Modelling of Energy Systems- Renewables and Efficiency

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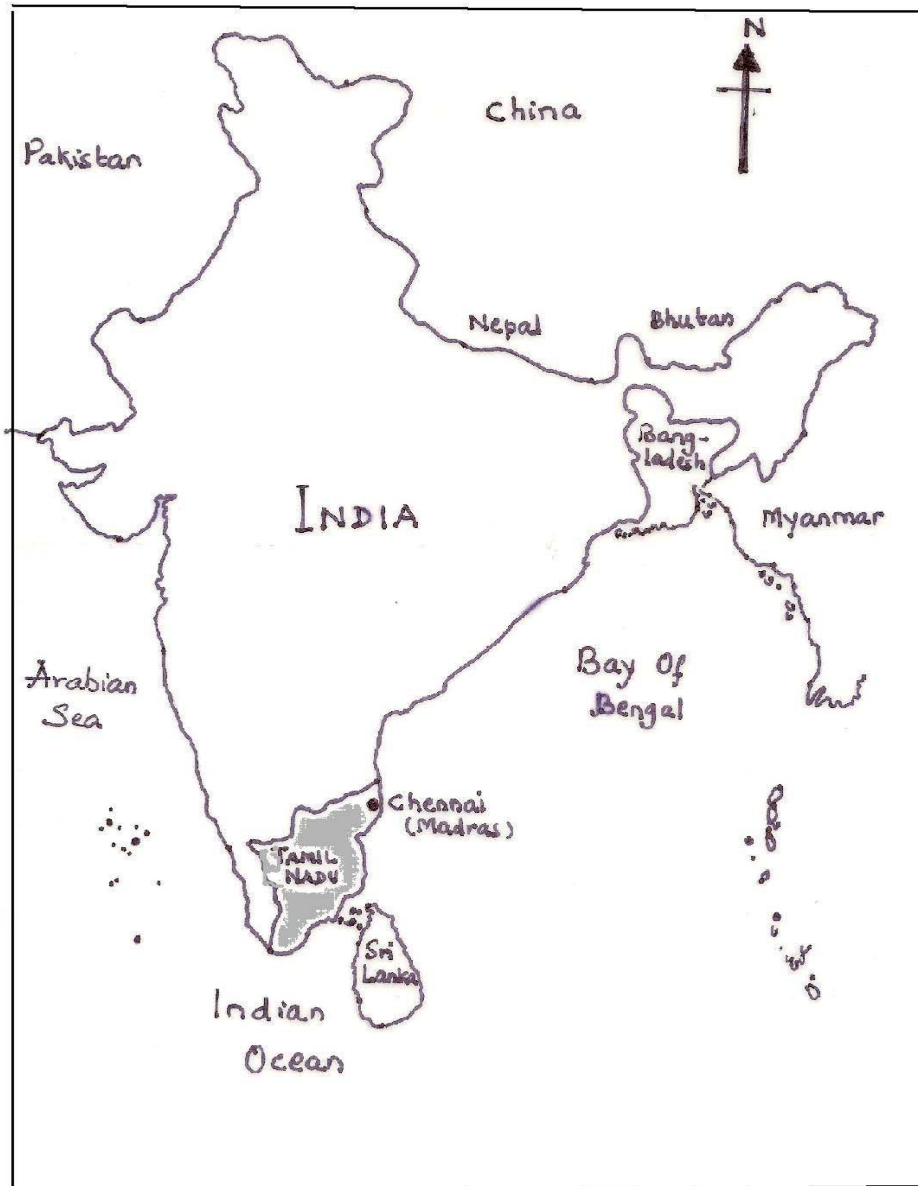
Indian Examples

- Analysis of wind integration into power system
- PV- Battery storage – Design space
- Solar Water Heater Diffusion
- Optimal response to time of use tariff
  - process scheduling
  - cool storage
  -cogeneration
- Benchmarking of glass furnace
- Decision Support System for energy planning

Issues in grid integration

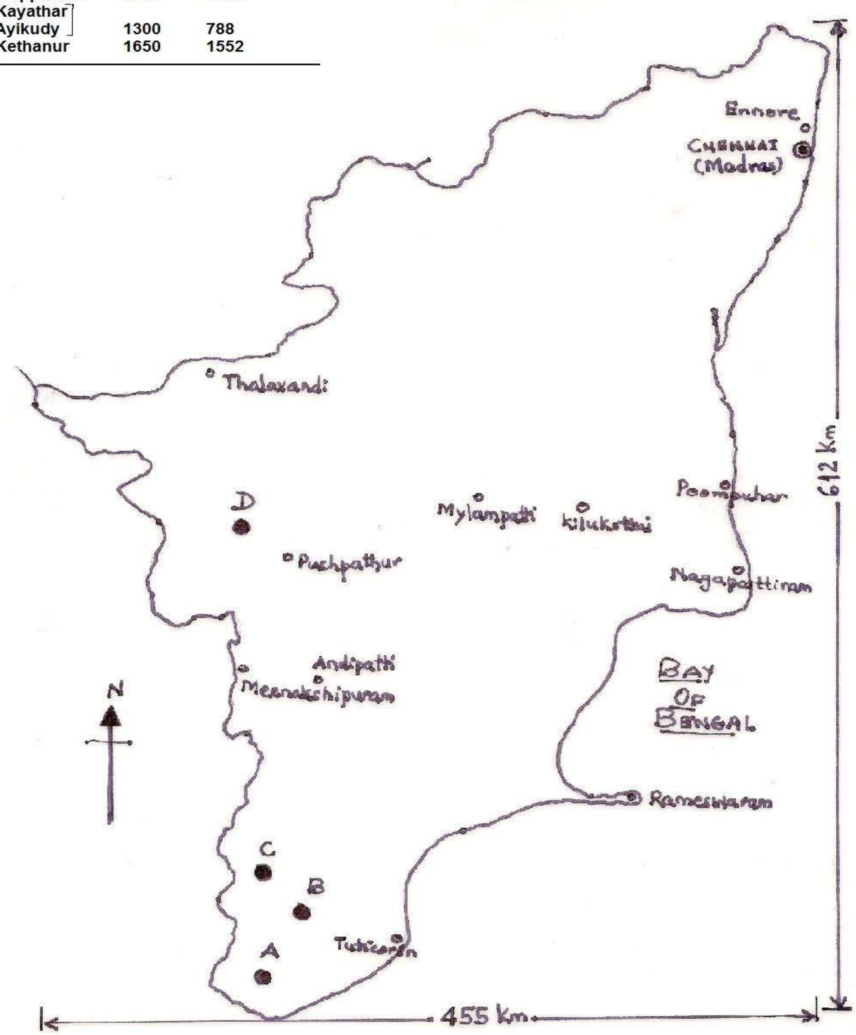
- Conventional power planning- hydro-thermal scheduling
- How do we deal with renewables?
- Capacity credit
- New methodology based on Load Duration Curve
- Illustrated for Wind in Tamil Nadu

Tamil Nadu location



Site Location		Gross Potential (MW)	Harnessed Potential (MW)
A	Muppandal	2100	1508
B	Kayathar		
C	Ayikudy	1300	788
D	Kethanur	1650	1552

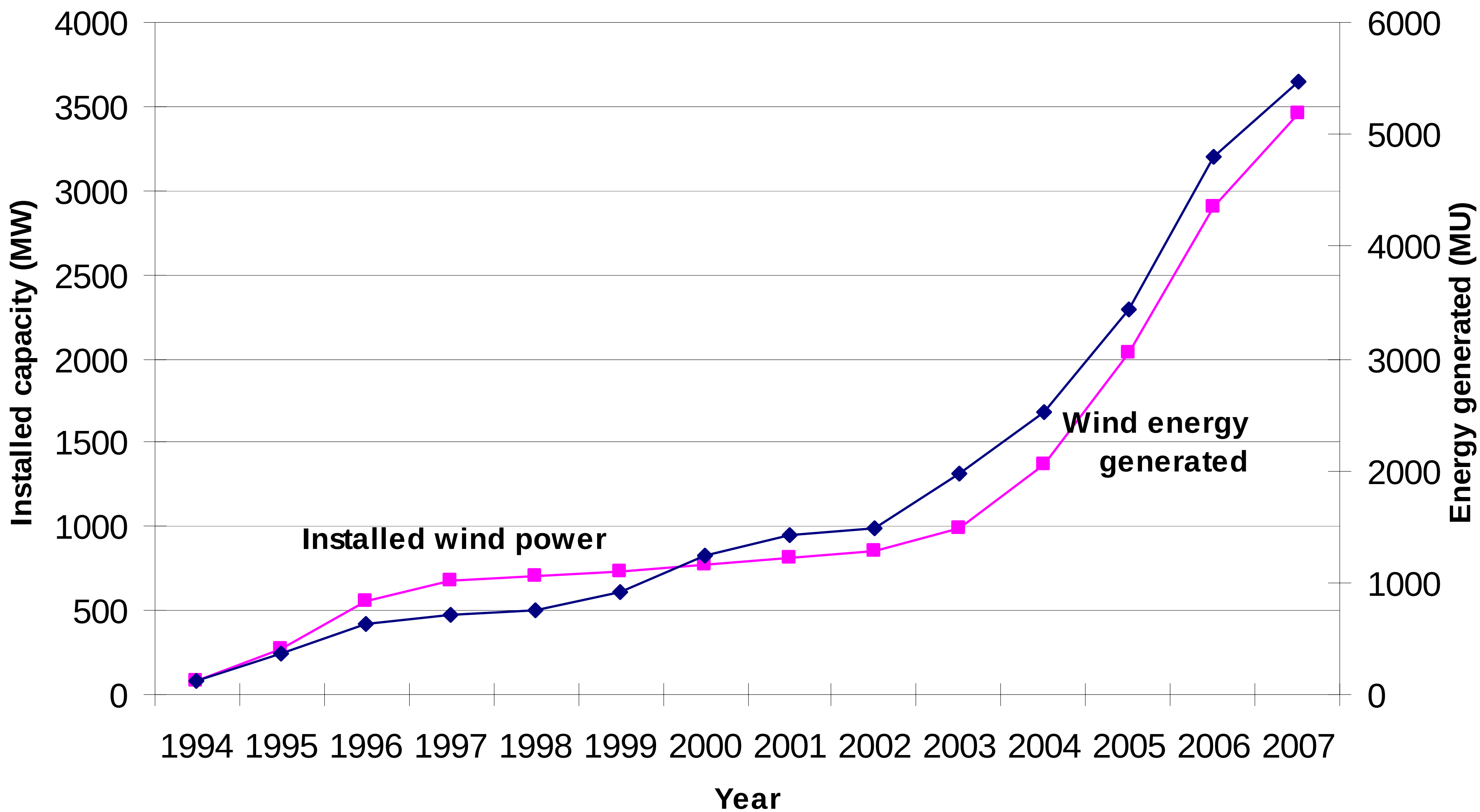
TAMIL NADU STATE
Wind Farmable Sites



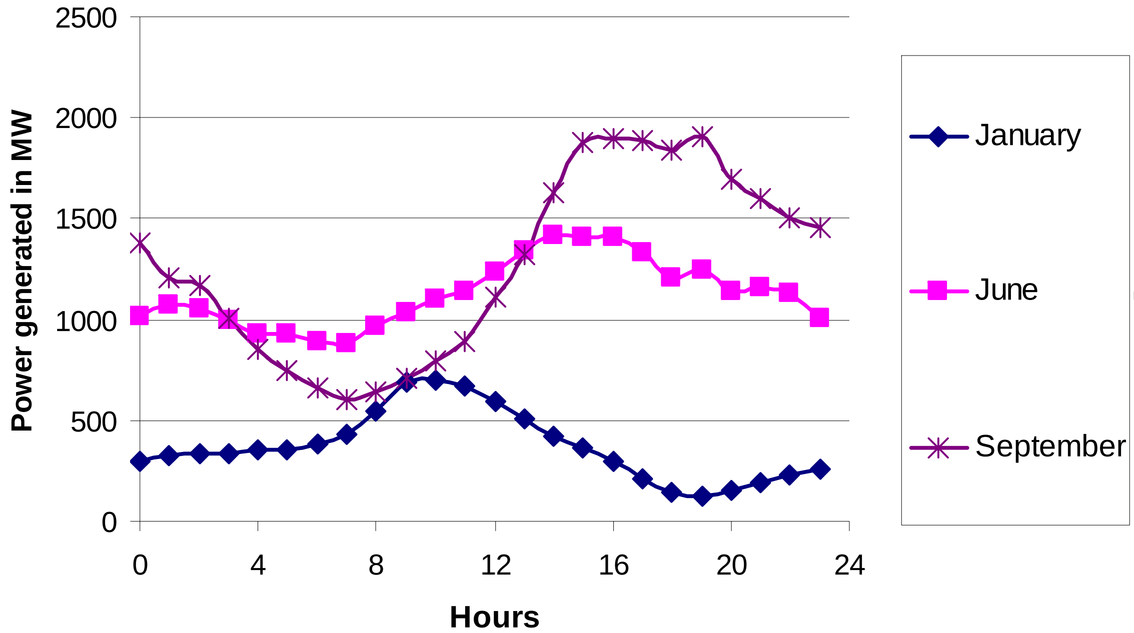
Tamil Nadu – Grid Details

Source	Installed capacity (MW)	Annual Energy generated (MU)	Annual average capacity factor (%)
Coal	2970	21230	81.6
Gas	424	1945	52.4
Hydro	2187	6290	32.8
Firm central share#	2825	17785	71.9
Wind (state + private)	3856	5270	18.6
Other renewables (solar PV, biomass and Bagasse based cogeneration)	556	1220	25.1
Independent power projects (coal, lignite, diesel or gas based)	1180	6360	61.5
Assistance from other regional grids	519	2280	50.1
Total	**14517**	**63370**	**49.8**

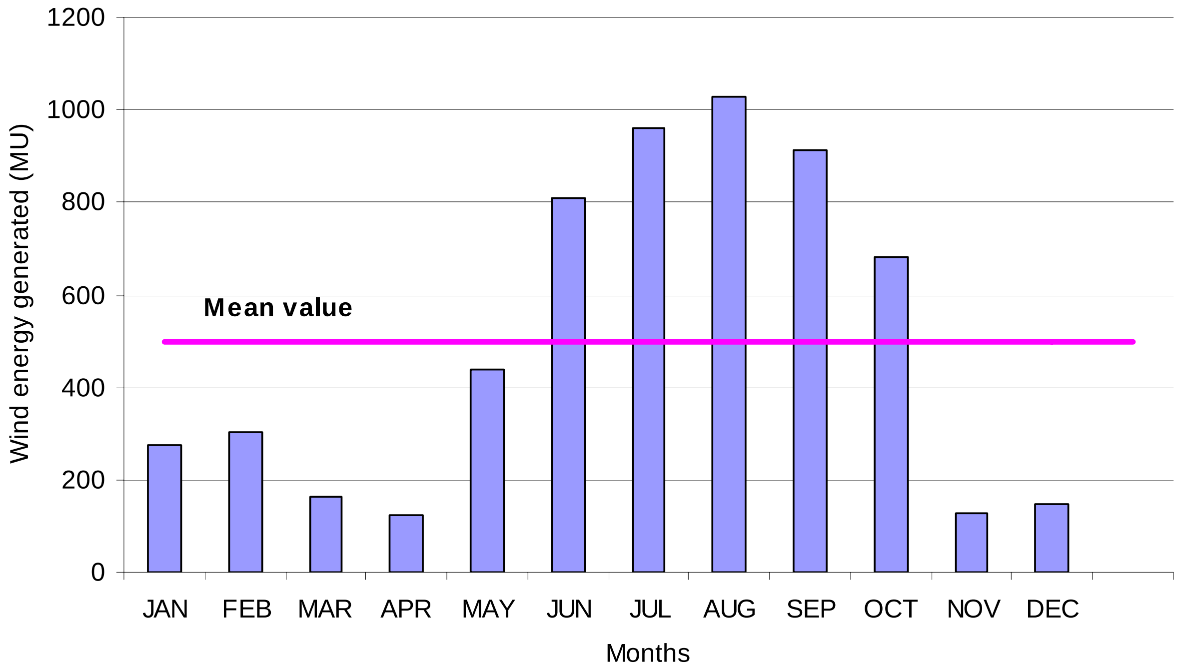
TN – Installed wind power and wind energy generated



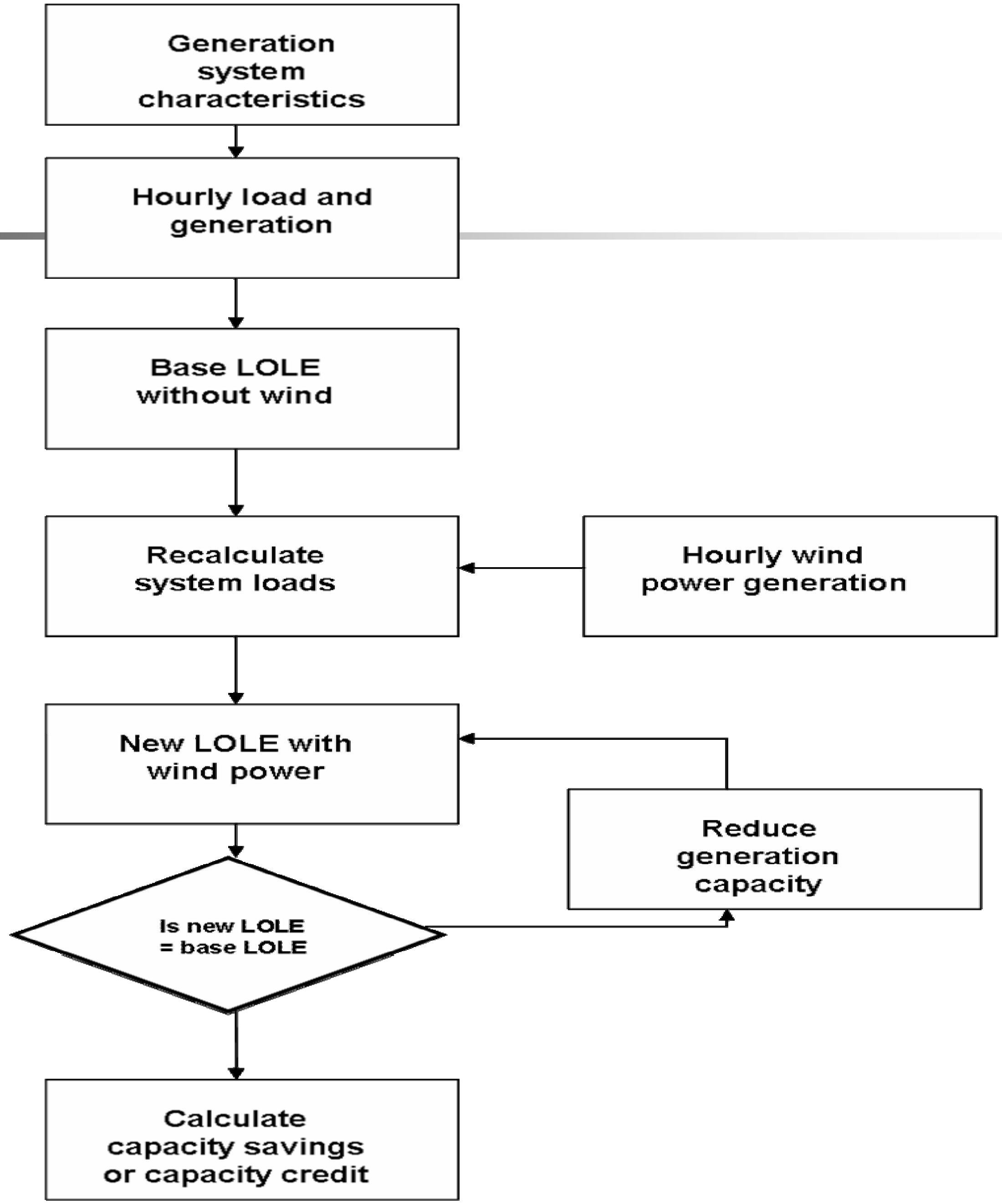
Hourly variation of wind power



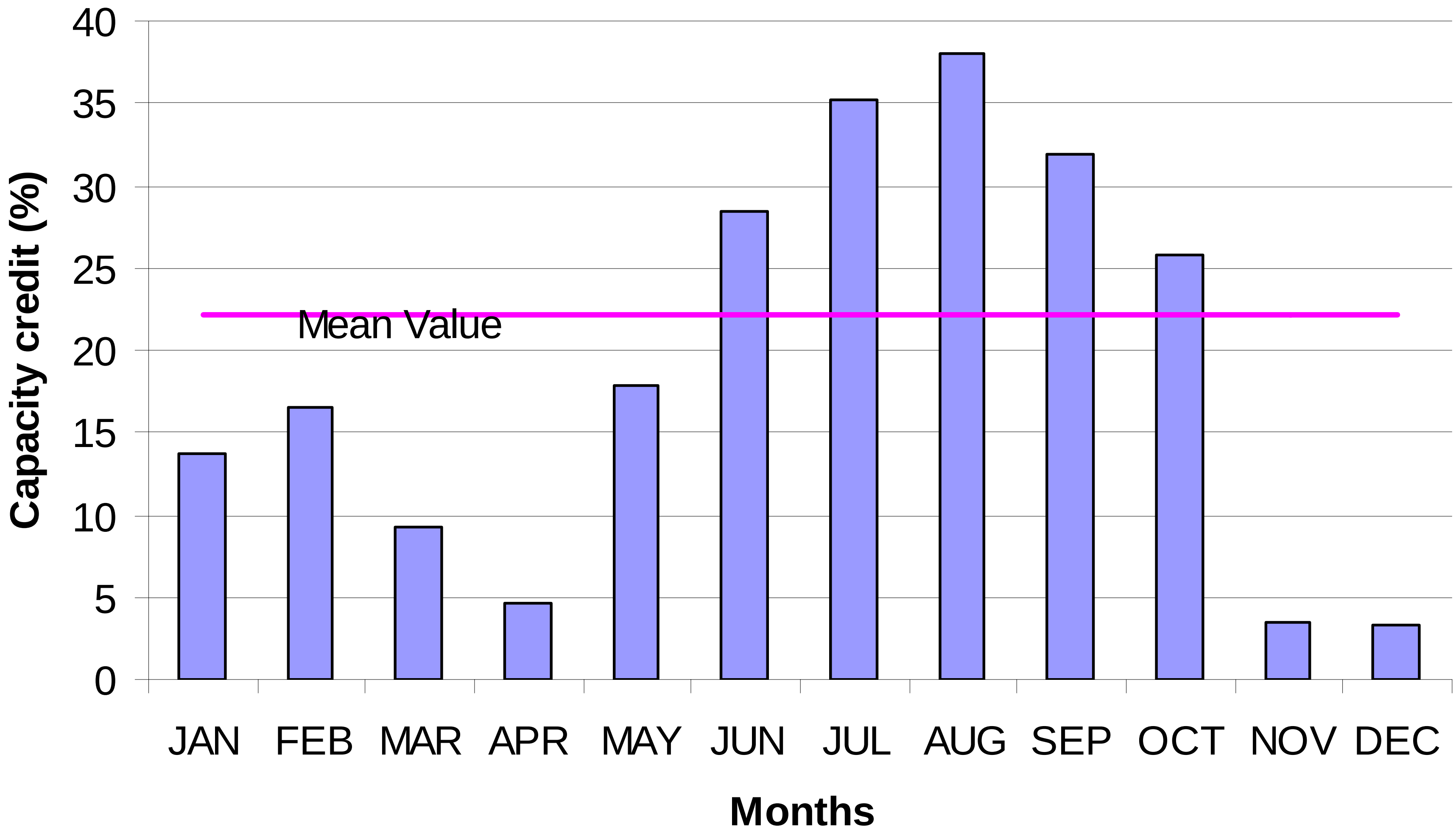
Monthly variation of wind energy generated

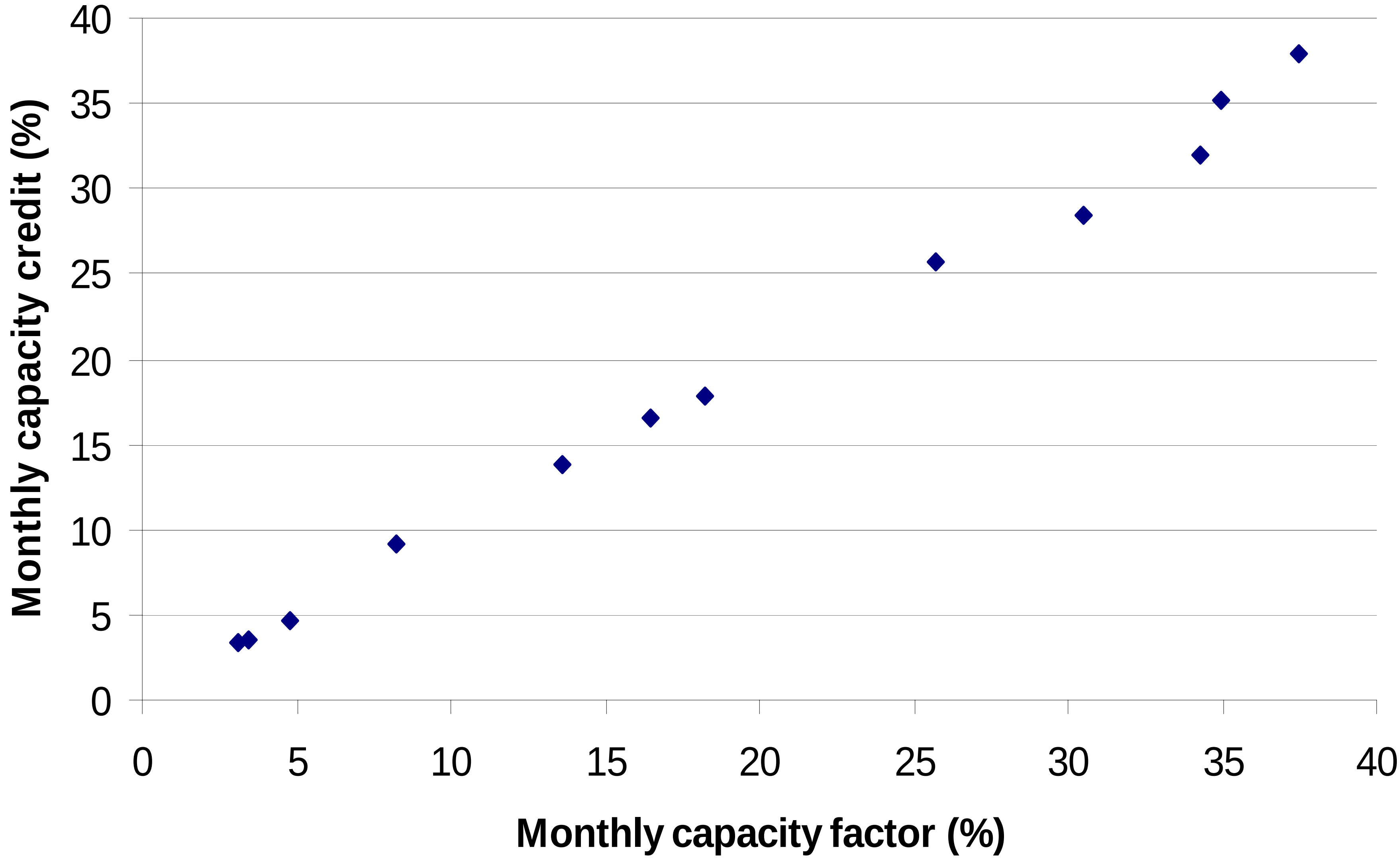


Capacity Credit Methodology



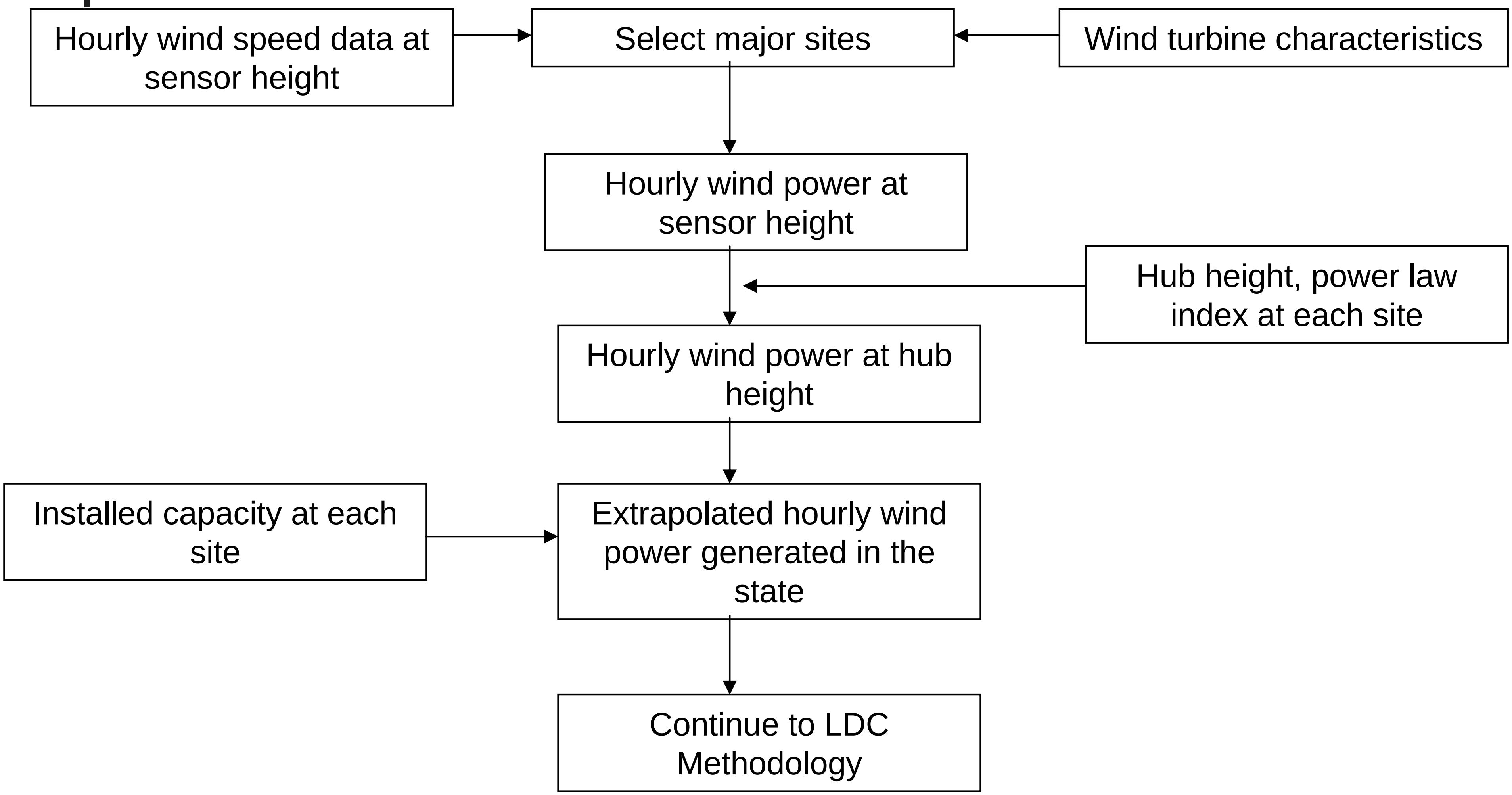
Variation of CC

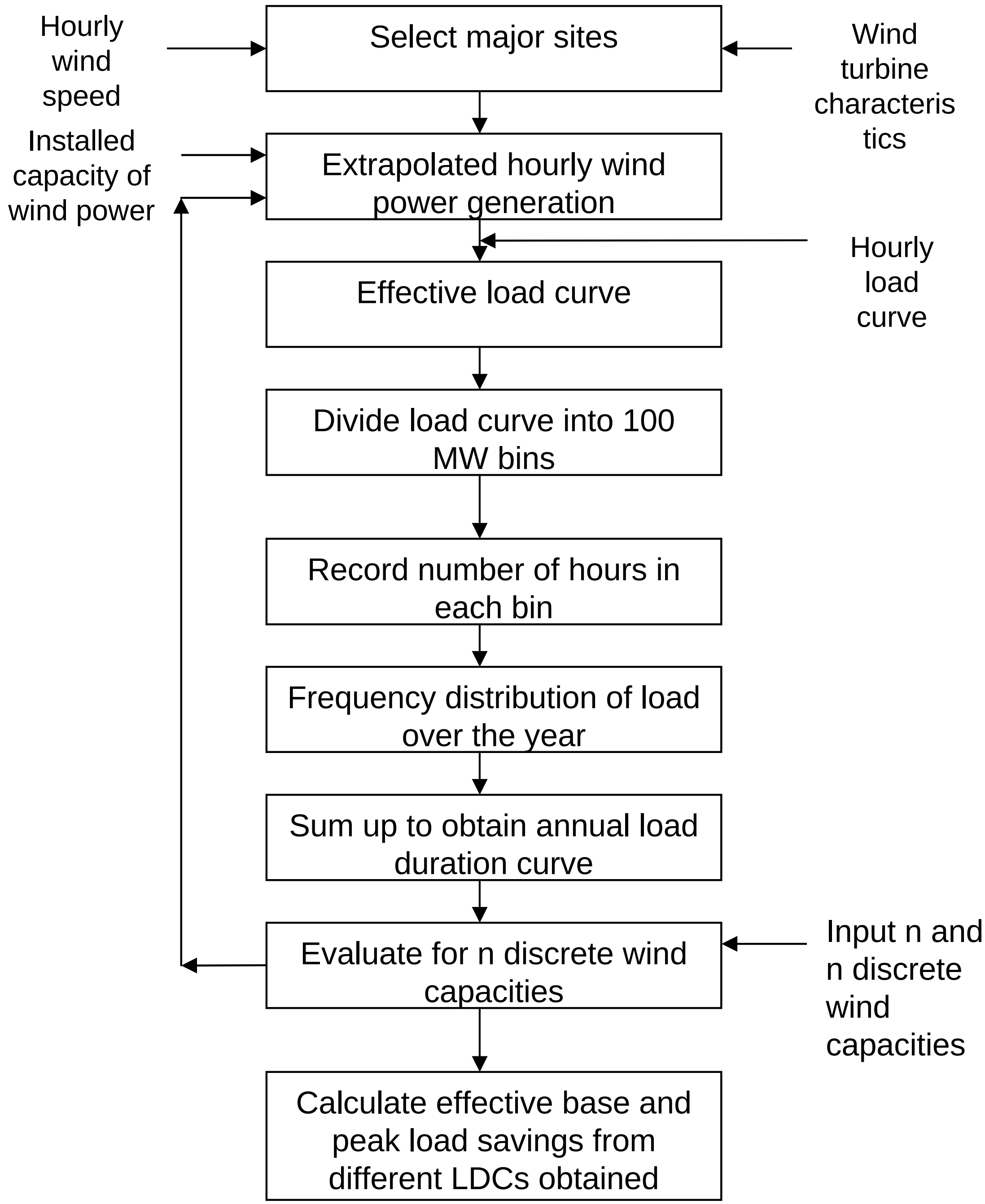



Monthly capacity credit (%)
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
Monthly capacity factor (%)

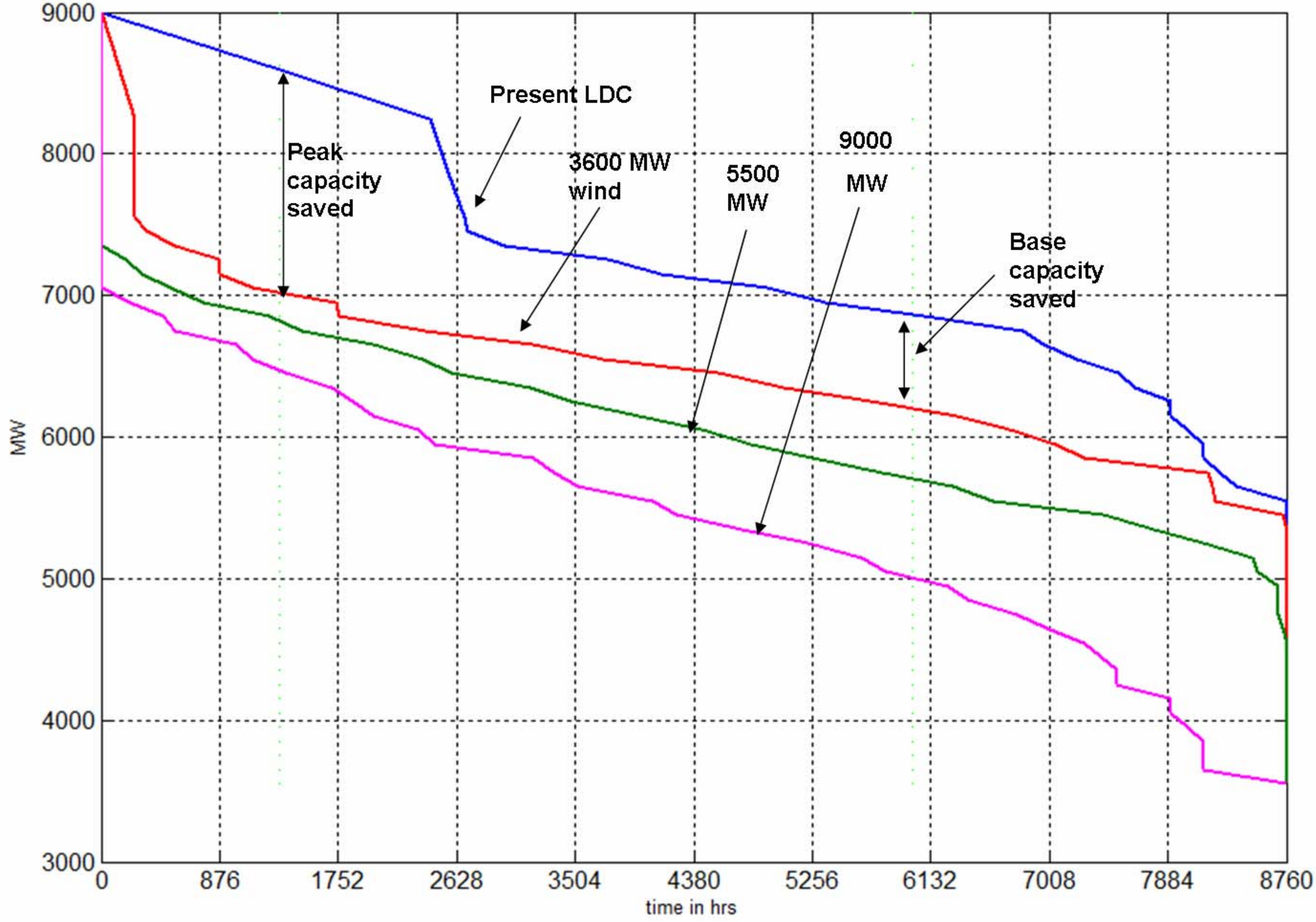
Percentage penetration of wind power (%)	Wind power installed capacity (MW)	Capacity credit (MW)
0	0	0
5.5	500	130
11.1	1000	240
16.7	1500	350
22.2	2000	460
33.3	3000	675
44.4	4000	895
61.1	5500	1220
77.8	7000	1550
88.9	8000	1750
100	9000	1965

