



Diffusion of Renewable Energy

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Outline

- Technology forecasting, Diffusion models
- Example for Solar Water Heaters in Pune
- Results for Pune
- Extrapolation for India
- Conclusions



Problem Context

- Transition from fossil to renewable
- Potential Estimation
- Decide Feasible growth rates
- Set targets



Technology Forecasting

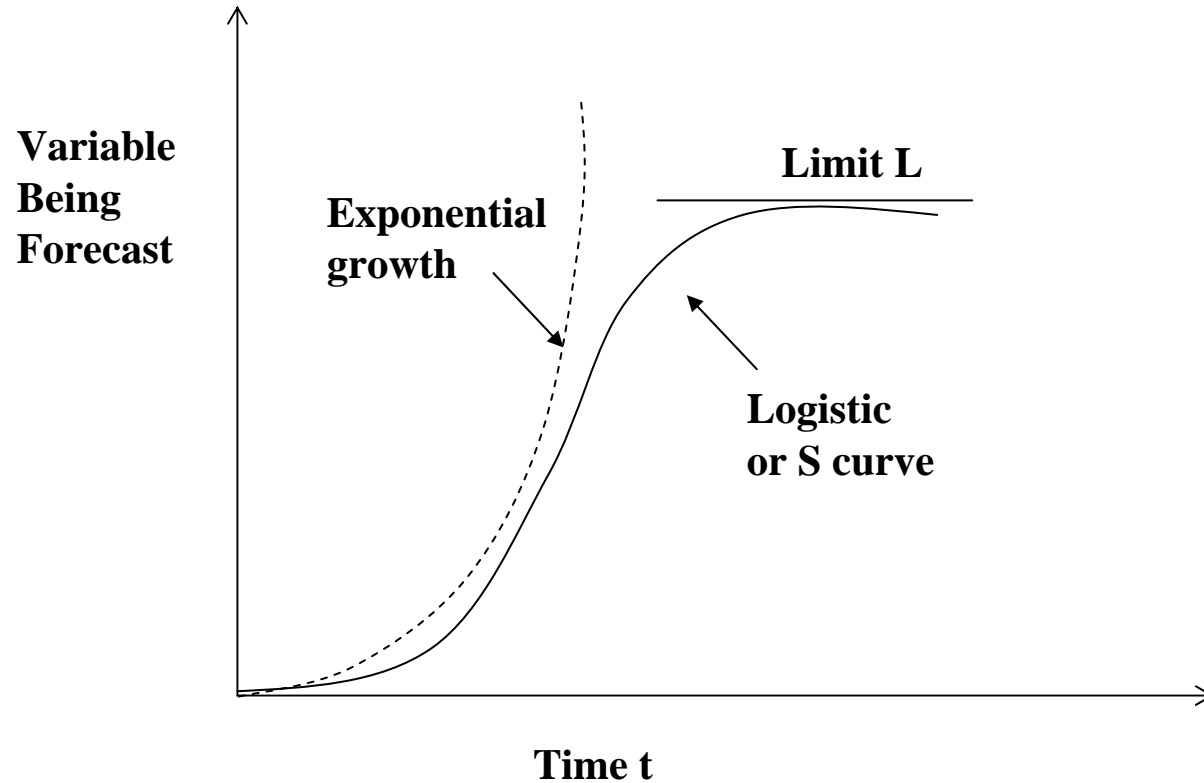
- Trend Extrapolation
- Growth Curve - limitless growth
 $y = y_0 e^{kt}$ (y_0, k - from data)
competitors trying to outdo others
- Co-efficients - obtained by regression -
report t, F statistic & uncertainty
limits.



Technology Forecasting

- Often growth limited by constraints
- Pearl Curve $y = L/(1 + ae^{-bt})$
 - S shaped Logistic Curve
 - Symmetric about point of inflection

Macro –Level Diffusion Models



Growth curves (Linstone and Sahal, 1976)



Technology Diffusion

- Even if new technology better - will not reach 100% acceptance :
postponement of acceptance,
supply bottlenecks,
information gaps



