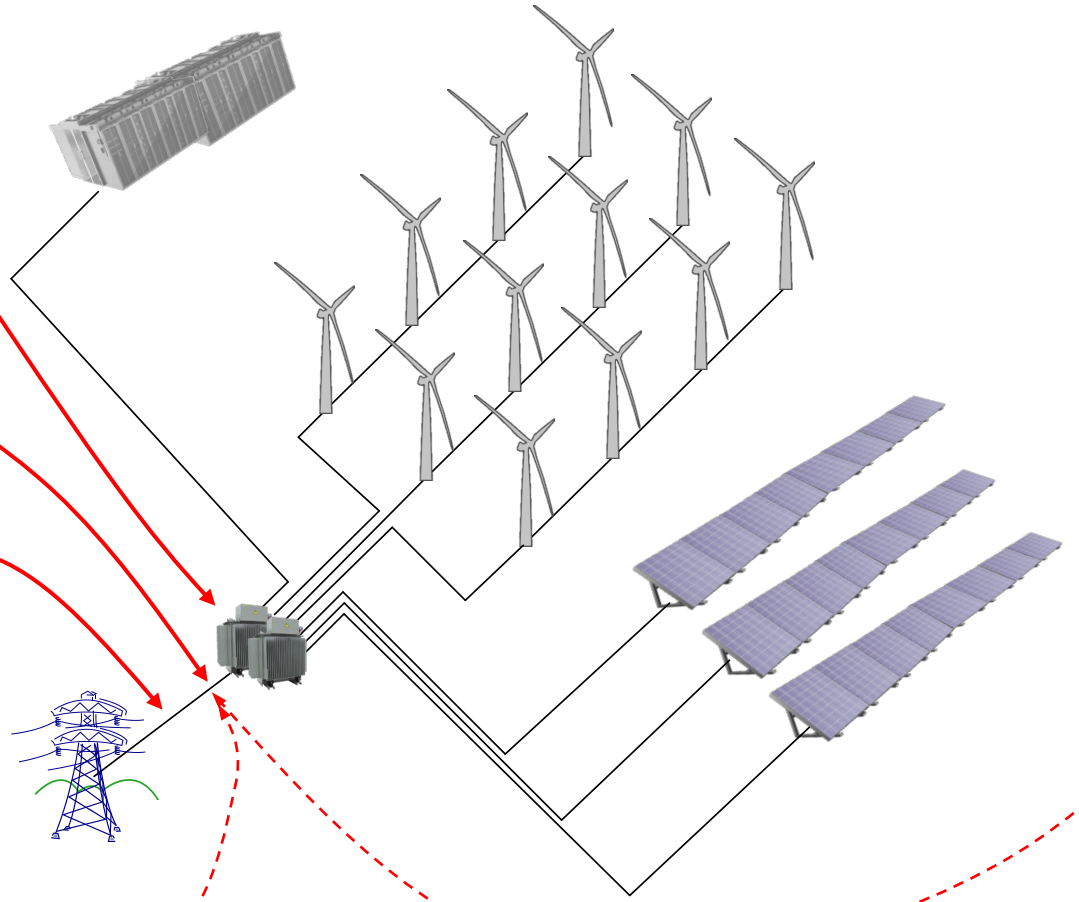
Kaushik Das, Alessandra Cossu, Juan Pablo Murcia Leon, Poul Ejnar Sørensen

Component sizing of a utility-scale hybrid power plant

Work done as a part of Indo-Danish project
“HYBRIDize” funded by Innovationsfonden Denmark