Methodology – Wind (Micro level)



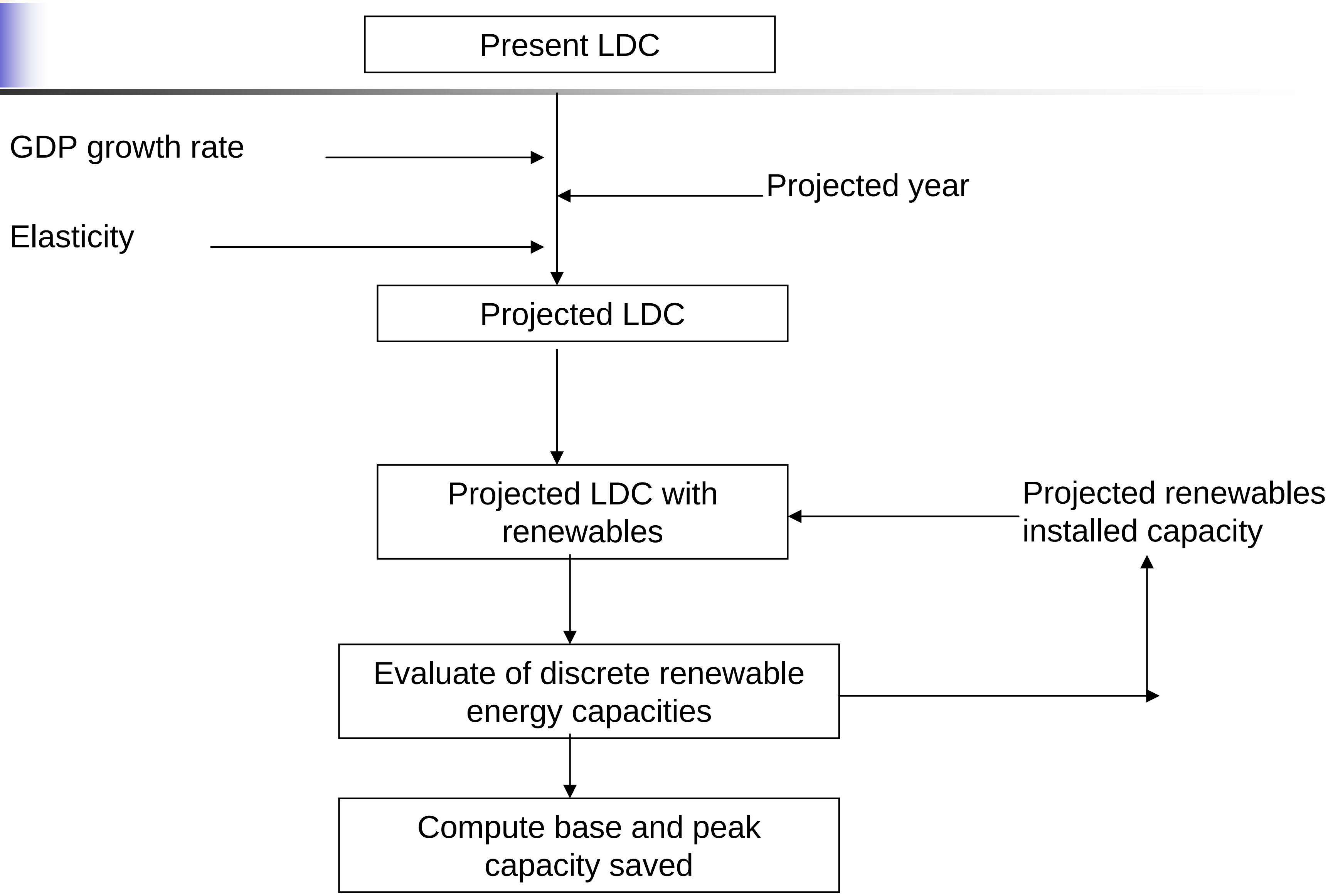

Hourly wind speed
Select major sites
Wind turbine characteristics
Installed capacity of wind power
Extrapolated hourly wind power generation
Hourly load curve
Effective load curve
Divide load curve into 100 MW bins
Record number of hours in each bin
Frequency distribution of load over the year
Sum up to obtain annual load duration curve
Evaluate for n discrete wind capacities
Input n and n discrete wind capacities
Calculate effective base and peak load savings from different LDCs obtained

Impacts on LDC

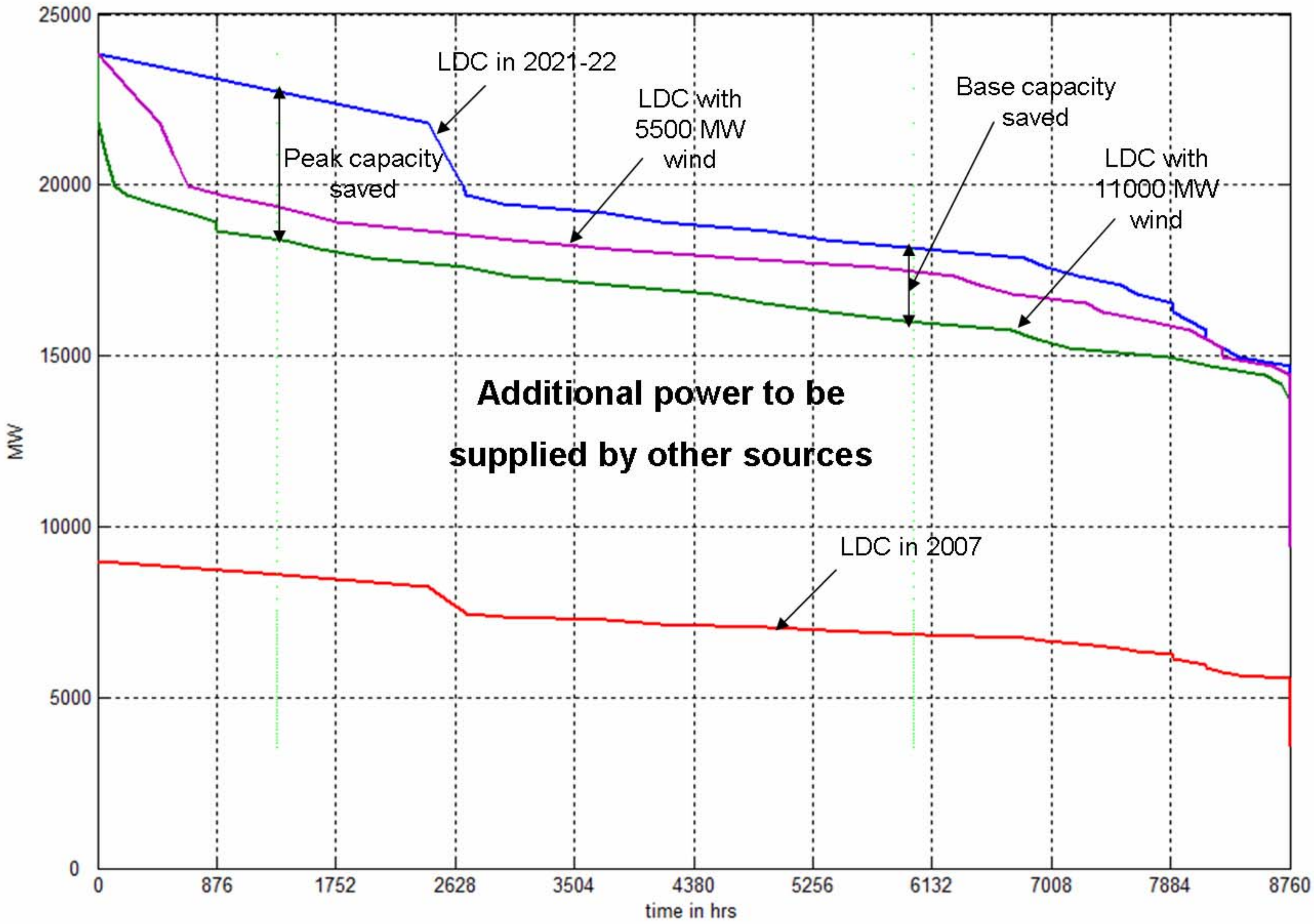


Wind power installed capacity (MW)	Base load capacity saved (MW)	Peak load capacity saved (MW)
0	0	0
500	60	70
1000	100	355
1500	150	1105
2000	240	1265
3000	470	1475
4000	770	1625
5500	1150	1775
7000	1460	1975
8000	1630	2085
9000	1855	2125

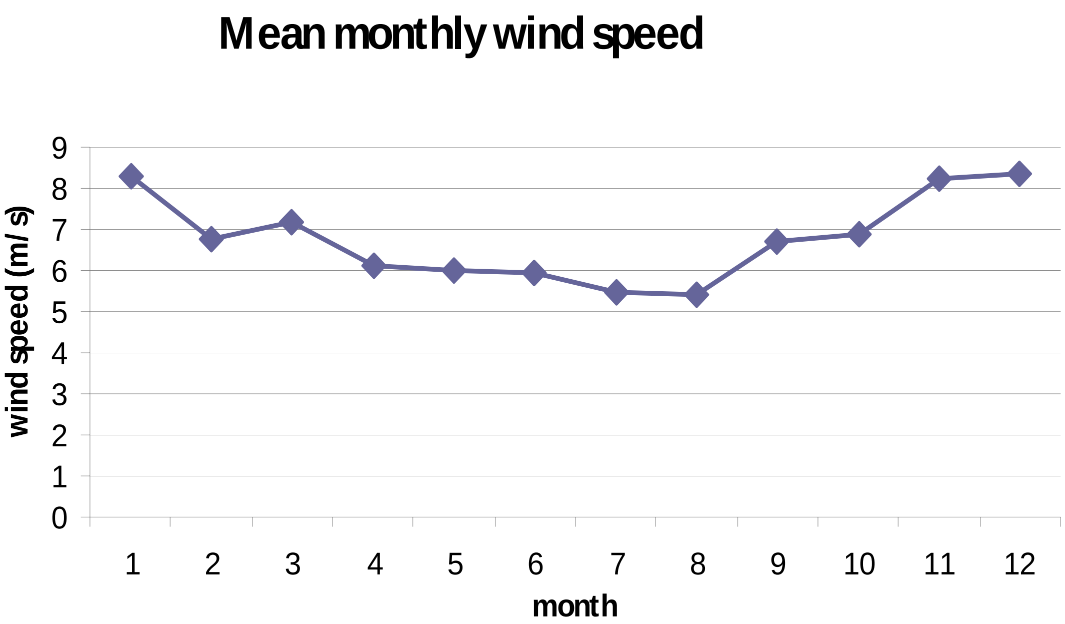
LDC Methodology for future scenarios



TN – Wind energy scenarios for 2021

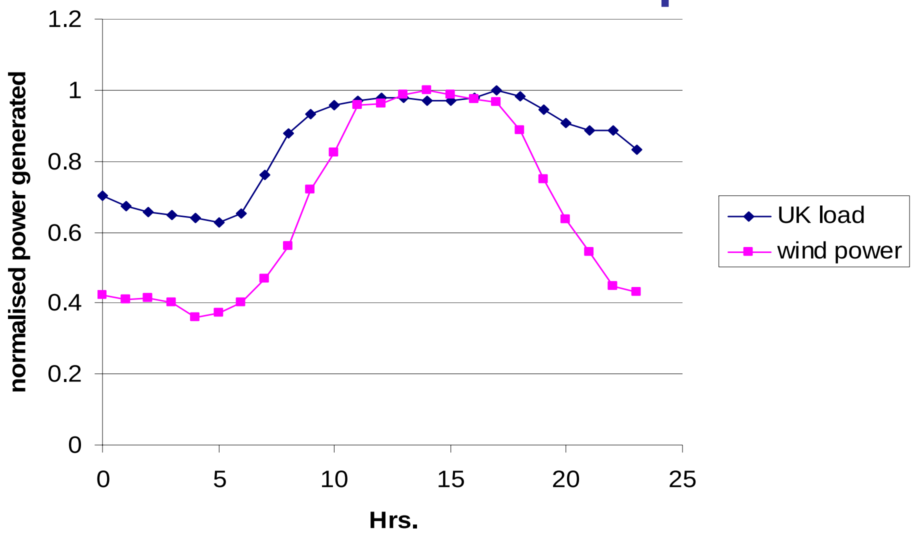


Simulation for UK

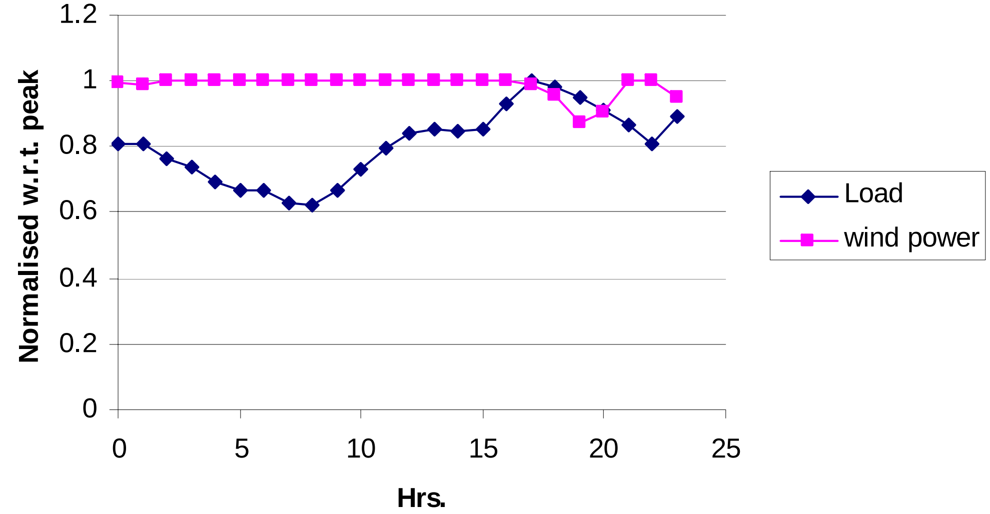


Site: Valley, Hollyhead, Anglessy (Wales)

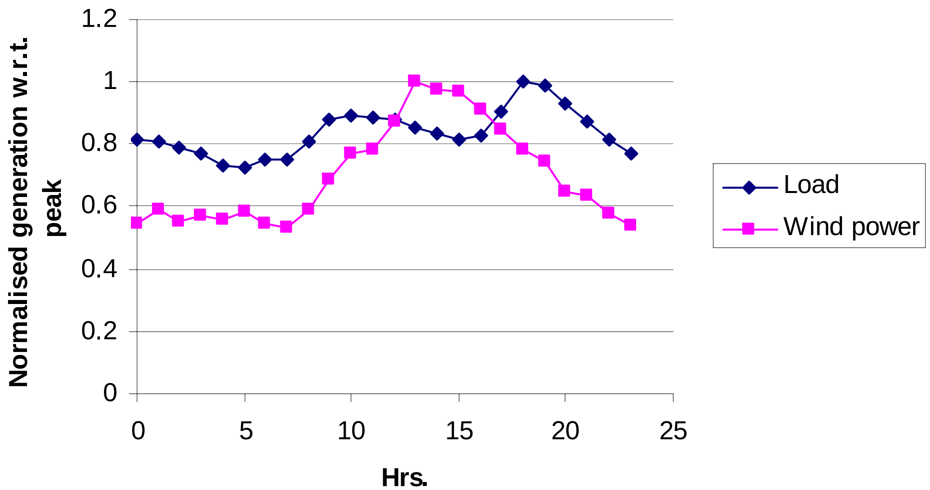
Wind power - load curve correlation in UK



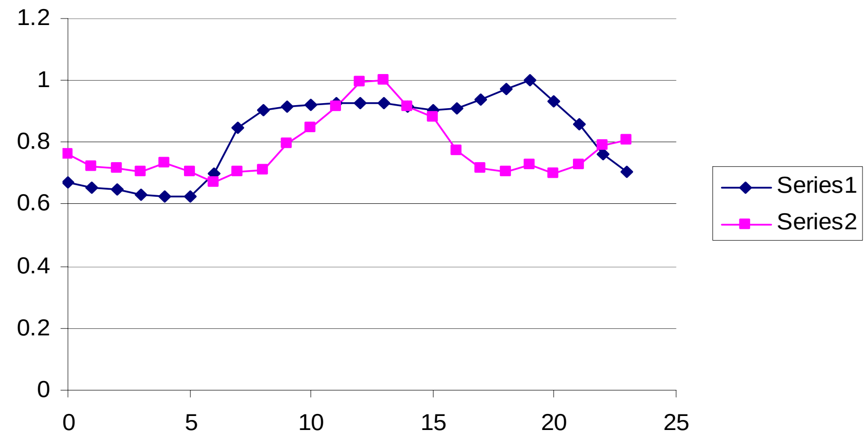
July – 0.88



Jan – (-)0.51



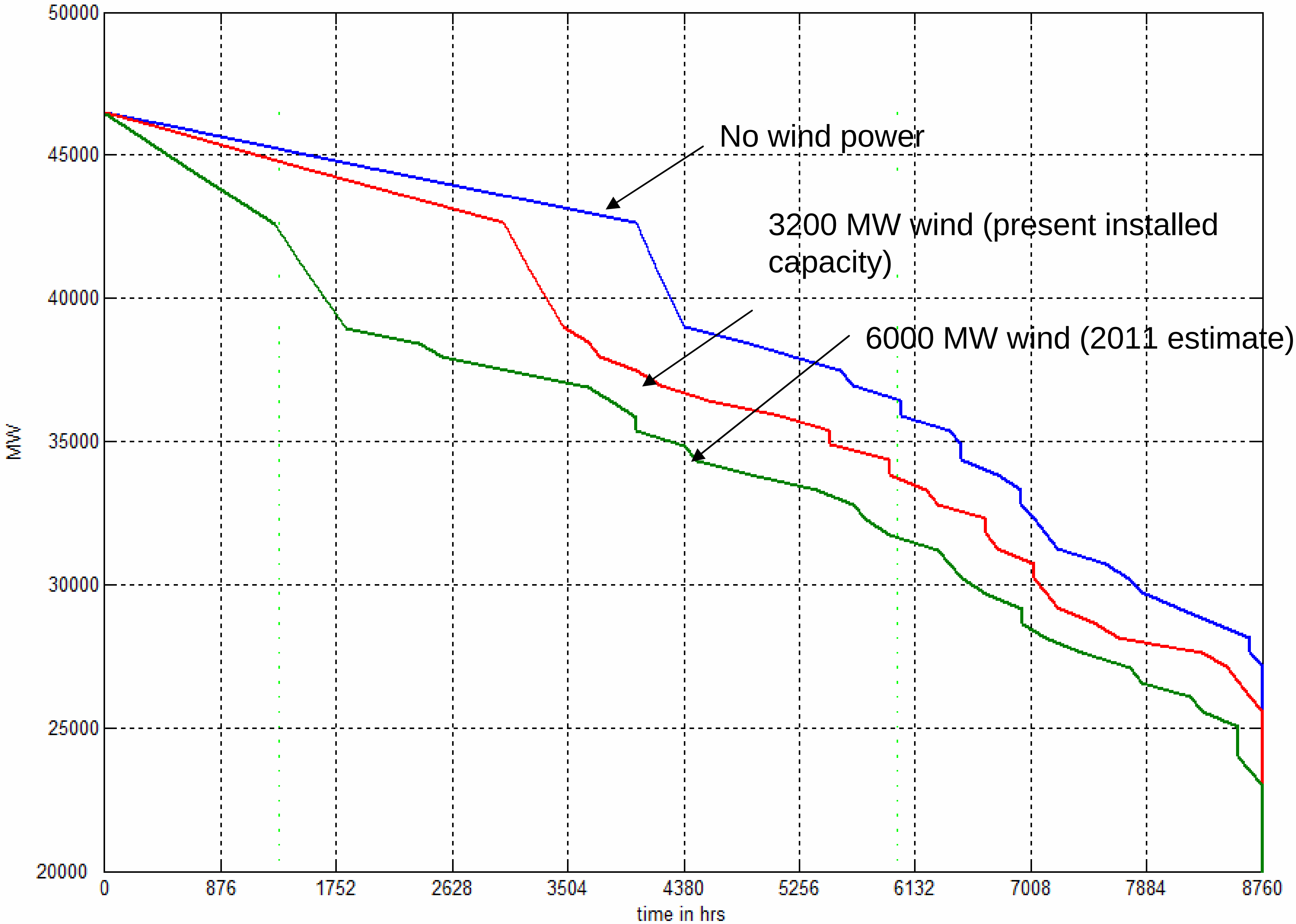
Mar – 0.48

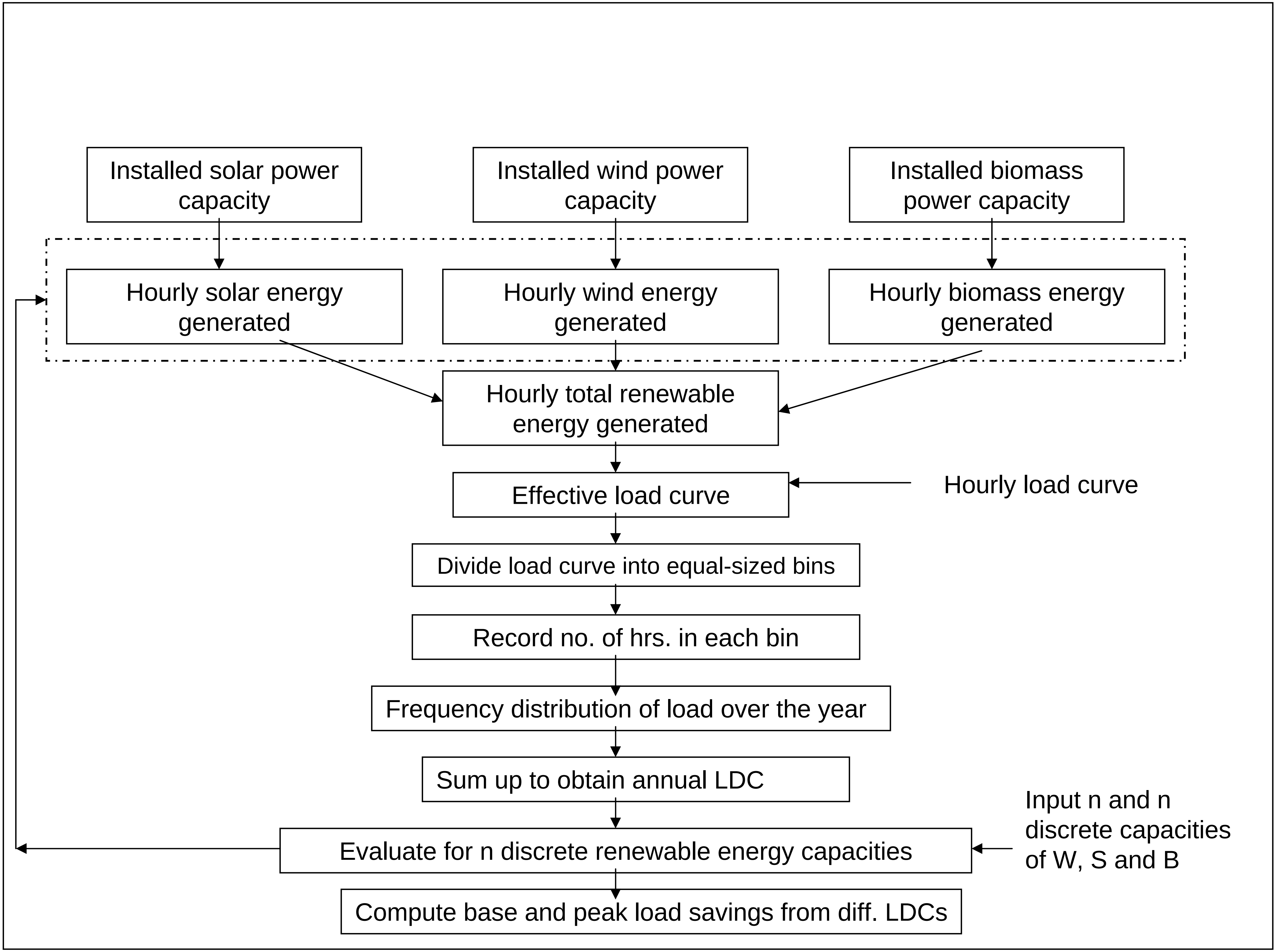


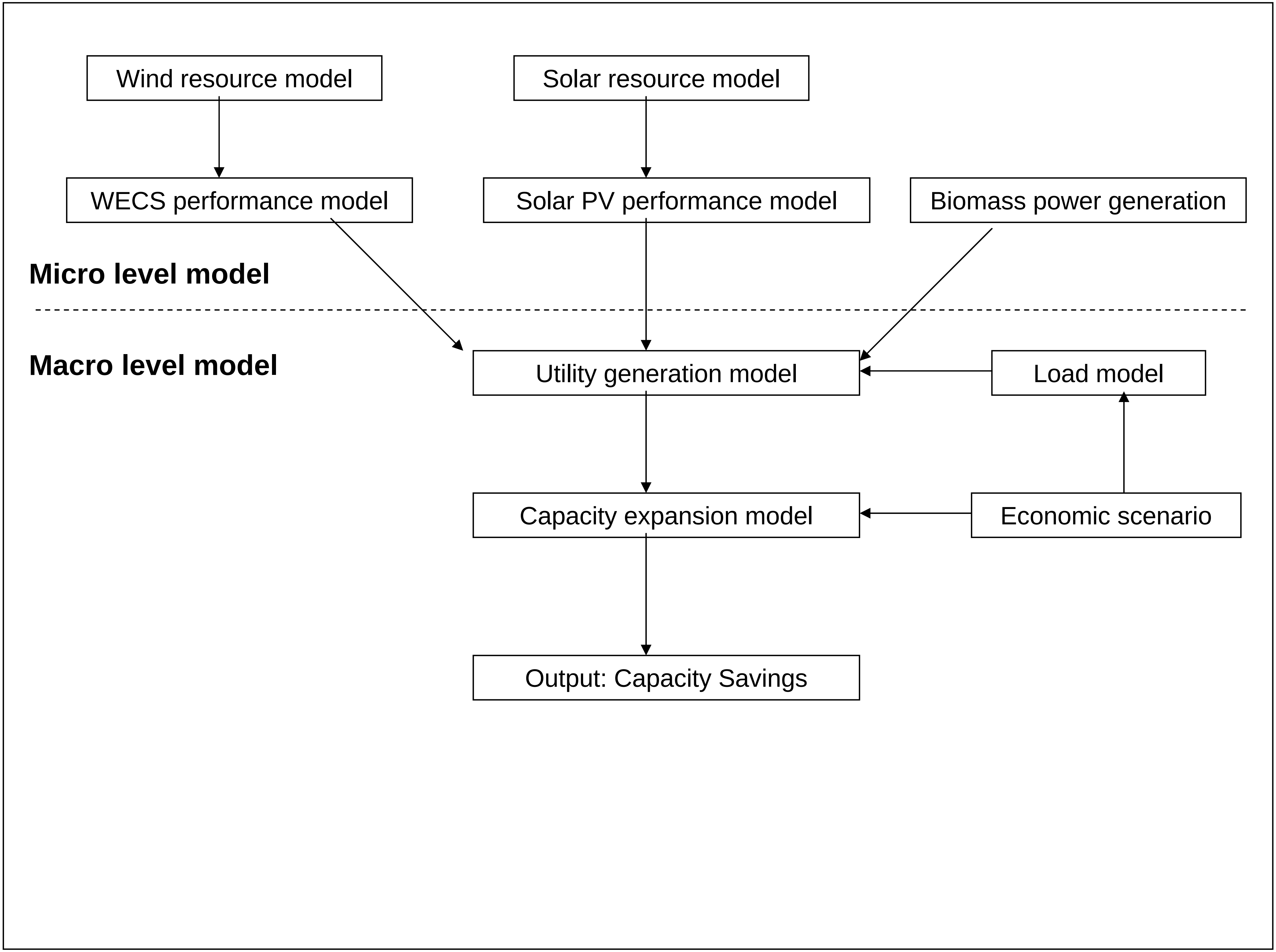
Oct – 0.39

Average correlation factor over the year = 0.38

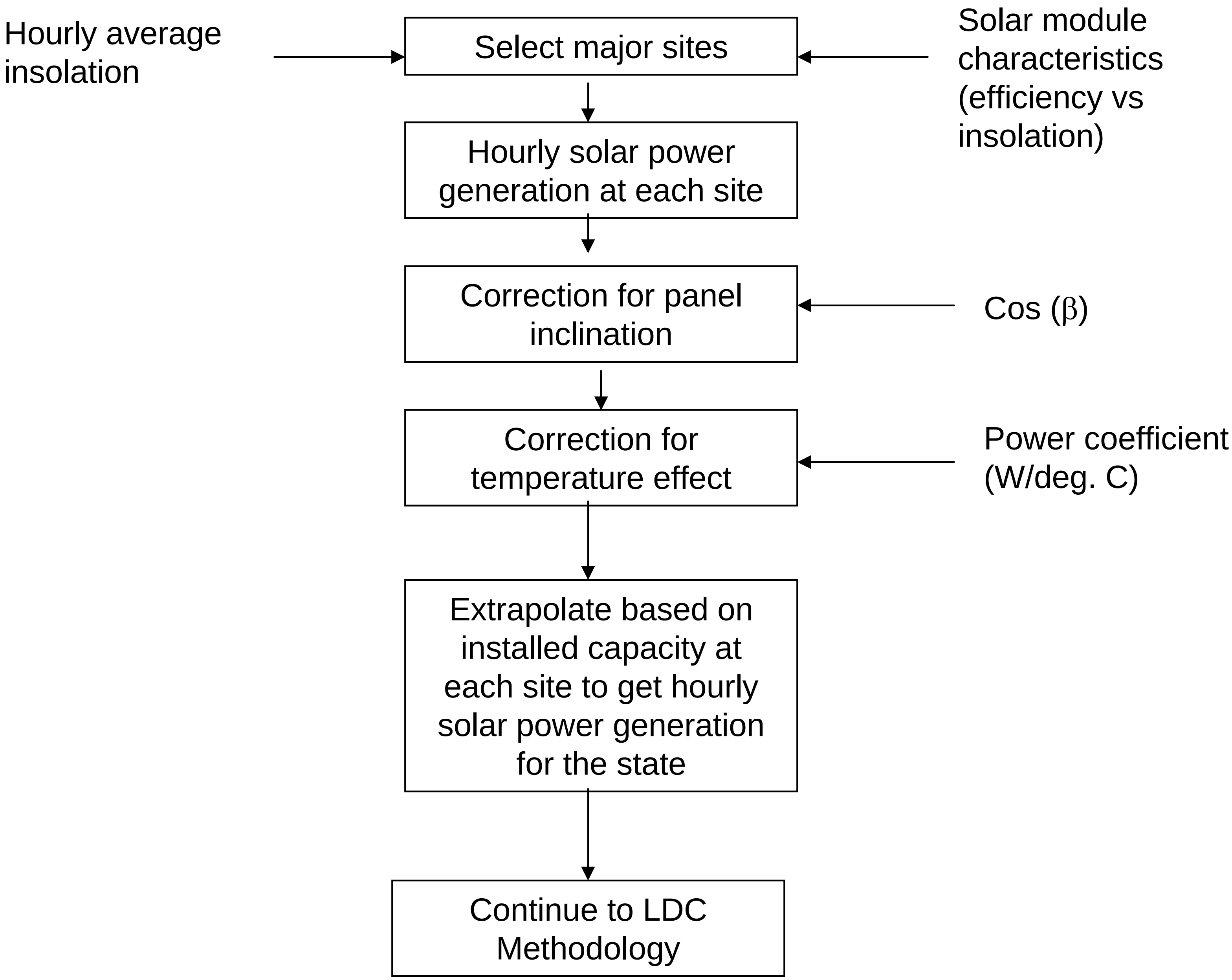
Results for UK



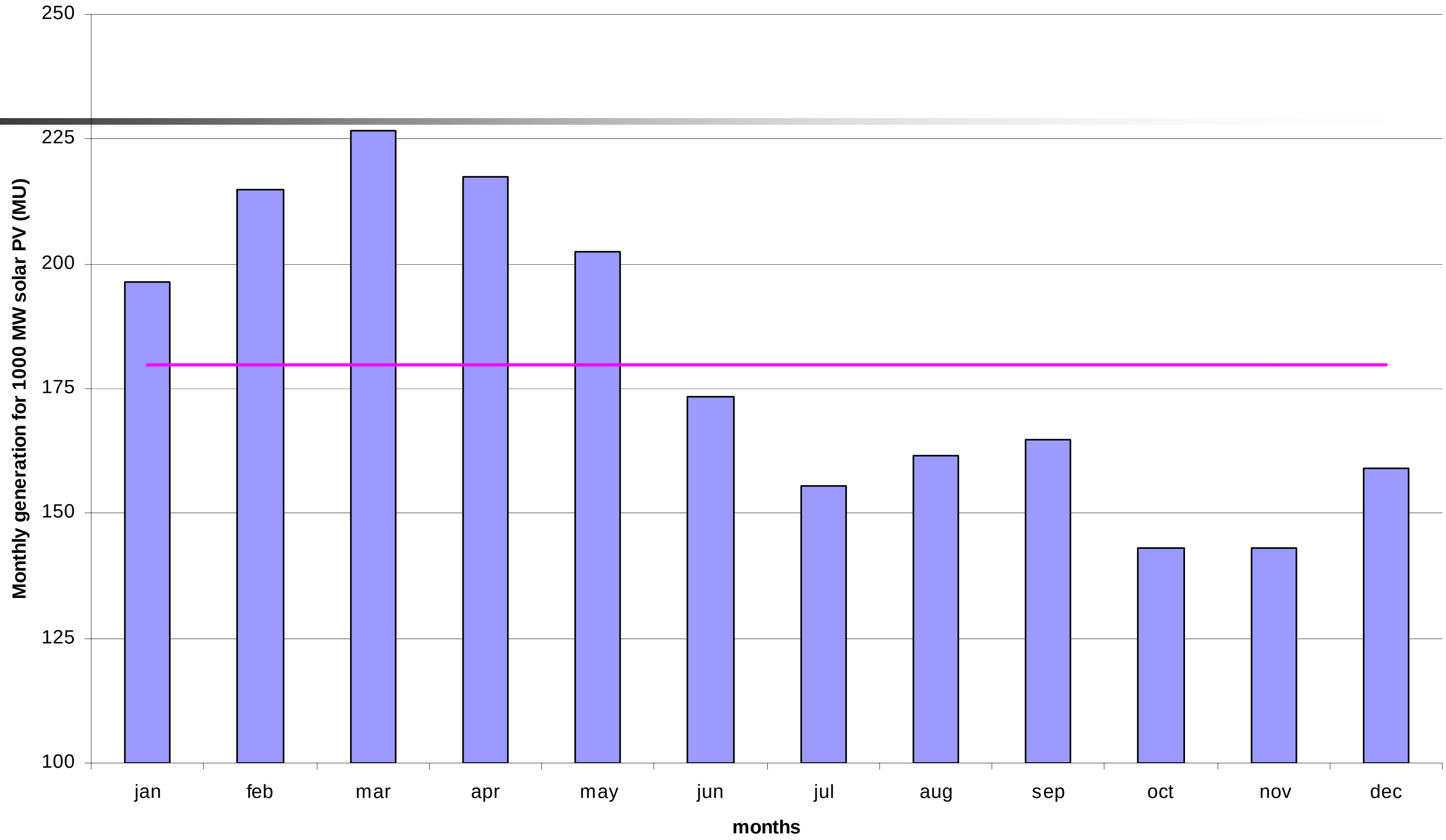

Installed solar power capacity
Installed wind power capacity
Installed biomass power capacity
Hourly solar energy generated
Hourly wind energy generated
Hourly biomass energy generated
Hourly total renewable energy generated
Effective load curve
Hourly load curve
Divide load curve into equal-sized bins
Record no. of hrs. in each bin
Frequency distribution of load over the year
Sum up to obtain annual LDC
Input n and n discrete capacities of W, S and B
Evaluate for n discrete renewable energy capacities
Compute base and peak load savings from diff. LDCs


Wind resource model
Solar resource model
WECS performance model
Solar PV performance model
Biomass power generation
Micro level model
Macro level model
Utility generation model
Load model
Capacity expansion model
Economic scenario
Output: Capacity Savings