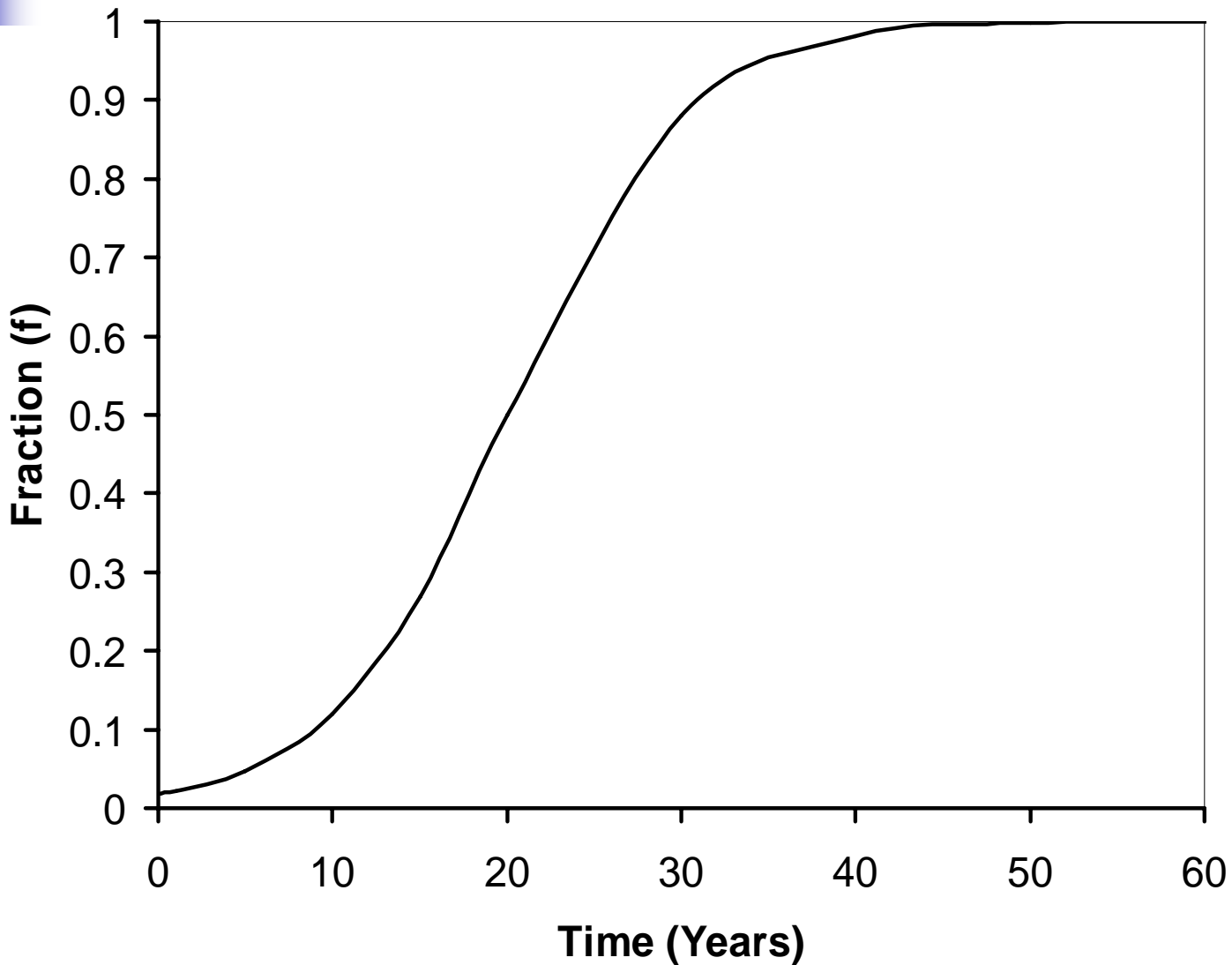
Fisher-Pry Model

- Fisher-Pry model for substitution
- $df/dt = bf(1-f)$

where f is the fractional market share
of the new improved technology

- $\ln(f/(1-f)) = a + bt$
where a, b are constants

Fisher-Pry Curve

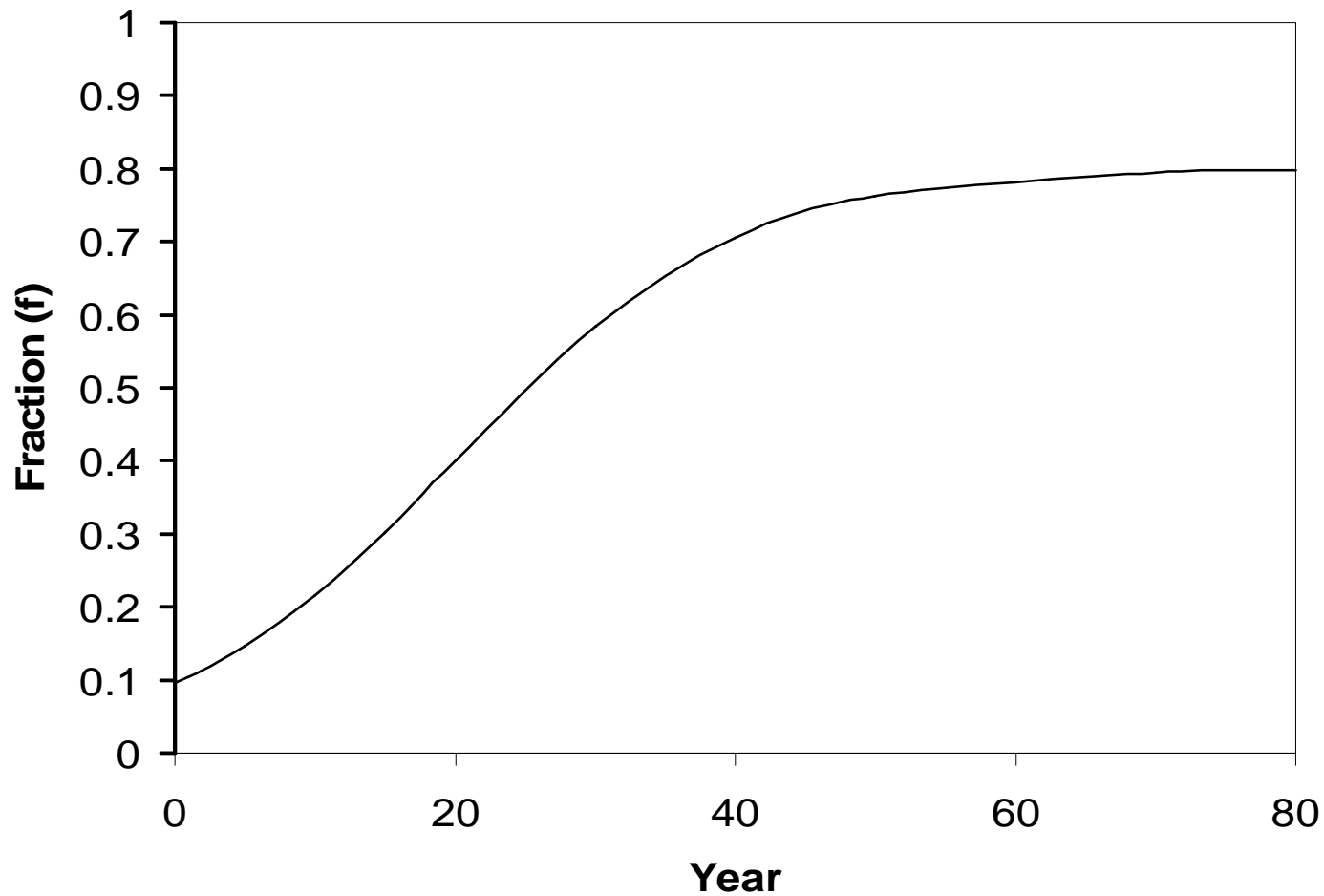


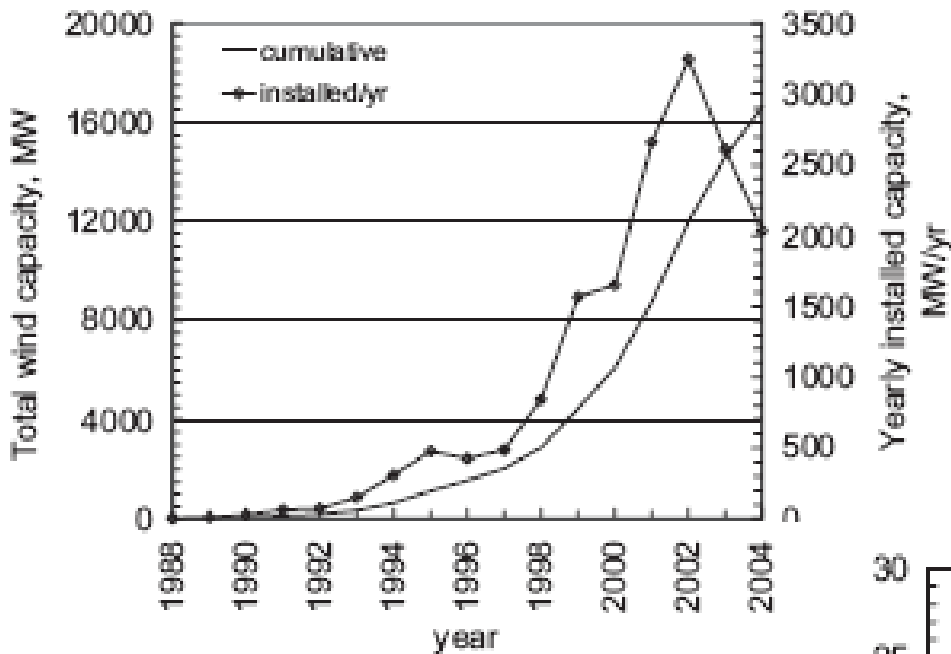


Blackman's Model

- Blackman's model –
Final market share not 100% but F
 $\ln (f/(F-f)) = a + bt$
Determine a, b by method of least square (regression) with initial substitution data
a,b by analogy

