STERG

SOLAR THERMAL ENERGY
RESEARCH GROUP

PV Enhanced Concentrating Solar Power (CSP) for Base Load Power Generation in South Africa

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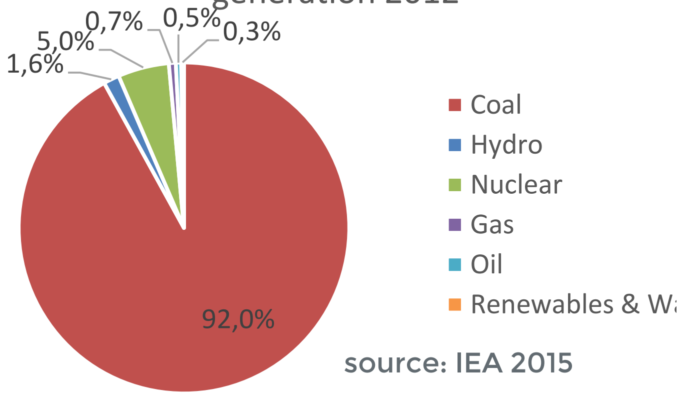
Contents

Motivation

Constrained fossil power system

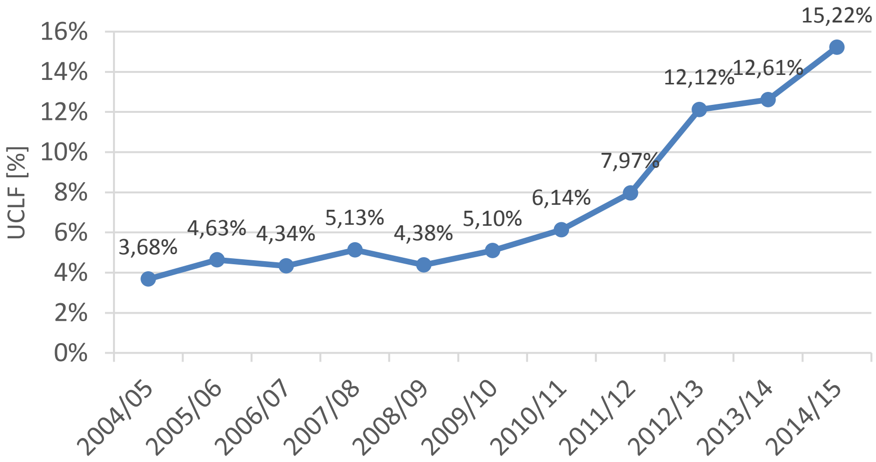
- electricity generation highly dependant on coal
- average age of power plant fleet: 34 years
- load shedding of up to 4 GW
- need for supply security

primary energy consumption for electricity generation 2012



source: IEA 2015

unplanned capability loss factor



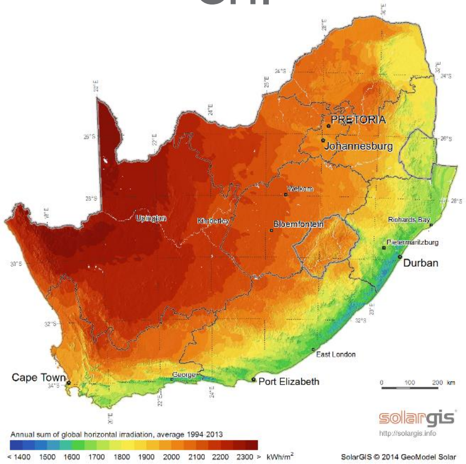
source: Eskom 2015a,b

Motivation

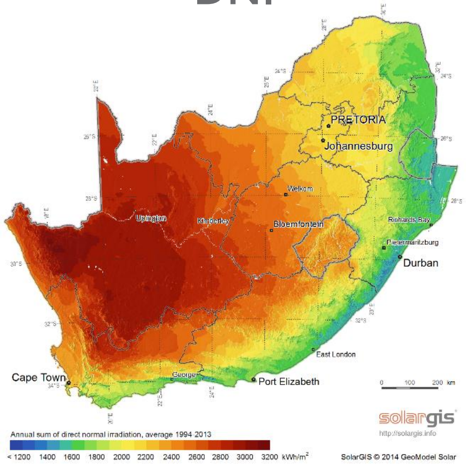
Solar resource in South Africa

- GHI up to 2,300 kWh/m²a (Seville 1,800 kWh/m²a)
- DNI up to 3,200 kWh/m²a (Seville 2,100 kWh/m²a)