Utility-scale Hybrid power plant



Cost of electrical infrastructure

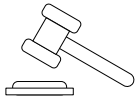
Connection requirements

Grid capacity and utilization

Ancillary services capability

Control centre

Forecasts



Electricity markets

Increase value of renewable generation

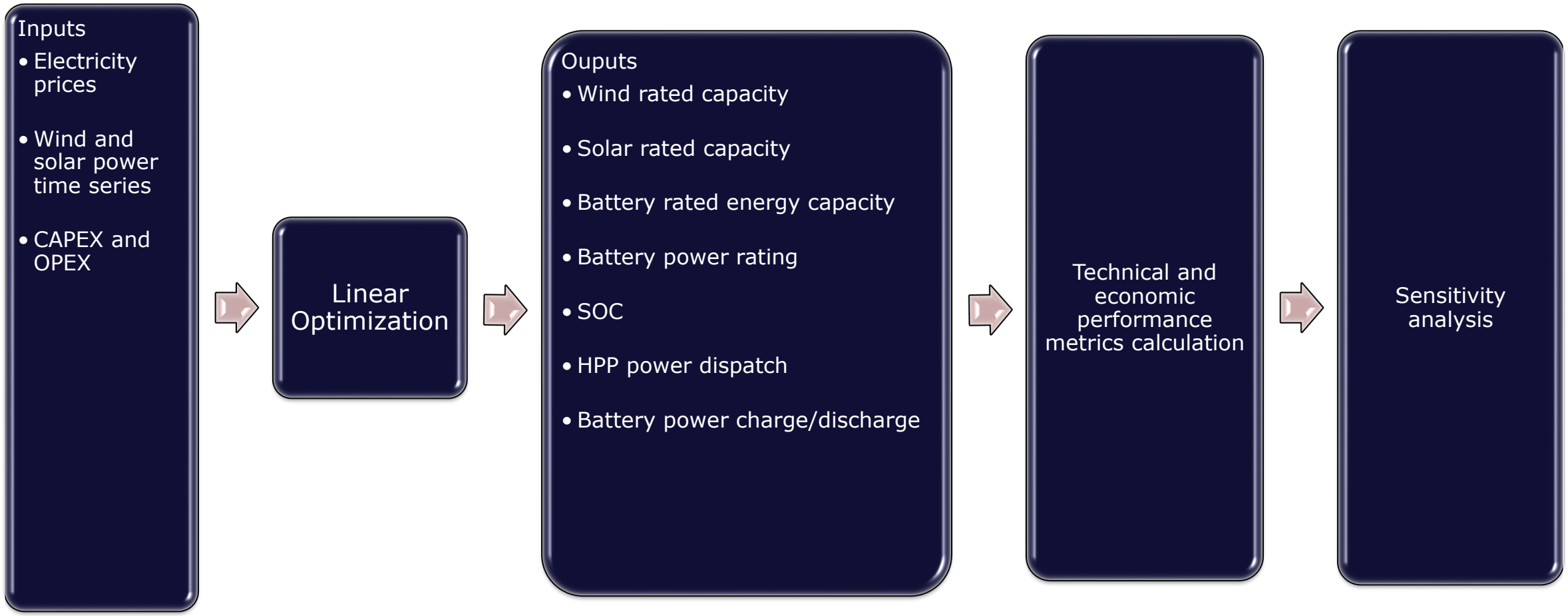
1. Energy markets
2. Ancillary services

Benefits of Hybrid Power Plants

- For System Operators/Society:
  - Optimal utilization of land, Delayed requirement for transmission infrastructure reinforcement, Improved grid stability and security, More RES integration with same grid connection, Increased flexibility, Reduced curtailment

- For Plant owners/developers/operators
  - Better utilization of grid connection through anti-correlation of wind and solar
  - Reduced infrastructure costs through optimal use of infrastructures
  - Energy arbitrage
  - Participation in different markets
  - Reduced development cost

Methodology



Methodology

Assumptions

- One year prices, wind and solar power time series extrapolated for the entire lifetime of the project
- Overplanting is allowed by regulation
- HPP developer is a price taker
- Uncertainties not considered