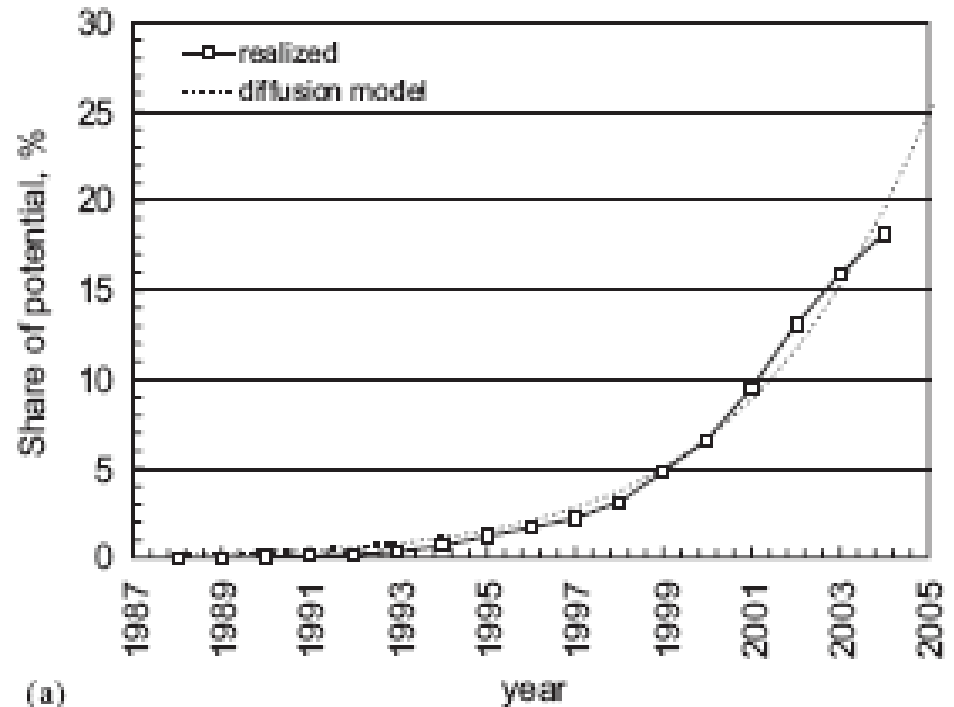
Blackman Curve





Penetration of Wind Energy in Germany

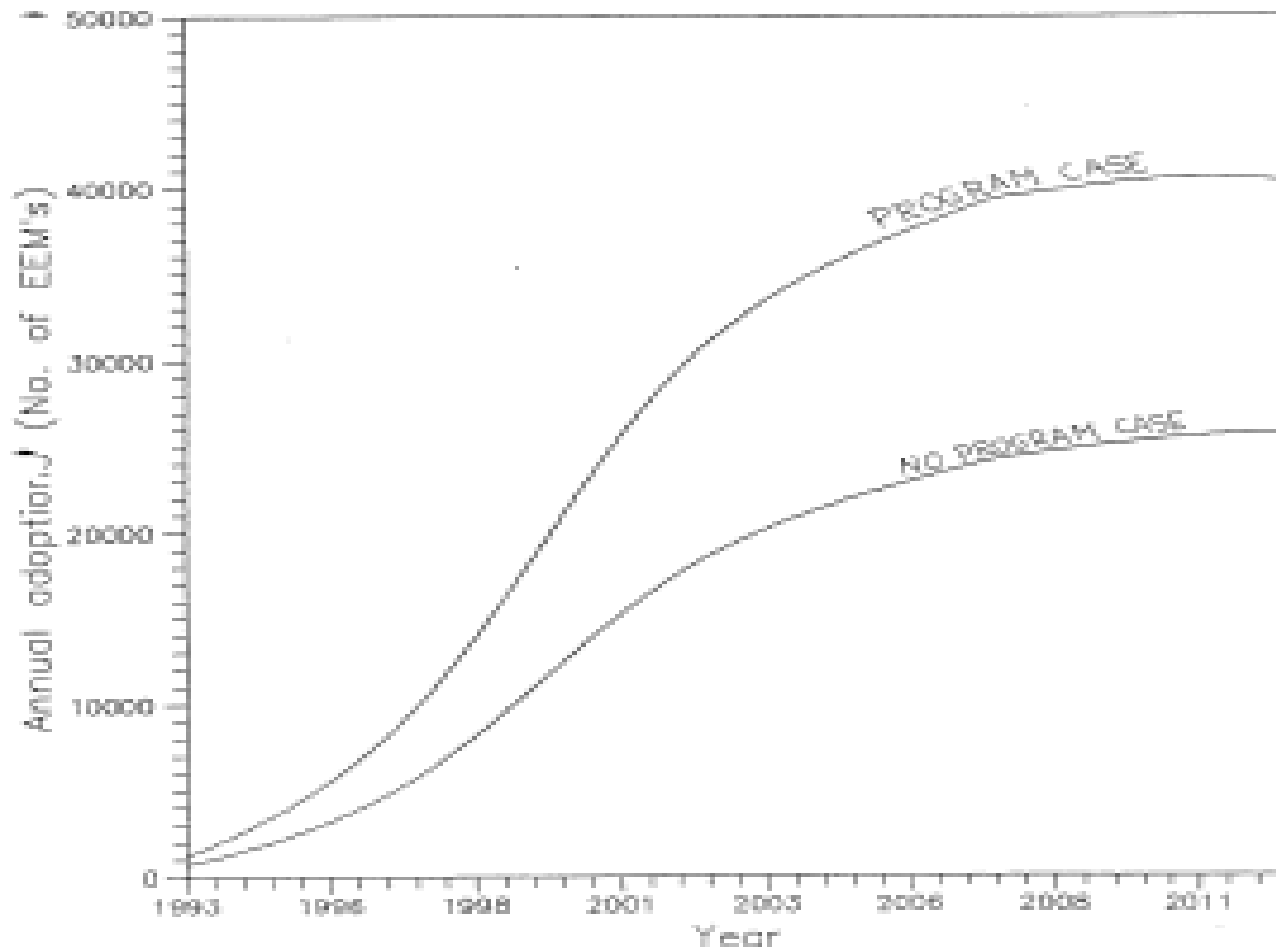
Source:
Peter Lund, Energy Policy,
34, No17, 2006



(a)

Accelerated Diffusion

Figure 1. Diffusion of Energy Efficient motors





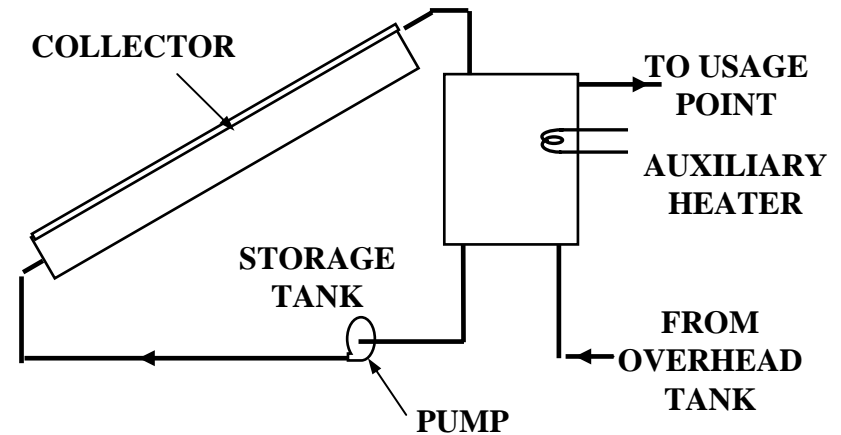
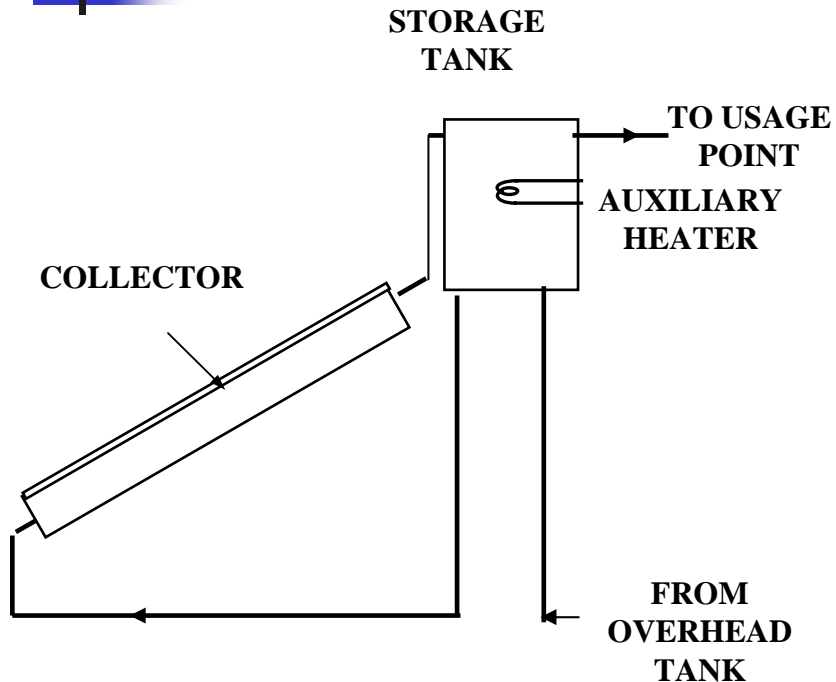
Solar Water Heaters

- Estimate potential for solar water heaters in a given area
- Develop generic framework
- On-going Ph.D. project of Indu R. Pillai

‘Diffusion of Renewable Energy Technologies’

Indu R. Pillai and Rangan Banerjee “Methodology for estimation of potential for solar water heating in a target area”, *Solar Energy, In Press, Available online 5 June 2006,*

Solar Water Heating System



Schematic of solar water heating system

♦ Solar Water Heating Systems in India

- Estimated Potential = 140million sq.m.(Basis not known)
- Installed Capacity = 1.5 million sq. m. (0.8% of estimated potential)



Diffusion Process

Micro-level decision model
(Decision of single user* or beneficiary to adopt or not)



Integration of multiple users to form aggregate market



Macro-level diffusion model
(Aggregate market and diffusion of product with respect to potential)

Potential Estimation



Estimated Potential



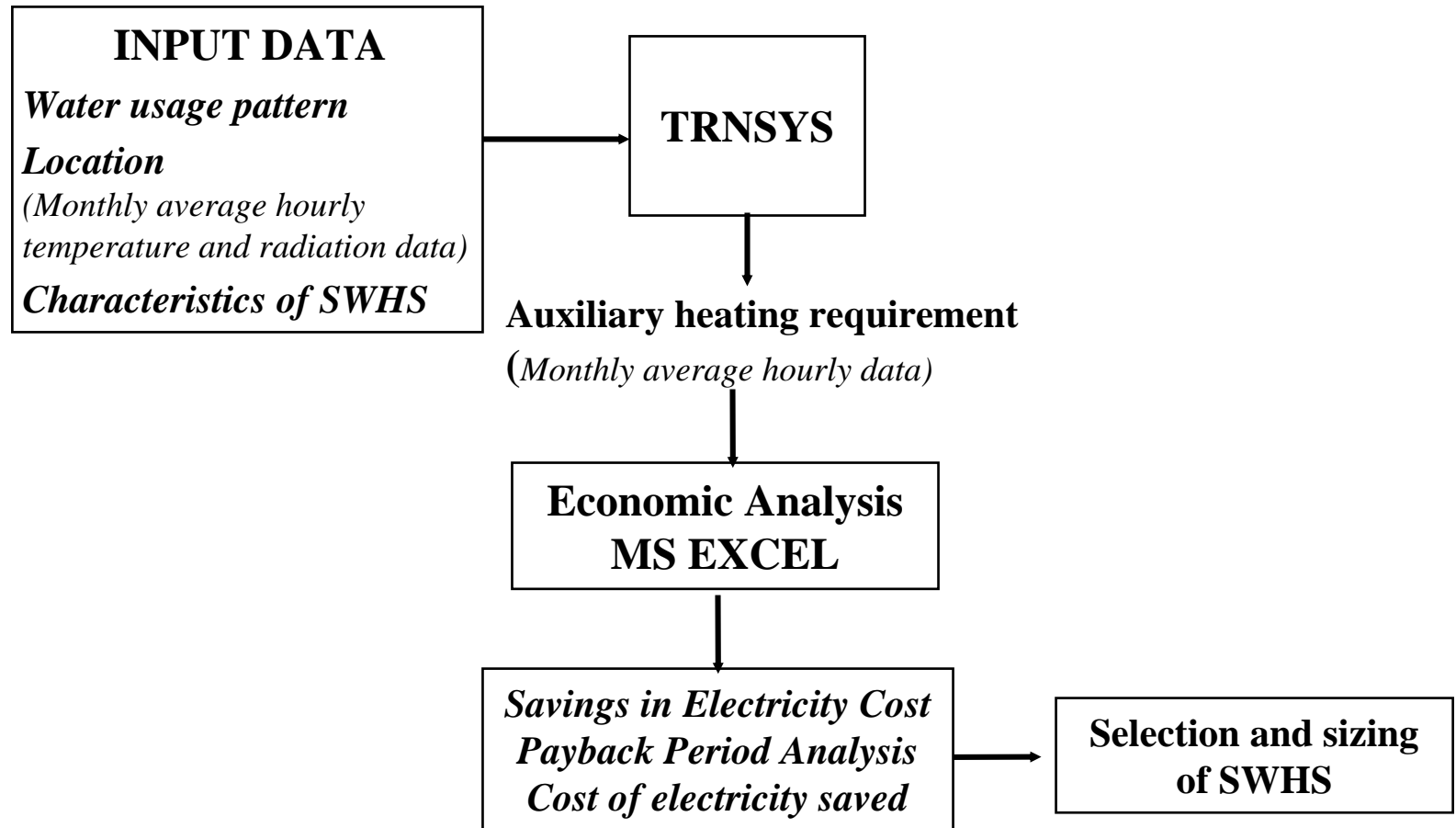
**Single user may be a person, a household, a society, an institution or an industry*