GHI



DNI

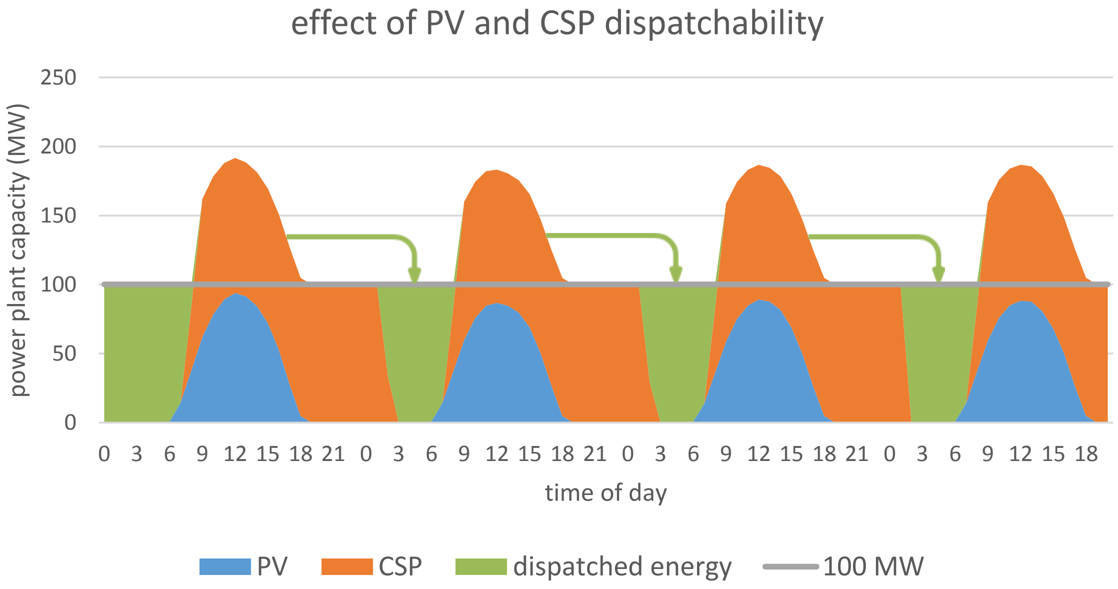


source: SolarGIS 2014a,b

Objective

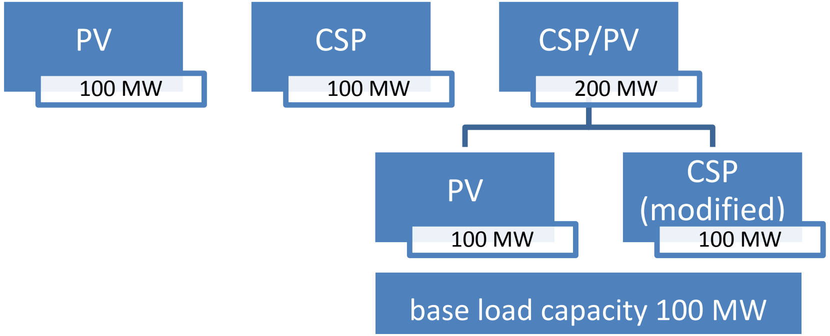
Research question

- Can the advantages of cheap PV and dispatchability of CSP with thermal energy storage (TES) be combined to supply 100 MW constant base load capacity in South Africa?



Methodology

- power plant simulation in SAM (NREL)
- fixed parameters for PV (one option)
- varying solar multiple (SM) and TES size for CSP (multiple options)
- simulated power plants:

