	79	70	72	71	68	60	57	48	37
PASHCHIM CHAMPARAN	25	42	51	51	71	54	50	63	46	48
PURBA CHAMPARAN	14	27	22	38	24	43	32	35	34	30
SITAMARHI	7	15	16	10	12	17	24	37	14	23
MUZAFFARPUR	30	35	33	45	36	39	36	42	30	31
VAISHALI	46	46	56	37	35	23	38	21	24	29
BEGUSARAI	21	18	14	12	43	10	13	12	2	3
SAMASTIPUR	24	28	23	28	22	34	15	14	27	19
DARBHANGA	19	16	27	32	26	23	21	22	30	19
MADHUBANI	12	16	15	19	18	18	20	18	26	21
SAHARSA	10	22	19	19	20	18	23	20	20	16
MADHEPURA	8	11	9	7	8	8	5	4	2	2
PURNIA	47	56	50	41	40	43	44	33	25	22
KATIHAR	46	54	66	64	54	73	38	46	35	47
KHAGARIA	0	3	2	1	2	2	1	3	1	6
MUNGER	197	224	156	136	102	87	62	48	47	57
BHAGALPUR	173	233	181	148	101	82	76	68	48	30

Unelectrified villages in undivided Bihar with connected electric load of less than 100 kW (contd.)

Name of District	up to 10	10 - 20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
SAHIBGANJ	324	414	396	120	160	245	5	104	64	45
DUMKA	298	642	567	512	365	312	182	148	122	113
DEOGHAR	356	409	307	257	151	90	80	70	36	28
DHANBAD	59	107	86	82	69	61	53	38	36	26
GIRIDIH	271	382	299	269	192	168	113	78	73	57
HAZARIBAG	357	381	320	260	223	67	241	125	85	74
PALAMU	264	274	252	246	219	172	154	28	207	108
LOHARDAGA	8	21	26	32	13	16	11	16	9	10
GUMLA	17	58	85	122	117	111	109	82	91	78
RANCHI	50	119	169	180	168	147	117	105	90	82
PURBI SINGHBHUM	103	153	147	148	113	99	81	63	47	42
PASHCHIMI SINGHBHUM	125	258	272	251	234	220	166	149	106	108
ARARIA	14	16	27	10	9	20	23	20	11	18
KISHANGANJ	23	34	40	30	34	39	21	32	22	31
Total	3588	5005	4537	4146	3438	3047	2423	2109	1844	1585
Fraction of villages with electrical load	0.11	0.16	0.14	0.13	0.11	0.10	0.08	0.07	0.06	0.05