Factors Affecting Diffusion Of SWHS

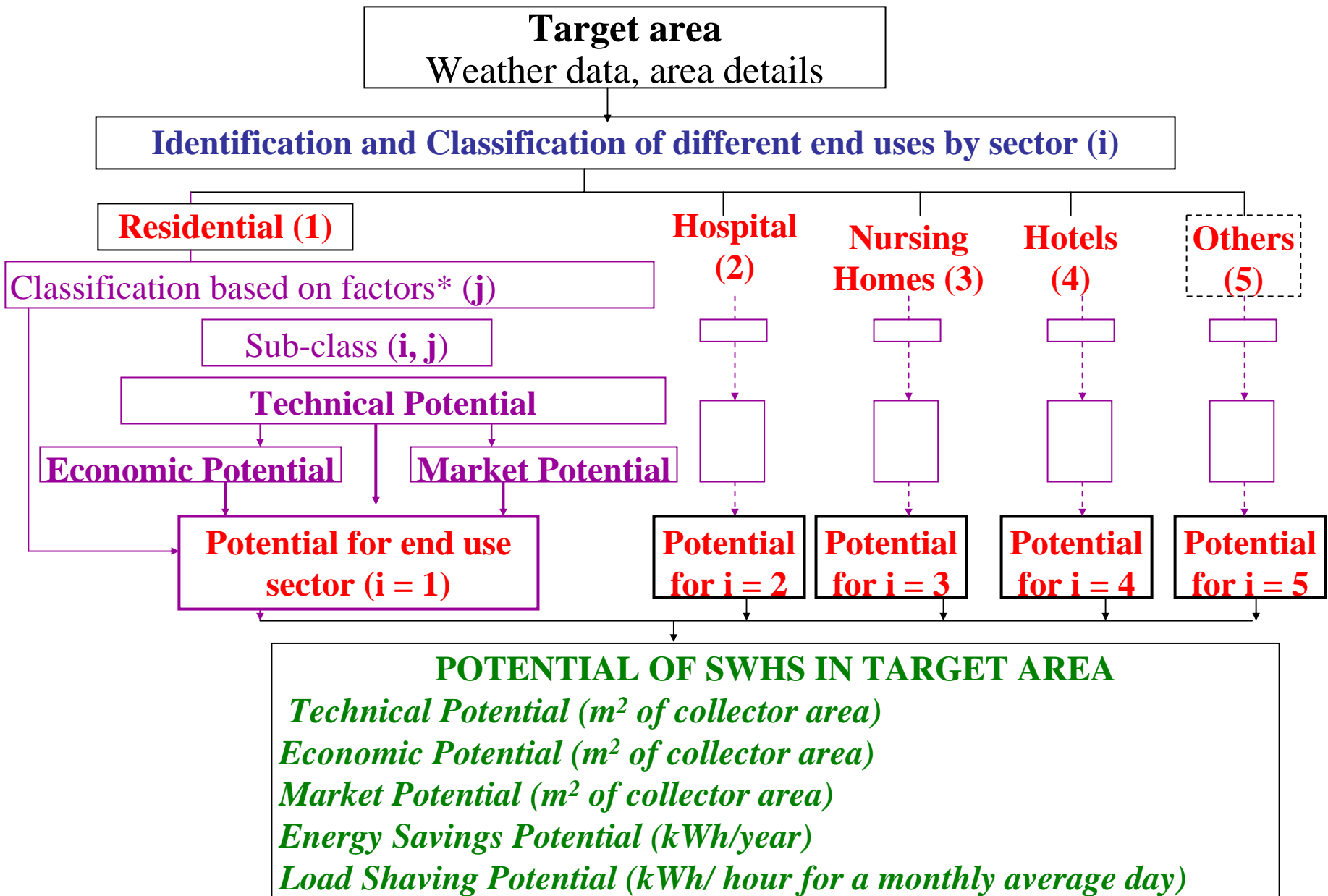
- Location- Insolation
- Water Usage Pattern
- Cost of electricity
- Capital Cost
- Reliability
- Potential savings
- Subsidies/ Financial Incentives

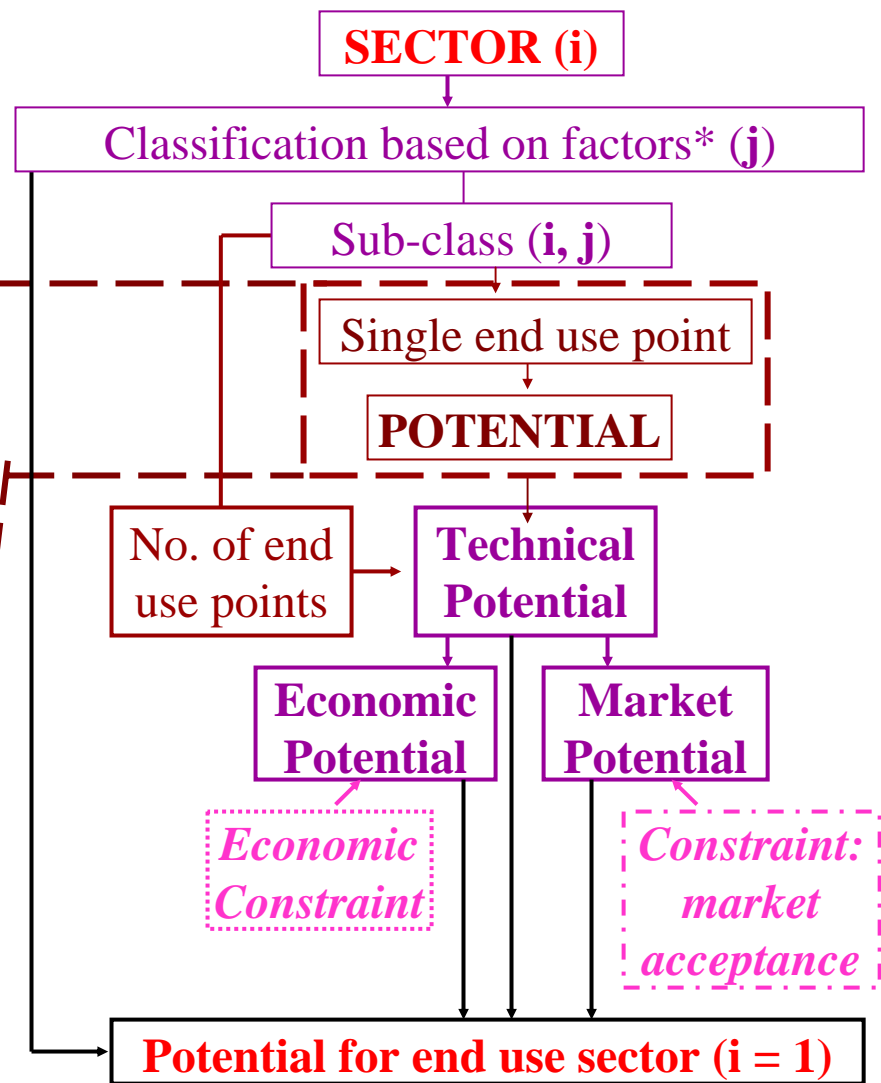
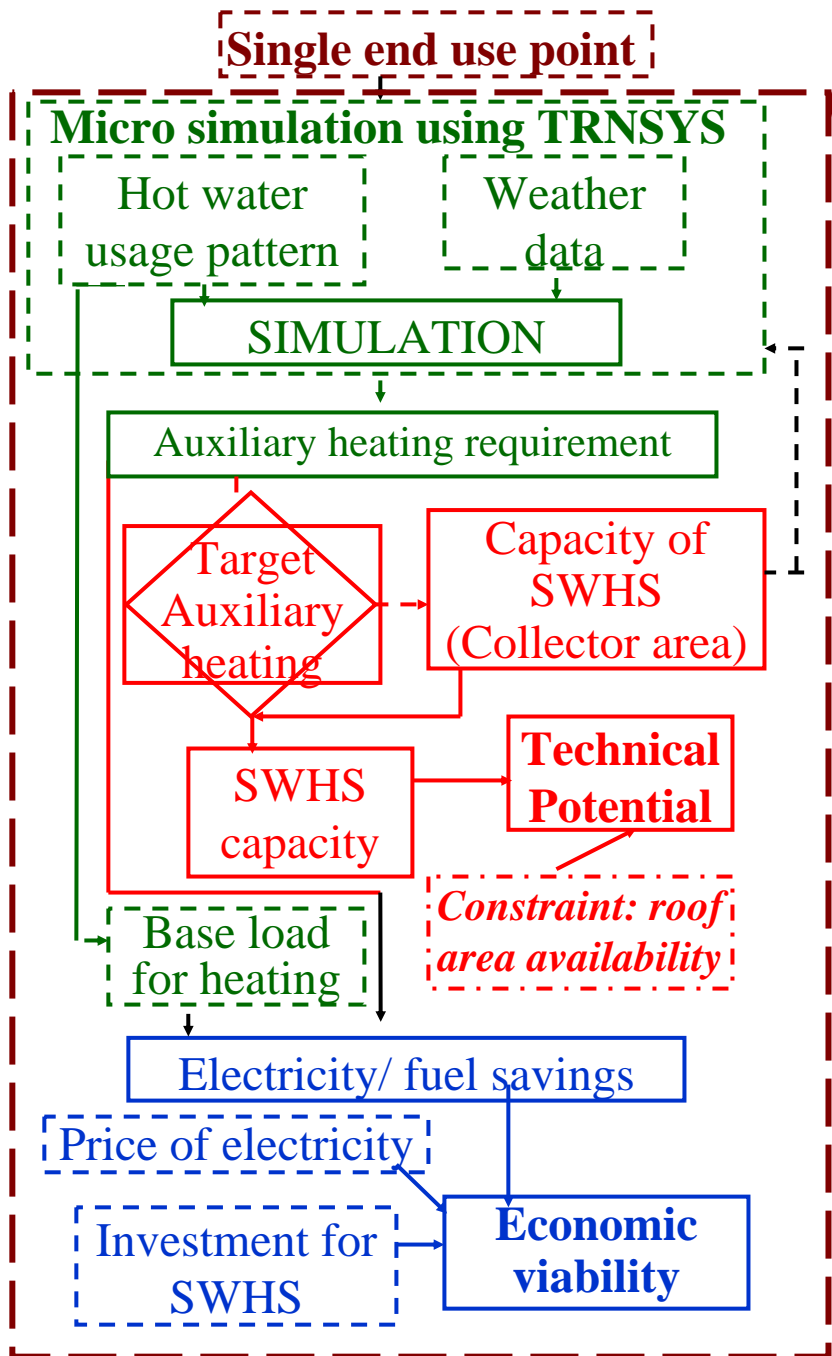
Micro Level Decision Model (Parametric Analysis)