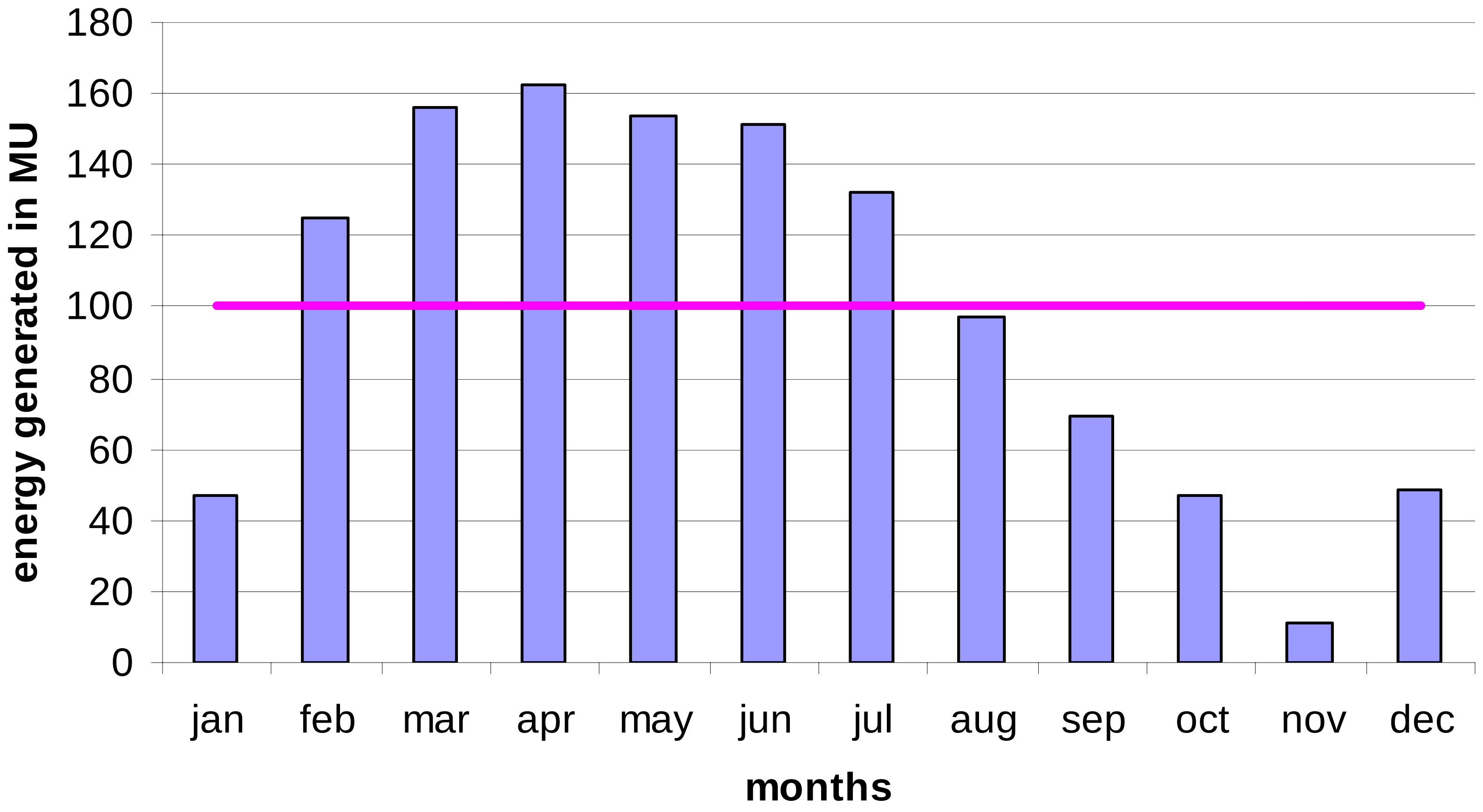
TN Solar Methodology (Micro-level)



Solar power – monthly variation

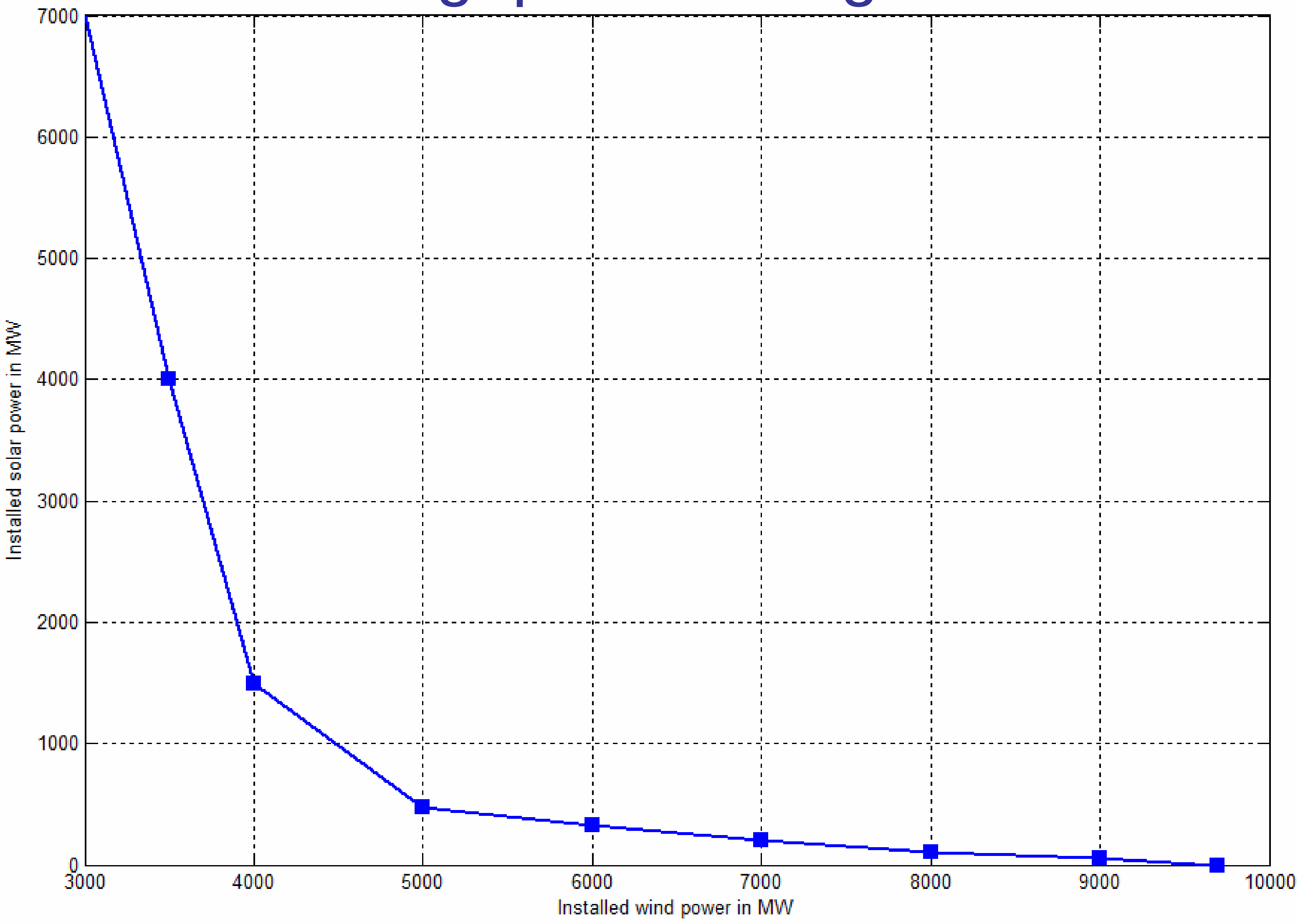


Biomass power – monthly variation

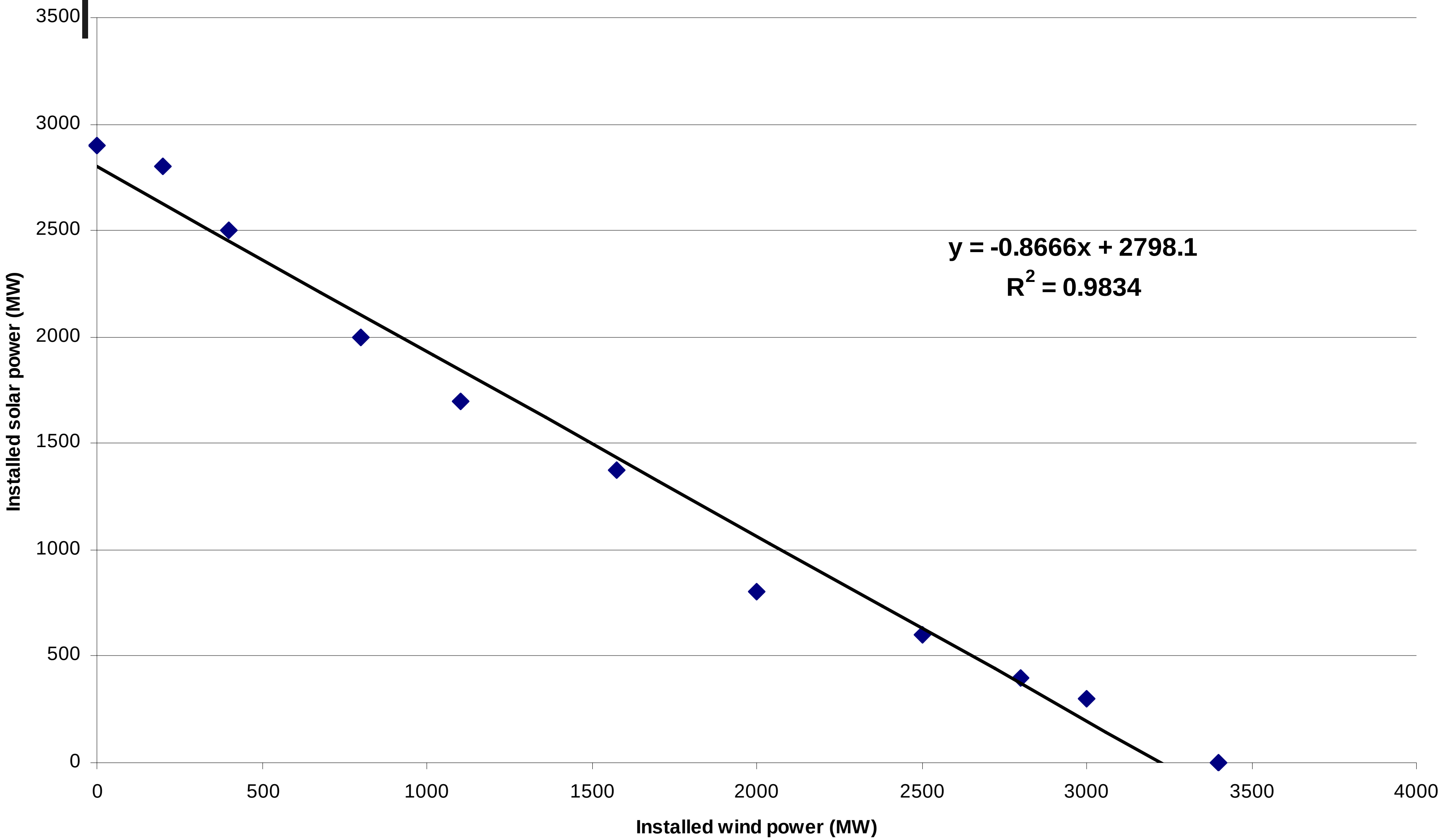


Installed capacity – 450 MW (340 MW from bagasse cogen)

Wind and solar power required for 1000 MW avg. peak saving

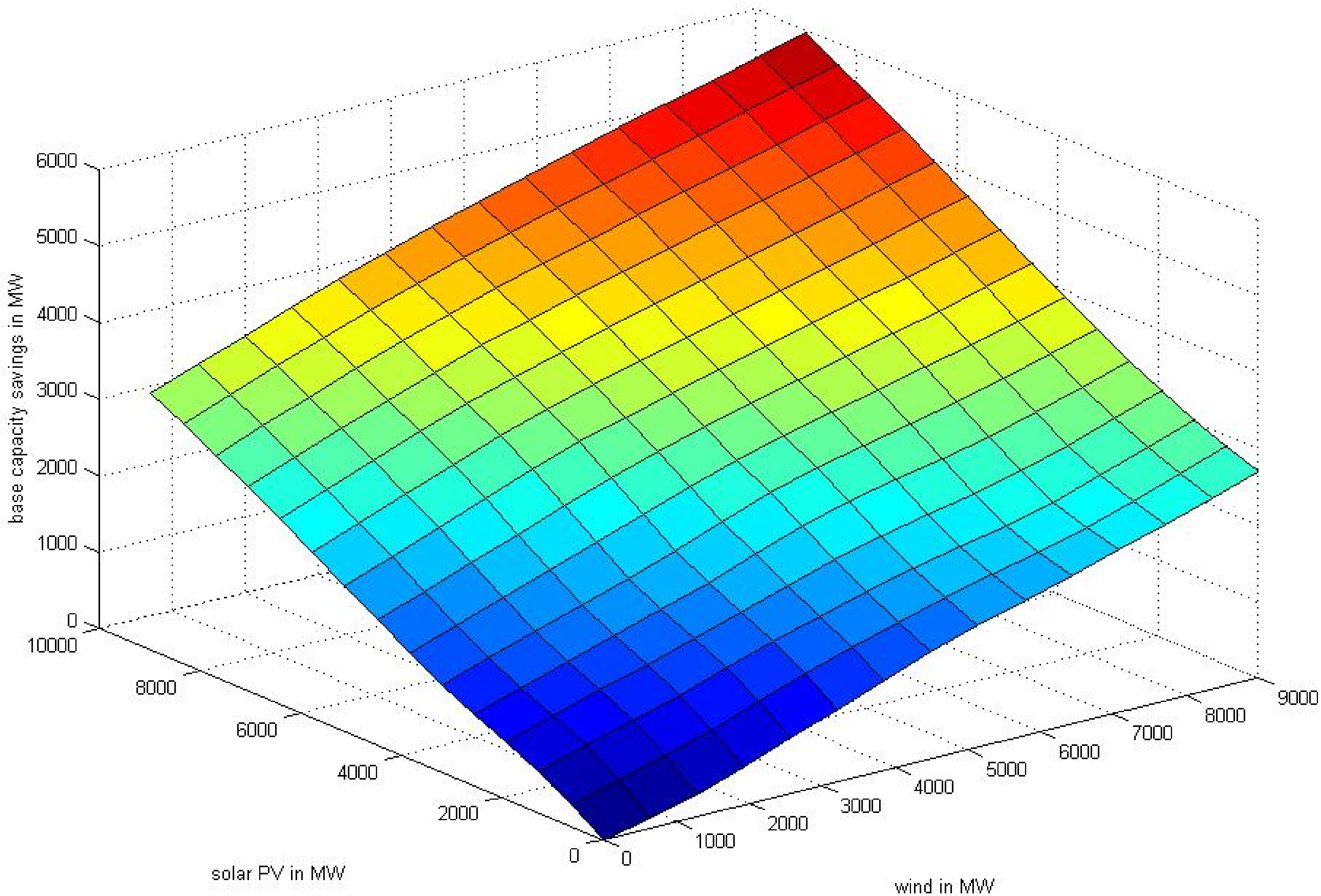


Wind and solar power installations to replace 1000 MW base power

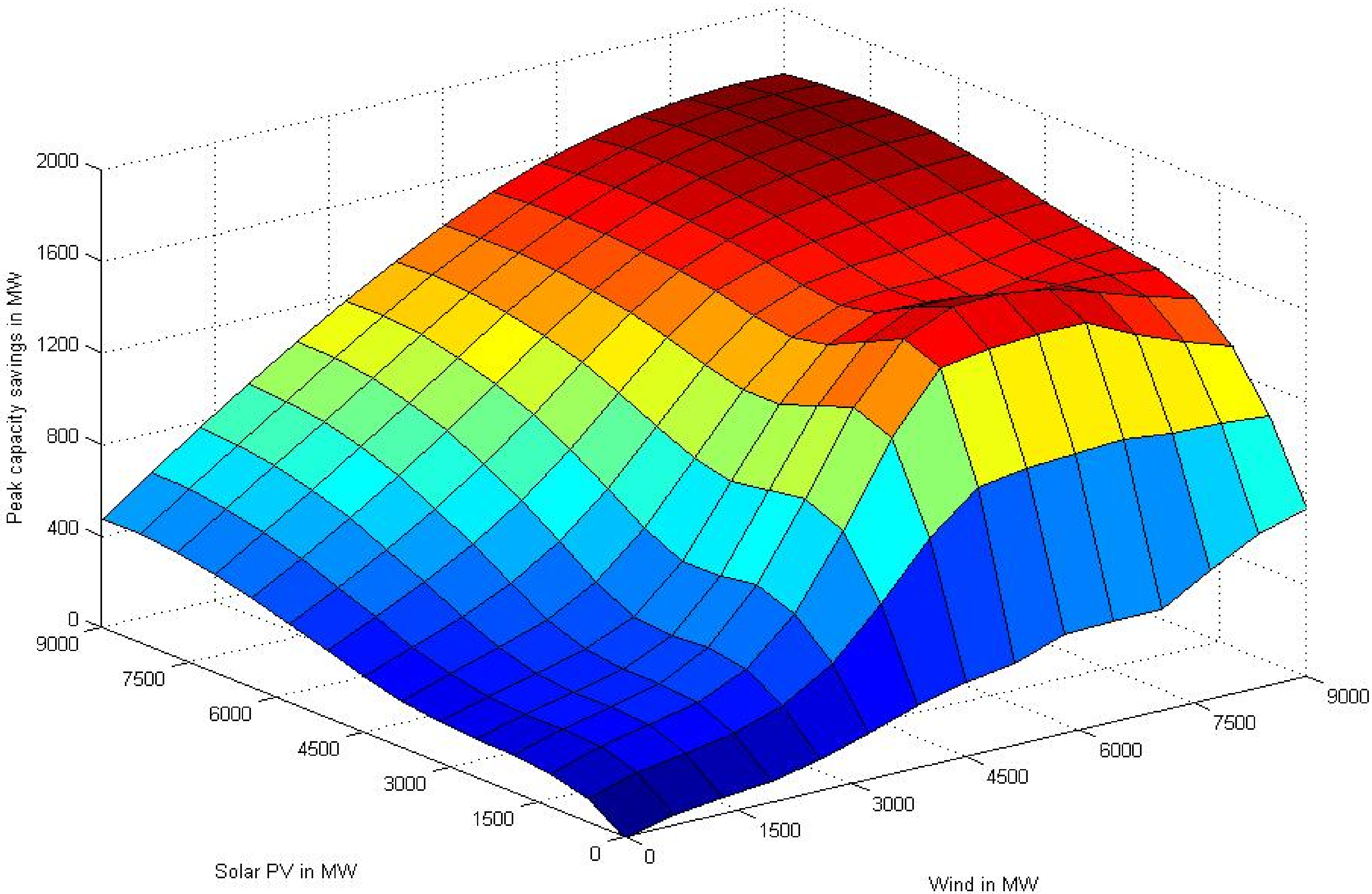


Slope = 0.8666 which is almost equal to ratio of capacity factors (0.18/0.21 = 0.857)

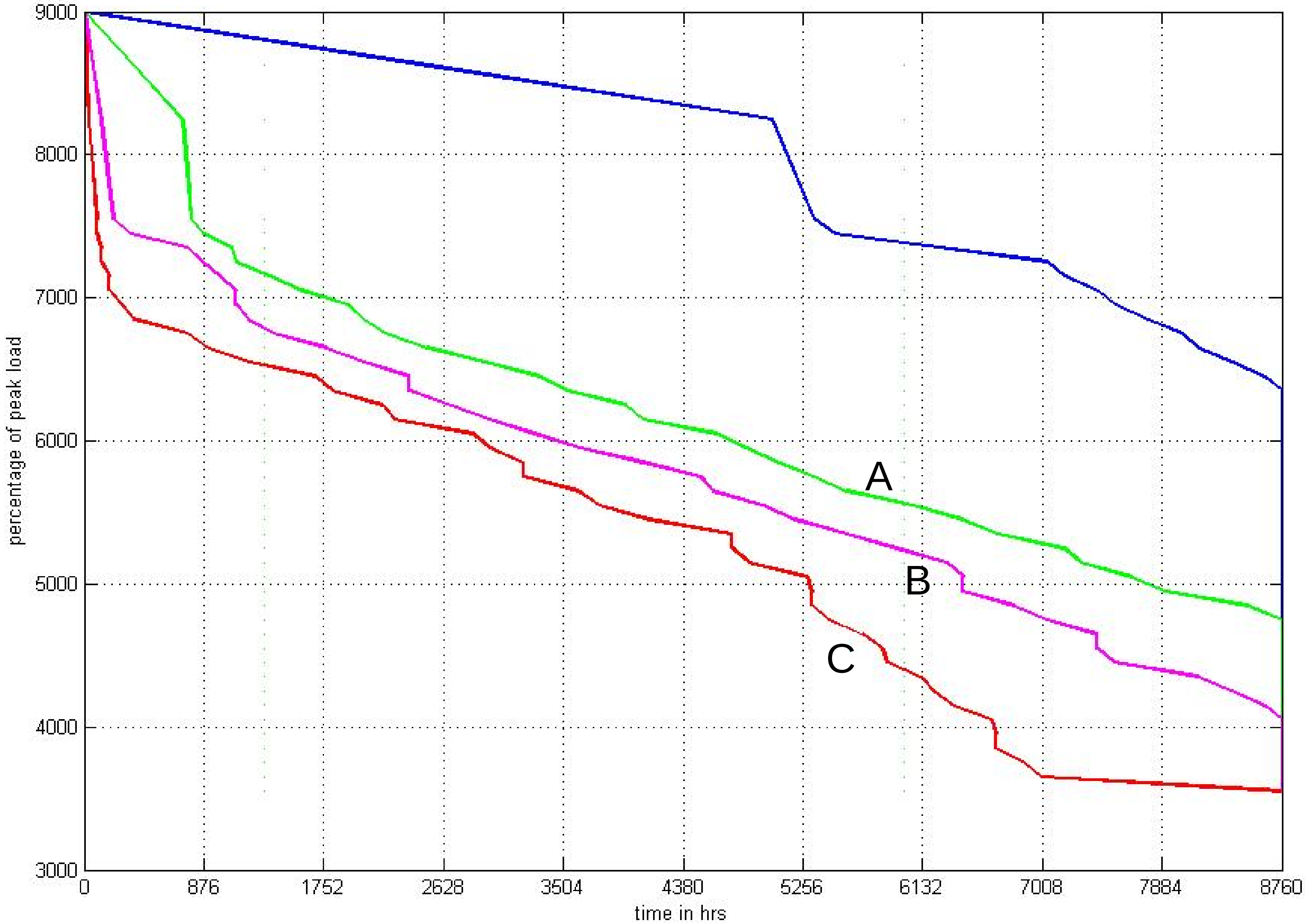
Base capacity savings with wind + solar



Peak capacity savings with wind + solar



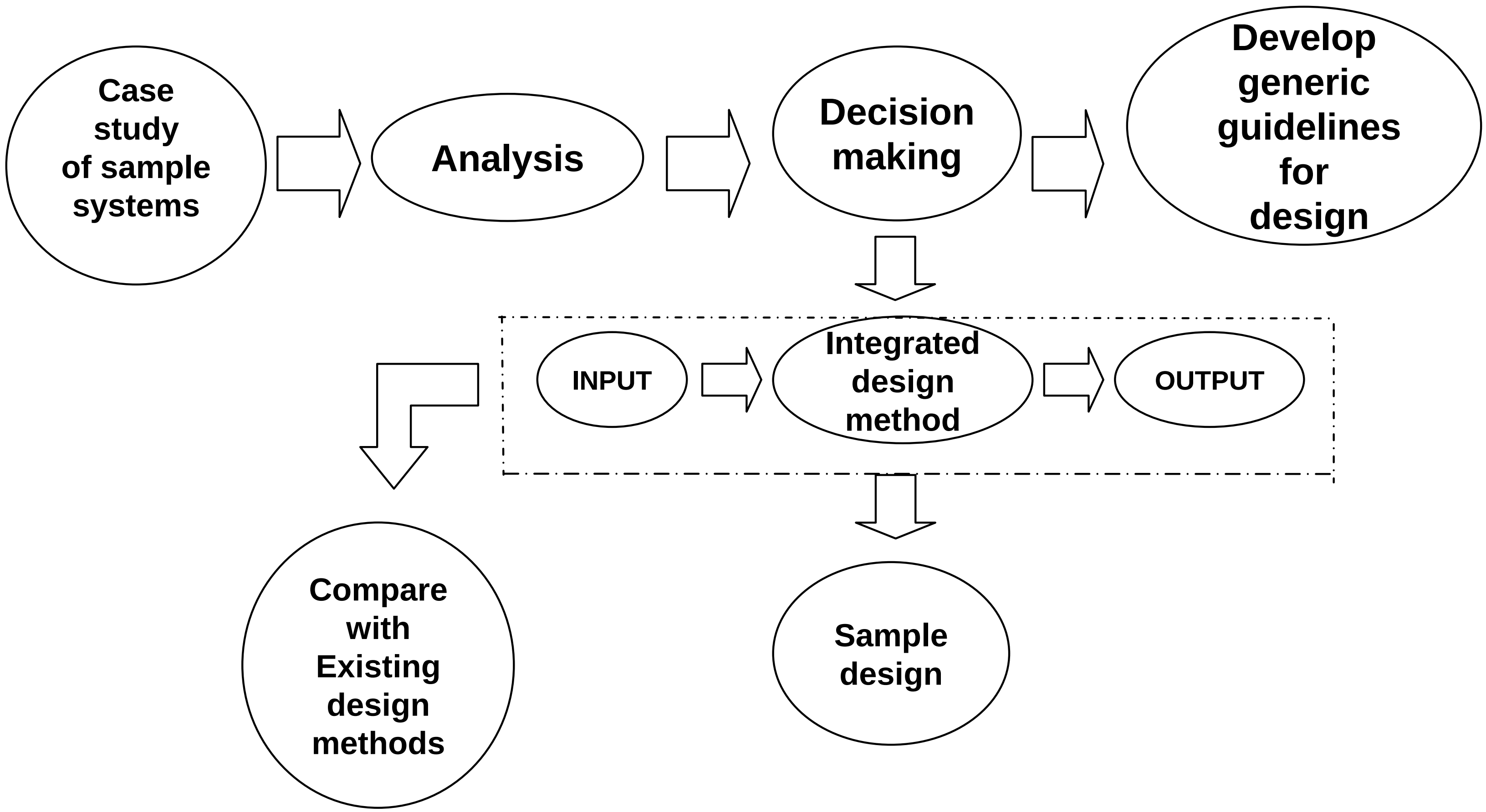
Hybrid scenarios – Impacts on LDC



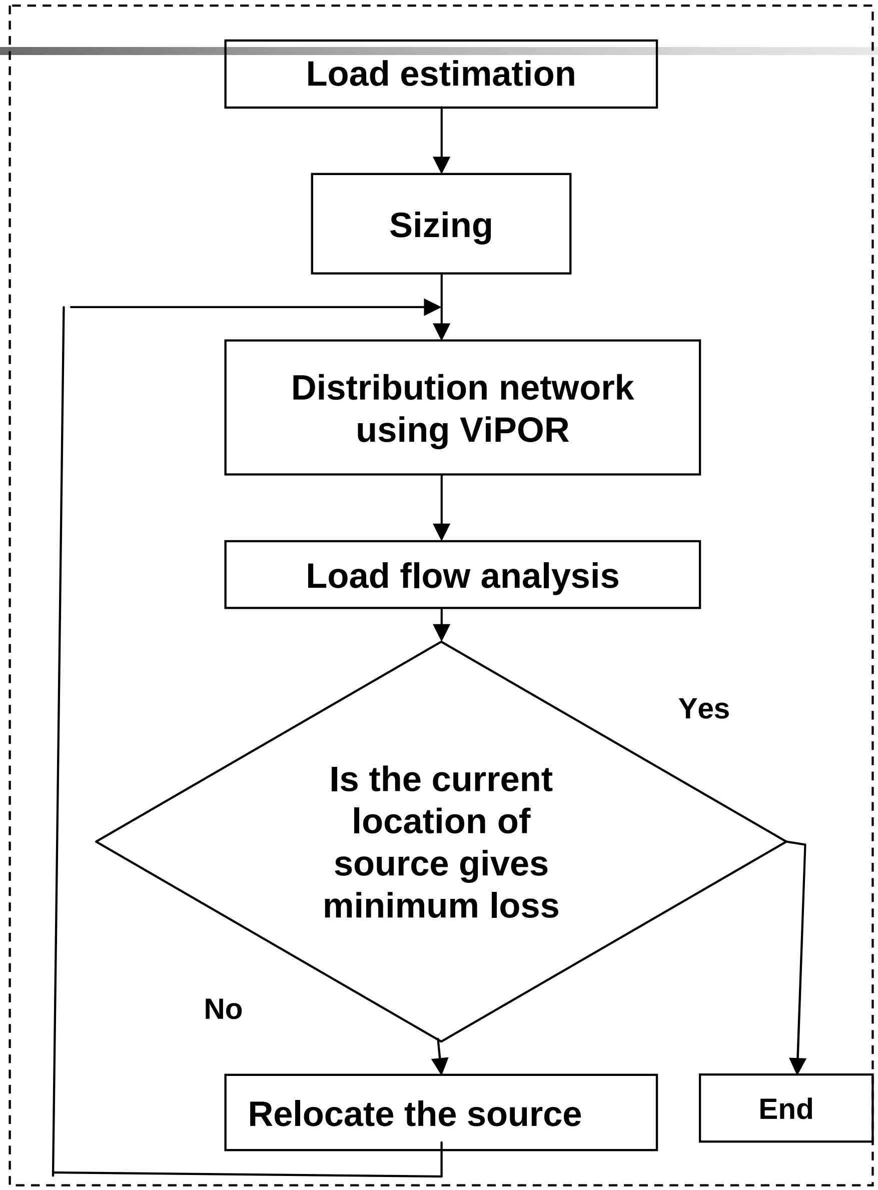
Impacts on LDC – capacity savings

Scenario	Wind (MW)	Solar (MW)	Biomass (MW)	Base capacity saved (MW)	Base capacity saved (% of installed RE capacity)	Peak capacity saved (MW)	Peak capacity saved(% of installed RE capacity)
A	4000	1000	1000	1568	30.31	1252	27.22
B	5000	1000	1500	2137	28.66	1423	26.79
C	3000	3000	3000	2984	33.15	2276	25.29

Design approach



Integrated design of Isolated power system



Integrated design-Summary

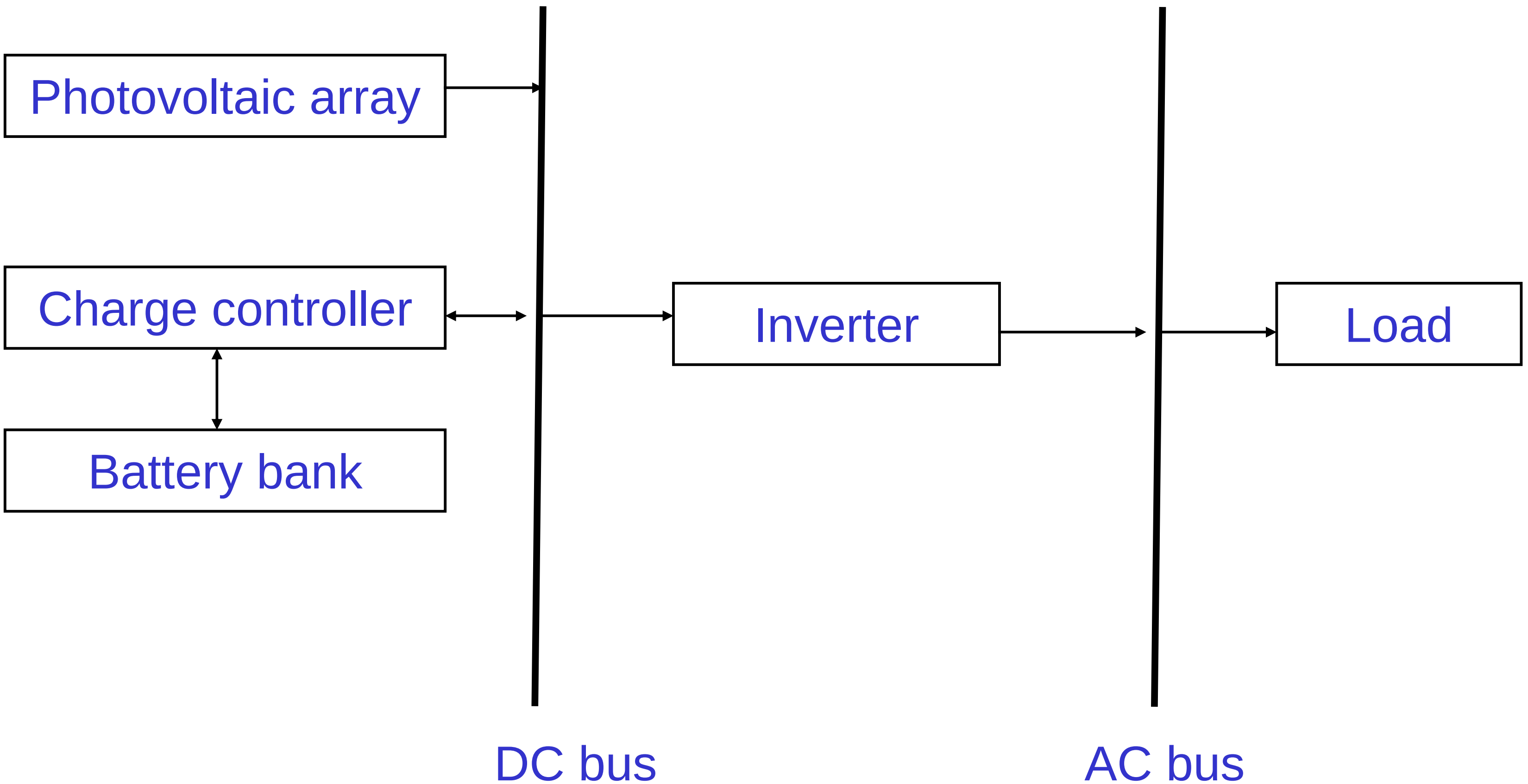
Name of the plant	Connected Load (kW)	Plant Capacity		Distribution loss (%)		Plant capacity factor (%)		Energy cost Rs / kWh	
		Existing	Designed	Existing	Designed	Existing	Designed	Existing	Designed
Solar PV, Rajmachi	1.4	5 kWp	4 kWp	4.6	0.5	8.3	11.5	32	25
Biomass gasifier, Dissoli	6.9	10 kW	10 kW	12.3	2.0	8.8	12	29-37	21-25
Biomass gasifier, Lonarwadi	10.7	20 kW	10 kW	14.6	2.7	5.6	14	43-54	16-25

Sizing of Photovoltaic-Battery Systems

Objective:

- To arrive at the set of all feasible configurations (Array rating and Battery capacity) to meet a given demand following a time-series simulation of the system

Schematic of the System



Mathematical model

- Energy balance

$$\frac{dQ_B}{dt} = (P_P(t) - D(t)) f(t)$$

Power from the photovoltaic array

- For a small time step, battery energy:

$$Q_B(t + \Delta t) = Q_B(t) + (P_P(t) - D(t)) f(t) \Delta t$$

Hourly energy balance

$$Q_B(t = 0) = Q_B(t = T)$$

Repeatability of battery energy

$$Q_B(t) \geq 0$$

Non negativity of battery energy

$$B_r = \frac{\max\{Q_B(t)\}}{DOD}$$

Battery storage requirement

Photovoltaic-Battery System Sizing (Deterministic Approach)

Inputs: Hourly solar insolation data, Hourly load data, Photovoltaic system efficiency, Power conversion efficiency

↓

Estimation of the solar insolation incident on the array

↓

System simulation to obtain the minimum array size and the corresponding battery capacity

↓

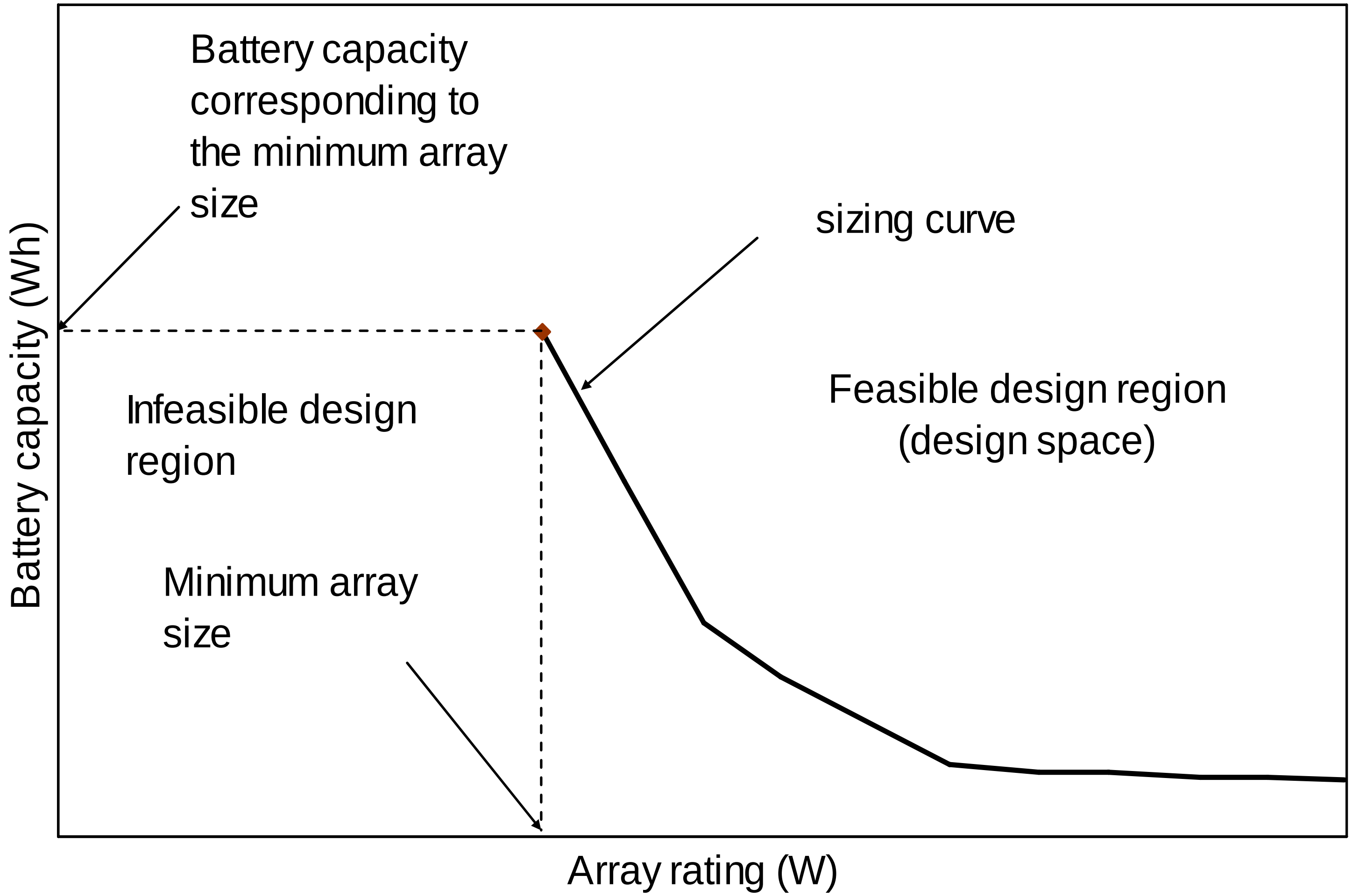
Calculation of the minimum storage capacity for different array sizes greater than the minimum