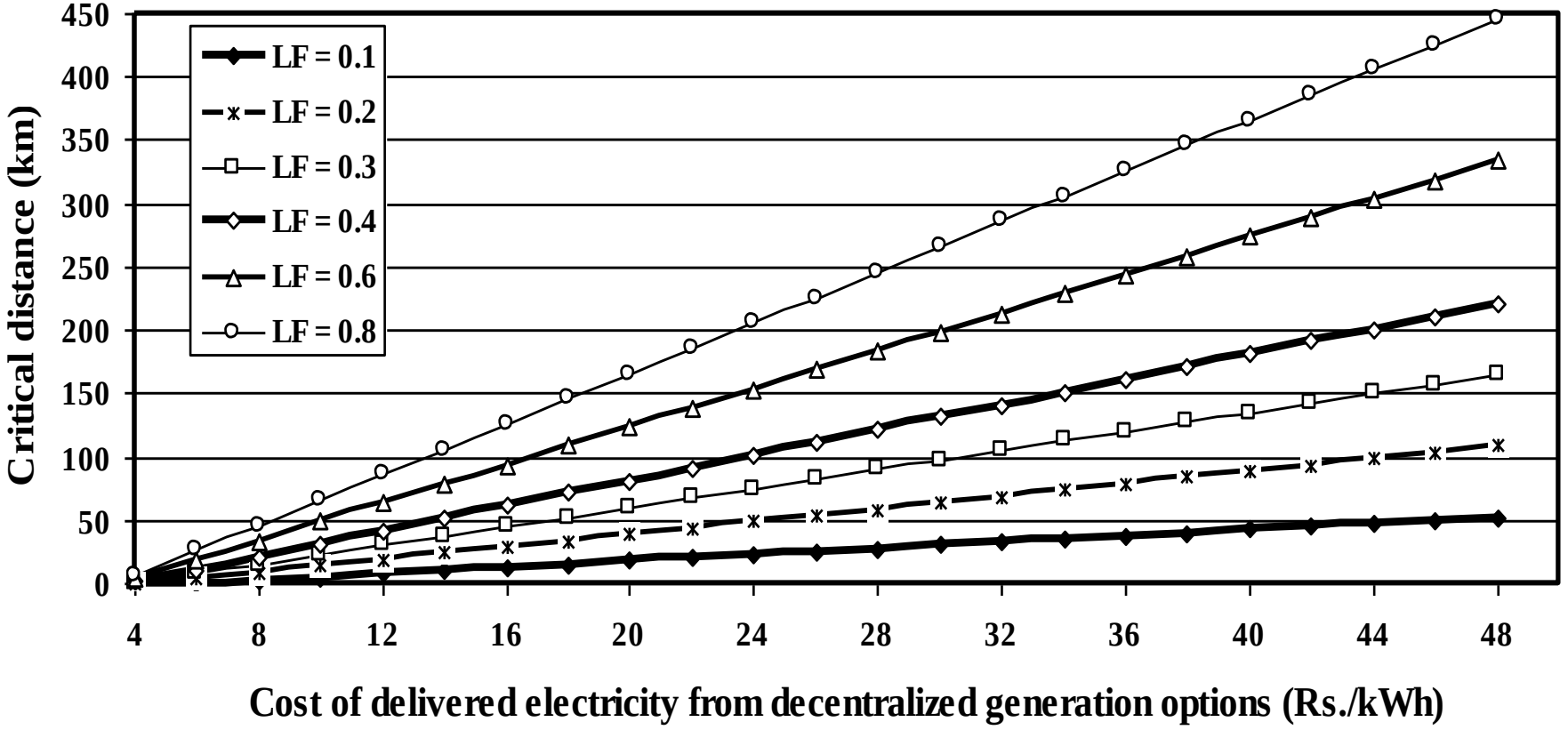
A Comparison of the unit capital cost of different electricity generating technologies