TRNSYS (Transient System Simulation Program developed at SEL, University of Wisconsin)

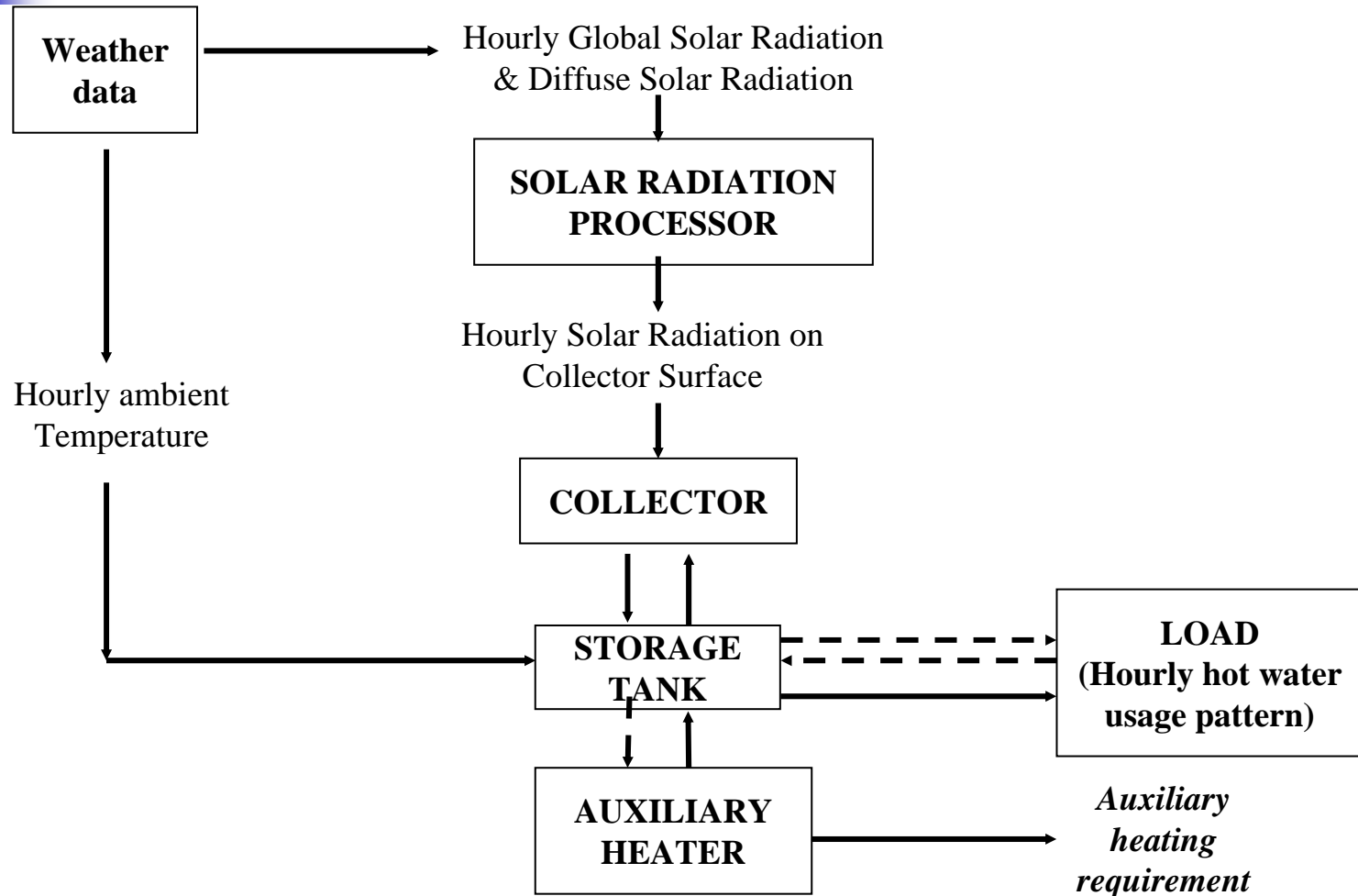
Model for Potential Estimation of Target Area





* Factors affecting the adoption/sizing of solar water heating systems

Information Flow Diagram of Micro –simulation for SWHS





Potential Of SWHS

Technical potential P_{ij} for sub-class j in sector i is

$$P_{ij} = f_j f_{aj} N_i P_{sj}$$

where j denotes sub-class of end use points in sector i .

P_{sj} is the simulation output for a single end use point

f_j denotes fraction of the end uses

m is the total number of sub-classes.