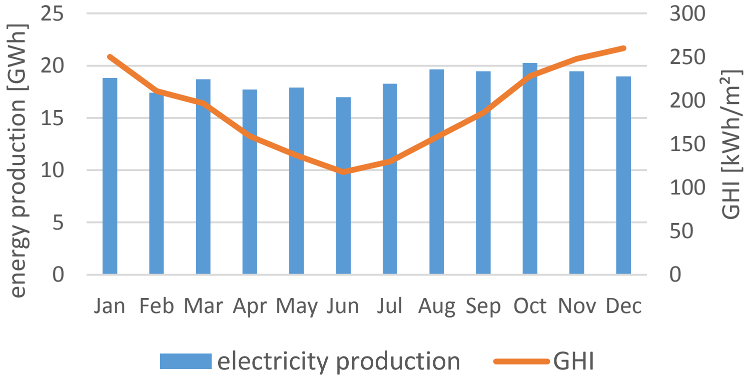


- comparison of plant performance, capacity factor and load profiles

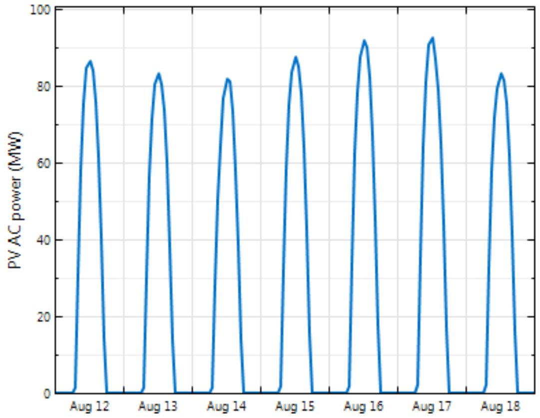
PV power plant simulation

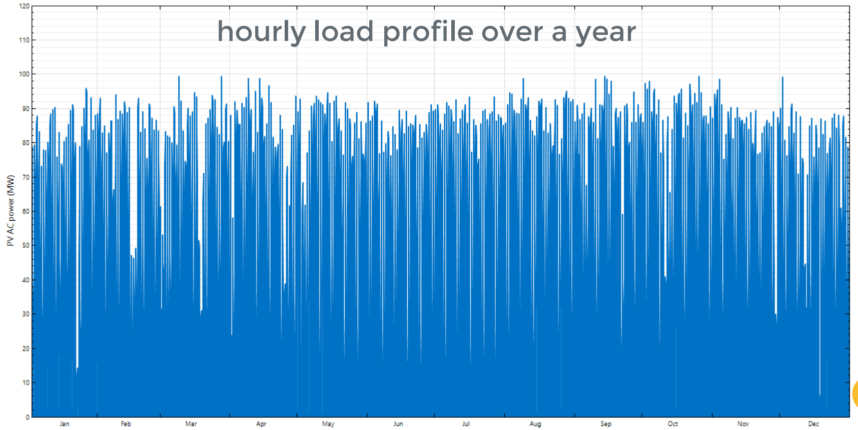
Item	Unit	Value
total module capacity	MW_p	110
total inverter capacity	MW_{AC}	100.3
annual energy	GWh	223.6
capacity factor	%	23.2
specific yield	kWh_{AC}/kW_{DC}	2,033
performance ratio	%	84.0

monthly PV electricity production



typical winter week





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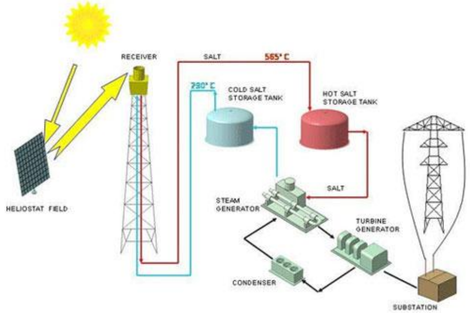
Central receiver with molten salt TES

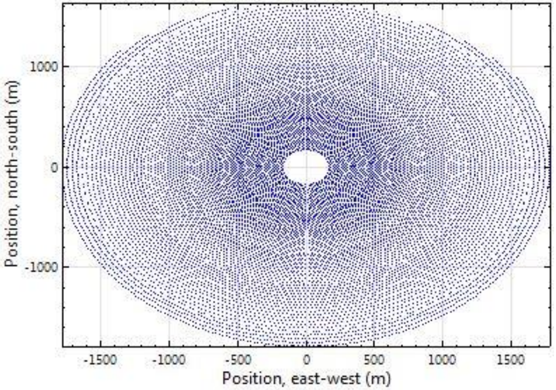
Simulated configurations

Item	Unit	Value											
Turbine capacity, gross	MW_e	115											
Turbine capacity, net	MW_e	100											
design HTF inlet temperature	°C	565											
design HTF outlet temperature	°C	290											
cycle gross efficiency	%	42											
steam generator thermal power	MW_{th}	273.8											
heat transfer fluid	-	Salt (60% $NaNO_3$, 40% KNO_3											
TES full load hours	h	14						16					
solar multiple	-	1.5	2	2.5	3	3.5	4	1.5	2	2.5	3	3.5	4
TES full load hours	h	18						20					
solar multiple	-	1.5	2	2.5	3	3.5	4	1.5	2	2.5	3	3.5	4