↓

Plot of sizing curve and the identification of the design space

Graphical representation

➢ Sizing curve for given solar insolation profile, load curve and system characteristics

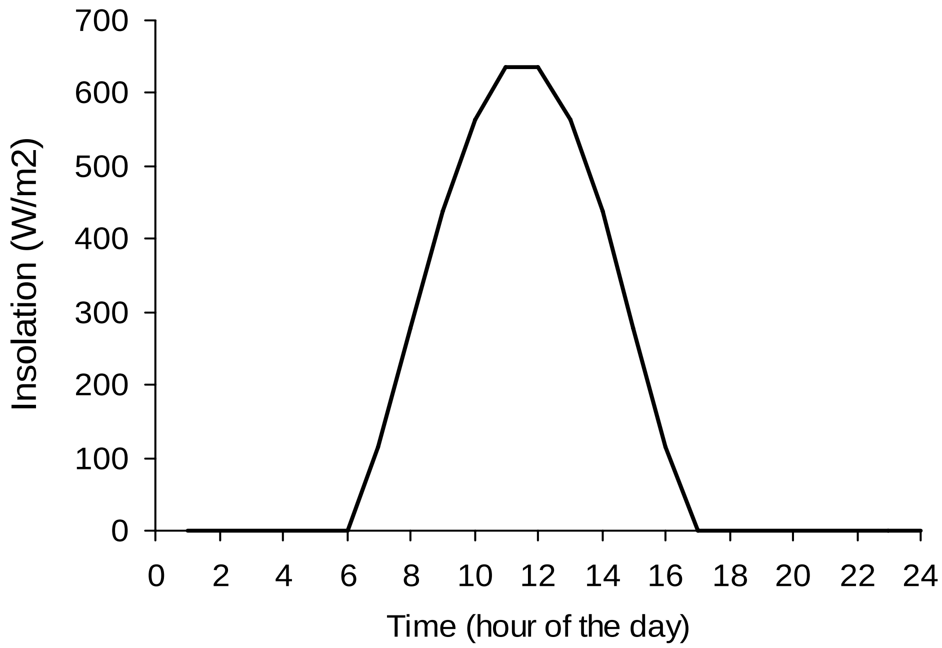


Photovoltaic-Battery System Sizing (Example)

For a remote location in Sagar island, West Bengal

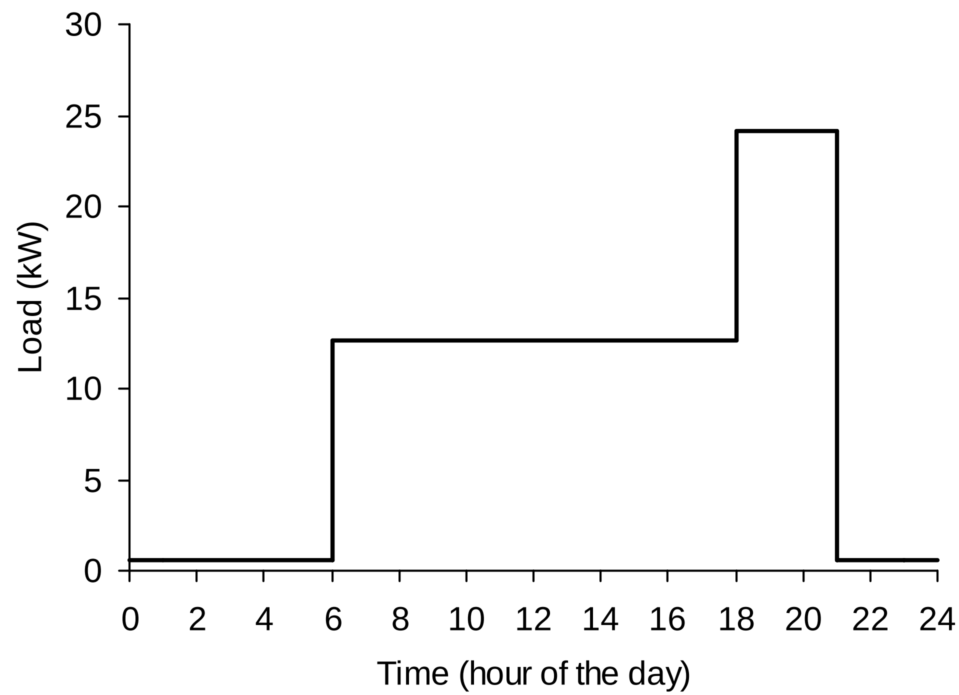
- Solar insolation profile

Averaged values for the month of December

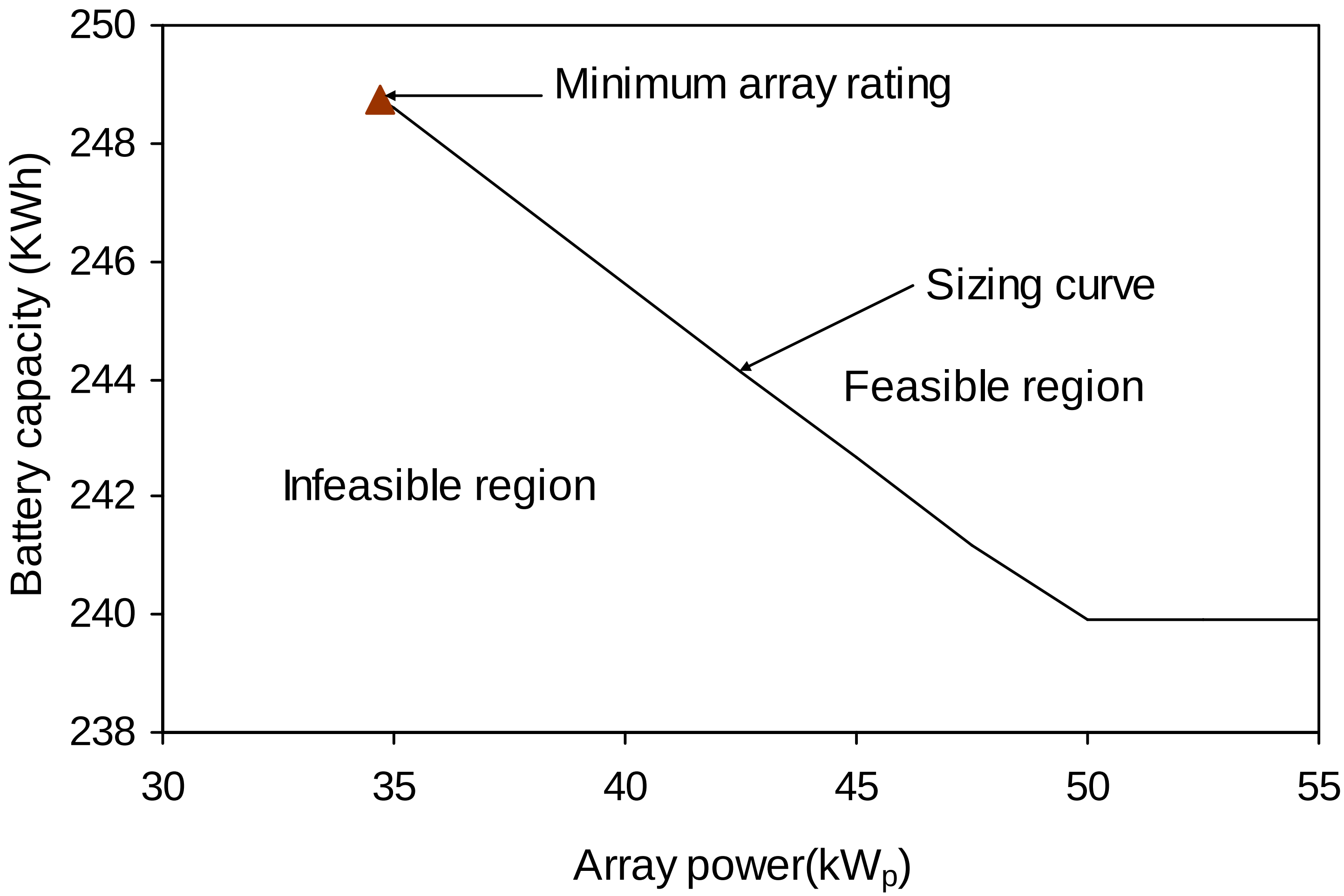


- Demand profile

For an average day



Sizing curve and Design-space for the example



Mathematical Formulations

- Chance constraint:

$$Probability\{D(t) \geq D_{actual}(t)\} \geq \alpha$$

- Incorporating energy conservation equation of the storage:

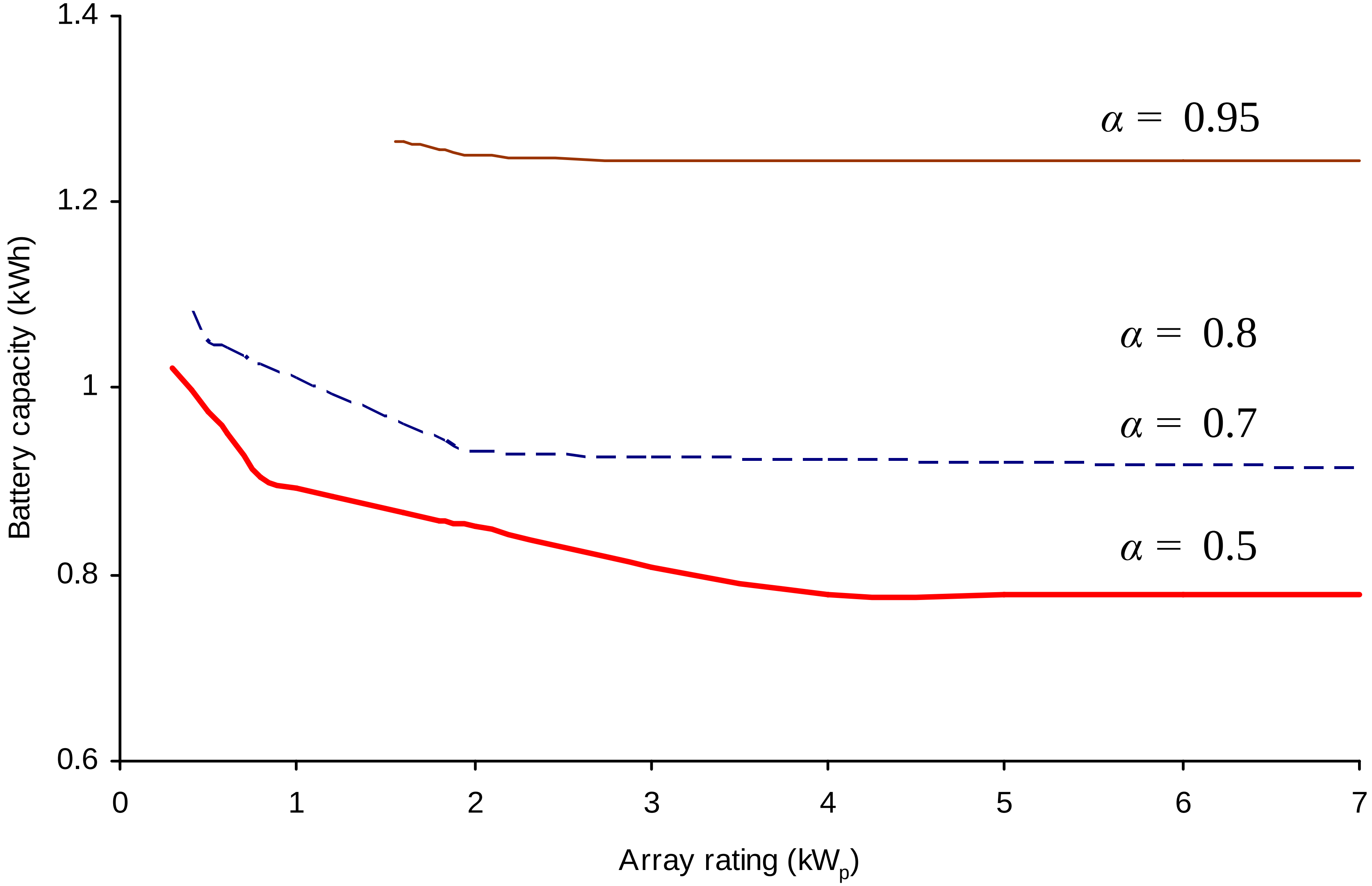
$$Probability\left\{\frac{Q_B(t+\Delta t)}{f(t)\Delta t} - \frac{Q_B(t)}{f(t)\Delta t} + D_{actual}(t) \leq P(t)\right\} \geq \alpha$$

- Deterministic equivalent:

$$\frac{Q_B(t+\Delta t)}{f(t)\Delta t} - \frac{Q_B(t)}{f(t)\Delta t} \leq (\mu_{P(t)} - D_{actual}(t) - \sigma_{P(t)} z_{\alpha})$$

- Generation of design space incorporating other constraints

PV-Battery System



Solar Water Heaters

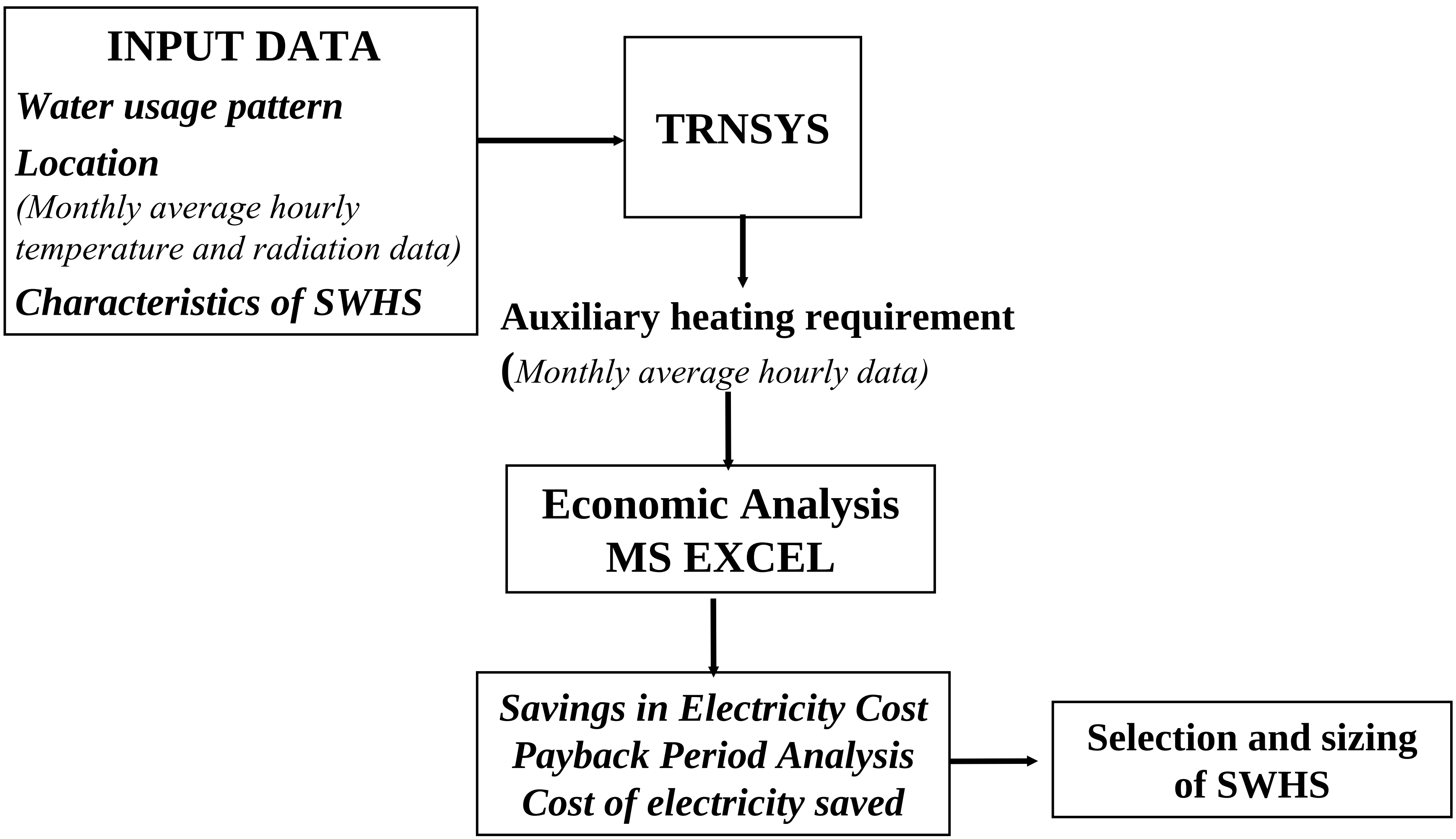
- Estimate potential for solar water heaters in a given area
- Develop generic framework

‘Diffusion of Renewable Energy Technologies’

Factors Affecting Diffusion Of SWHS

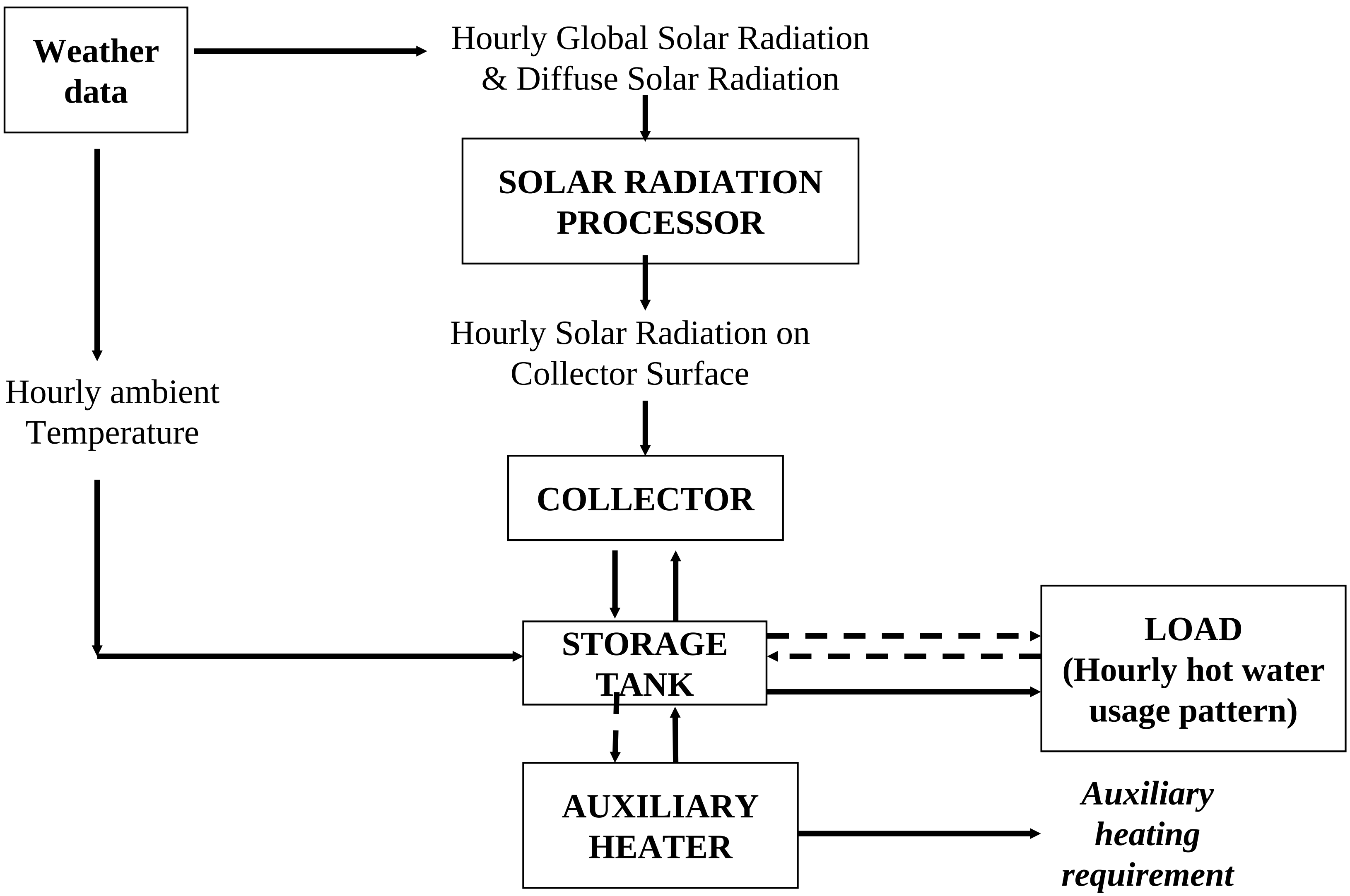
- Location- Insolation
- Water Usage Pattern
- Cost of electricity
- Capital Cost
- Reliability
- Potential savings
- Subsidies/ Financial Incentives

Micro Level Decision Model (Parametric Analysis)

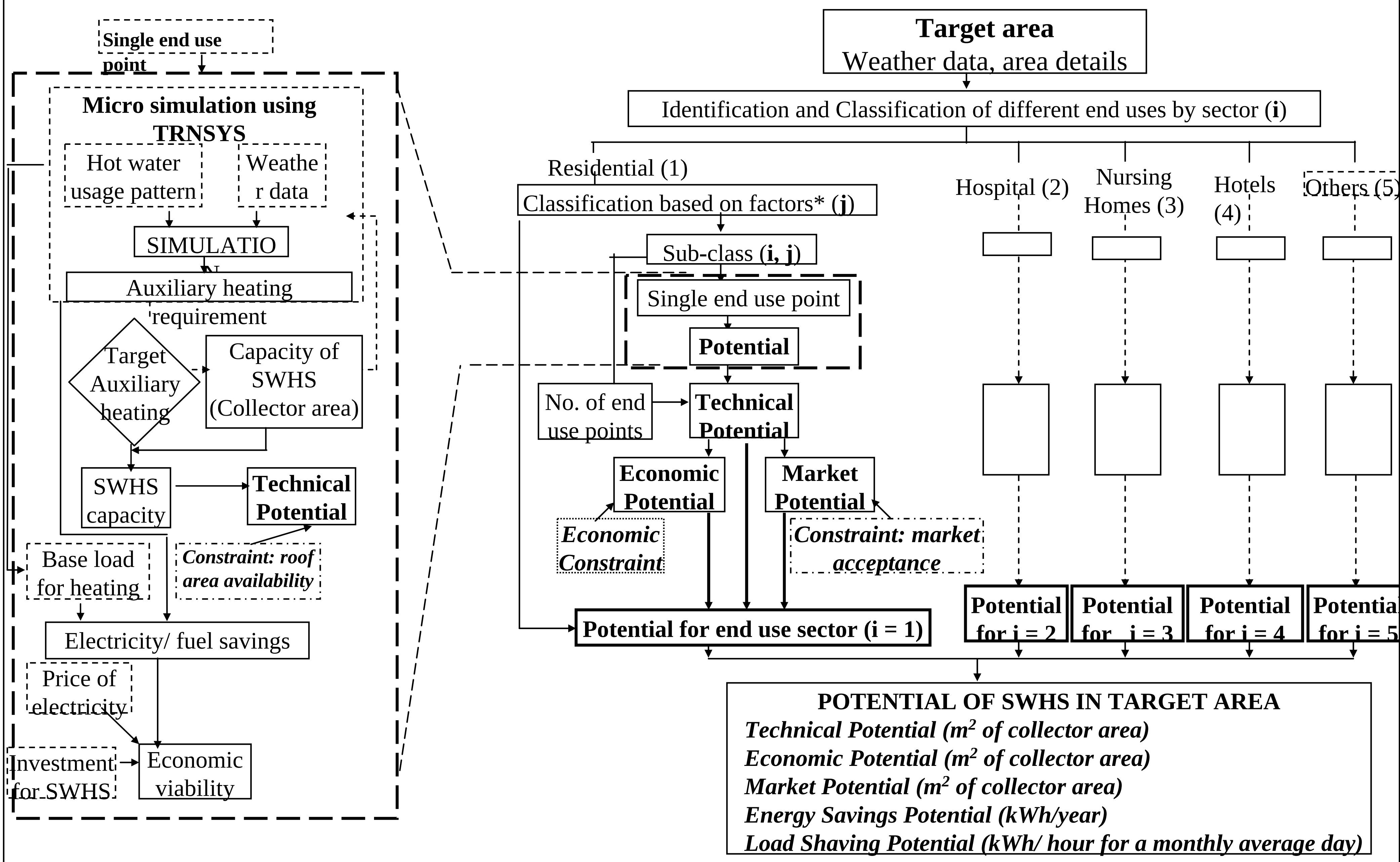


TRNSYS (Transient System Simulation Program *developed at SEL, University of Wisconsin)*

Information Flow Diagram of Micro – simulation for SWHS



Model for Potential Estimation of Target Area



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

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

$$P_i = \sum_{j=1}^{m} P_{ij}$$

where *i* denotes sector

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

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

Economic Potential

Economic potential of SWHS

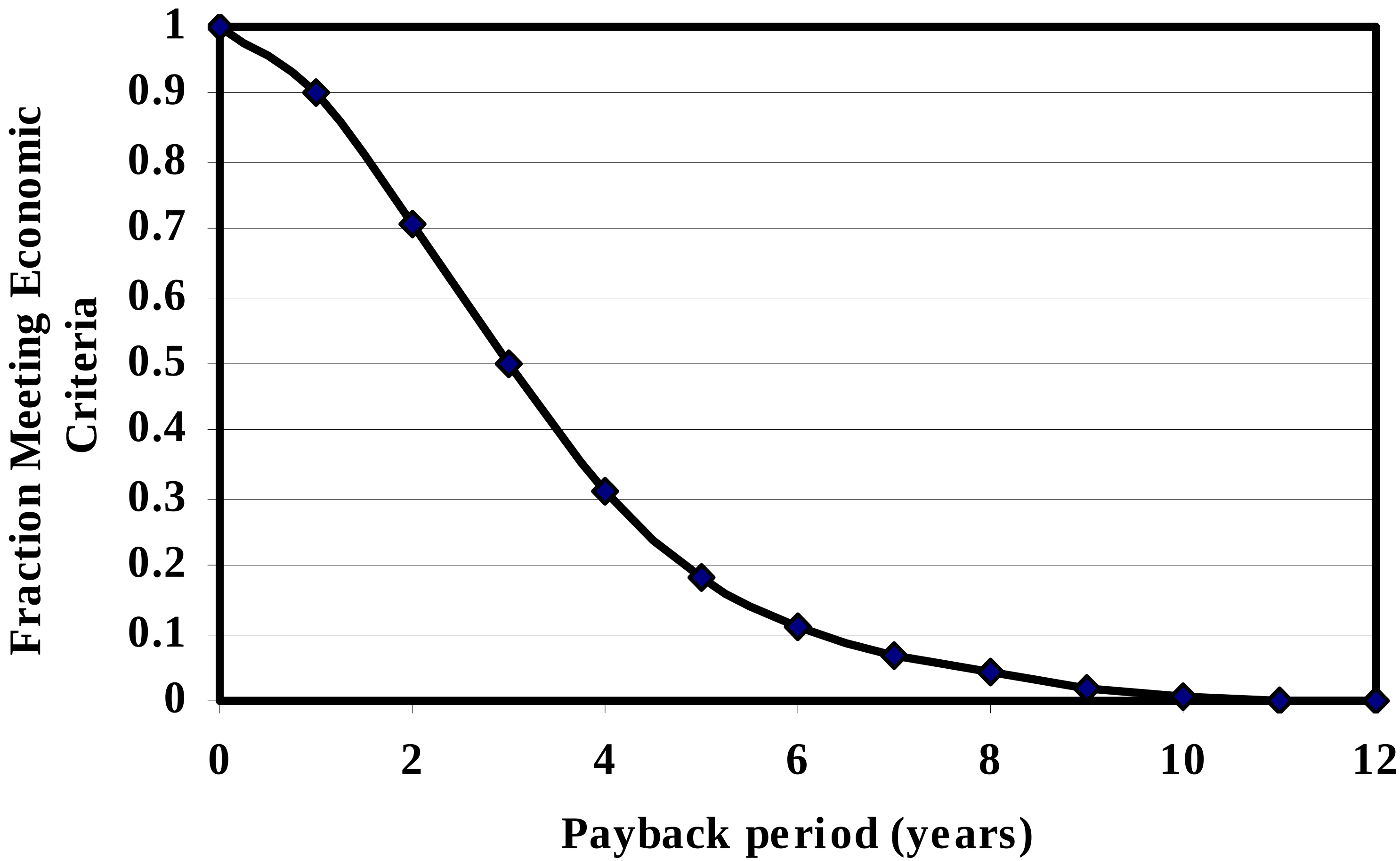
P(E): subset of technical potential

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

v_e = 0, if payback period > maximum acceptable limit

v_e = 1, if payback period < maximum acceptable limit

Payback Acceptance Schedule



MARKET POTENTIAL

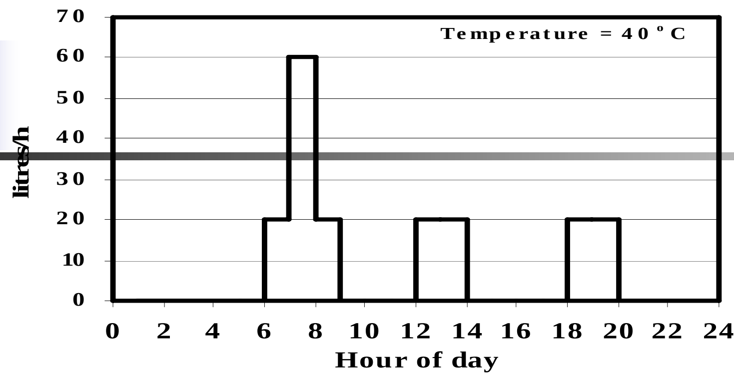
$$P(M)_{ij} = f_{pj} P_{ij}$$

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

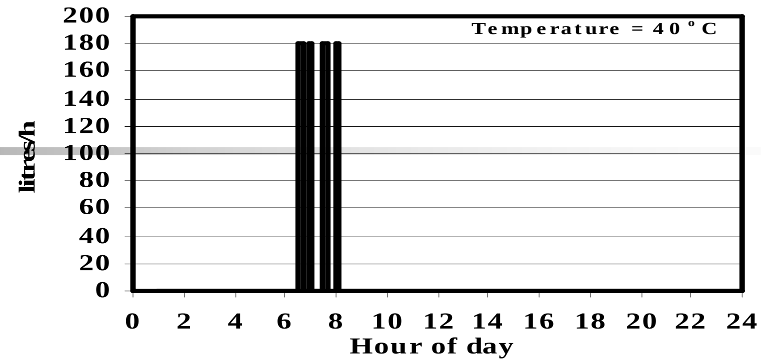
Input Data For Potential Estimation Of SWHS in Pune

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

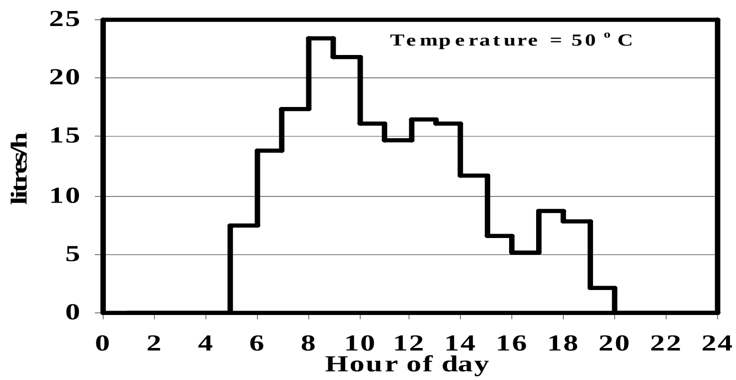
Hot Water Usage Patterns (Pune)



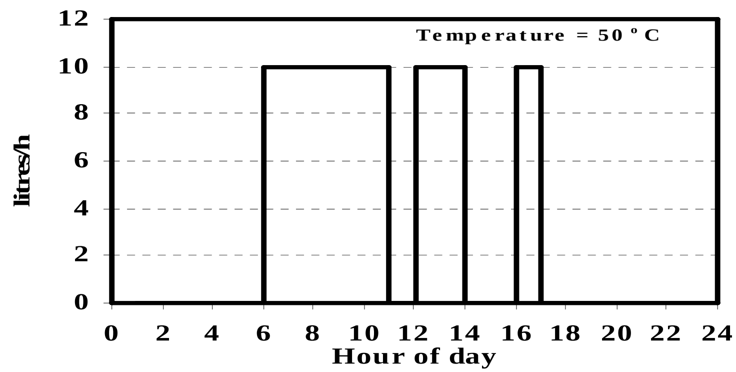
(a) Residential (1) [Gadgil, 1987]



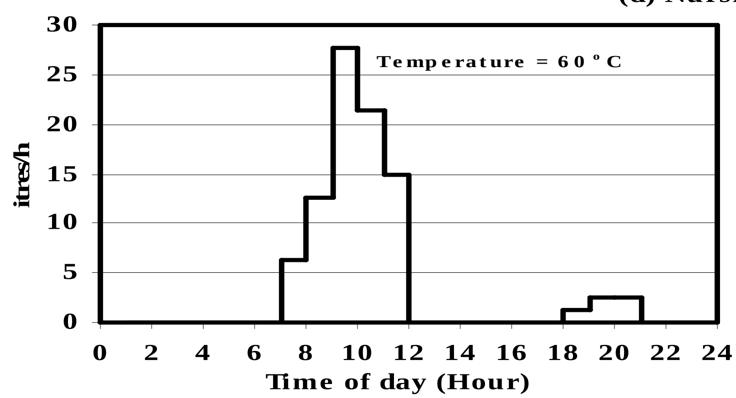
(b) Residential (2) [Narkhede, 2001]



(c) Hospital (1 bed)

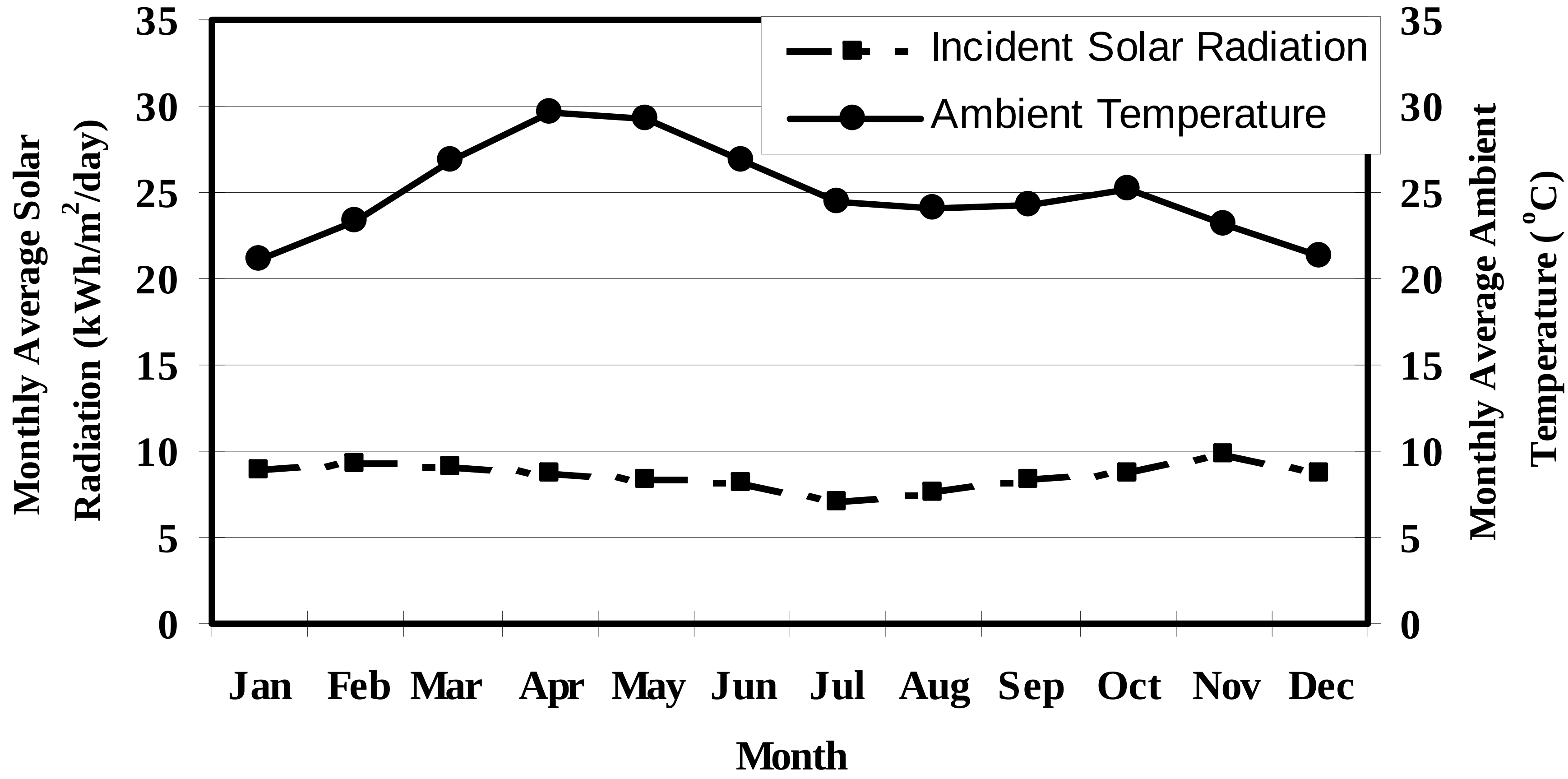


(d) Nursing Home (1 bed)



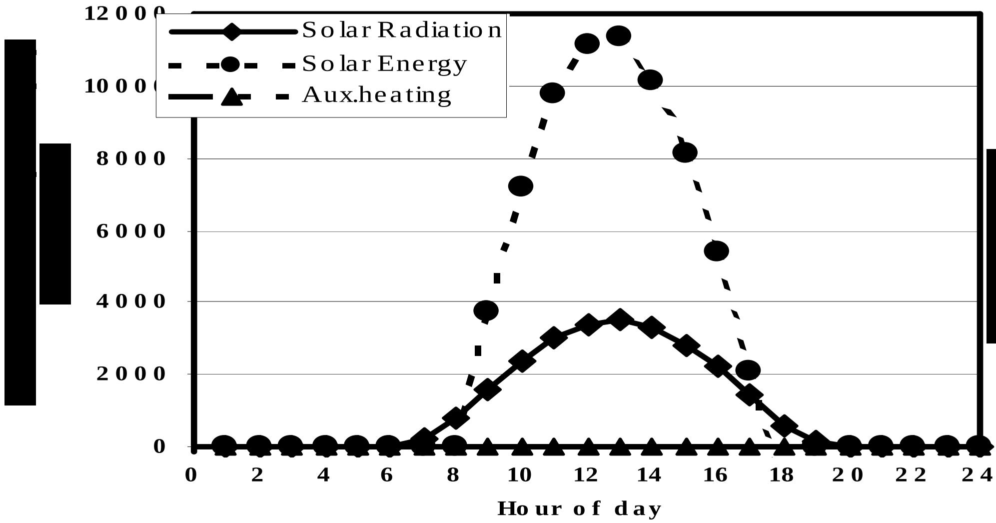
(e) Hotel - 1 guest

Monthly Average Ambient Conditions in Pune

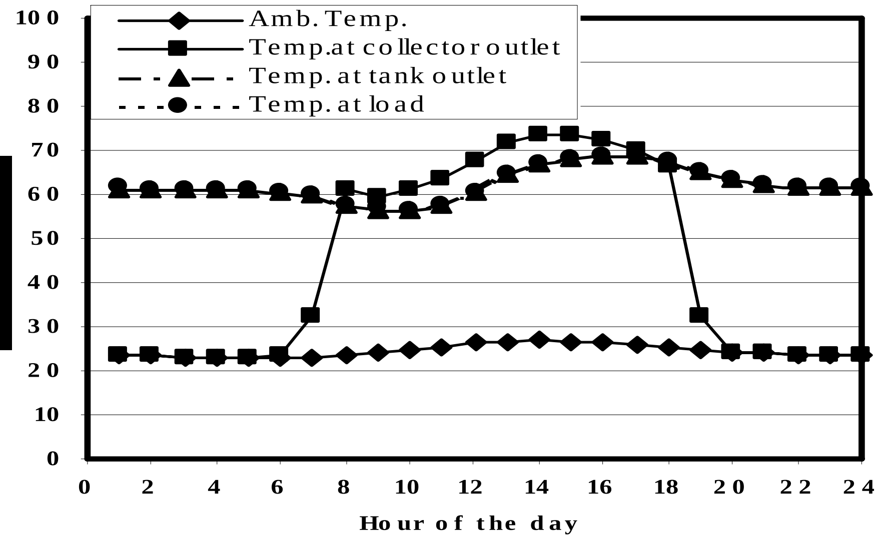


Mani, A. (1980) 'Handbook of solar radiation data for India'.