Case study – Peak power plant

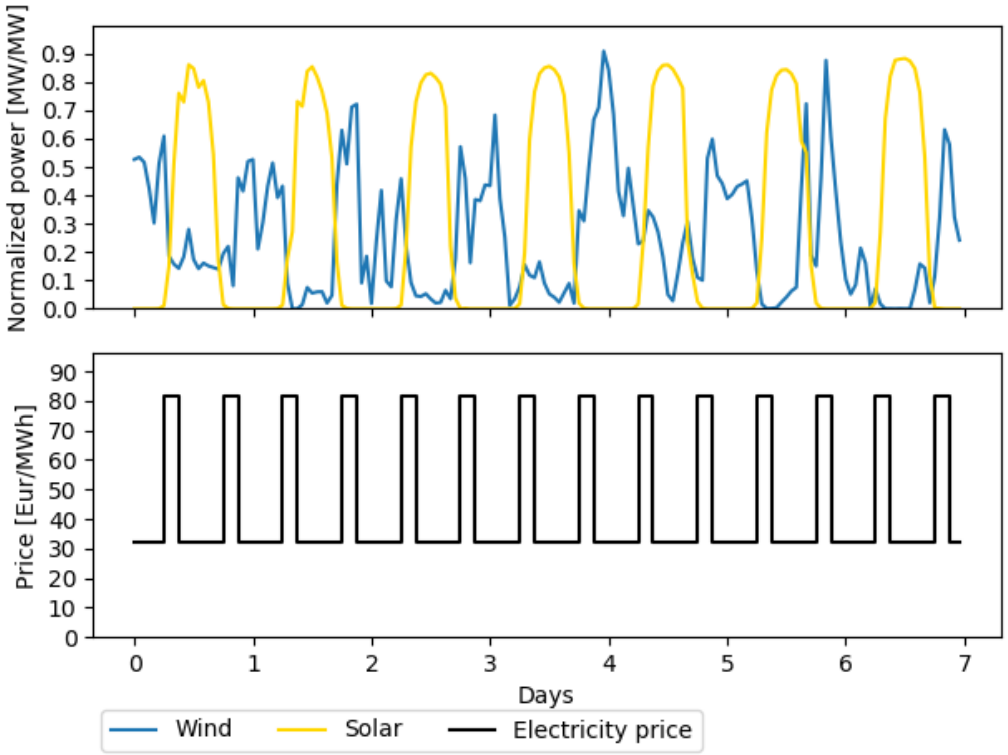
Power Purchase Agreement

- Peak/Off-peak fixed tariffs according to awarded tenders
- Grid connection capacity – 300 MW
- 25 years contract
- Six peak hours every day