f_{aj} is fraction of roof area availability

N_i is the number of end uses points in sector i

Technical Potential for sector i is

$$P_i = \sum_{j=1}^m P_{ij} \text{ where } i \text{ denotes sector}$$

Technical Potential of SWHS $P(T)$ in the target area is

$$P(T) = \sum P_i$$



Economic Potential

Economic potential of SWHS

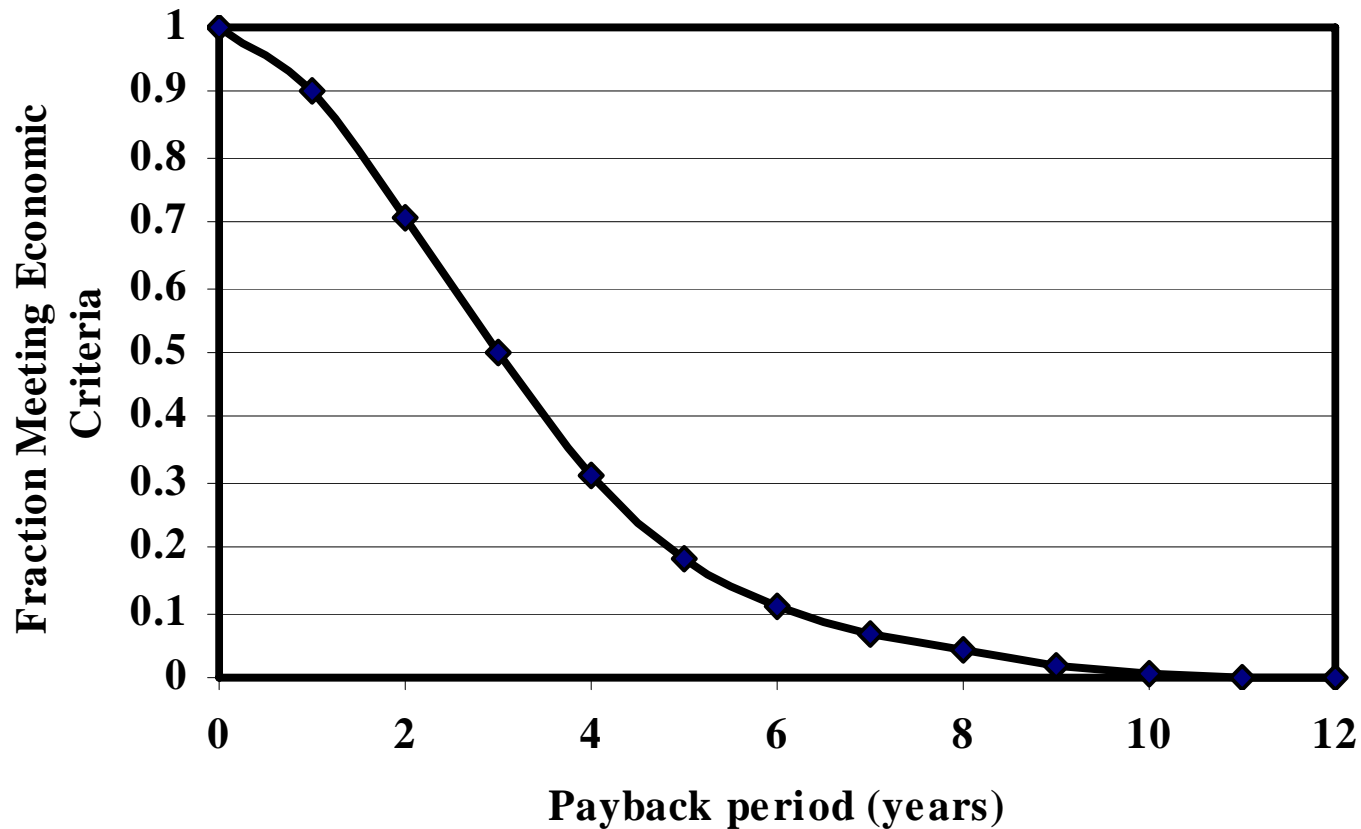
$P(E)$: subset of technical potential

$$P(E)_{ij} = v_e P_{ij}$$

$v_e = 0$, if payback period > maximum acceptable limit

$v_e = 1$, if payback period < maximum acceptable limit

Payback Acceptance Schedule



MARKET POTENTIAL

$$P(M)_{ij} = f_{pj} P_{ij}$$

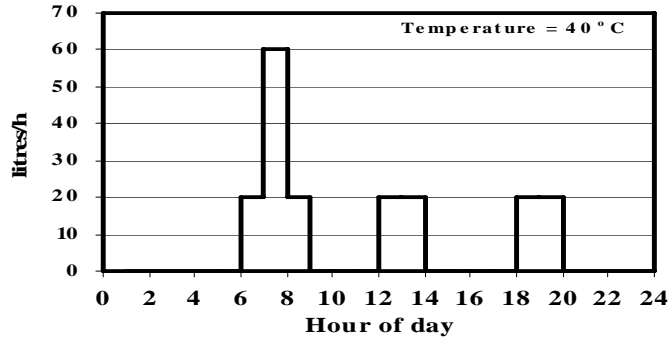
$f_{p,j}$ is fraction of potential adopters meeting economic criteria.



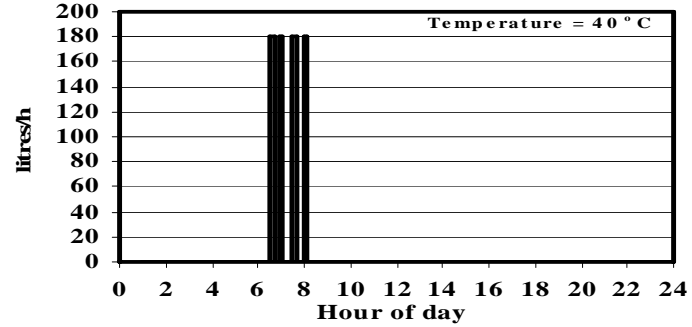
Input Data For Potential Estimation Of SWHS in Pune

Target Area		Pune	
Area		138 sq.km	
Total Number of households		5.17 lakhs	
Number of households with more than three rooms		1.41 lakhs	
Average number of persons in each household		5	
Number of hospitals		394	
Capacity range of hospitals		1-570 beds	
Number of nursing homes		118	
Capacity range of nursing homes		1-50 beds	
Number of hotels		298	
Capacity range of hotels		10-414 inmates	
Number of households residing in single ownership houses		35250	
Number of buildings (4 flats in each floor)		6 floors	1400
		10 floors	880
		11 floors	840
Cost of electricity (Rs./kWh)	Residential	2.80	
	Commercial	4.00	

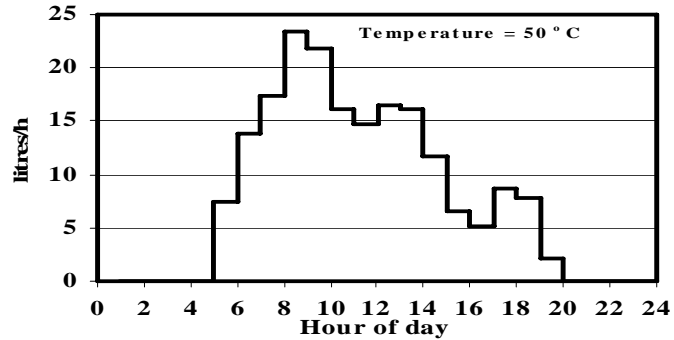
Hot Water Usage Patterns (Pune)



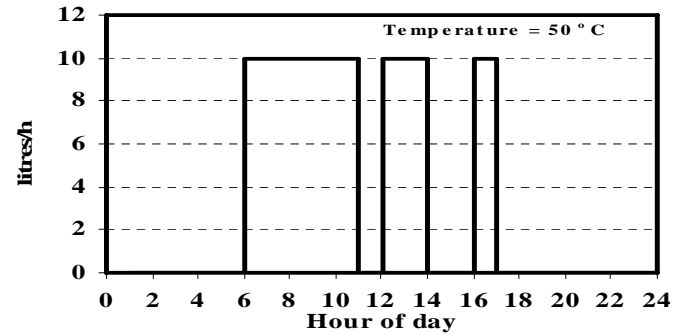
(a) Residential (1) [Gadgil, 1987]



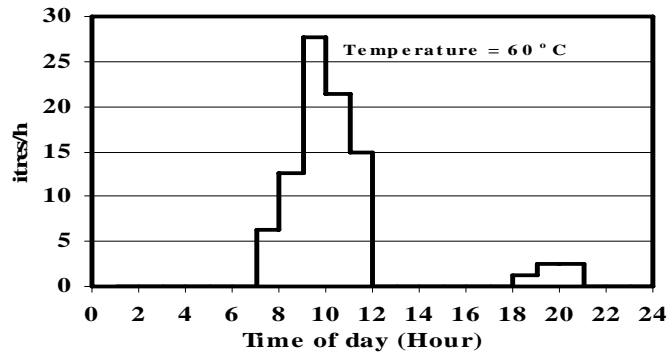
(b) Residential (2) [Narkhede, 2001]



(c) Hospital (1 bed)