Gemasolar (Seville, Spain)



heliostat field layout SM 3



Control "strategy"

- No possibility to provide hourly load profile of PV in SAM to determine CSP demand
- Very simplistic implementation:
  - TES dispatch control with 24 h representing an average day every month
  - based on average monthly PV generation profile
  - CSP fills the gap to 100 MW
- Huge improvement possible but sufficient for this study

	12am	1am	2am	3am	4am	5am	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm
Jan	9	9	9	9	9	9	9	8	7	5	4	3	3	3	4	5	6	8	9	9	9	9	9	9
Feb	9	9	9	9	9	9	9	8	7	5	4	3	3	3	3	4	6	8	9	9	9	9	9	9
Mar	9	9	9	9	9	9	9	8	6	5	4	3	3	3	4	5	6	8	9	9	9	9	9	9
Apr	9	9	9	9	9	9	9	8	6	5	3	3	3	3	4	5	6	8	9	9	9	9	9	9
May	9	9	9	9	9	9	9	9	6	4	3	2	2	3	3	5	7	9	9	9	9	9	9	9
Jun	9	9	9	9	9	9	9	9	6	5	3	3	2	3	3	5	7	9	9	9	9	9	9	9
Jul	9	9	9	9	9	9	9	9	6	5	3	2	2	2	3	4	6	9	9	9	9	9	9	9
Aug	9	9	9	9	9	9	9	9	6	4	3	2	2	2	3	4	6	8	9	9	9	9	9	9
Sep	9	9	9	9	9	9	9	8	6	4	3	2	2	2	3	4	6	8	9	9	9	9	9	9
Oct	9	9	9	9	9	9	9	7	6	4	3	3	2	3	3	5	7	8	9	9	9	9	9	9
Nov	9	9	9	9	9	9	9	8	6	4	3	3	3	3	4	5	7	8	9	9	9	9	9	9
Dec	9	9	9	9	9	9	9	8	6	5	4	3	3	3	4	5	6	8	9	9	9	9	9	9