Peak Tariff [EUR/MWh]	Off-Peak Tariff [EUR/MWh]	Peak Hours
81.5	32	6-9 18-21

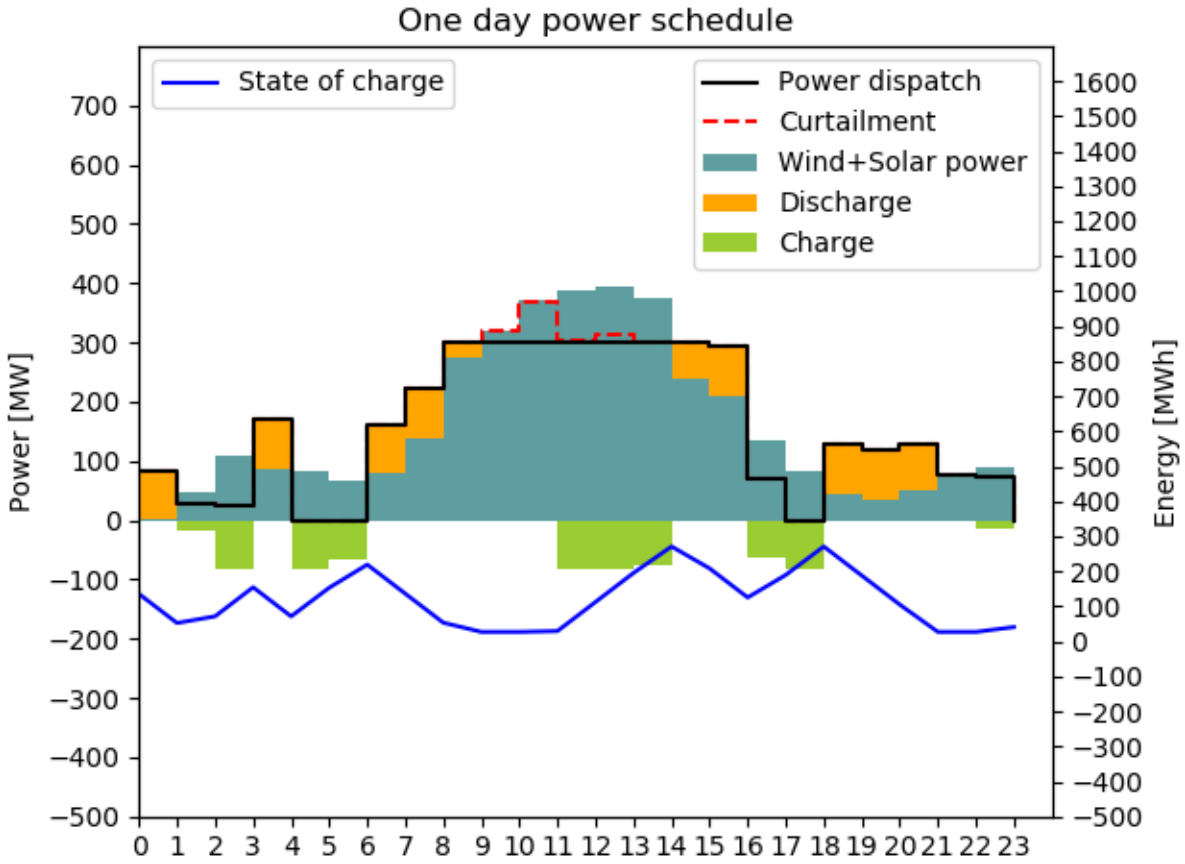
Location: India, Telengana region

Solar CF	Wind CF
23.5 %	29.5 %



Results

Base case



Optimal sizes of HPP technologies

	Capacity	Unit
Wind	171	MW
Solar	378	MW
Battery energy	271	MWh
Battery power	83	MW

Comparison of different technology mix

	Solar Contracted capacity	Wind Contracted capacity	Wind Solar Optimized	Optimal	Unit
Wind	-	300	129	171	MW
Solar	300	-	347	378	MW
Battery energy	-	-	-	271	MWh
Battery power	-	-	-	83	MW
Potential wind-solar energy at nominal capacity	617	775	1047	1219	GWh
HPP Annual energy production	617	775	1026	1199	GWh
Capacity factor	23	29	39	46	%
Full load hours	2057	2584	3421	3997	Hours
Total curtailment	0	0	21	20	GWh
Potential wind-solar energy curtailed	0	0	2	2	%
LCOE	29	38	32	39	€/MWh
NPV	37	36	72	82	M€