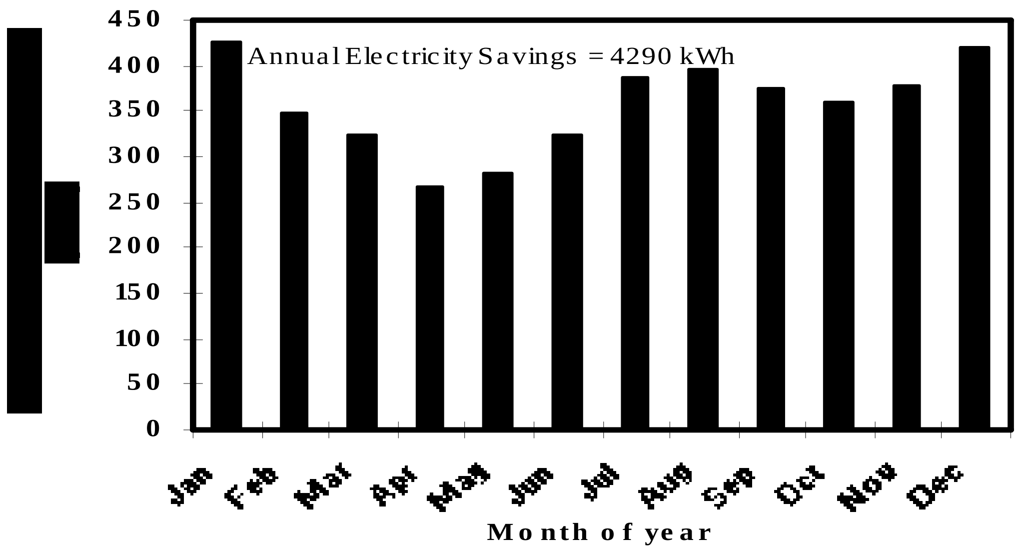
Sample simulation output and potential estimation for hospital with 5 beds



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



(b) Temperature profiles for a typical day

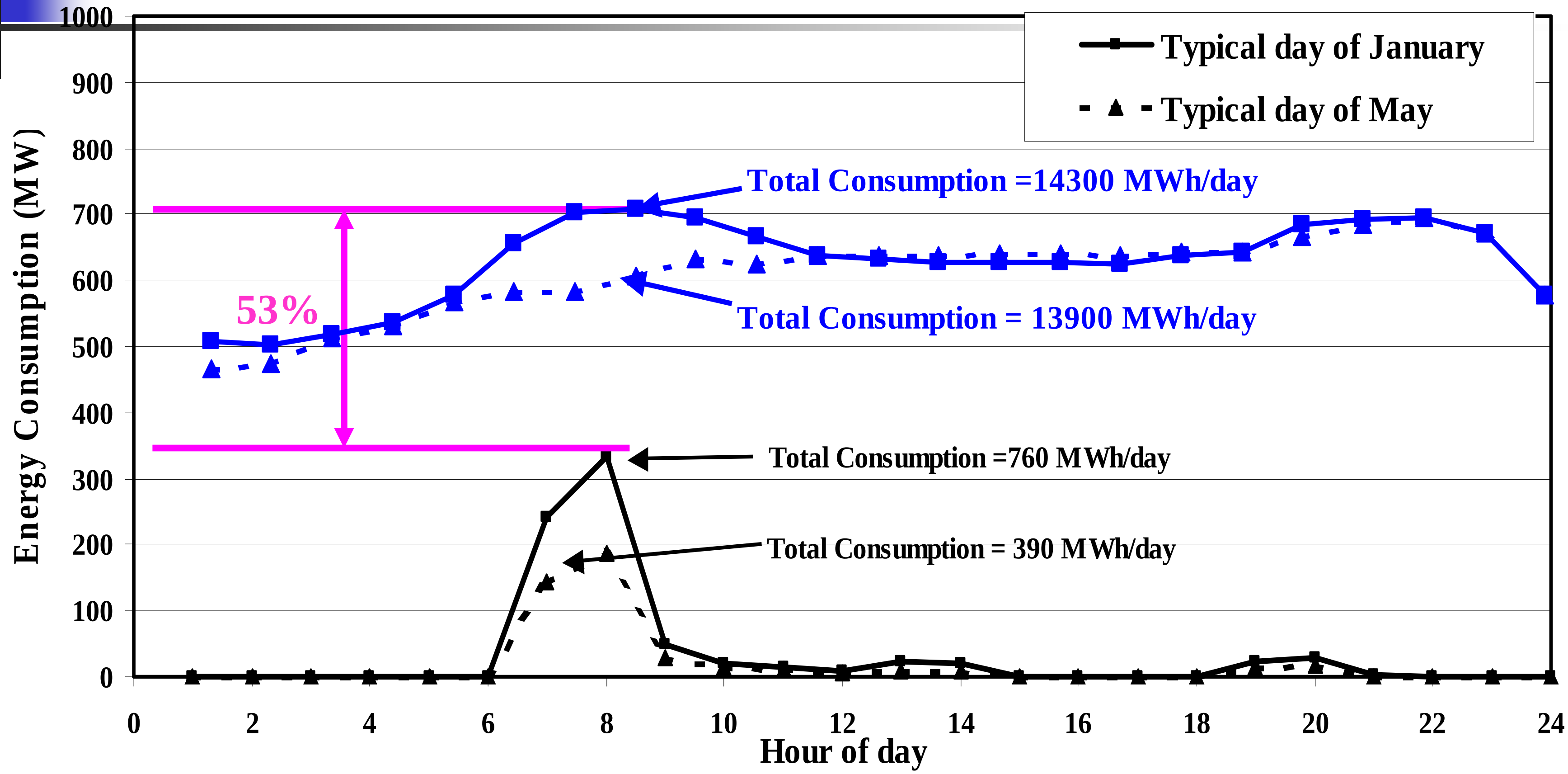


(c) Monthly variation in electricity savings

Potential Estimation of Sectors (Pune)

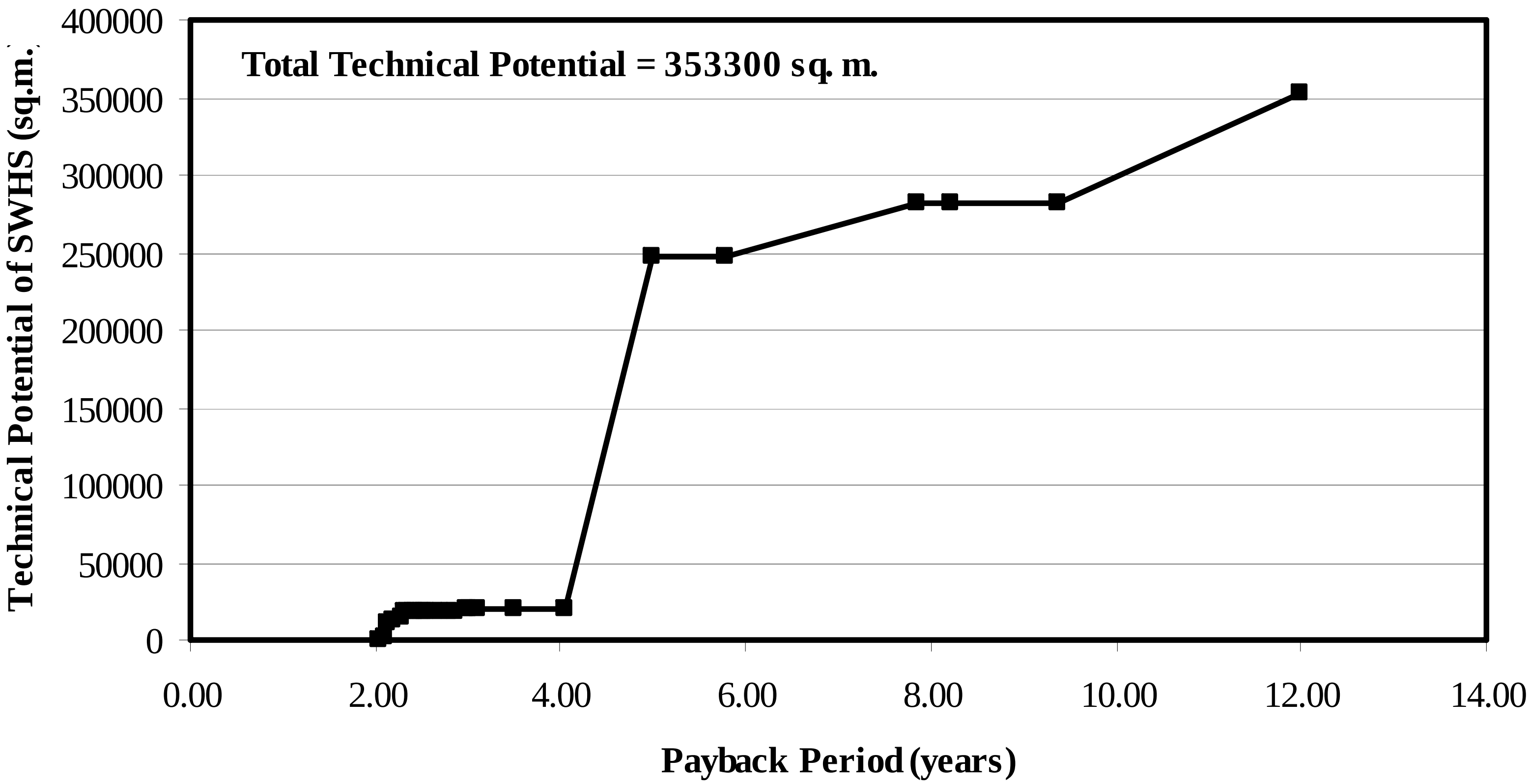
Sector		Technical Potential		Market Potential	
		Collector area (m^2)	Annual Electricity savings (kWh)	Collector area (m^2)	Annual Electricity savings (kWh)
Residential	Single houses	106000	37200000	2100	740000
	Multi-storeyed	227400	165000000	41000	29700000
Hospitals		5500	5900000	1700	1600000
Nursing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

Load Curve Representing Energy Requirement for Water Heating



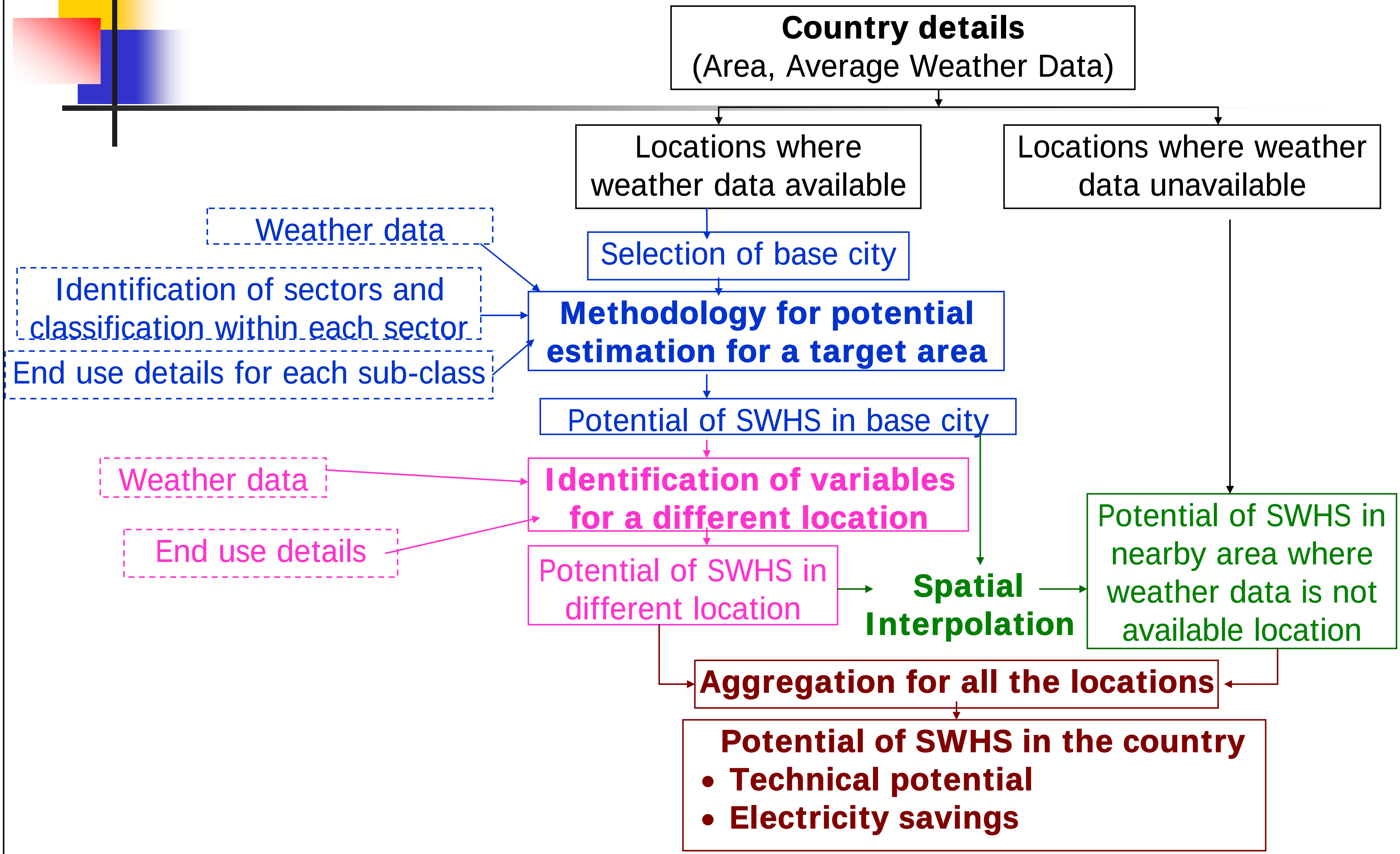
- *Total Electricity Consumption of Pune*
- *Electricity Consumption for water heating of Pune*

Achievable Potential Of SWHS For Different Payback Periods (Pune)

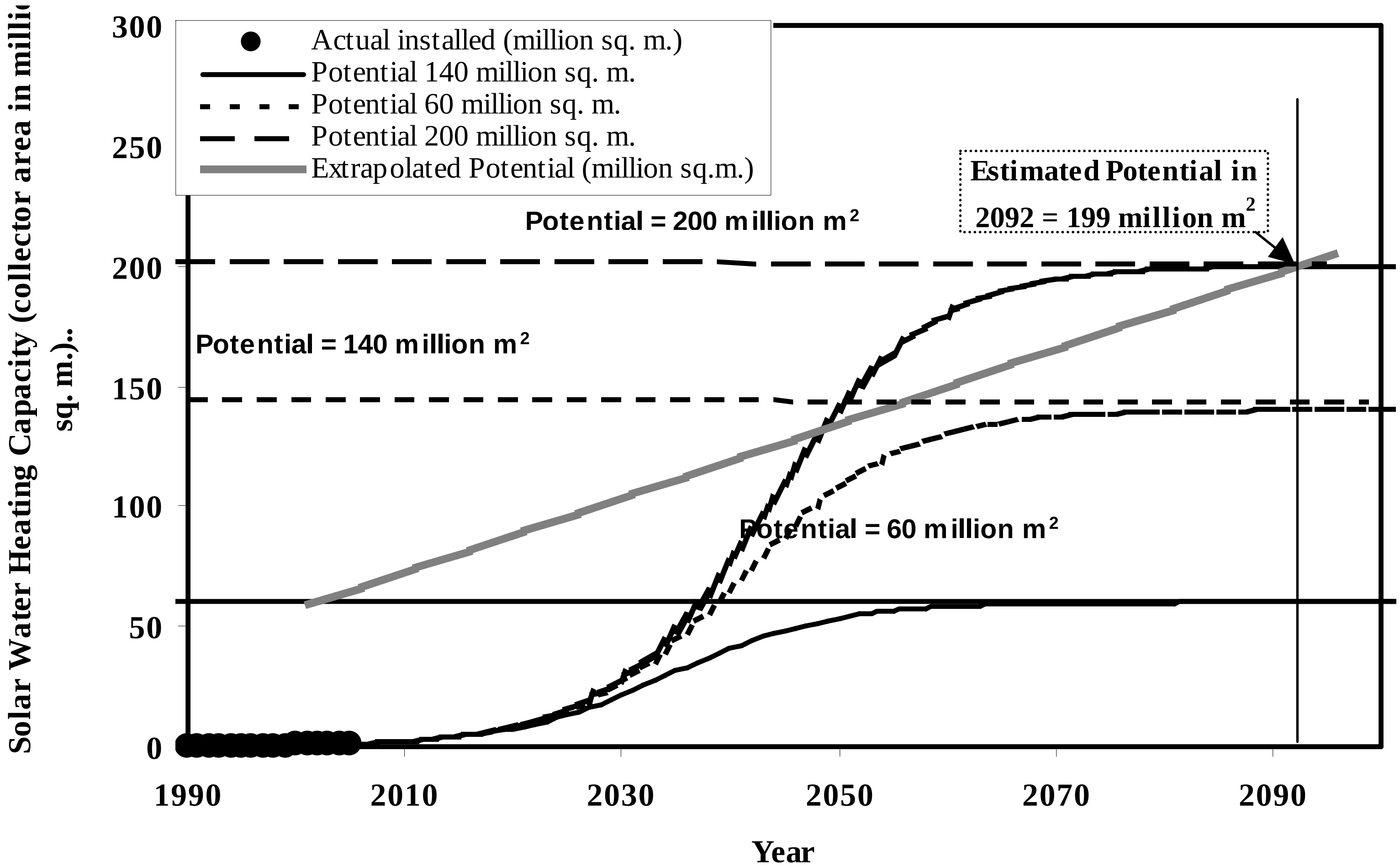


Economic potential (limit=payback period of 5 years) =19700 m^2 collector area

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

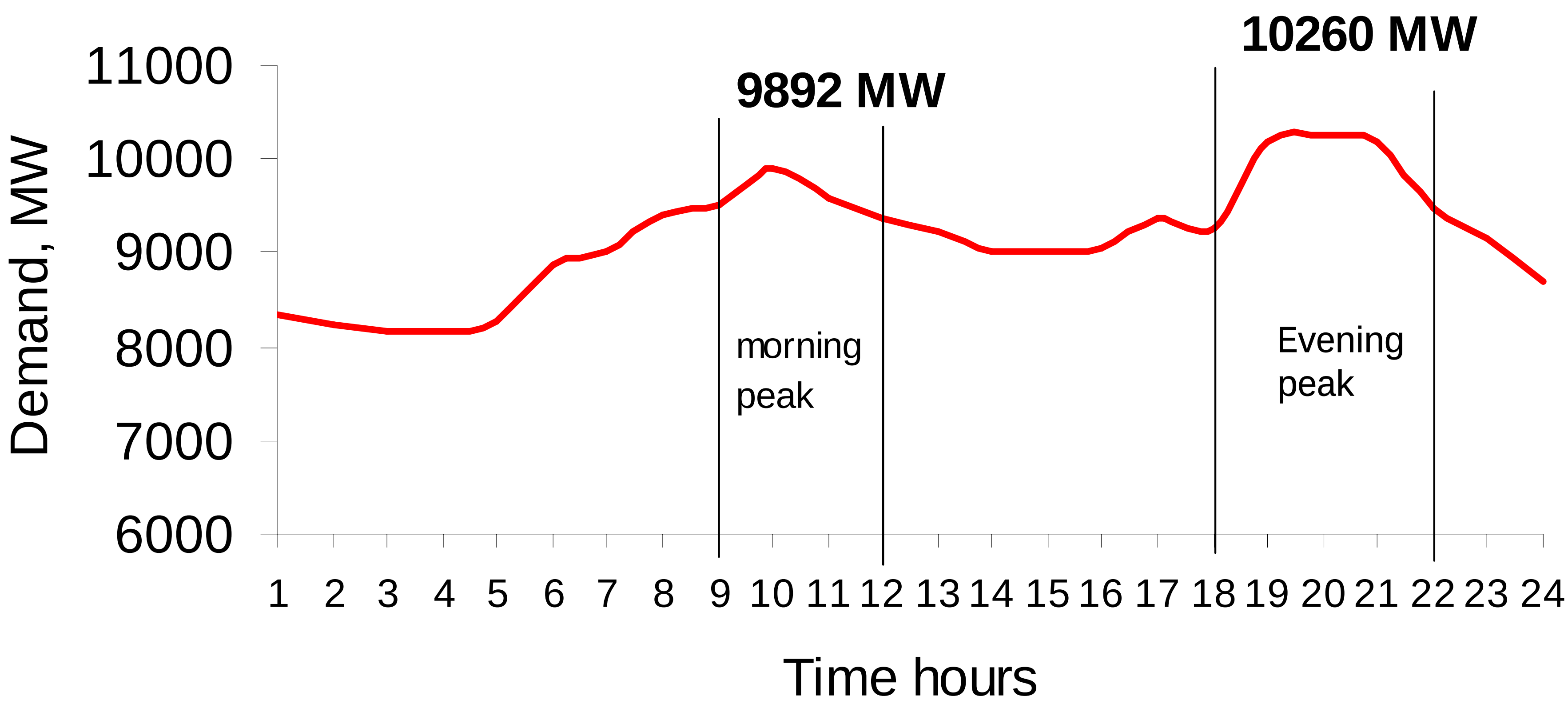


Diffusion of SWH

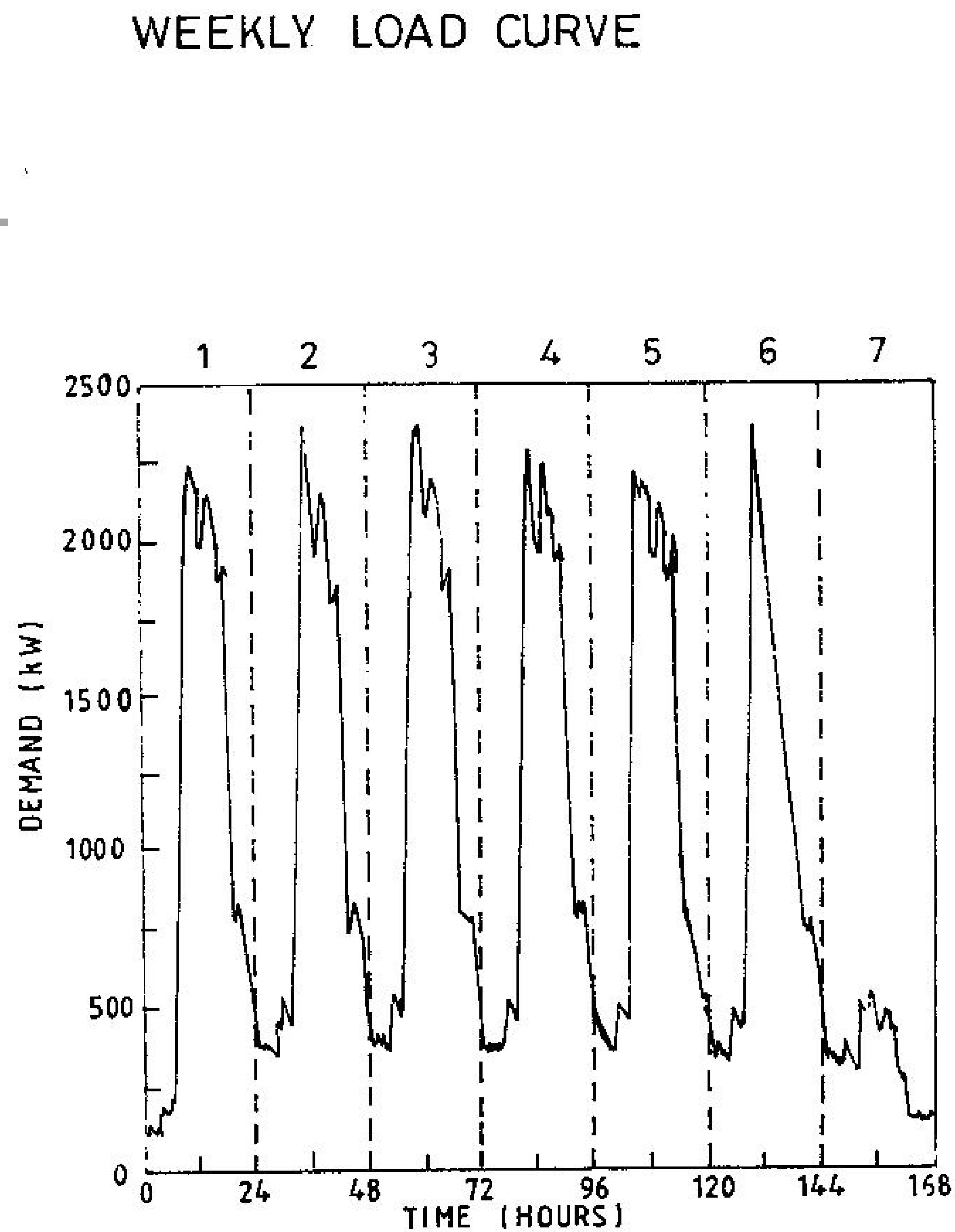


Load curve of a typical day –MSEB

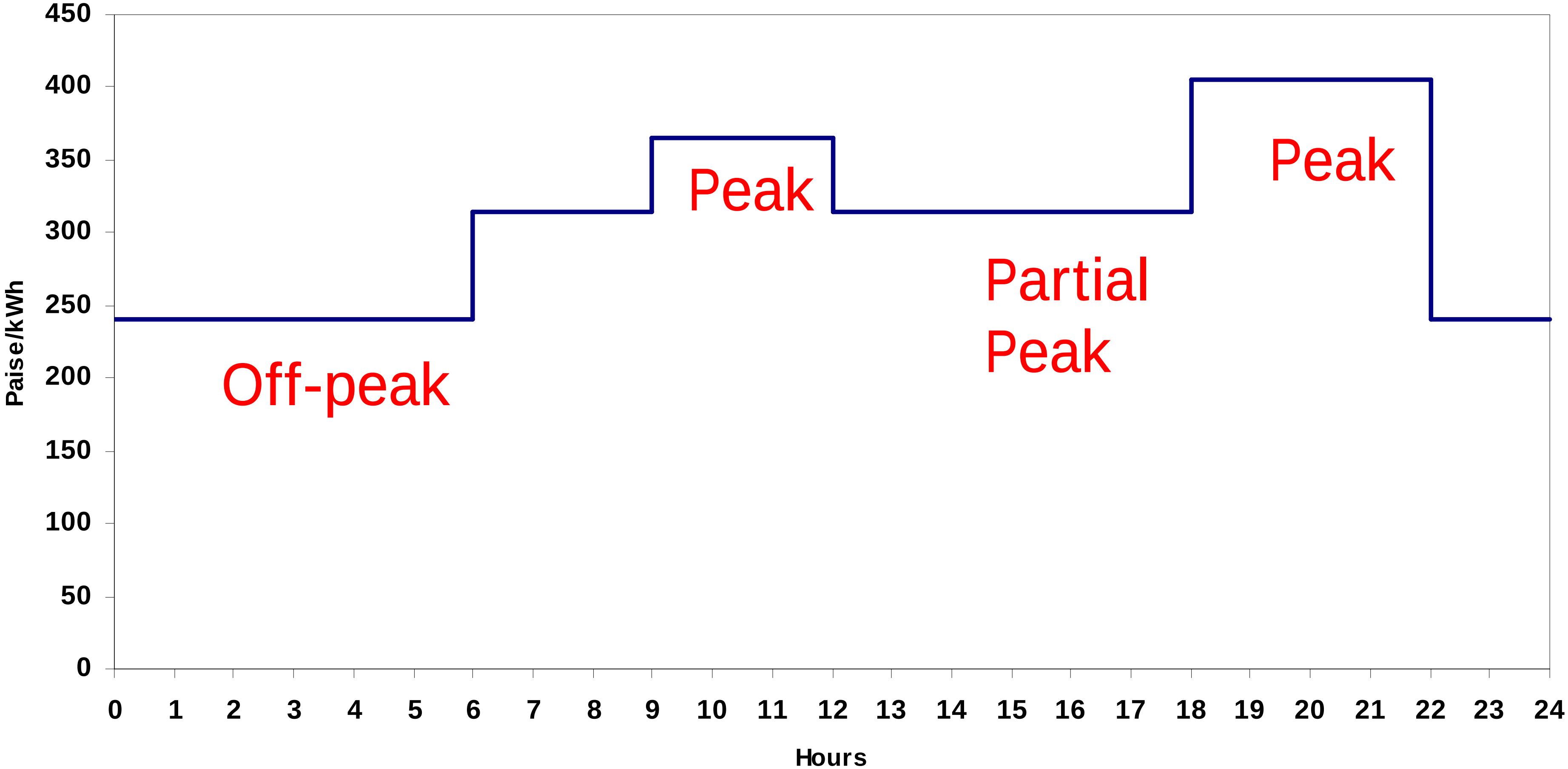
(8/11/2000 source: WREB annual report-2001)



Sample Industrial Load Profile (Mumbai)



Time of Use Tariff (MSEB-HT Ind., Jan 2002)



ILM Research Objective

- Determine optimal response of industry for a specified time varying tariff – *develop a general model applicable for different industries*
  - Process Scheduling- Continuous/ Batch
  - Cool Storage
  - Cogeneration

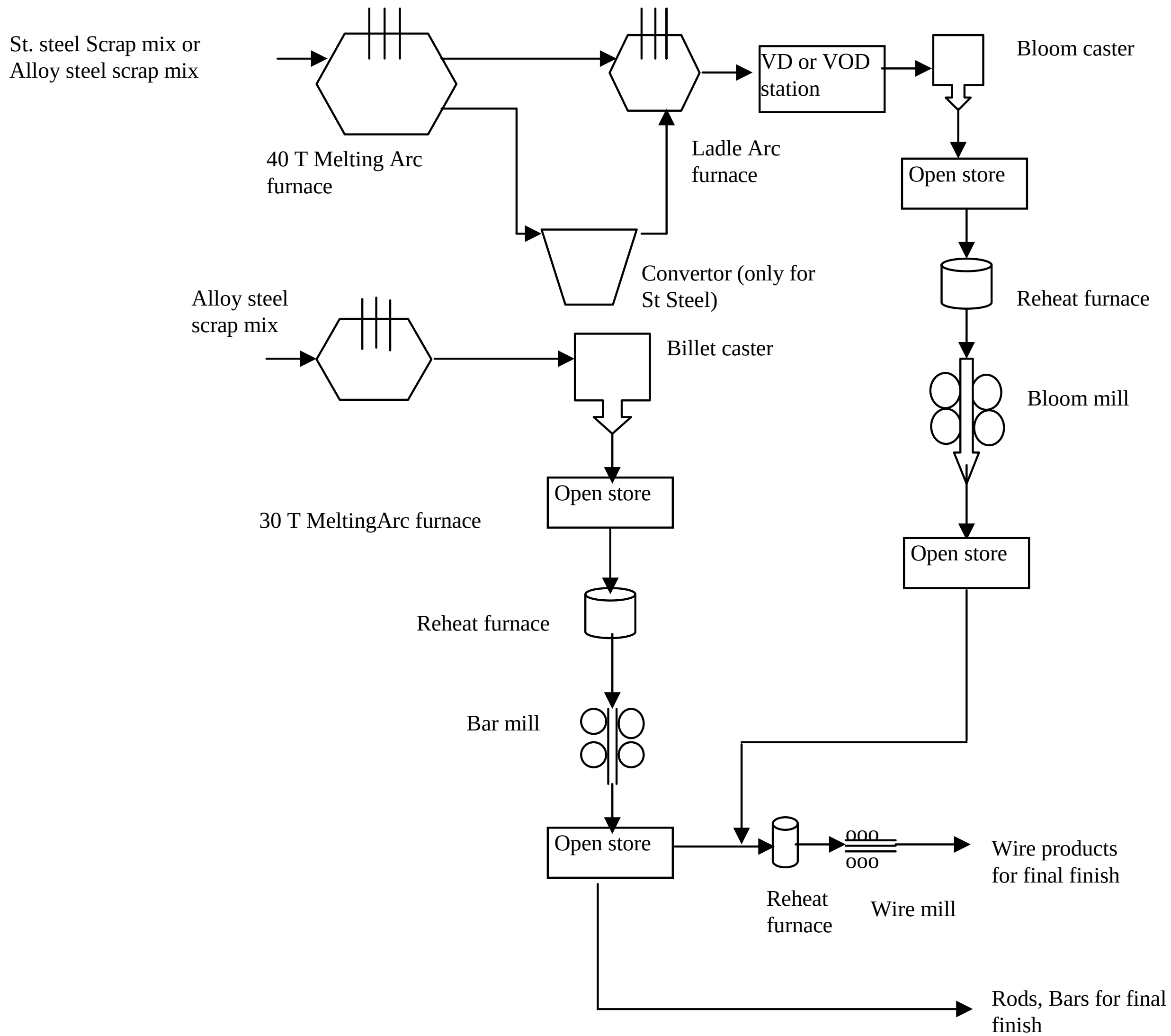
Process Scheduling

- Variable electricity cost normally not included
- Flexibility in scheduling
- Optimisation problem – Min Annual operating costs
- Constraints – Demand, Storage and equipment
- Models developed for continuous and batch processes (Illustrated for flour mill and mini steel plant)
- Viable for Industry

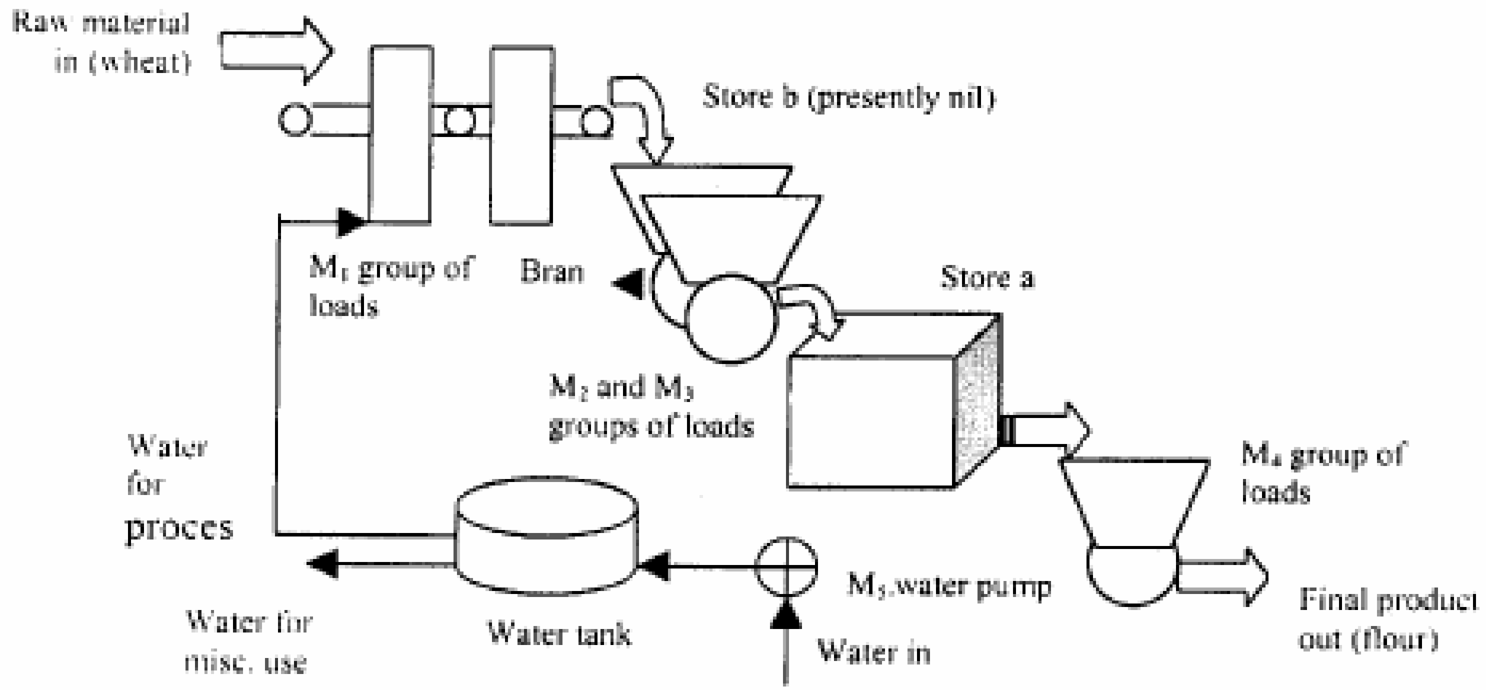
Process Scheduling

- Batch processes- batch time, quantity, charging, discharging, power demand variation (load cycles)
- Raw material constraints, Allocation constraints, Storage constraints, Sequential Constraints, maintenance downtime