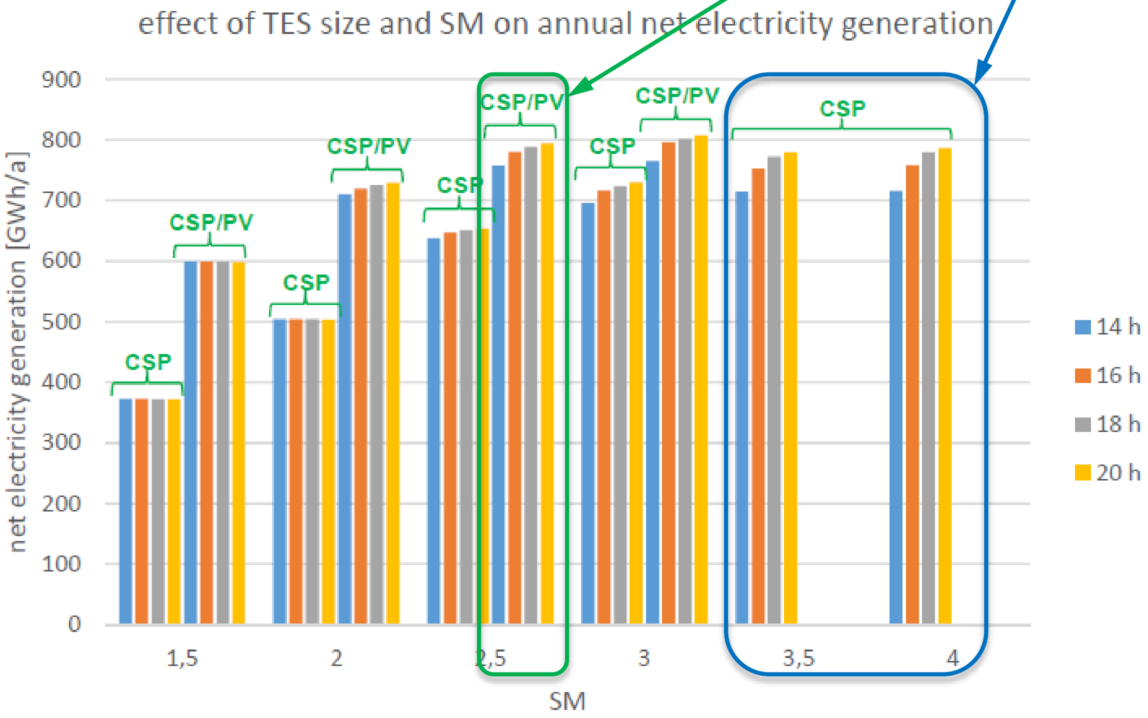
TES dispatch control matrix

Period	Turbine output fraction [%]
2	20
3	30
4	40
5	50
6	60
7	70
8	80
9	95

CSP vs. CSP/PV

Net electricity generation

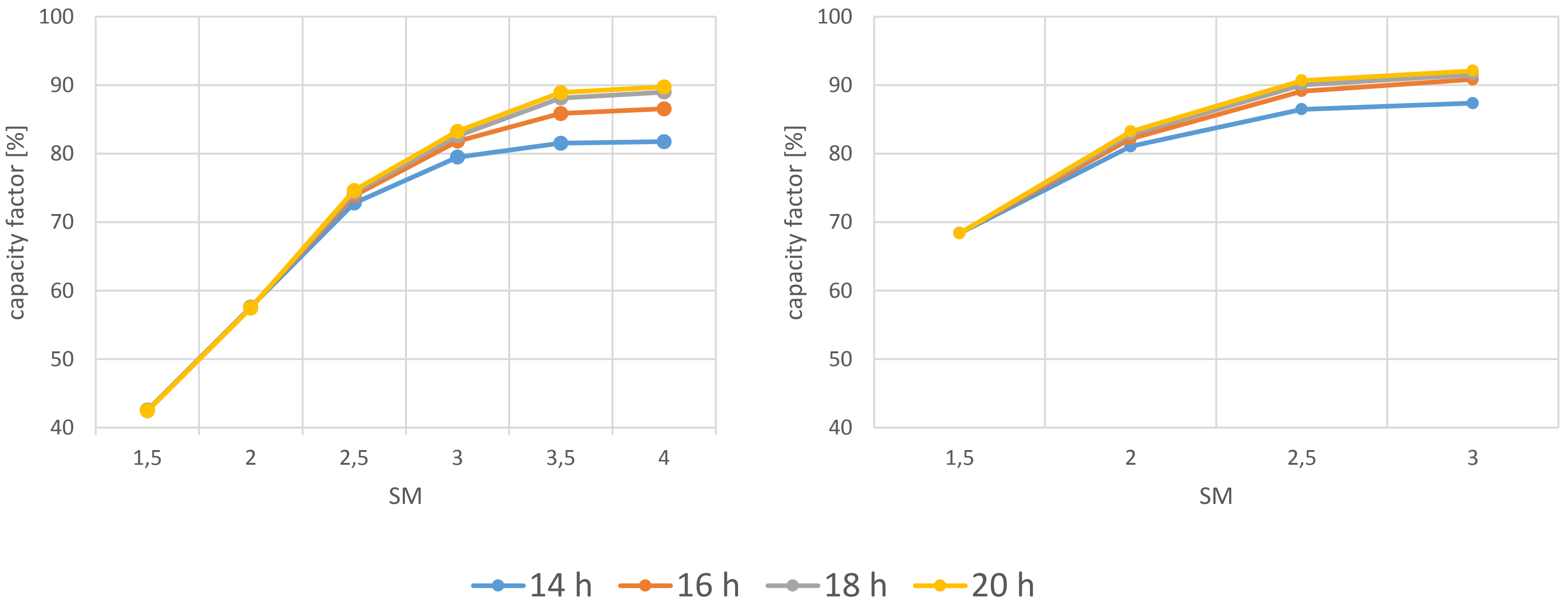
higher electricity yield with small CSP/PV than with larger standalone CSP



CSP vs. CSP/PV

Capacity factors

CSP **CSP/PV** *based on 100 MW (actually 200 MW installed)