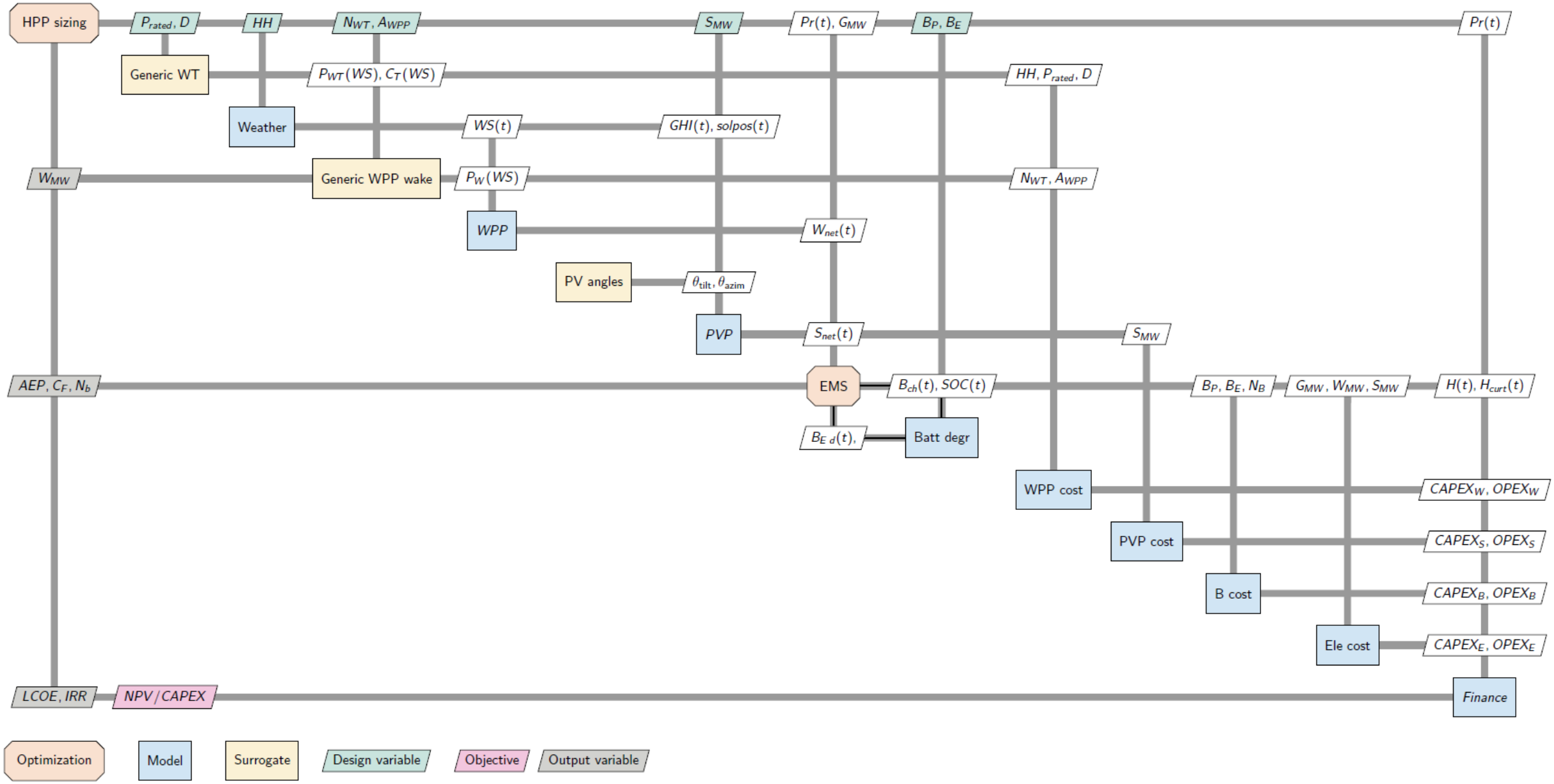
Comparison with different price profile inputs

	Optimal	Market Prices	Evening peaks	Unit
Wind rated capacity	171	0	316	MW
Solar rated capacity	378	377	210	MW
Battery energy capacity	271	0	0	MWh
Battery power rating	83	0	0	MW
Potential wind-solar energy at nominal capacity	1219	775	1248	GWh
HPP Annual energy production	1199	761	1225	GWh
Capacity factor	46%	29%	47%	%
Full load hours	3997	2536	4084	Hours
Total curtailment	20	14	23	GWh
Potential wind and solar energy curtailed	2%	2%	2%	%
CAPEX	488	233	485	€
IRR	9%	11%	8%	%
LCOE	39	29	36	€/MWh
NPV	82	95	51	M€