Steel Plant Flow Diagram



Flour Mill



Group of process interlocked loads

M_1 - conveyor belts, dry stirrer, separators, washers and conditioners

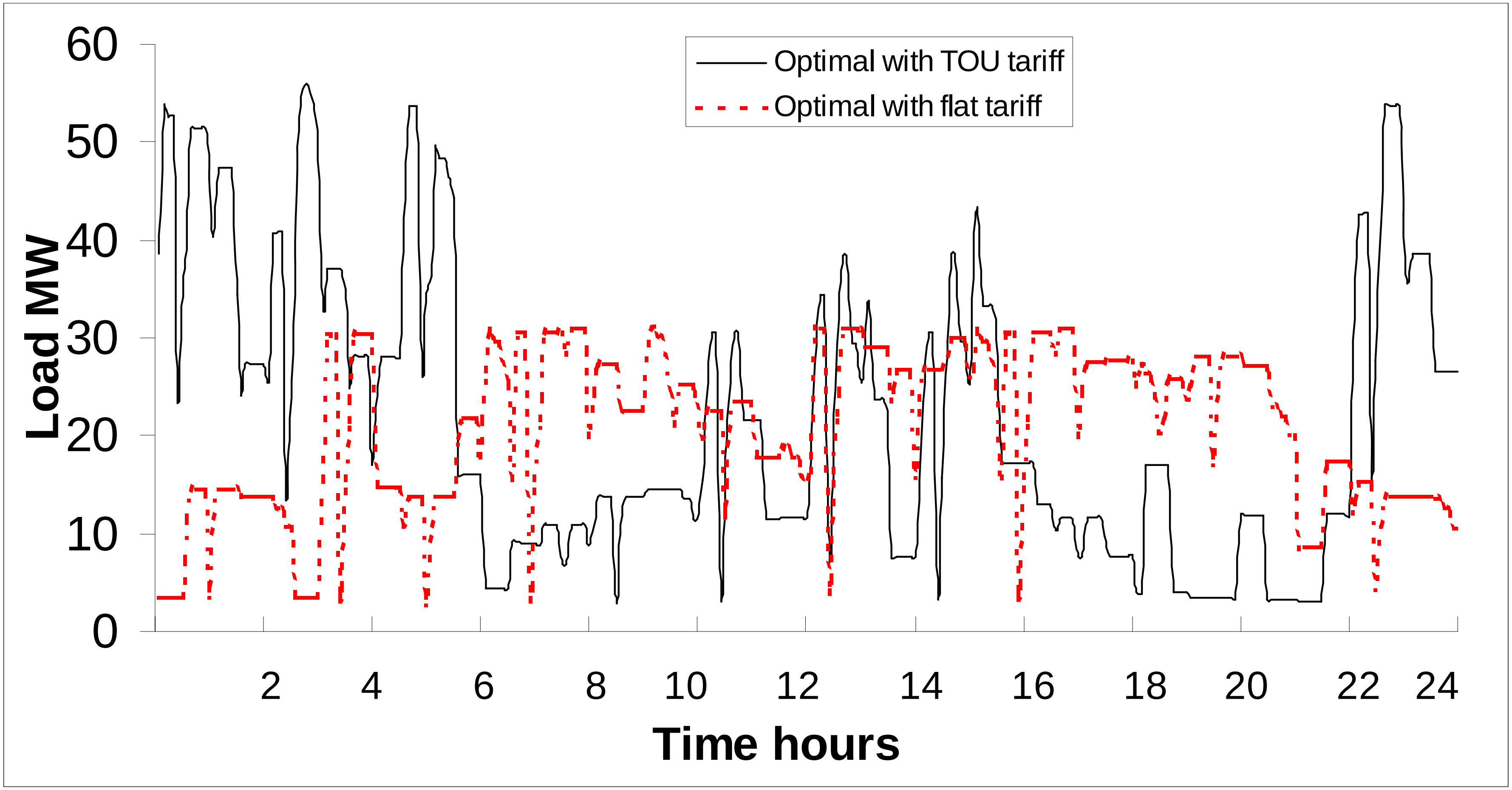
M_2 - grinder mills, conveyors set 1

M_3 - grinder mills, conveyors set 2

M_4 - roller mills, plansifiers, pneumatic lifters

M_5 - water pump

Steel Plant Optimal Response to TOU tariff



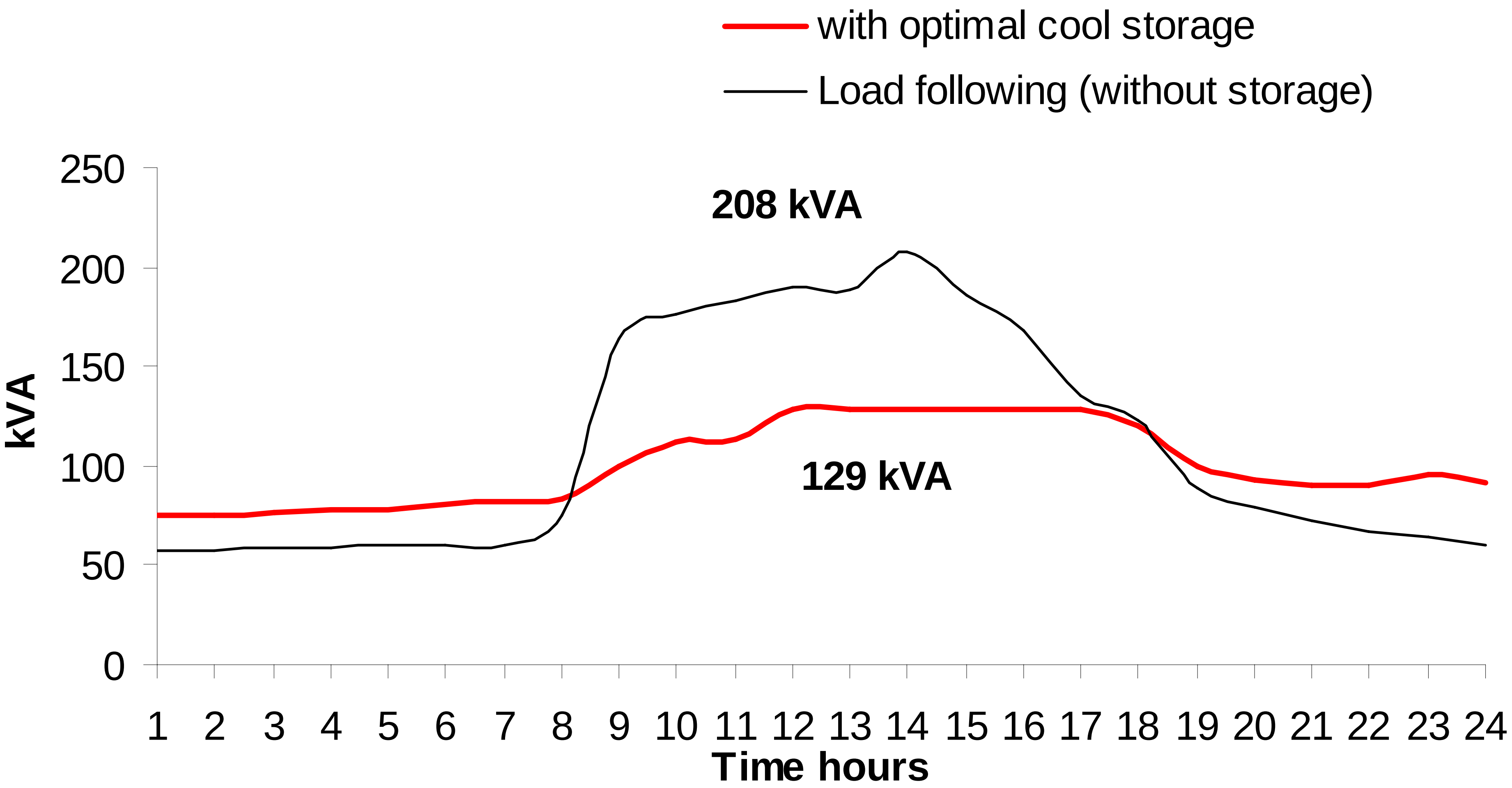
Process Scheduling Summary

Example	Structure	Results	Saving
Flour Mill Continuous	Linear, IP 120 variables 46 constraints	Flat- 2 shift - 25%store TOU-3 shift	1% 6.4% 75%peak reduction
Mini Steel Plant Batch	Linear, IP 432 variables 630 constraints	Flat TOU Diff loading	8% 10% 50% peak reduction

Cool Storage

- Cool Storage – Chilled water operate compressor during off-peak
- Commercial case study (BSES MDC), Industrial case study (German Remedies)
- Part load characteristics compressor,pumps
- Non- linear problem – 96 variables, Quasi Newton Method
- MD reduces from 208 kVA to 129 kVA, 10% reduction in peak co-incident demand, 6% bill saving

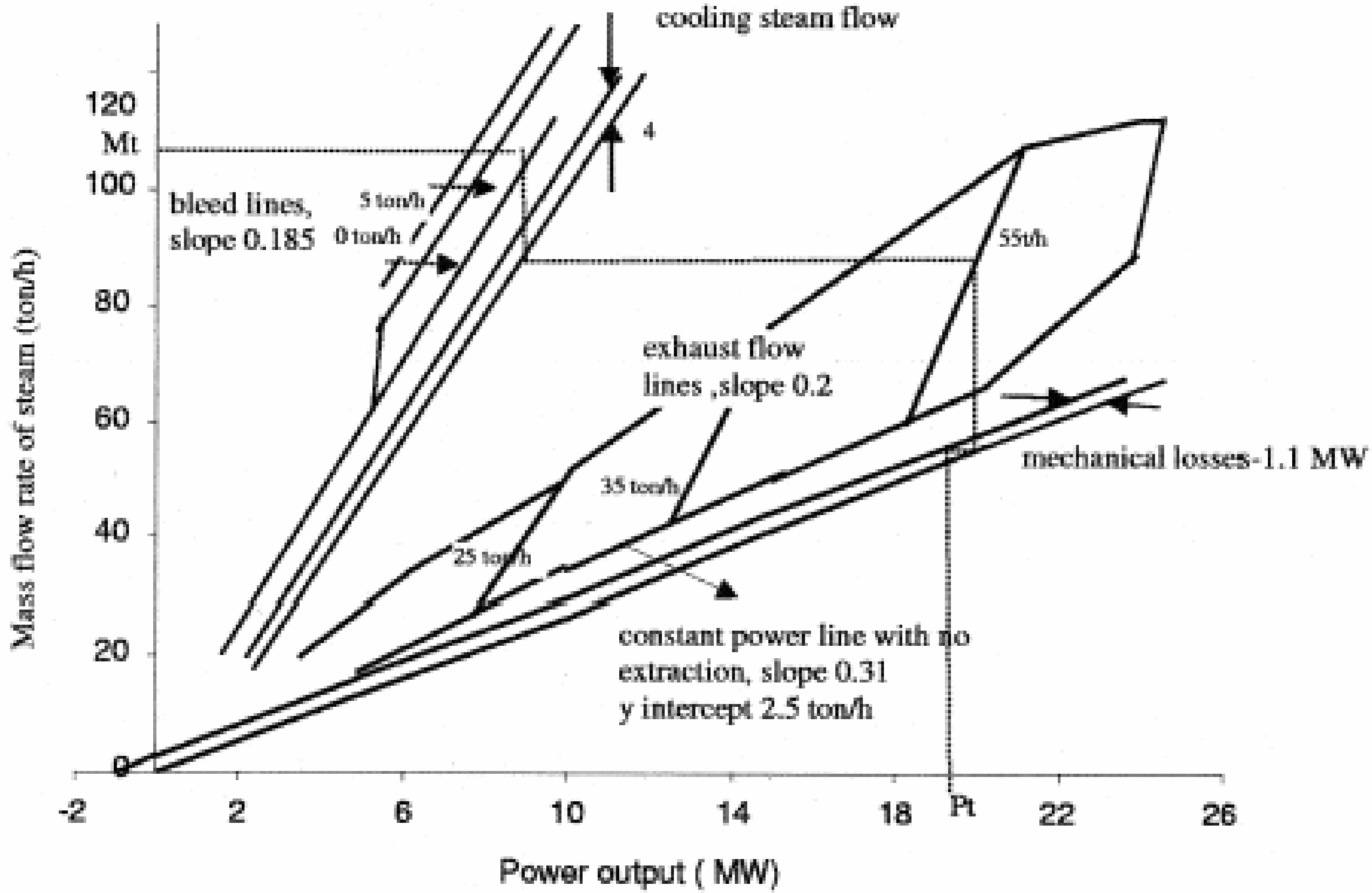
Cool Storage of Commercial Complex -under TOU tariff



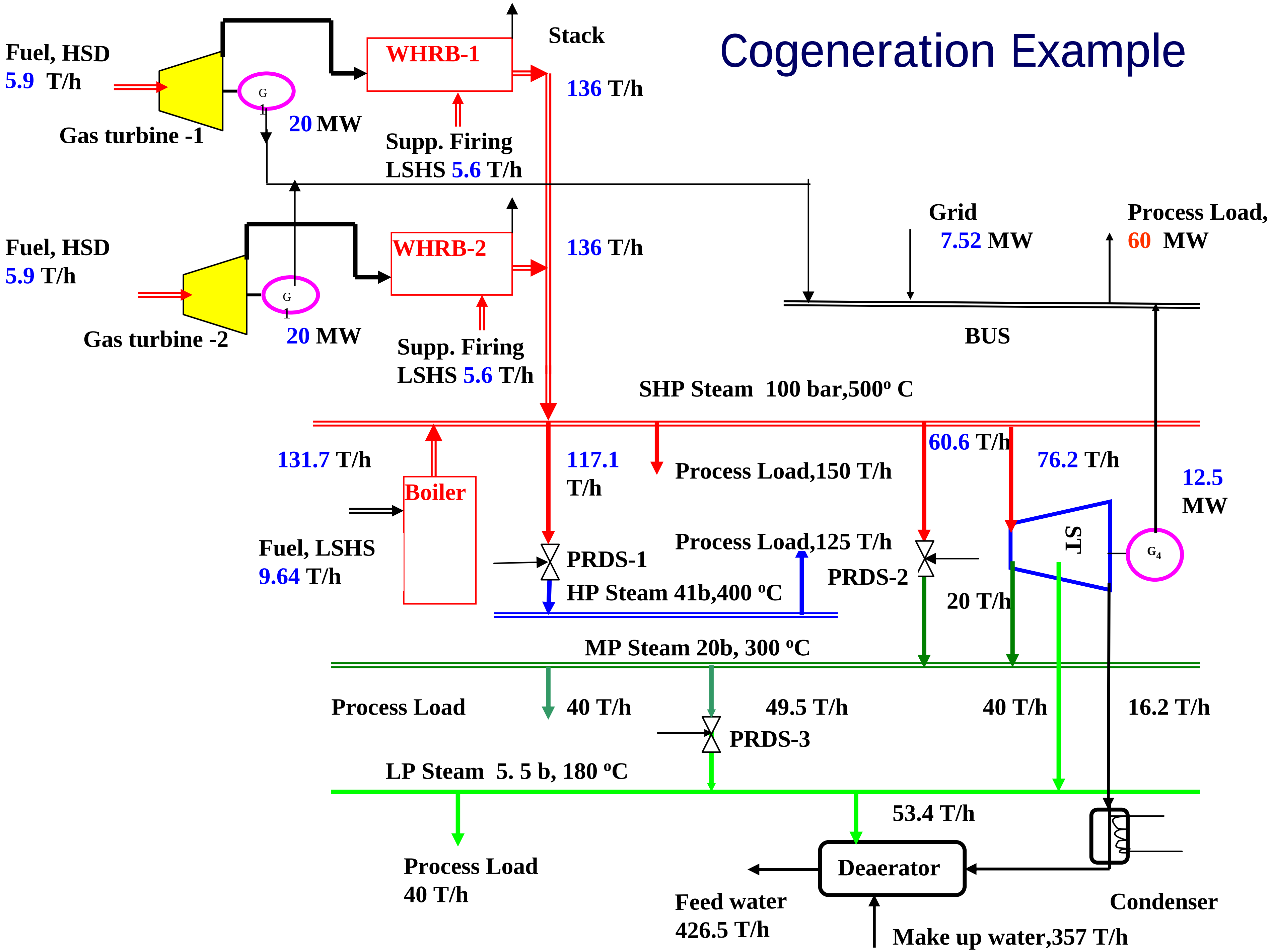
Cogeneration

- Process Steam, Electricity load vary with time
- Optimal Strategy depends on grid interconnection(parallel- only buying, buying/selling) and electricity,fuel prices
- For given equipment configuration, optimal operating strategy can be determined
- GT/ST/Diesel Engine – Part load characteristics – Non Linear
- Illustrative example for petrochemical plant- shows variation in flat/TOU optimal.

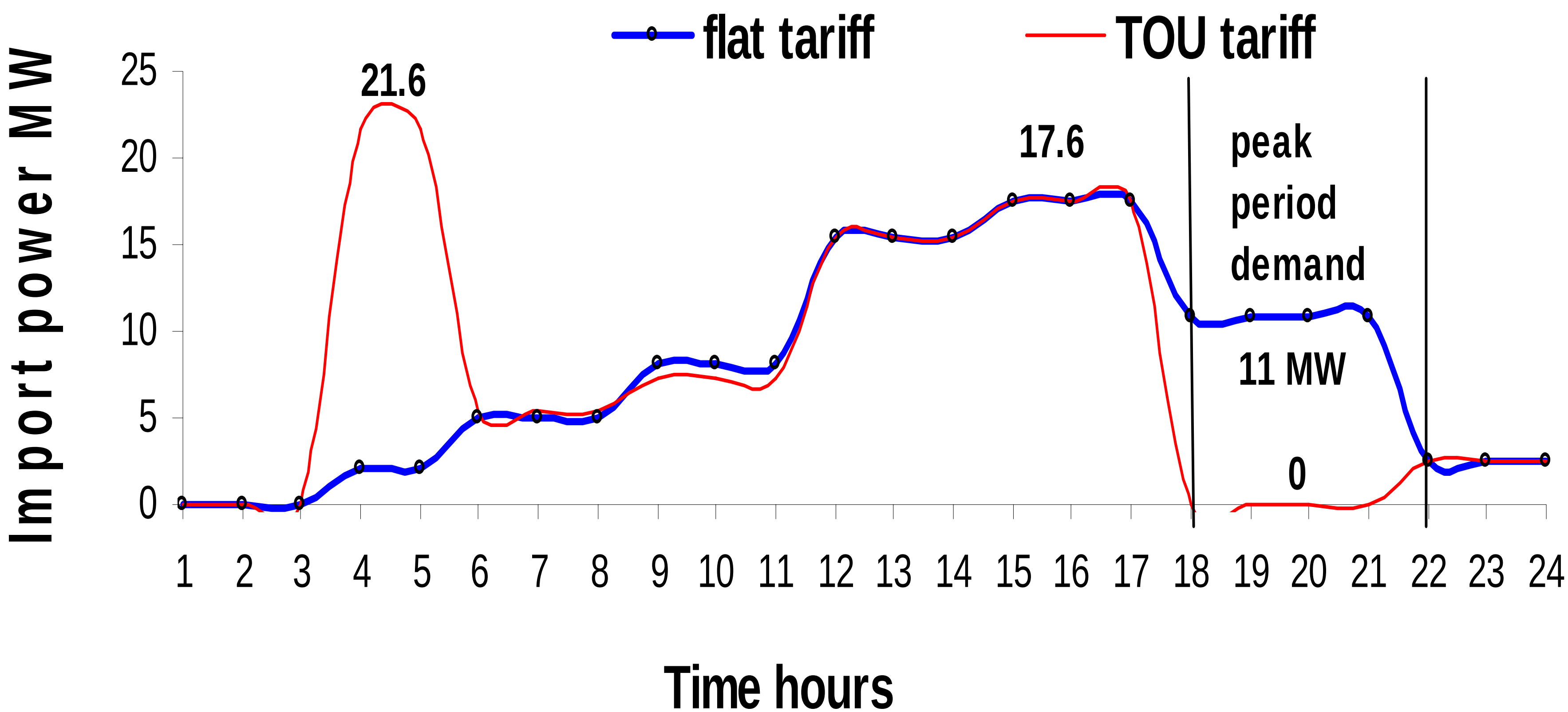
Willans Line



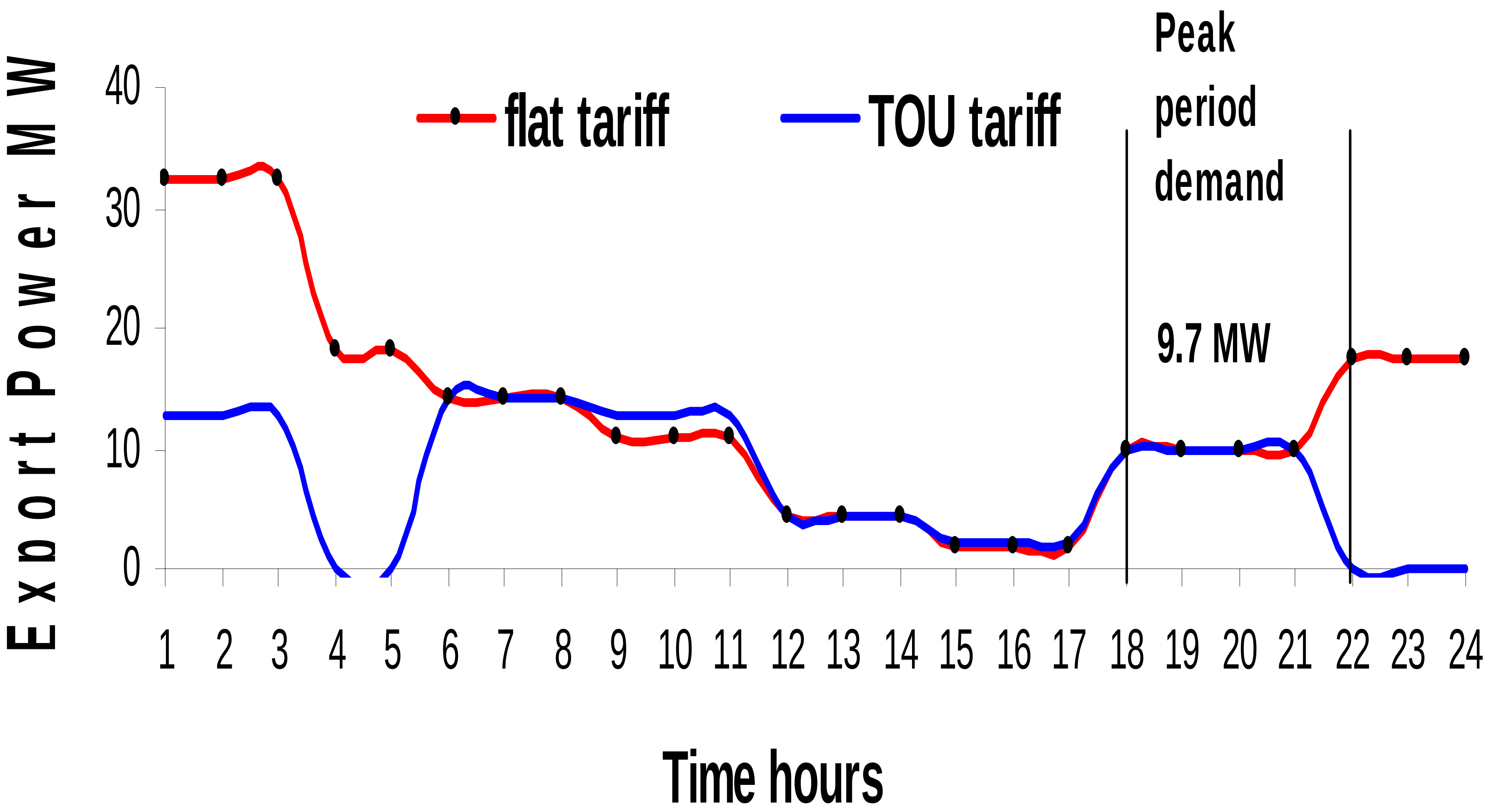
Cogeneration Example



Import Power from Grid with Cogeneration for a Petrochemical Plant

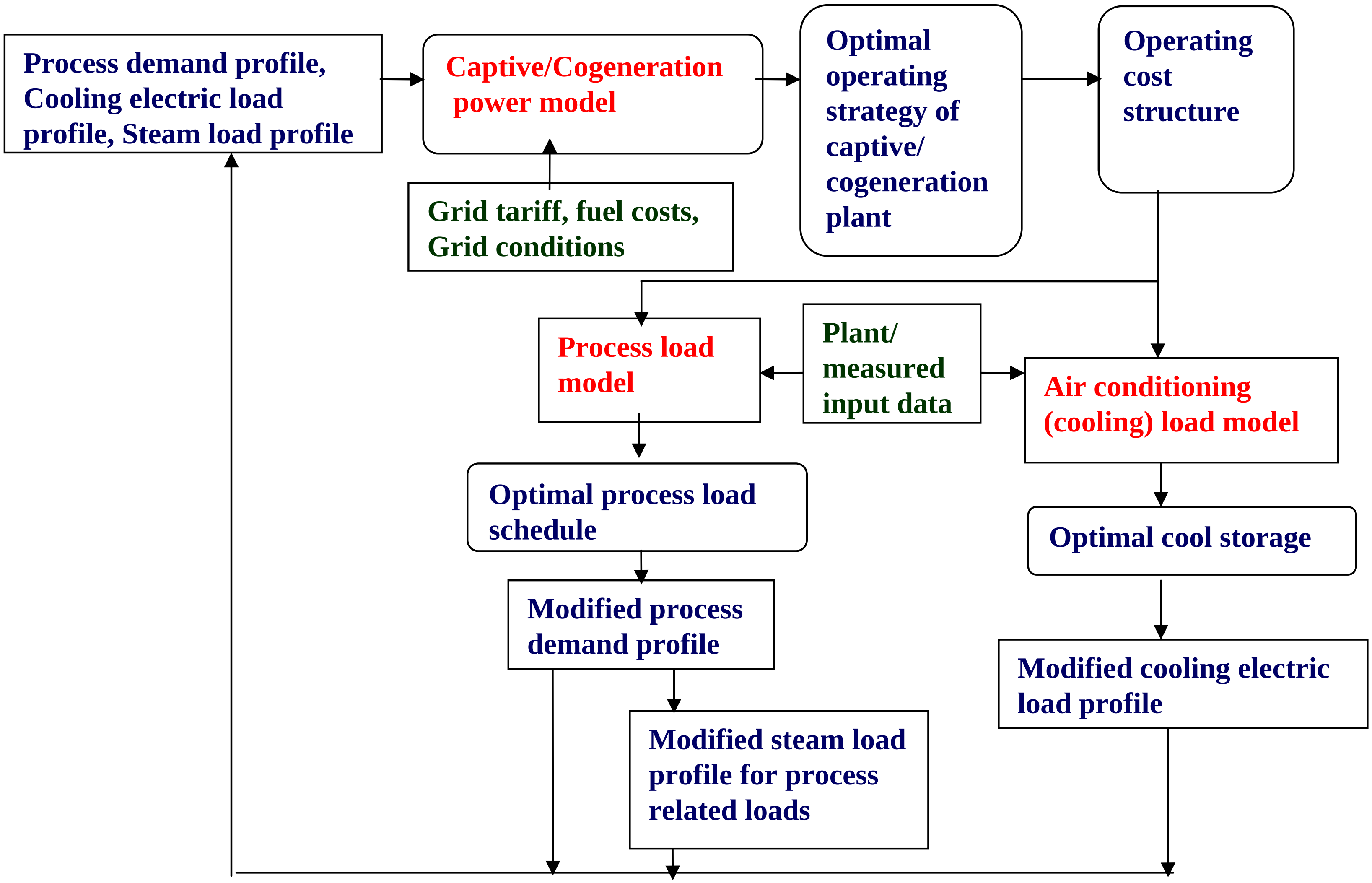


Export power to the grid with Cogeneration for a Petrochemical Plant

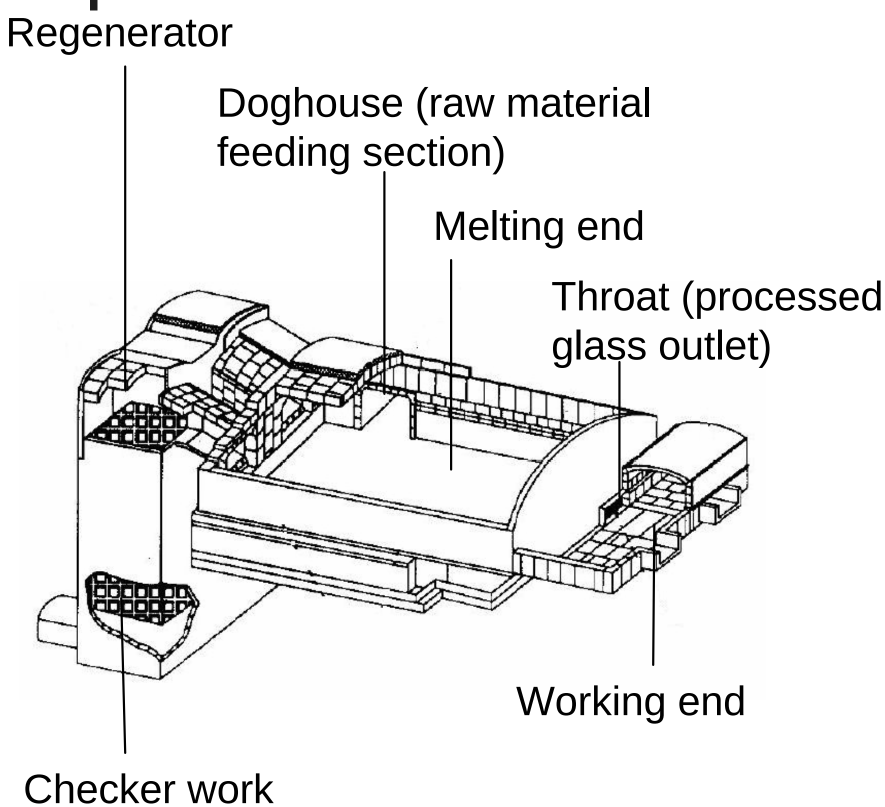


Industrial Load Management

- Integrated approach



Glass furnace



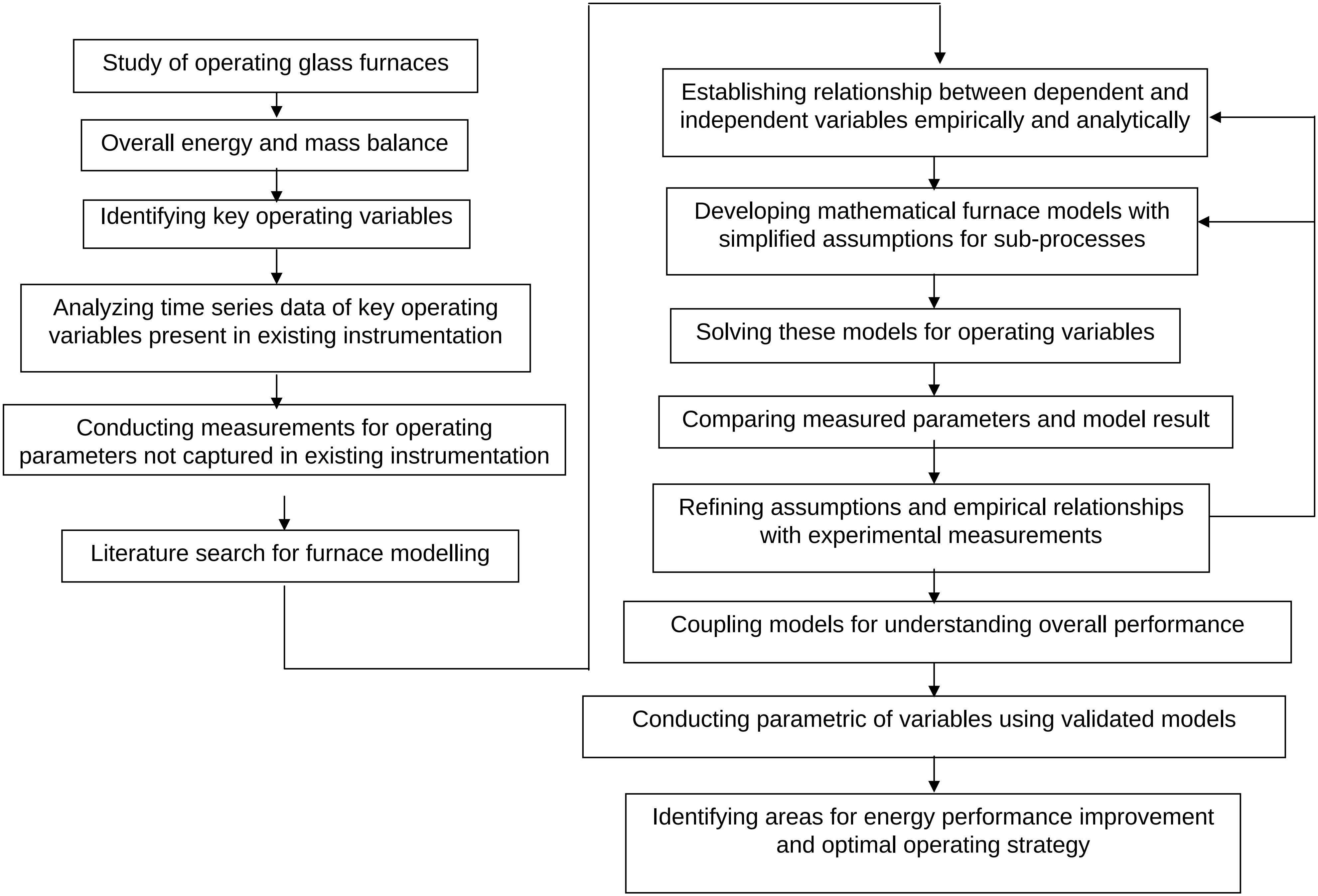
- Classification of furnace
  - Type of firing (Cross fired / end fired)
- Raw material
  - Batch material (like silica, soda ash etc.)
  - Cullet (recycled glass)
- Heat source
  - Flame direct contact with glass
- Minimum energy requirement
  - Heating of raw material up to reaction temperature
  - Endothermic heat of reaction for batch material

Modeling practices for glass furnace

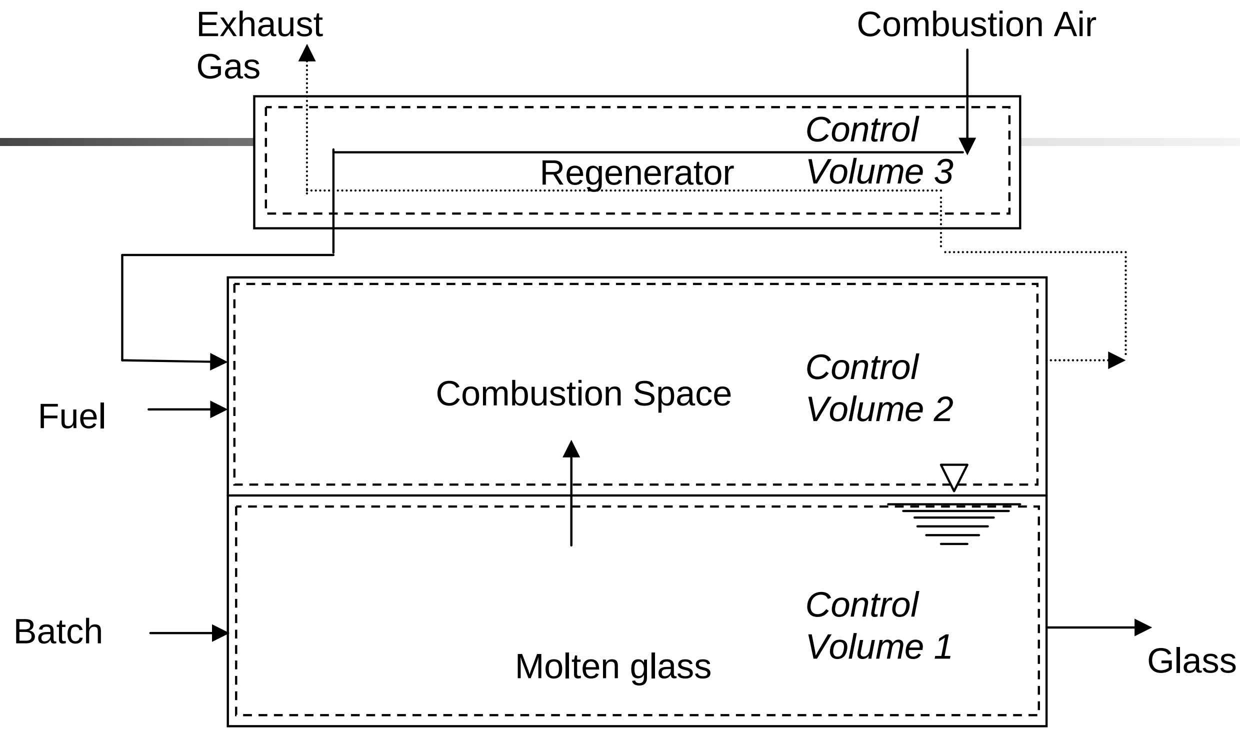
- Continuum Process model
  - Commonly used
  - Glass furnace process in continuum equation
    - Three dimensional Navier-Stokes Equation and Hottel's zone method for radiation
- Process models used mainly troubleshooting and screening variables