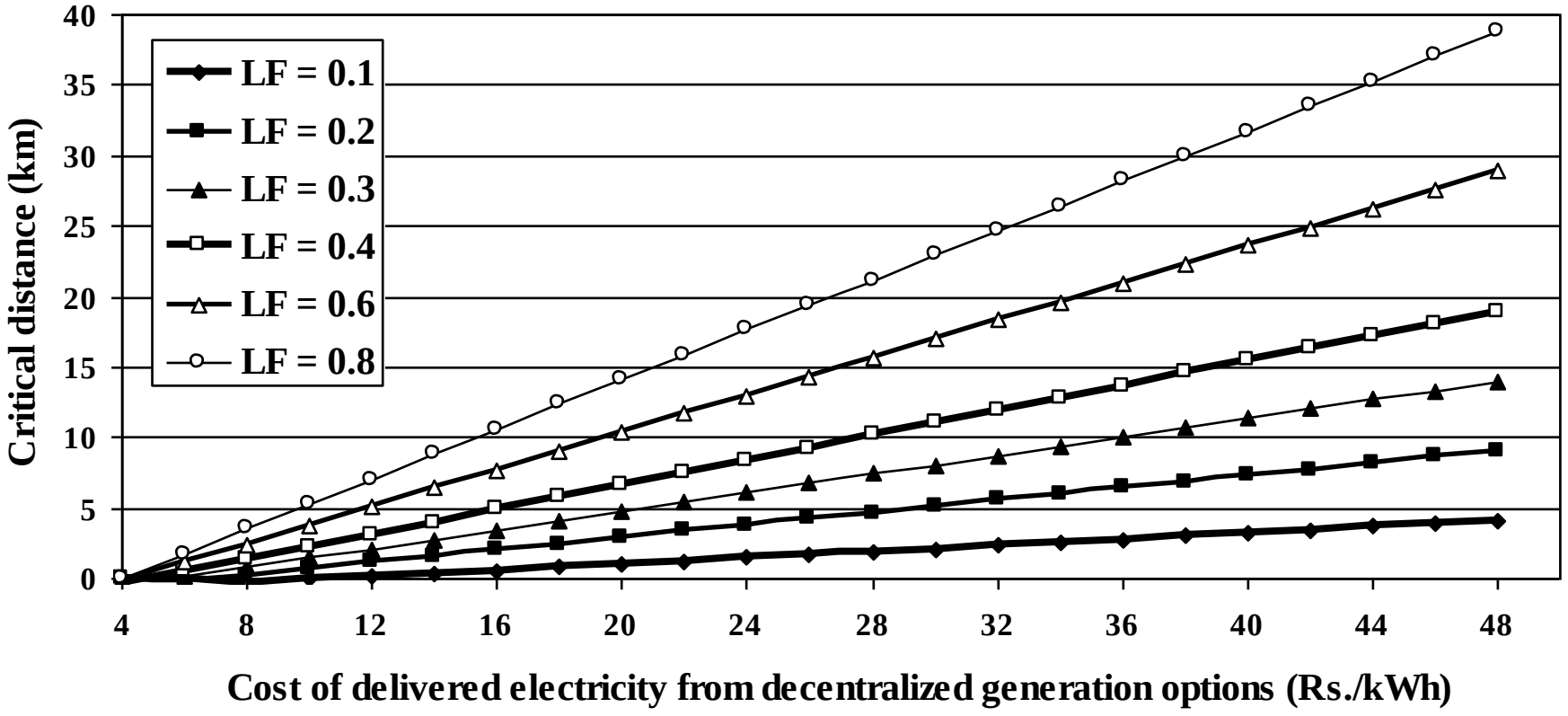
Unit capital cost & LUCE of some decentralized electricity generation technologies

S. No.	Name of technology	Range of unit capacity of technology (kW)	Range of unit capital cost of technology (Rs./kW)	Estimated range of levelised unit cost of electricity (Rs./kWh)
1.	Biomass gasifiers			
a.	Dual fuel engine system	5-40	122,000-44,000	25.00-13.14
b.	100% producer gas engine system	9-40	95,000-75,000	18.53-15.02
2.	Diesel generating set	5-40	35,000-16,500	21.38-13.51
3.	Small hydro power	10-50	130,000-233,000	6.01-10.25
4.	Photovoltaic system	2.5-25.0	308,000-279,000	47.14-29.26
5.	Small wind electricity generators	1-50	203,000-67,000	44.17-6.30

Critical distance of grid extension for delivered electricity from decentralized option in plain areas – 25 kW load



Critical distance of grid extension for delivered electricity from decentralized option in hilly areas – 25 kW load



Conclusions emerging from Section-VII

- **Results of the calculations made indicates that all renewable energy based decentralized electricity supply options considered in this study (such as micro hydro, dual fuel biomass gasifier systems, small wind electricity generators and photovoltaic) could be financially attractive as compared to grid extension for providing electricity in small and remote villages under certain conditions**
- **Micro hydro appears to the best option for hilly areas subject to availability of the resource**

Conclusions emerging from Section-VII (contd.)

- **Dual-fuel biomass gasifier based decentralized electricity generating units are the second best option for providing electricity in remote villages (subject to availability of biomass on a sustainable basis)**
- **PV and small wind electricity generators could be suited for providing electricity for lighting and powering televisions and transistor radios to small villages with households population of about 20 or less in remote and inaccessible areas**

Thank you

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