HyDesign

HyDesign is a software by DTU for design and operational strategies of utility-scale hybrid plant (comprising of wind, solar, electrical storage and power2X)

Sizing


HPP sizing
P_{rated}, D
HH
N_{WT}, A_{WPP}
S_{MW}
$Pr(t), G_{MW}$
B_P, B_E
$Pr(t)$
Generic WT
$P_{WT}(WS), C_T(WS)$
HH, P_{rated}, D
Weather
$WS(t)$
$GHI(t), solpos(t)$
W_{MW}
Generic WPP wake
$P_W(WS)$
N_{WT}, A_{WPP}
WPP
$W_{net}(t)$
PV angles
$\theta_{tilt}, \theta_{azim}$
PVP
$S_{net}(t)$
S_{MW}
AEP, C_F, N_b
EMS
$B_{ch}(t), SOC(t)$
B_P, B_E, N_B
G_{MW}, W_{MW}, S_{MW}
$H(t), H_{curt}(t)$
$B_{E,d}(t),$
Batt degr
WPP cost
$CAPEX_W, OPEX_W$
PVP cost
$CAPEX_S, OPEX_S$
B cost
$CAPEX_B, OPEX_B$
Ele cost
$CAPEX_E, OPEX_E$
$LCOE, IRR$
$NPV/CAPEX$
Finance
Optimization
Model
Surrogate
Design variable
Objective
Output variable

Sizing – Peak power plant case in India

Site	Good solar	Good solar	Good wind	Good wind	Bad solar & wind	Bad solar & wind
Design objective	NPV/C_H	LCOE	NPV/C_H	LCOE	NPV/C_H	LCOE
clearance [m]	21	10	60	60	47	10
sp [m2/W]	243	180	286	330	314	180
p rated [MW]	1	1	1	1	3	1
Nwt	0	0	300	300	5	0
wind density [MW/km2]	8	5	5	5	5	5
solar MW [MW]	379	400	129	0	396	400
battery power [MW]	87	0	76	0	111	0
battery energy/power [h]	2	1	1	1	2	1
NPV over CAPEX	0.205	0.153	0.556	0.395	0.001	-0.123
NPV [MEuro]	53.2	35.5	135.0	56.8	0.2	-28.4
IRR	7.5 %	6.6 %	10.4 %	8.7 %	5.5 %	0.0 %
LCOE [Euro/MWh]	39.4	32.9	23.6	19.8	47.2	36.6
CAPEX [MEuro]	259.8	231.4	242.6	144.0	298.6	231.4
OPEX [MEuro]	3.1	3.3	4.9	3.8	3.4	3.3
penalty lifetime [MEuro]	0.5	5.4	7.2	17.9	0.8	10.3
CF	21 %	23 %	38 %	29 %	20 %	20 %
grid [MW]	300	300	300	300	300	300
wind [MW]	0	0	300	300	15	0
solar [MW]	379	400	129	0	396	400
Battery Energy [MWh]	174	0	76	0	222	0
Battery Power [MW]	87	0	76	0	111	0
Total curtailment [GWh]	0.0	0.0	31.3	0.0	0.0	0.0
Awpp [km2]	0.0	0.0	60.0	60.0	3.0	0.0
Rotor diam [m]	72.4	84.1	66.7	62.1	110.3	84.1
Hub height [m]	57.2	52.1	93.4	91.1	102.1	52.1
Number of batteries	2	0	2	0	2	0

Discussion

- Sizing of HPP is a complex problem involving multiple complex optimization
- Peak-power plant case study demonstrates value of designing plants beyond LCoE
  - HPP more valuable to provide peak power than individual technology plants
  - HPP not feasible as peak power plant with market prices
  - Additional financial support required
- Increase in capacity factor means better utilization of grid


DTU