- Limitations of process models
  - Data intensive inputs
  - Needs specialized skills and computational facilities to use
  - Energy performance not studied
  - Not easy to link operating parameters and impact on energy performance

Approach for study



Control volume



$$\dot{m}_{bh} \times h_{bh} + \dot{Q}_g = \dot{Q}_{l,wall,g} + \underbrace{\dot{m}_g \times h_g}_{\dot{Q}_{g,sensi}} + \underbrace{\dot{m}_g \times \sum h_{rk}}_{\dot{Q}_{g,rk}} + \underbrace{\dot{m}_{bh,f} \times h_{bh,f}}_{\dot{Q}_{bh,f}} + \underbrace{\dot{m}_w \times (h_{w,100^oC} + h_{w,lat})}_{\dot{Q}_w} \qquad \text{Eq. 1}$$

$$\underbrace{\dot{m}_{fu} \times CV}_{\dot{Q}_{fu}} + \underbrace{\left(\dot{m}_{comb,air,nonreg} + \dot{m}_{noncomb,air,nonreg}\right) \times h_{air,\infty}}_{\dot{Q}_{air,nonreg}} + \underbrace{\dot{m}_{air,comb,reg} \times h_{air,comb,reg}}_{\dot{Q}_{air,reg}} = \dot{Q}_{l,wall,comb} + \dot{Q}_g + \underbrace{\dot{m}_{tot,f} \times h_f}_{\dot{Q}_{l,reg,f}} \qquad \text{Eq. 2}$$

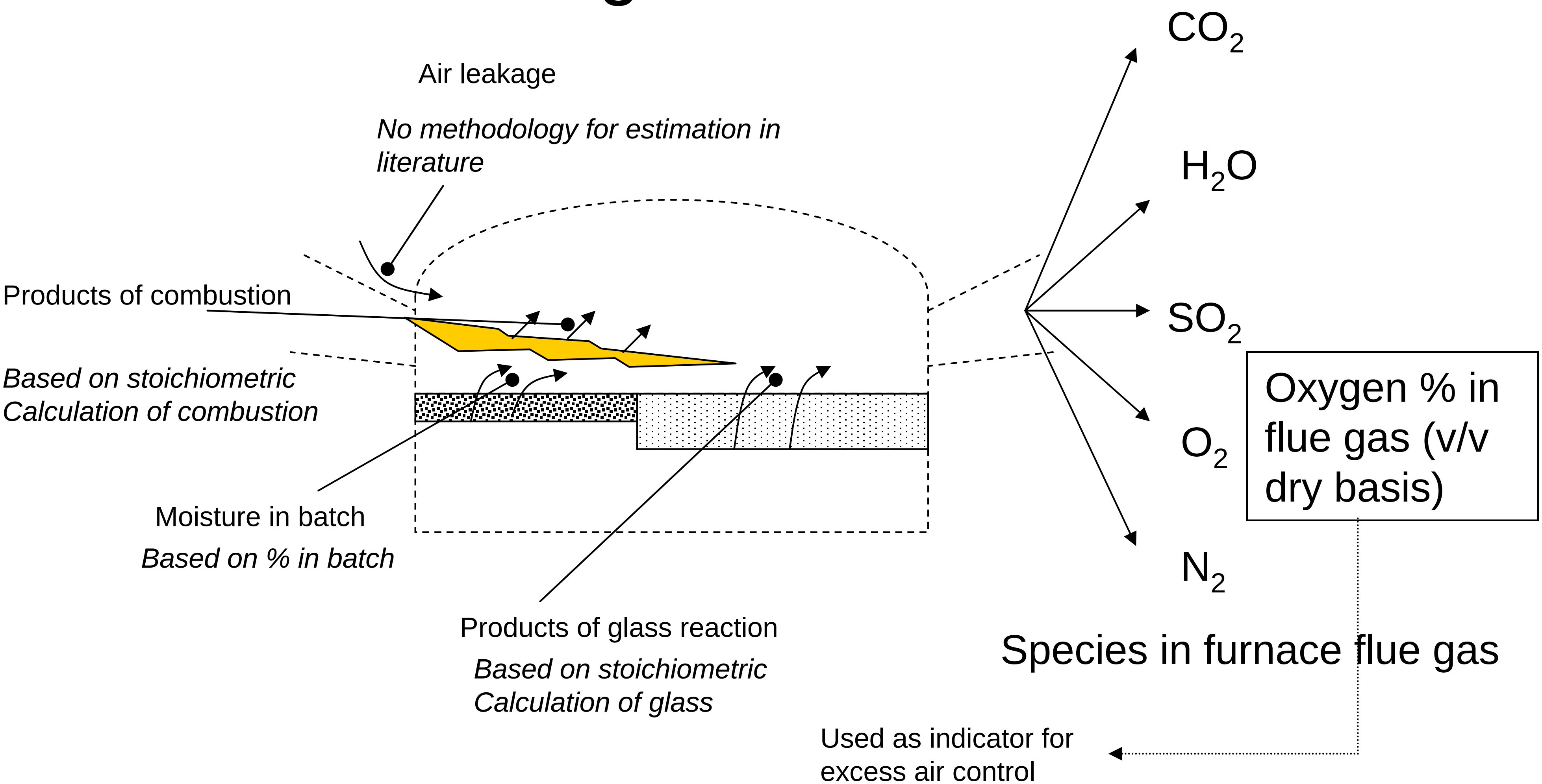
$$\dot{m}_{f,tot,in} \times h_{f,in} + \dot{m}_{air,leak,reg} \times h_{air,leak} = \dot{m}_{f,tot,out} \times h_{f,out} + \dot{Q}_{l,wall,reg} + \dot{m}_{air,comb,reg} \times \left(h_{air,comb,reg,out} - h_{air,comb,reg,in}\right) \qquad \text{Eq. 3}$$

Mass balance of furnace

- Input streams
  - Batch material
    - Cullet (recycled glass)
    - Raw material
    - Moisture
  - Fuel
  - Combustion air (from regenerator)
  - Air leakage (Any air other than inlet from regenerator)
- Output streams
  - Molten glass
    - Cullet
    - Glass from raw material
  - Flue gas to regenerator
    - Combustion products
    - Glass reaction products
    - Water vapors
    - Air (Not reacted in combustion)
  - Flue gas leakage from furnace

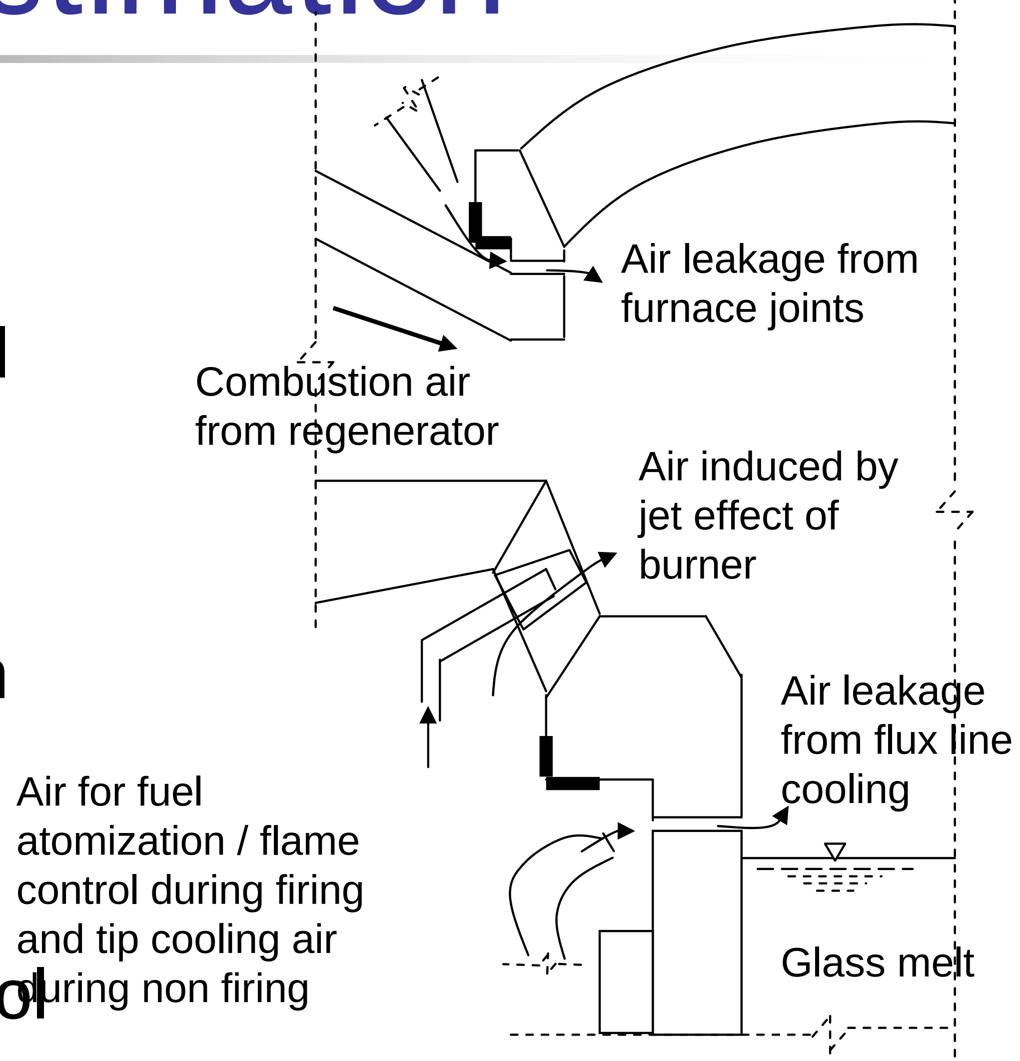
Mass balance estimation

Estimation of flue gas formation



Air leakage estimation

- Furnace operates positive pressure
  - Air leakage in local negative pressure area
  - Air leakage due to higher pressure on air side
  - Air supplied for atomization and flame length control

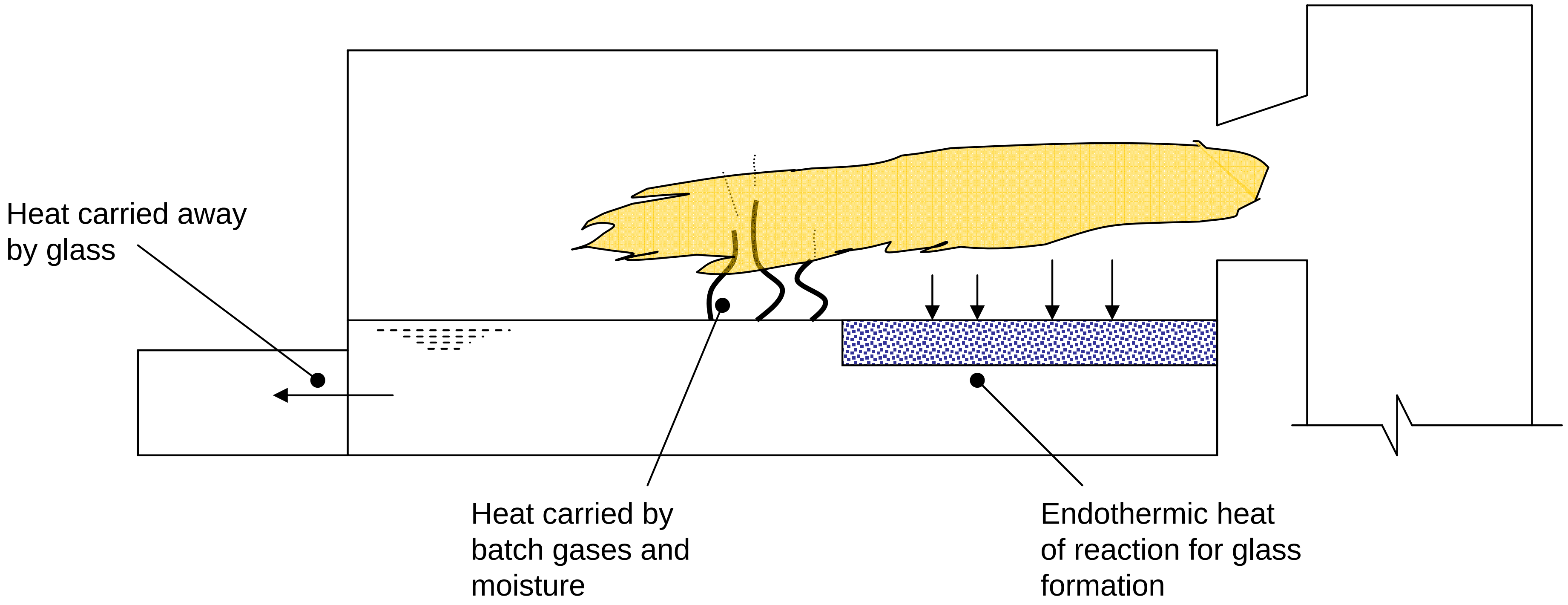


Energy balance for furnace

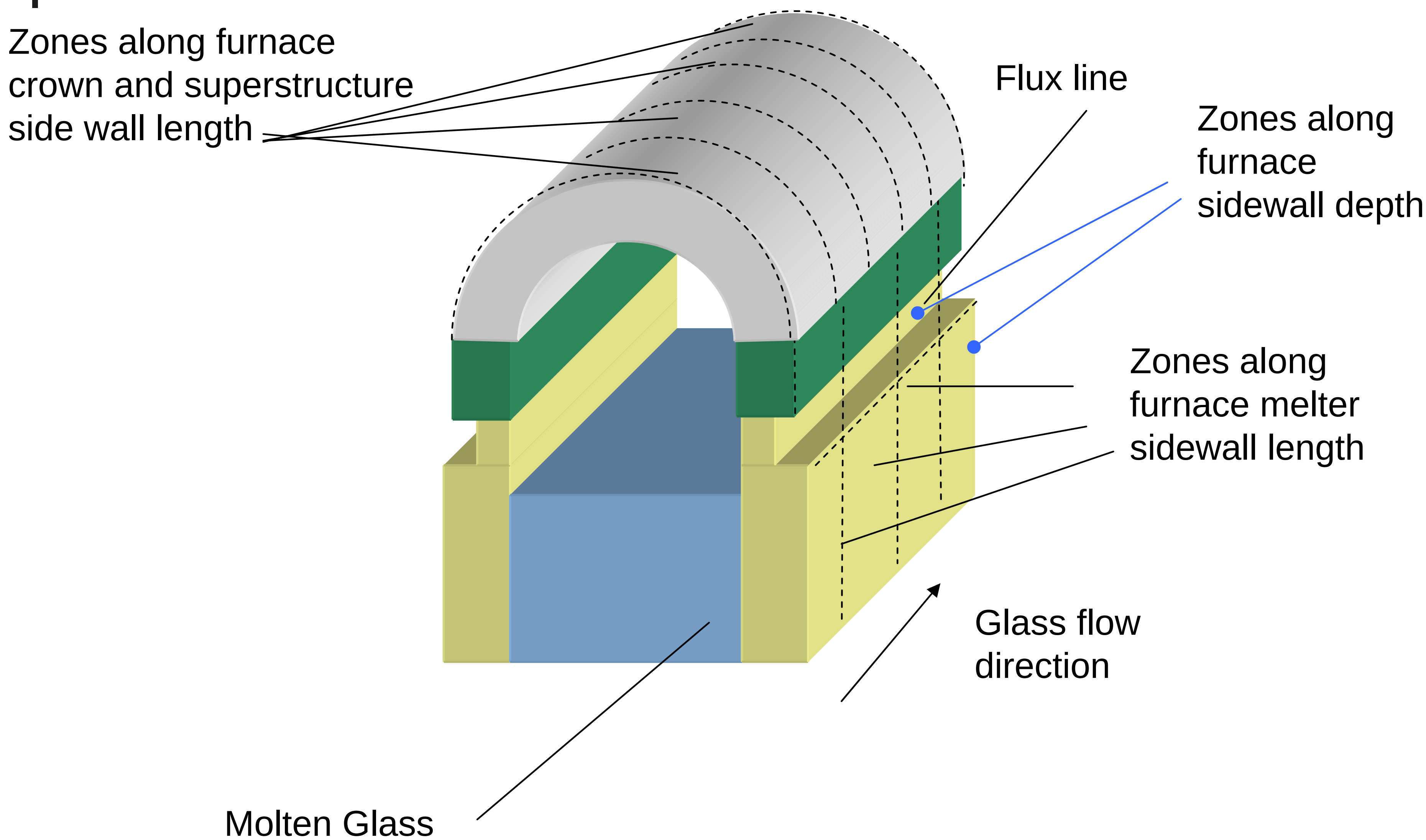
- Input streams
  - Energy from fuel
  - Energy from preheated combustion air
  - Energy from batch material
  - Energy from air leakage
- Output streams
  - Energy carried in glass
    - Heat of reaction
    - Sensible heat of glass
  - Energy carried in flue gas
    - Energy for air leakage
    - Energy for batch gases
    - Energy for moisture
    - Energy for combustion air
  - Energy loss from walls
    - Surface heat loss from walls
    - Radiation losses (due to opening)

Energy balance glass melt

- Heat of reaction for glass
- Heat carried by glass
- Heat carried by batch gas



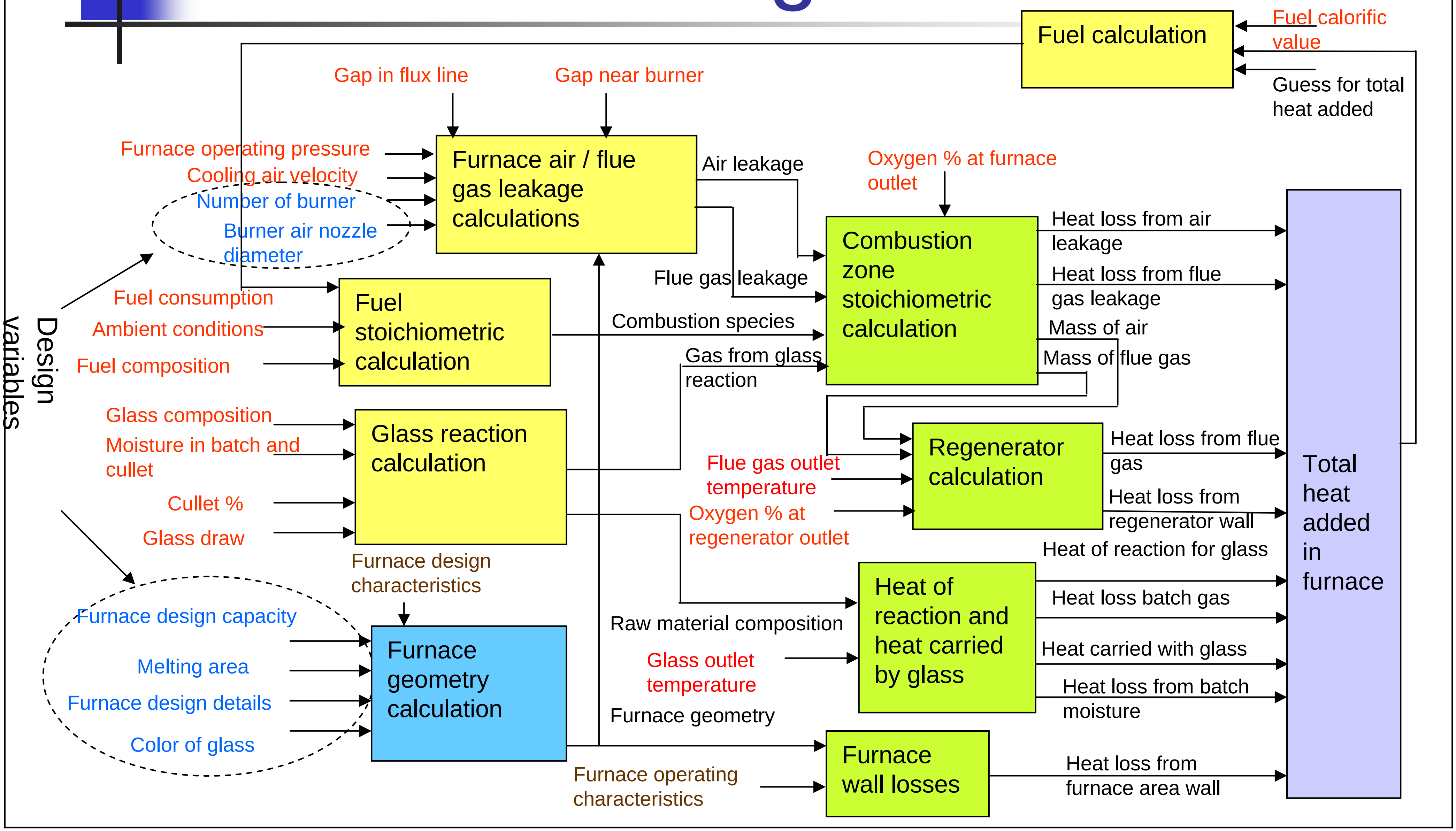
Furnace wall losses



Furnace model input parameters

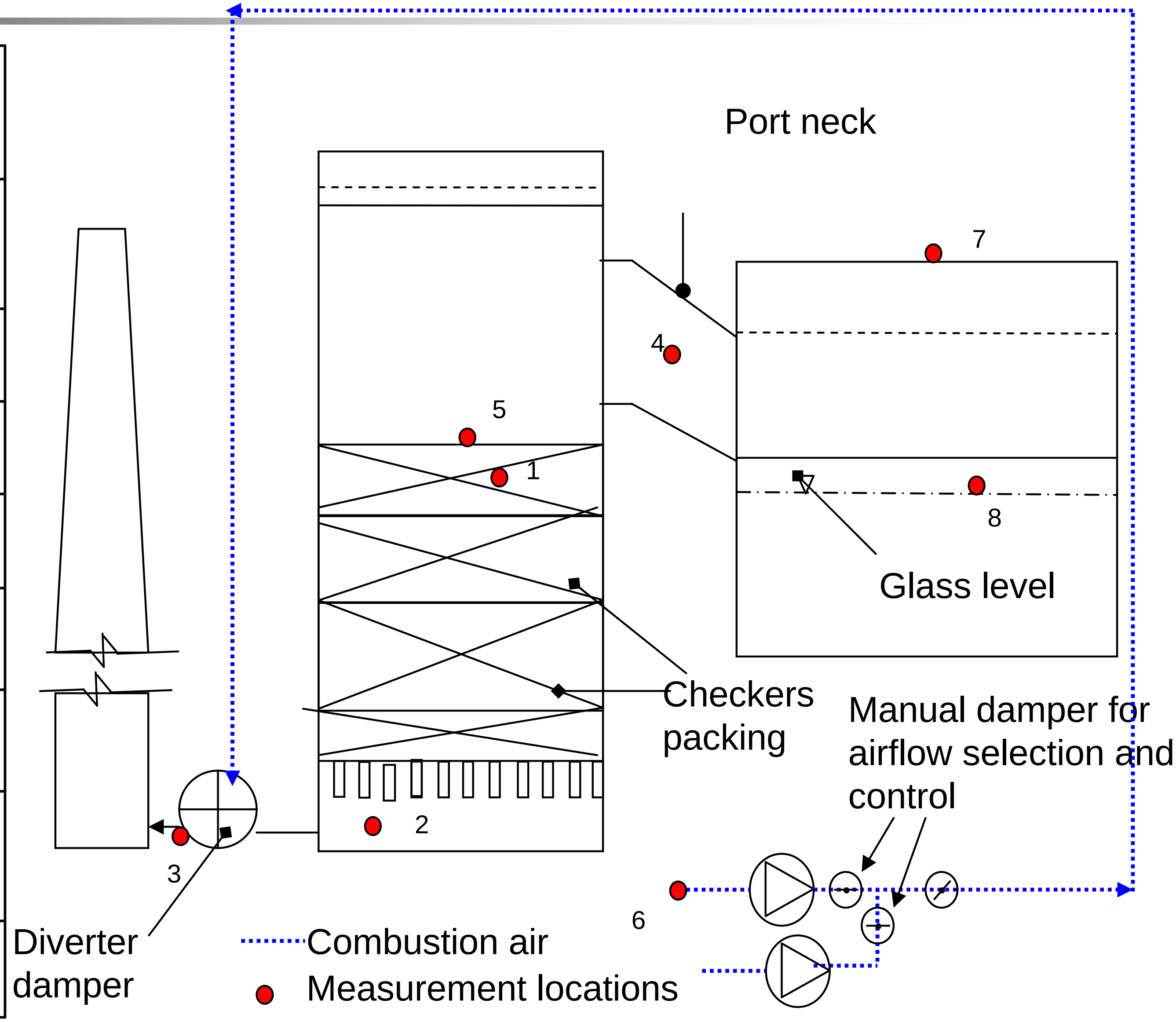
- Design parameter
  - Design capacity of furnace
  - Melting area
  - Length to width ratio
  - Height of combustion volume
  - Refractory and insulation details
- Operating parameters
  - Furnace draw
  - Type of fuel
  - Batch to cullet ratio
  - Moisture in batch
  - Furnace pressure
  - Oxygen at furnace outlet
  - Atomization pressure
  - Reversal time
  - Flux-line and burner tip cooling air pressure

Model flow diagram

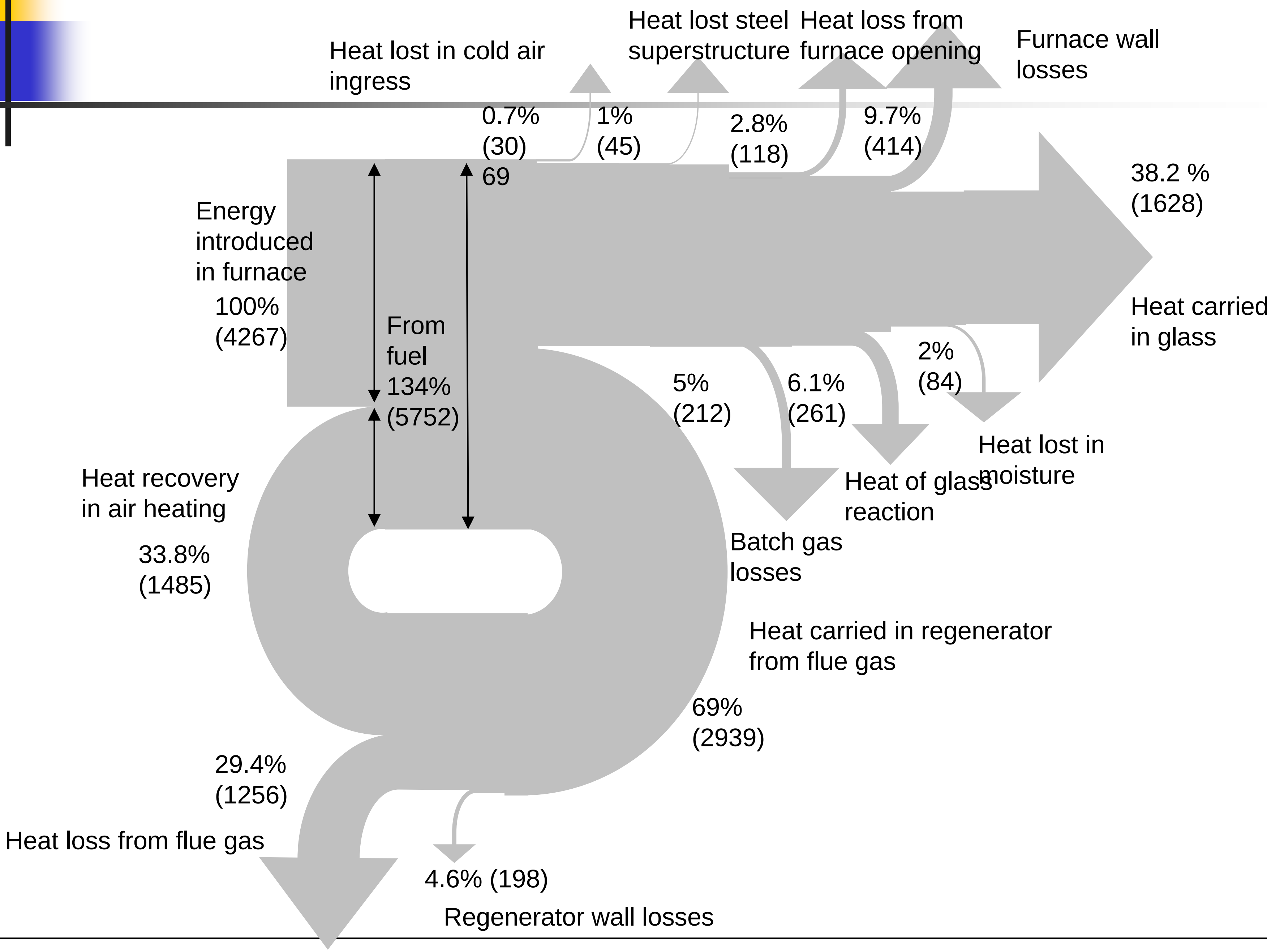


Furnace measurement

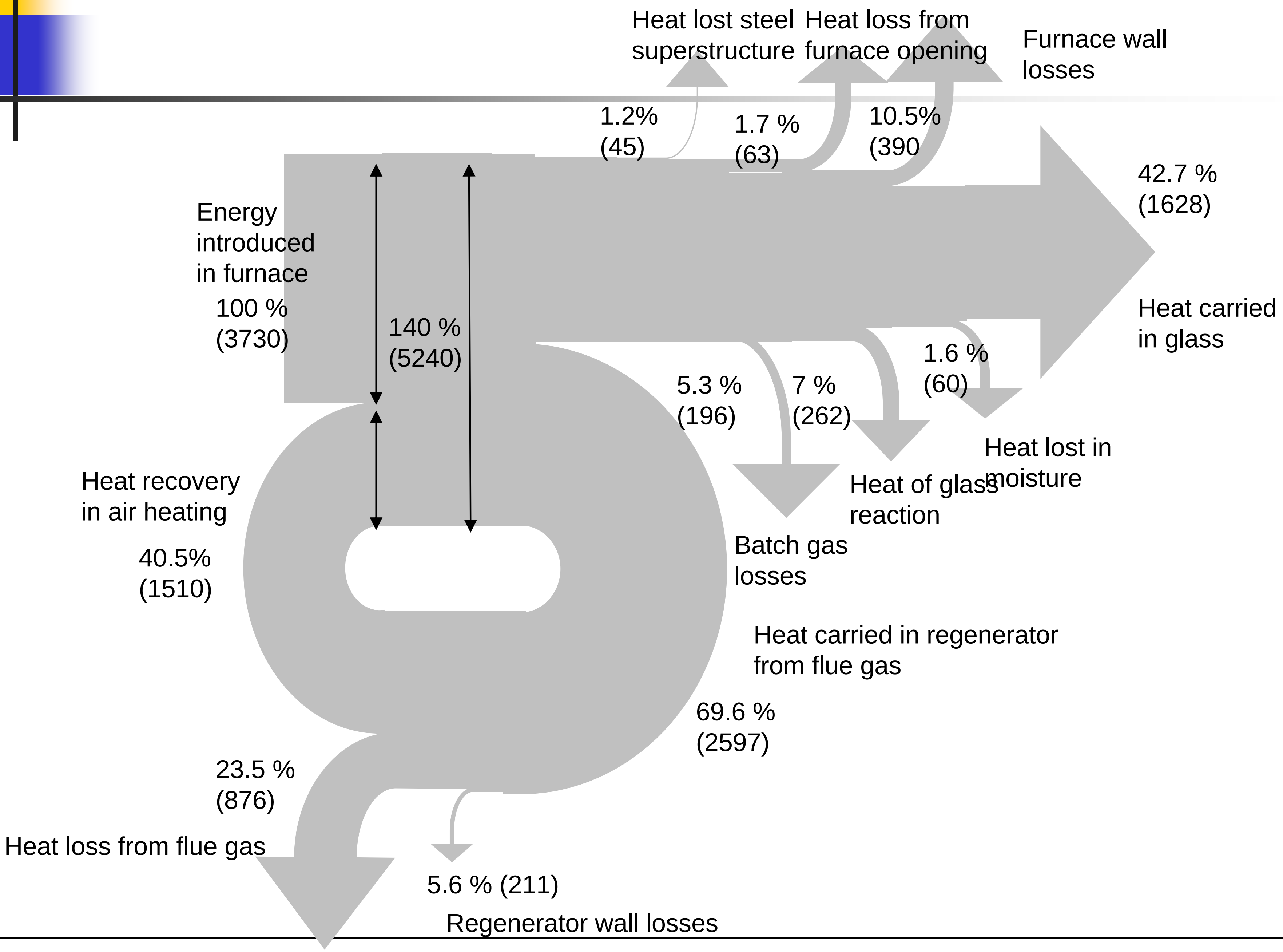
Measurement location	Type of measurement
1	Oxygen % , Pyrometer checkers surface temperature
2	Oxygen %, Flue gas temperature
3	Oxygen %, Flue gas temperature
4	Oxygen %, Skin temperature
5	Pyrometer checkers surface temperature
6	Velocity of air at the suction of blower
7	Outside wall temperature for crown and side wall
8	Pyrometer glass surface temperature



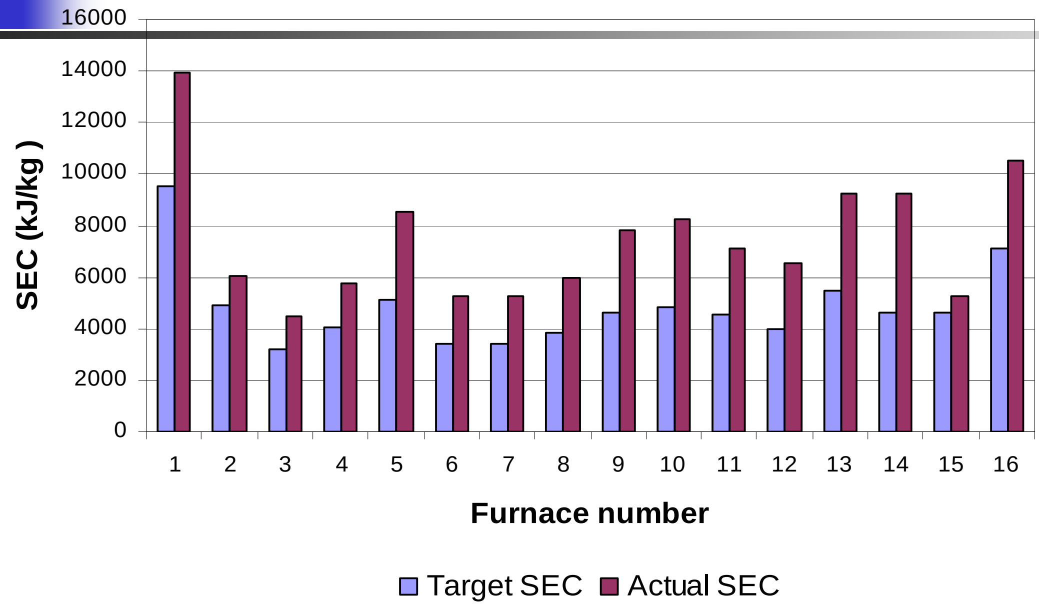
Model results: Actual SEC

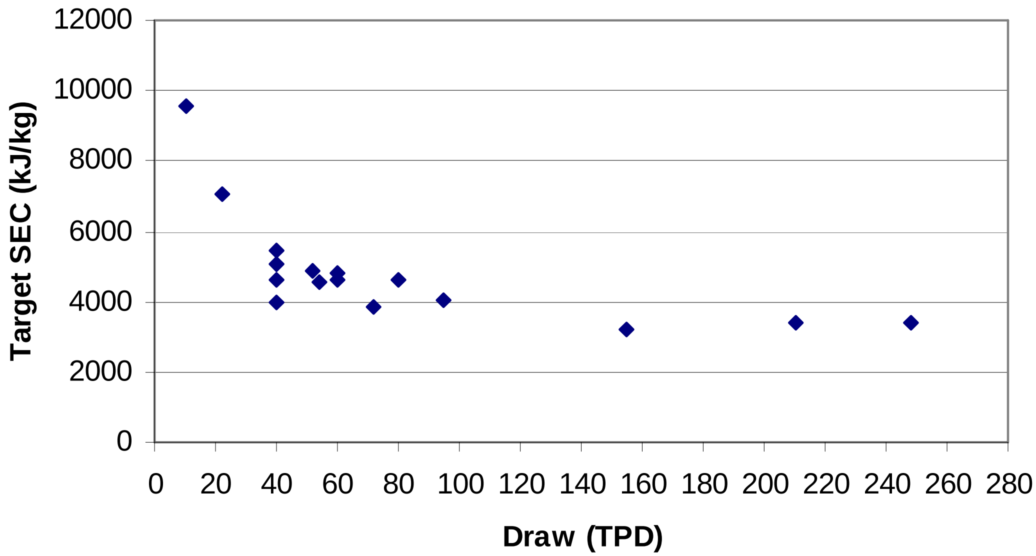


Model results: Target SEC



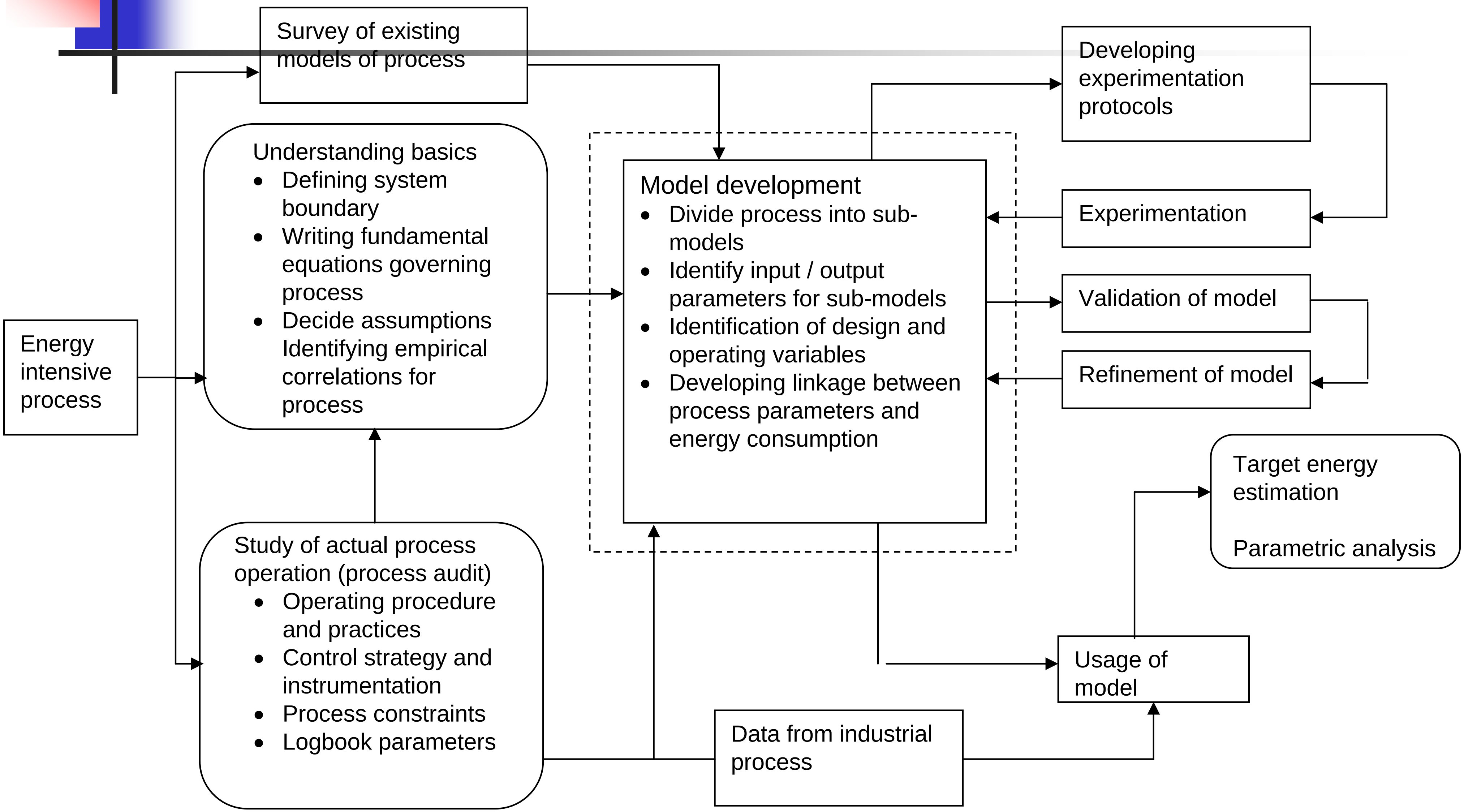
Conclusions





- Target SEC estimated for 16 industrial furnaces
- Effect of furnace draw on target SEC is demonstrated