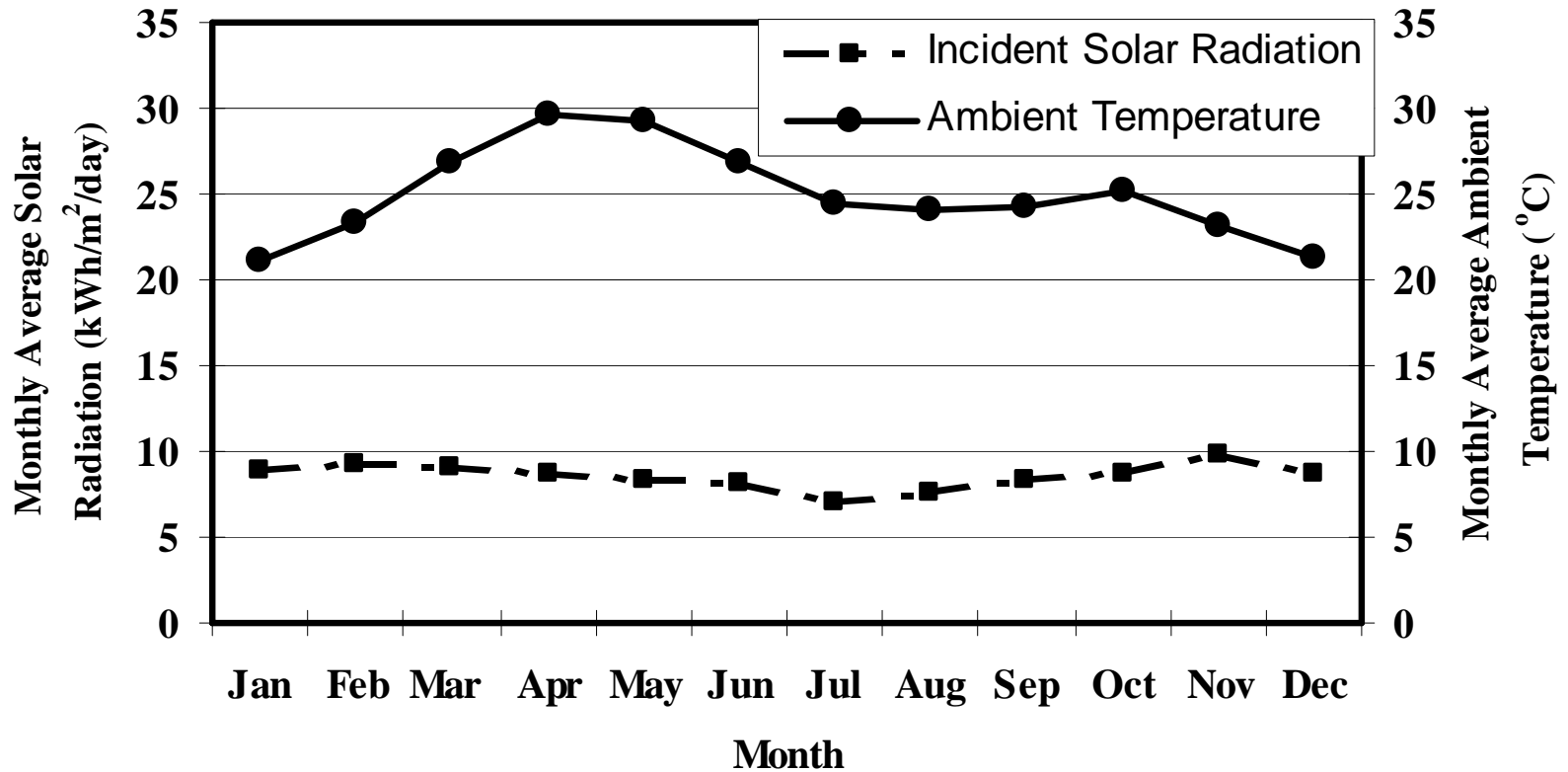


(d) Nursing Home (1 bed)



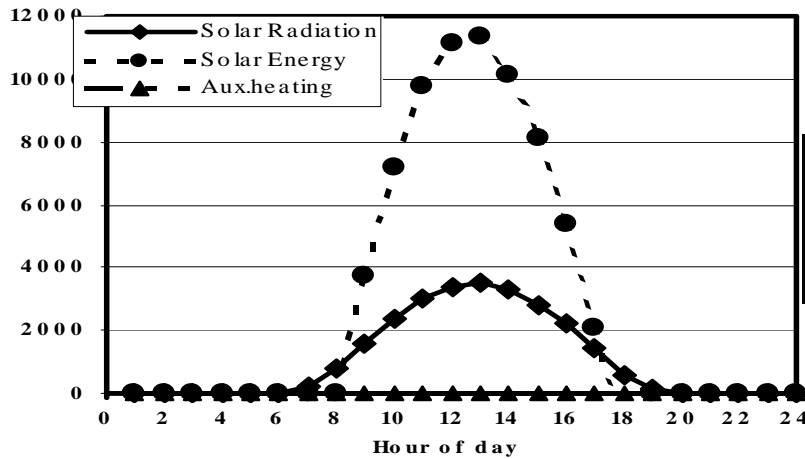
(e) Hotel - 1 guest

Monthly Average Ambient Conditions in Pune

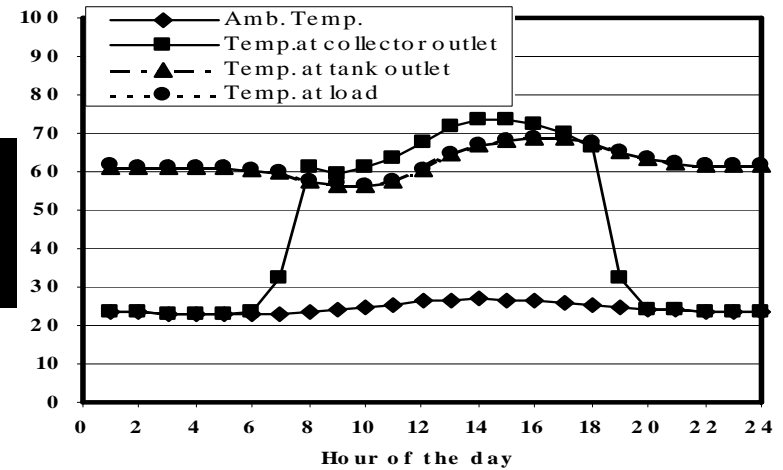


Mani, A. (1980) 'Handbook of solar radiation data for India'.

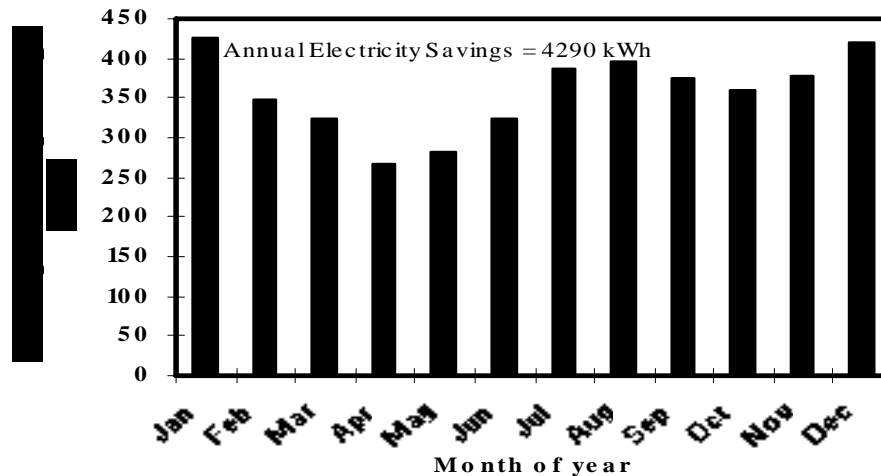
Sample simulation output and potential estimation for hospital with 5 beds



(a) Energy flow/ Solar Radiation for a typical day



(b) Temperature profiles for a typical day



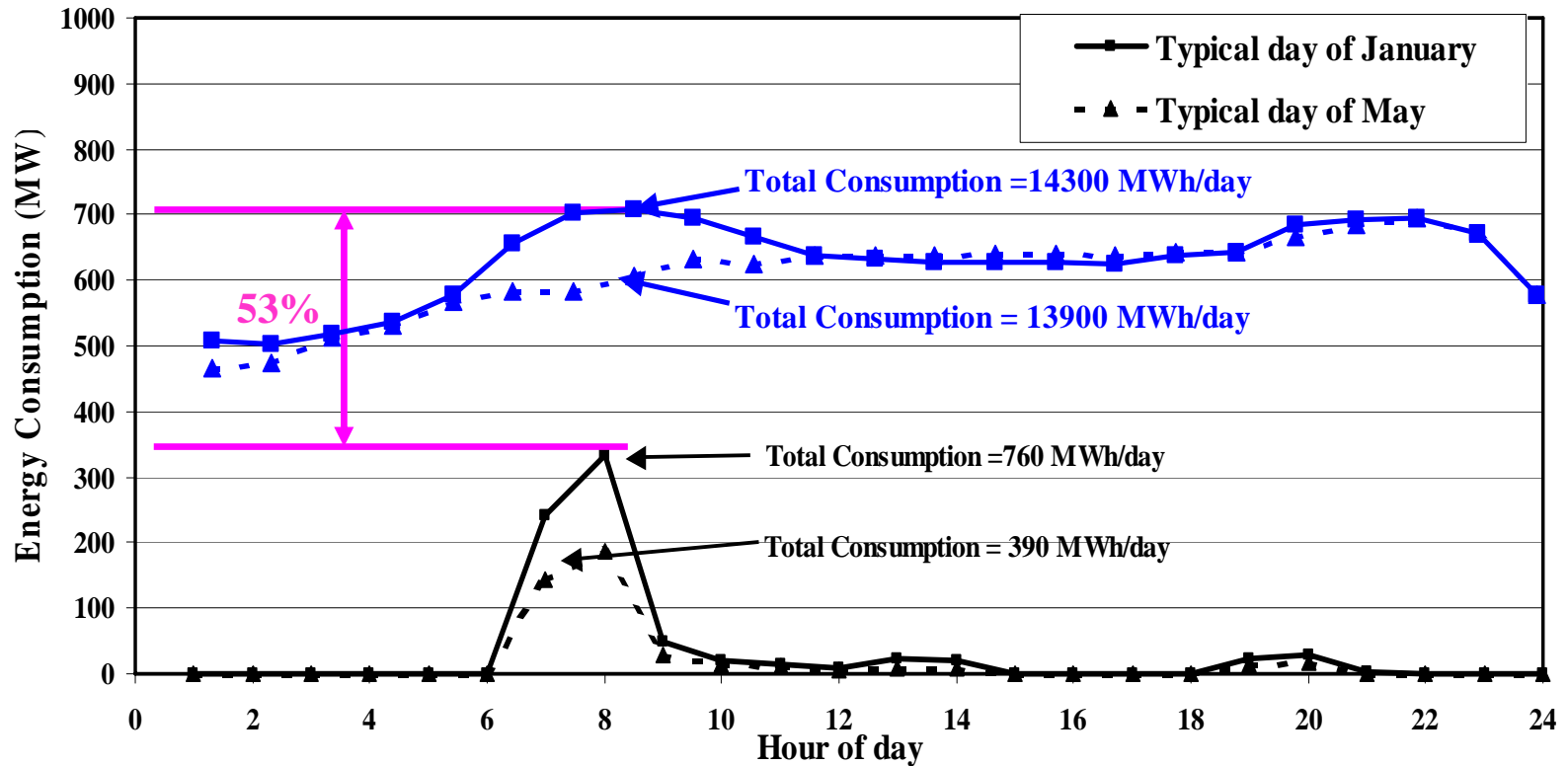
(c) Monthly variation in electricity savings