Generalized approach for model based benchmarking



Energy Planning Research Objective

- Energy Planning - Aggregated at National Level
- Sectoral Planning - Oil, Electricity
- Limited Efforts in Local Level Energy Planning
- Energy critical input for development
- Need for micro level energy planning

Objective: Develop a tool for improving local level energy decisions

DSS Modules

- Energy Models in Literature – aggregate , homogenous unit, optimisation, no linkage with decision structure
- Study of decision structure, proposed an accounting framework
- Disaggregation by sector, end-uses
- DST-UNDP project – Bankura district in West Bengal

Analysis District level – with block as an unit
Block level- with village as an unit

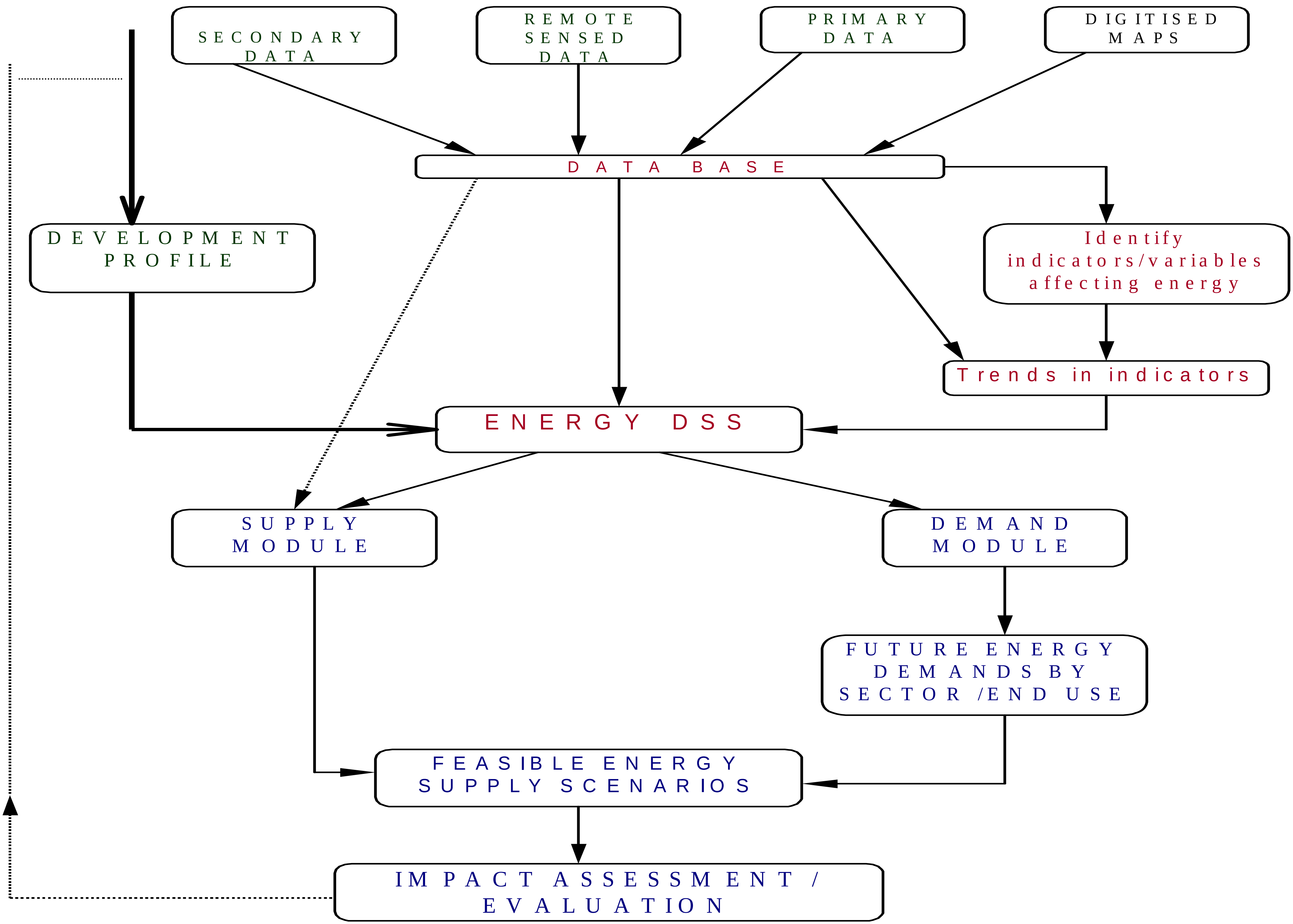
Energy decisions for district officials

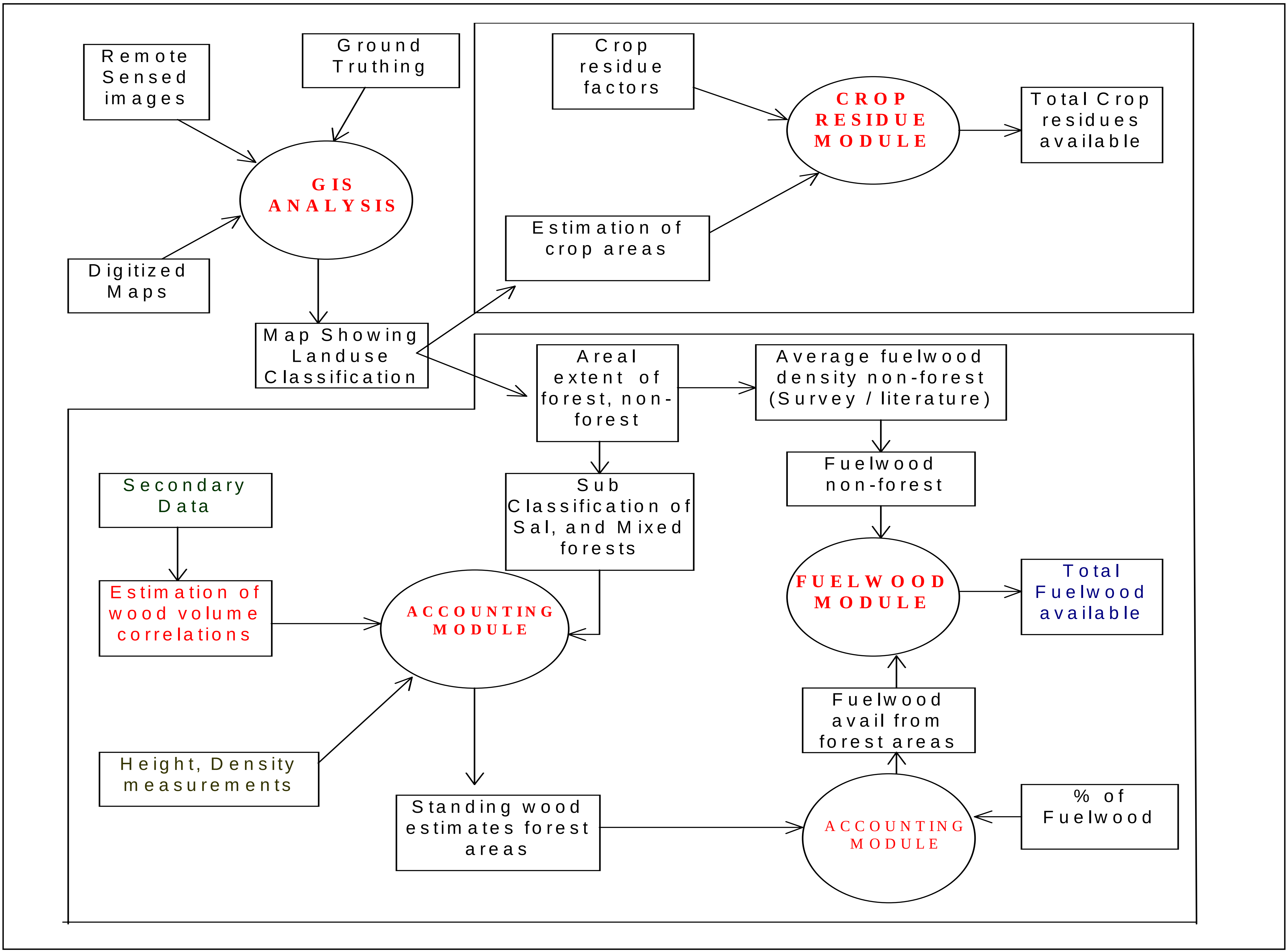
District Magistrate	Ratifying departmental decisions
Zilla Parishad Sabadhipati	Sanctioning/selecting schemes
Manager, DIC	Sanctioning industries, biogas plant, Priority list of industries.
DE,WBSEB/Addnl CE(Rural Elec)	Mouza electrification
Controller food,civil supplies	Distribution of kerosene, coal.
Lead Bank Officer	Preparation of District credit plan
District forest Officer (DFO, working plan)	Managing forest area
District Planning Officer	Prepares district plan

Typical Energy Decisions

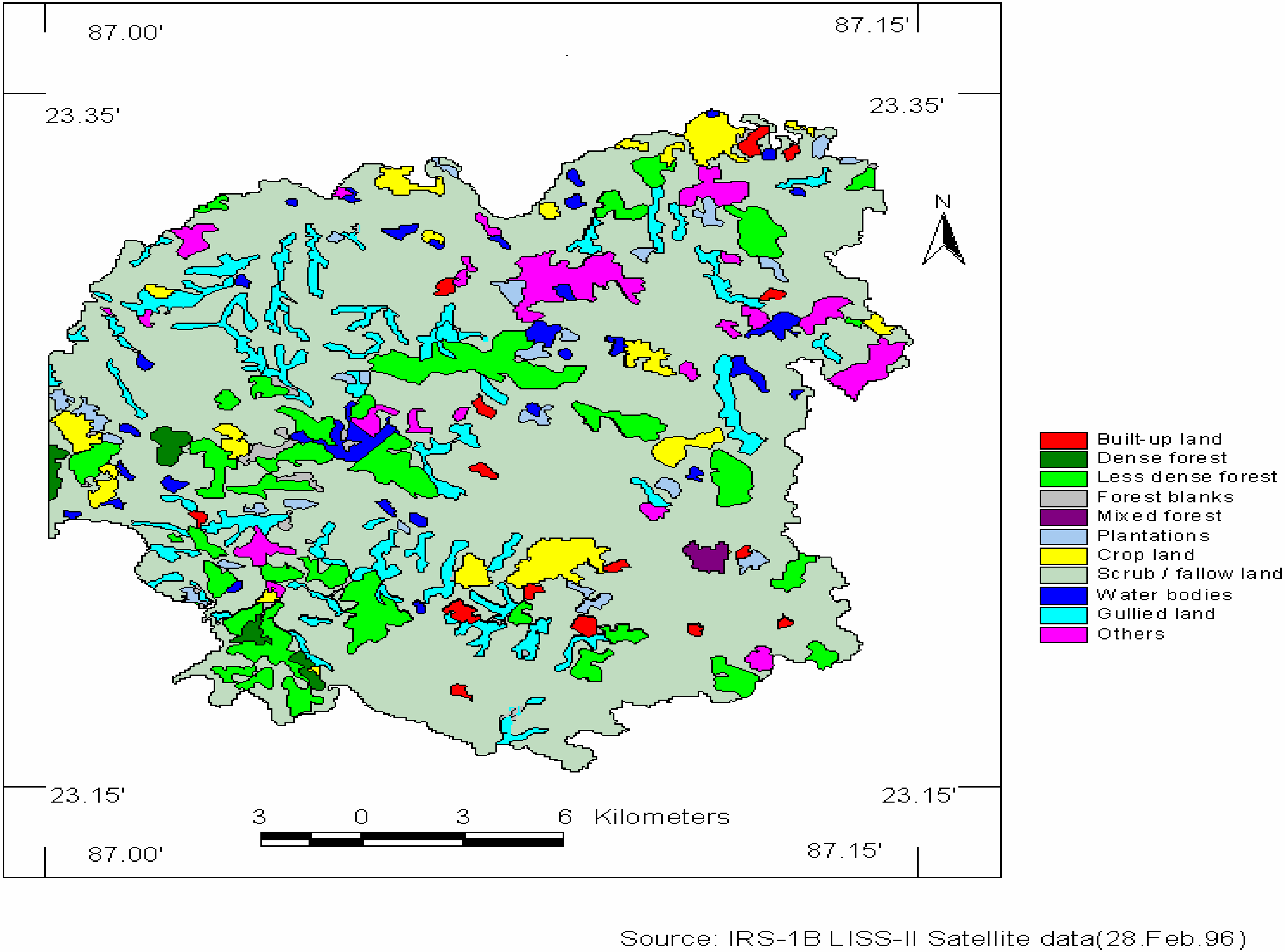
- District – Fund Allocation to blocks, Mouza electrification, Industrial devpt., Coal – elect., fuel / ration shops Sanctions.
- Block– Fund Allocation to GPs, Kerosene allocation, industry promotion, marketing support.
- Gram Panchayat – Agriculture / irrigation schemes, Co-op industry, request for fuel/ration shop, electricity.
- Household – Fuel choice, Device choice.

DSS Frame Work





Remote Sensed images
Ground Truthing
GIS ANALYSIS
Digitized Maps
Map Showing Landuse Classification
Crop residue factors
CROP RESIDUE MODULE
Total Crop residues available
Estimation of crop areas
Areal extent of forest, non-forest
Average fuelwood density non-forest (Survey / literature)
Fuelwood non-forest
Secondary Data
Sub Classification of Sal, and Mixed forests
FUELWOOD MODULE
Total Fuelwood available
Estimation of wood volume correlations
ACCOUNTING MODULE
Fuelwood avail from forest areas
Height, Density measurements
Standing wood estimates forest areas
ACCOUNTING MODULE
% of Fuelwood



Landuse / landcover map of Gangajalghati block, Bankura district

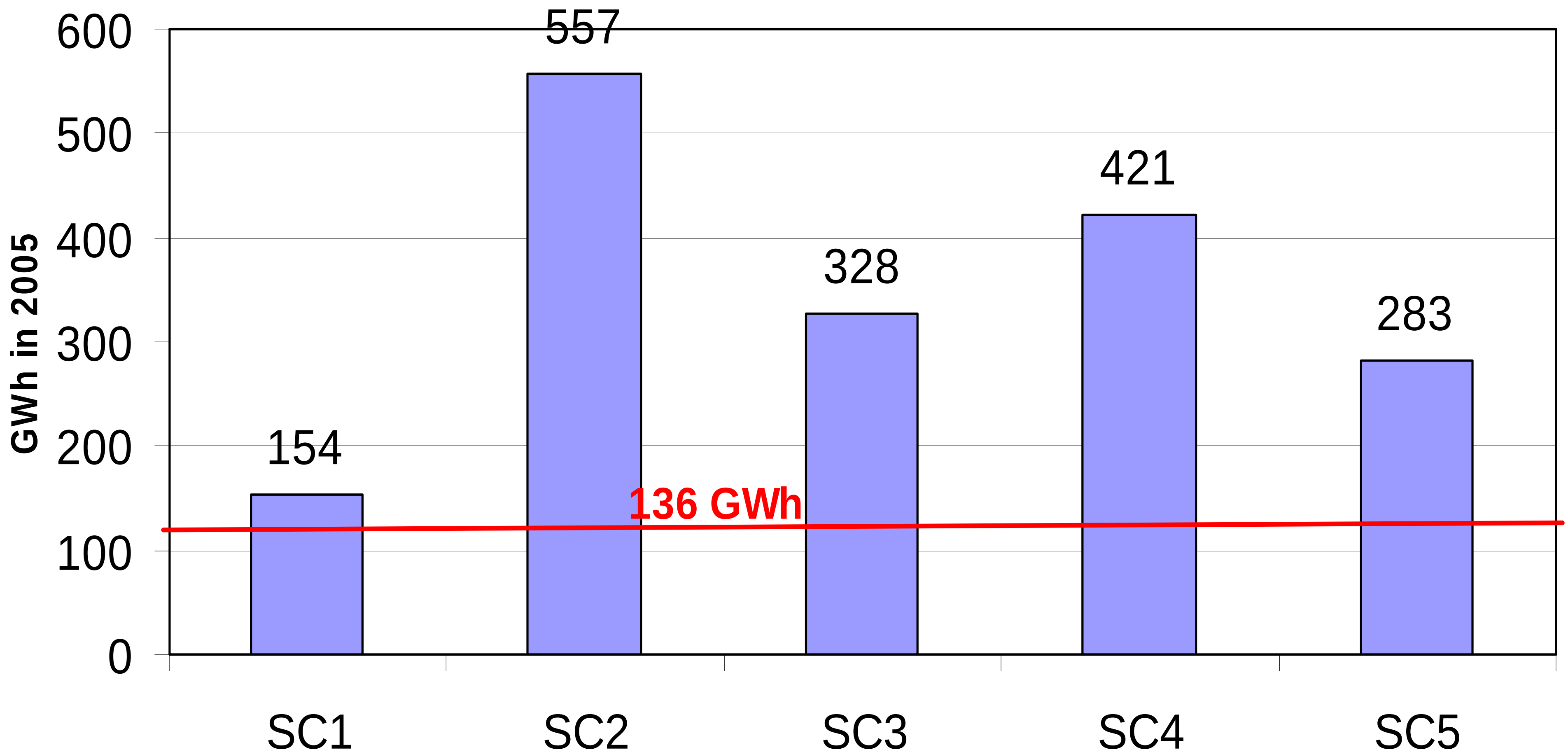
Drivers for Demand Scenarios

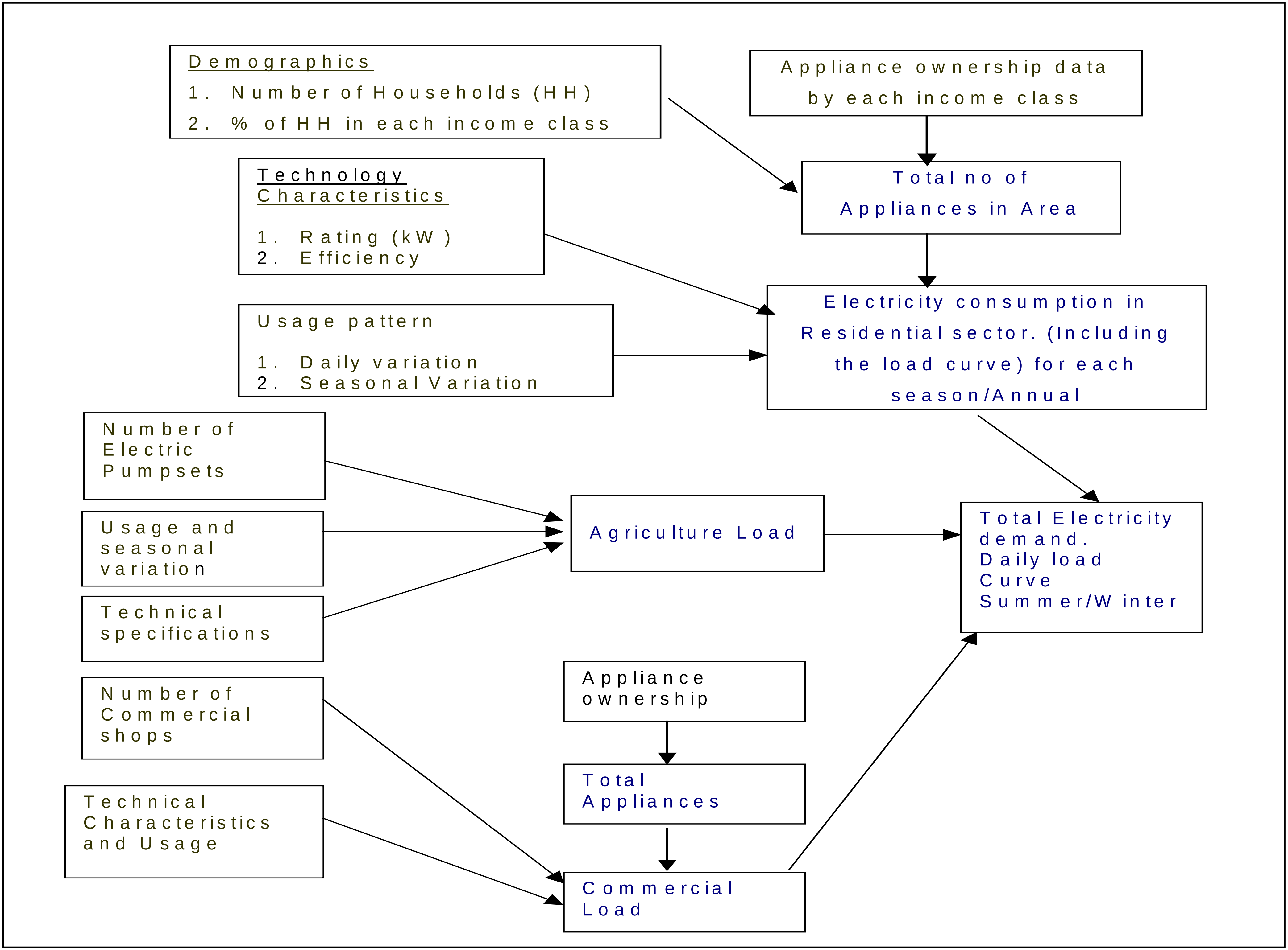
	Residential cooking	Residential Non-cooking	Agriculture	Industrial
Drivers	Population Low-Med-High (L-M-H) Income No Transition(NT)/ Transition(T)	Population (no of Households) Low-Med-High (L-M-H) Income NT-T Electrification NE-ME-AE	Rainfall Low-Med-High LR – MR – HR Irrigation NI – LI- MI – HI Crop Pattern NTC/TC1/TC2 Pump Electric NE/ME/AE	Growth Low-Med-High LG/MG/HG *Rice mills linked to agricultural scenarios
No of combinations	6	18	108	3+

Select Scenario cases

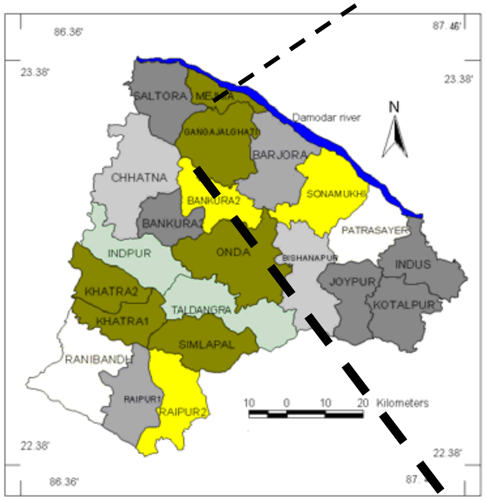
	Population	Income	Village Electrification	Rain	Irrigation Land	Crop Pattern	Pump Electrified	Ind. Growth
SC1	L	NT	NE	HR	NI	NTC	NE	LG
SC2	H	T	AE	LR	HI	TC2	AE	HG
SC3	M	T	ME	MR	MI	TC2	ME	MG
SC4	L	T	AE	HR	HI	TC1 TC2	AE	HG
SC5	L	T	ME	HR	MI	TC1	ME	MG

Electricity Demand in 2005

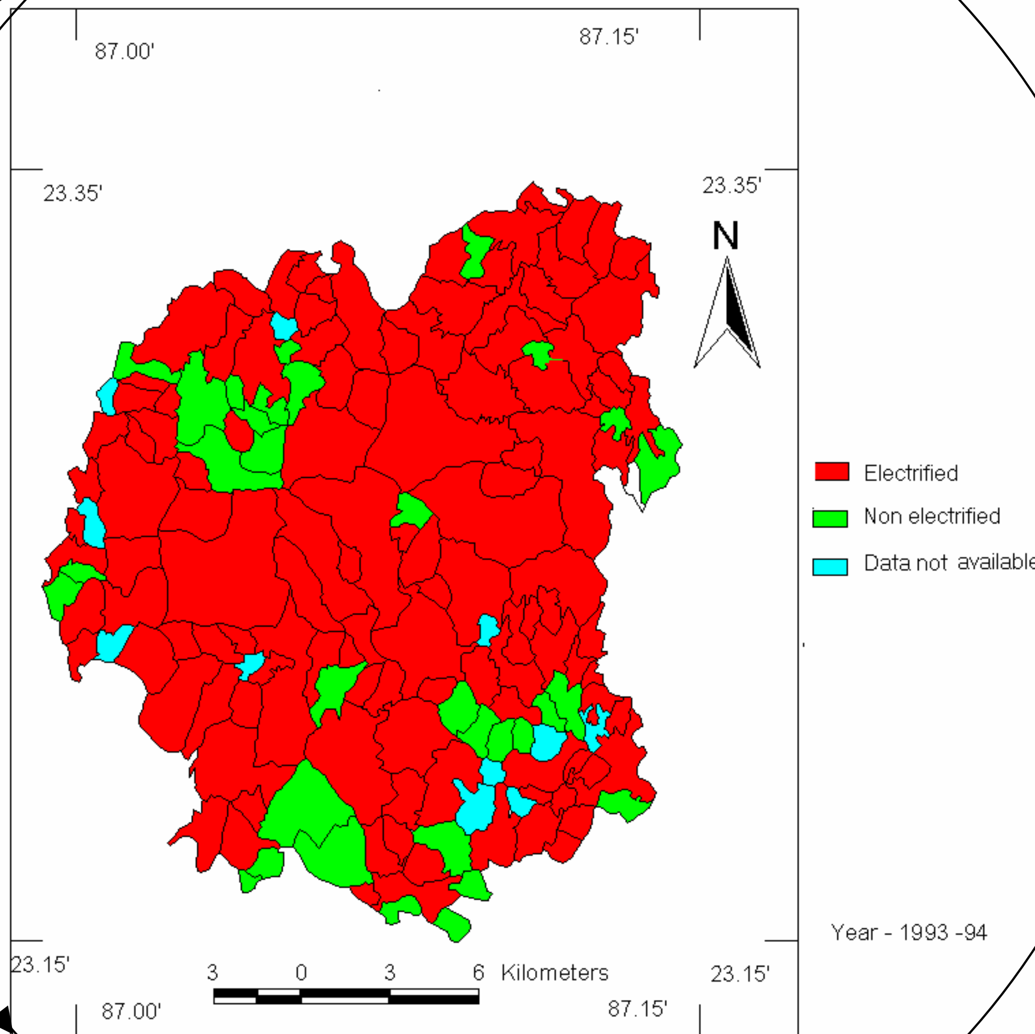



Demographics
1. Number of Households (HH)
2. % of HH in each income class
Appliance ownership data by each income class
Total no of Appliances in Area
Technology Characteristics
1. Rating (kW)
2. Efficiency
Usage pattern
1. Daily variation
2. Seasonal Variation
Electricity consumption in Residential sector. (Including the load curve) for each season/Annual
Number of Electric Pumpsets
Usage and seasonal variation
Technical specifications
Agriculture Load
Total Electricity demand. Daily load Curve Summer/Winter
Appliance ownership
Total Appliances
Number of Commercial shops
Technical Characteristics and Usage
Commercial Load

Village Electrification example

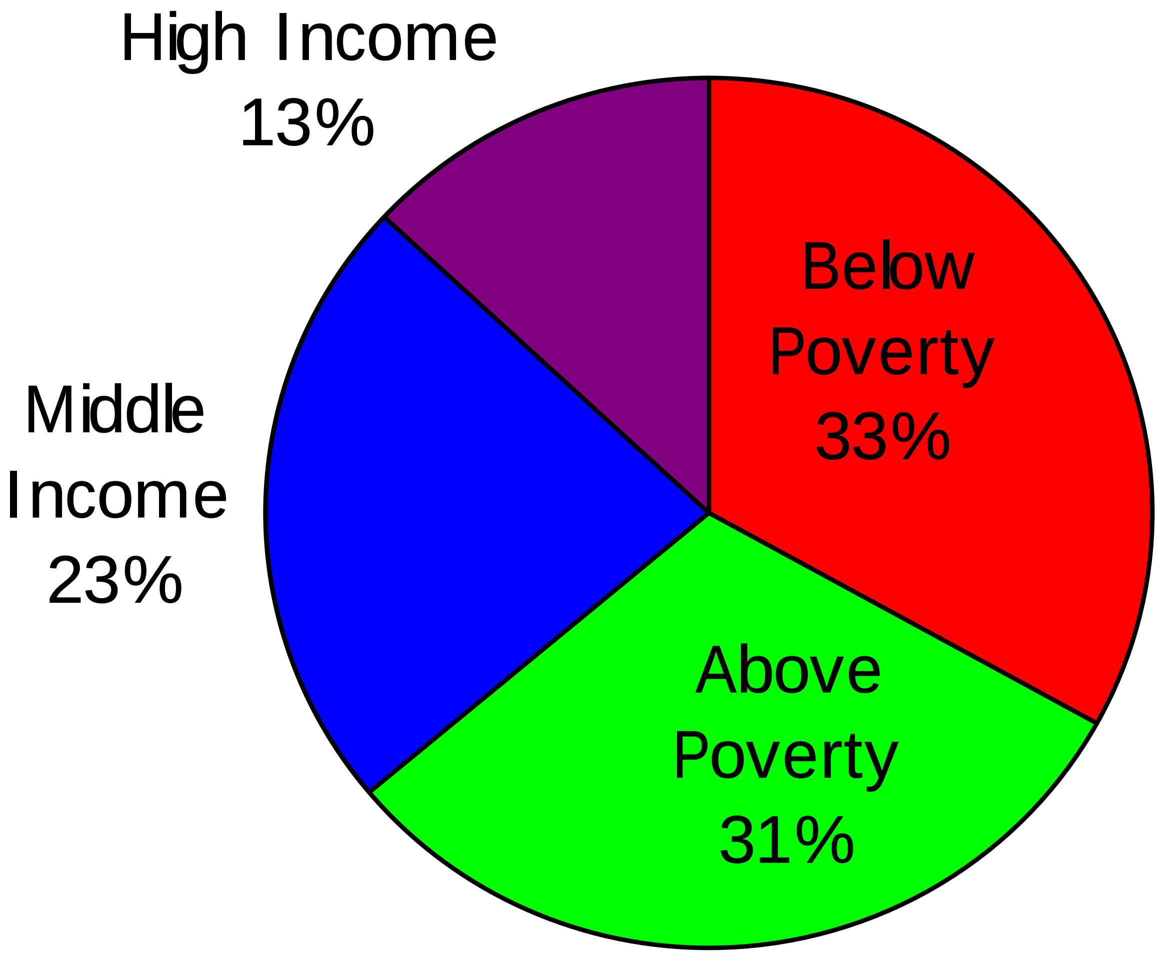


Adminstrative map of Bankura district, West Bengal.

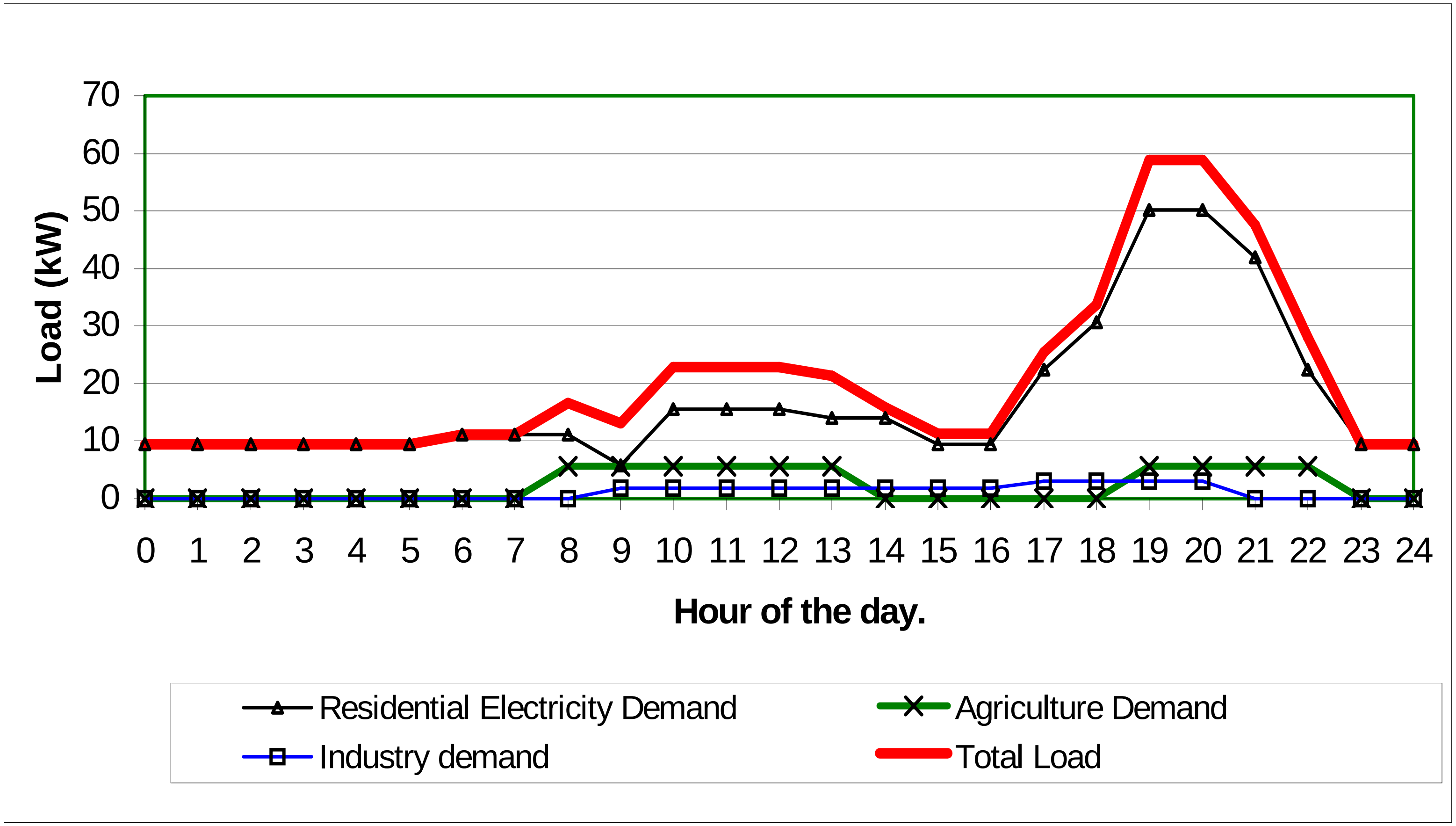


Source - Village level indicator

Map showing electrified and not electrified villages in Gangajalghati block



Income class distribution in Rajamele in 1994.



Daily load curve for Rajamele village in Summer in 2005

DSS Capability/Use

- Energy Quantification- from data already available/collected by Govt
- Assess impacts of development paths
- Quantify future commercial fuel demands – elec/coal/LPG/kerosene
- Rural Electrification- Load Profile Estimation,Sizing, Option Selection, Impact Assessment
- Spatial Representation of results
- Classification of areas as biomass surplus/deficit

Summing Up

- Examples – illustrate variety of optimisation/ simulation models for energy sector
- Decision context and model formulation critical
- Reality check - Applicability
- Generalisation important but..
- Data intensity and uncertainty

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Ph.D. - 2008

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Faculty

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Ph.D. - 2009

Santanu B.
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Thank you

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