Potential Estimation of Sectors (Pune)

Sector		Technical Potential		Market Potential	
		Collector area (m ²)	Annual Electricity savings (kWh)	Collector area (m ²)	Annual Electricity savings (kWh)
Residential	Single houses	106000	37200000	2100	740000
	Multi-storeyed	227400	165000000	41000	29700000
Hospitals		5500	5900000	1700	1600000
Nursing homes		600	500000	300	280000
Hotels		13800	15900000	9300	10740000
TOTAL		353300	224500000	54400	43100000

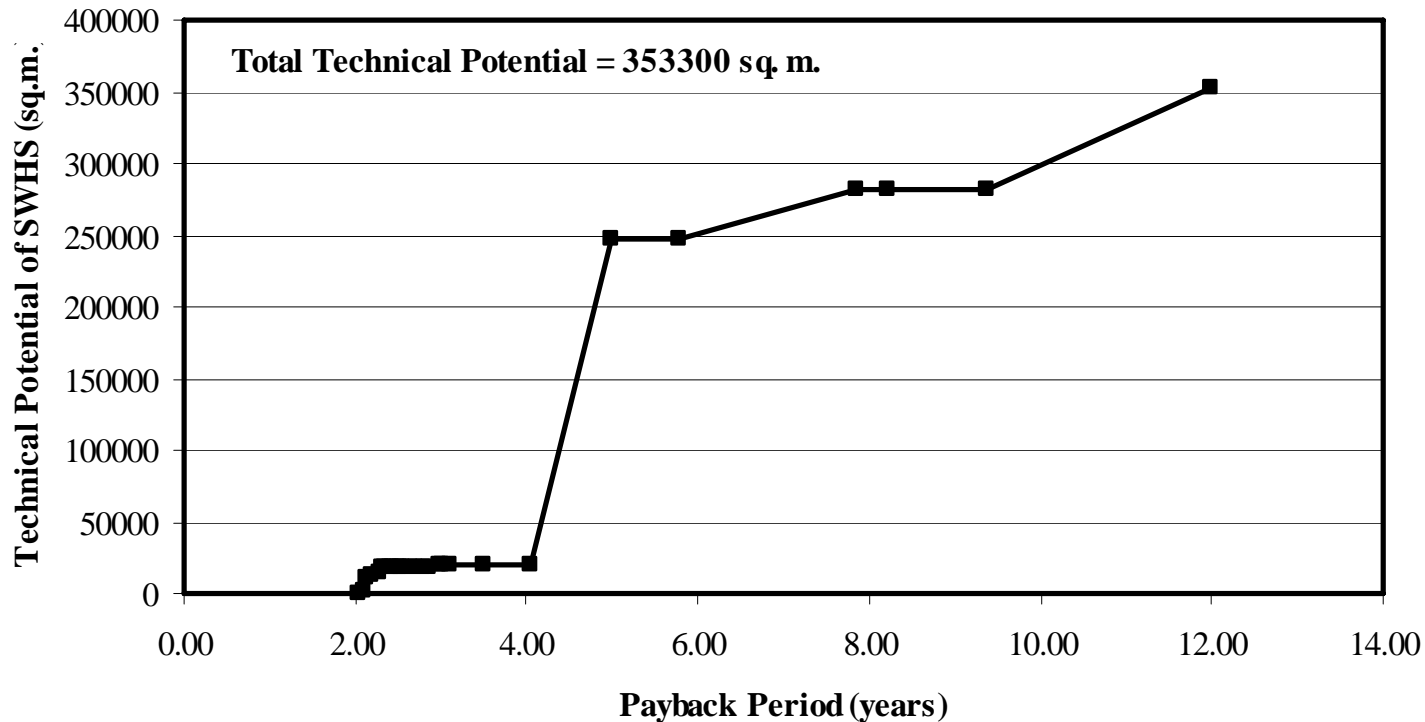
Load Curve Representing Energy Requirement for Water Heating



■ *Total Electricity Consumption of Pune*

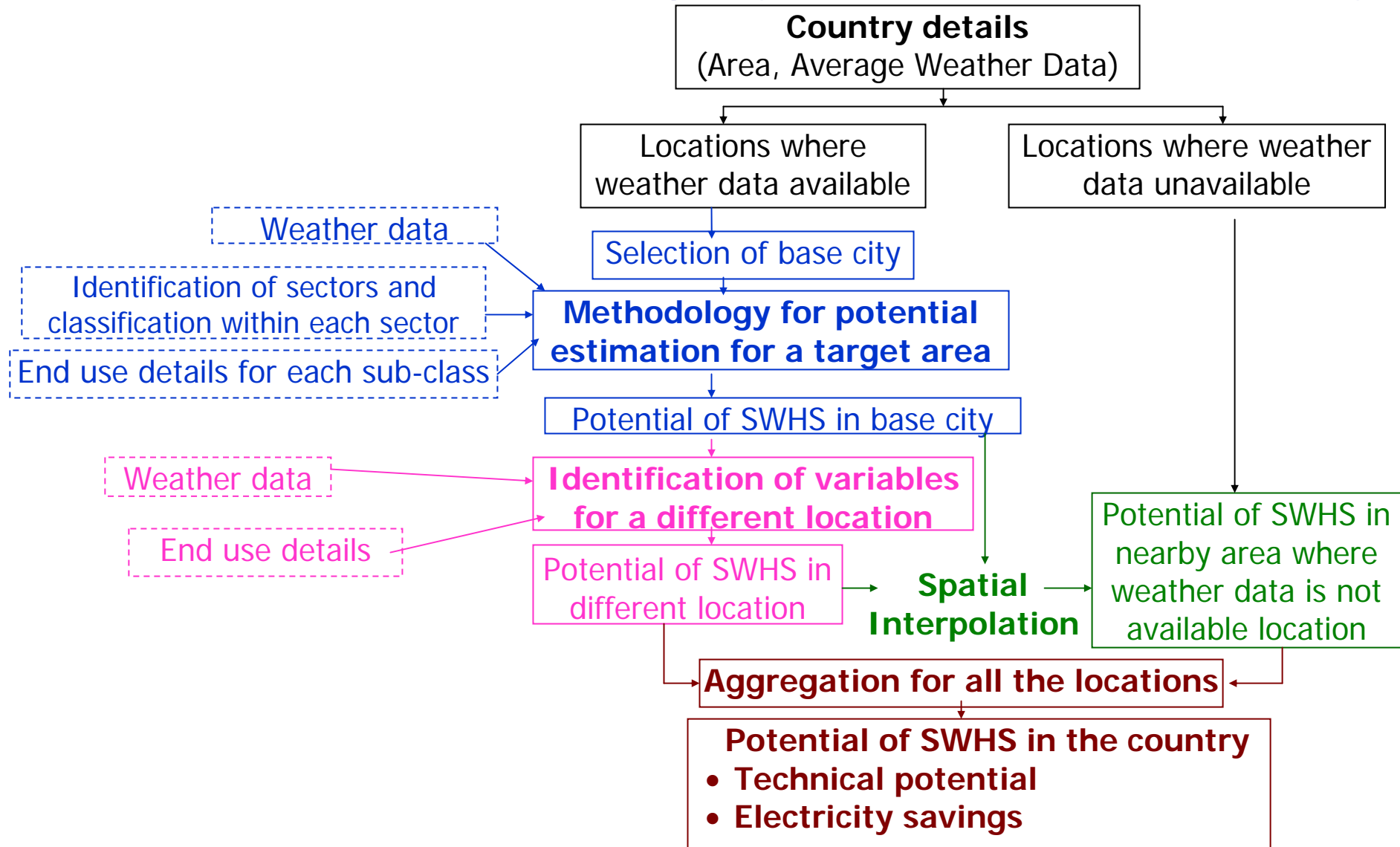
■ *Electricity Consumption for water heating of Pune*

Achievable Potential Of SWHS For Different Payback Periods (Pune)



Economic potential (limit=payback period of 5 years) = 19700 m² collector area

Framework for Potential Estimation of Solar Water Heating Systems in a Country





Conclusions

- Models for Substitution, diffusion to establish feasible growth rates
- Framework developed linking micro-macro simulation
- Example of Pune city (significant reduction in morning peak)
- Framework to be extrapolated for country
- Can be used for all renewables



References

- Indu R. Pillai , R Banerjee“Methodology for estimation of potential for solar water heating in a target area”, *Solar Energy, In Press*
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- Peter Lund, Market penetration rates of new energy technologies, Energy Policy, Volume 34, Issue 17, November 2006, Pages 3317-3326.
- Data Source- MEDA,MNES, PMC