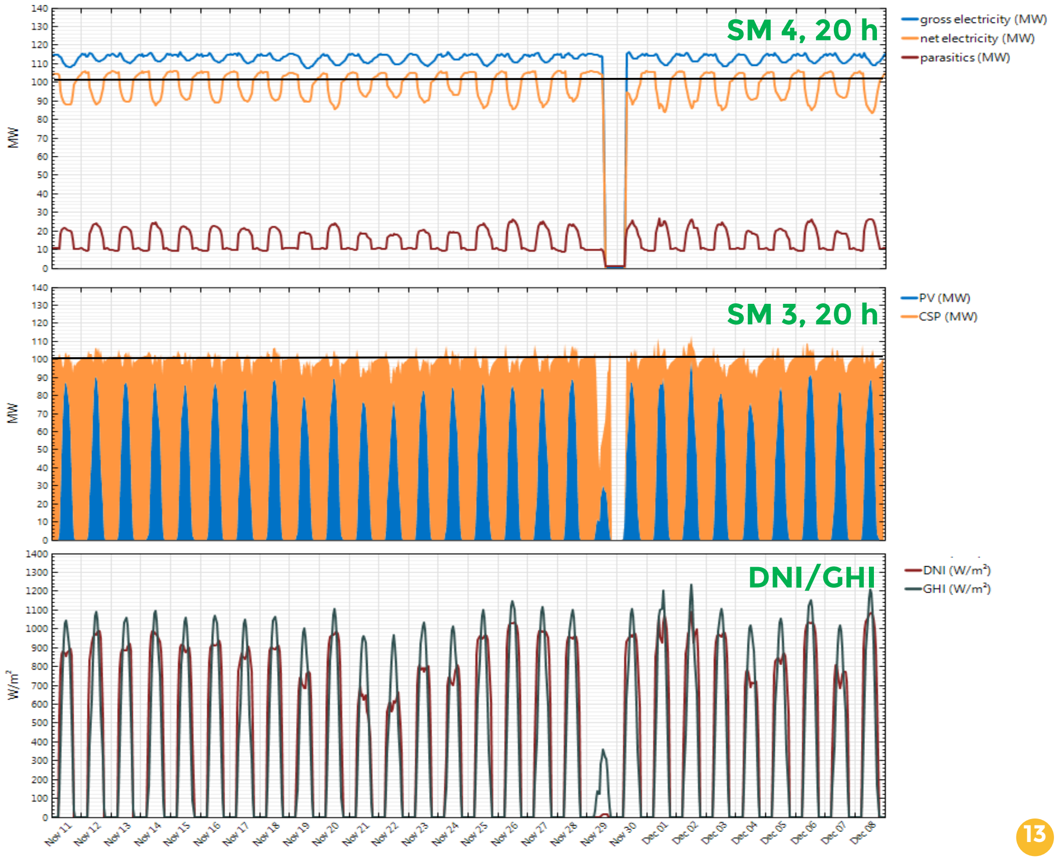
CSP vs. CSP/PV

Load profiles

CSP

CSP/PV

solar resource



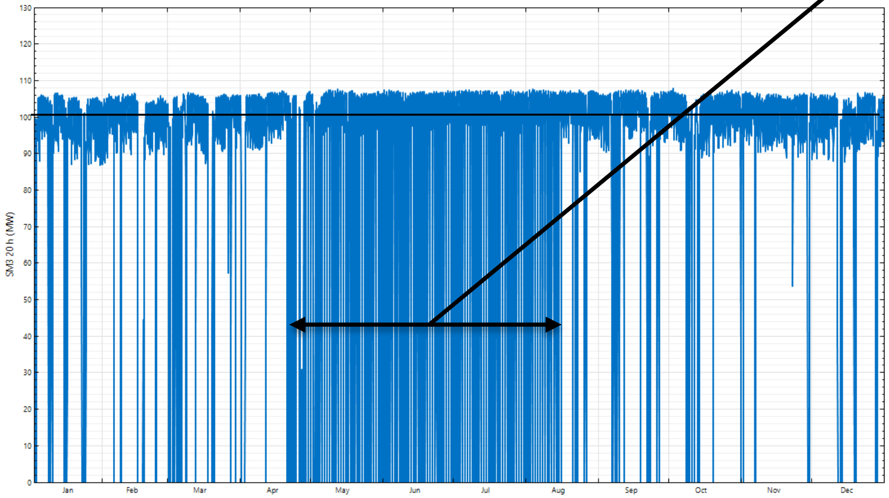
CSP vs. CSP/PV

Hourly load profile over a year

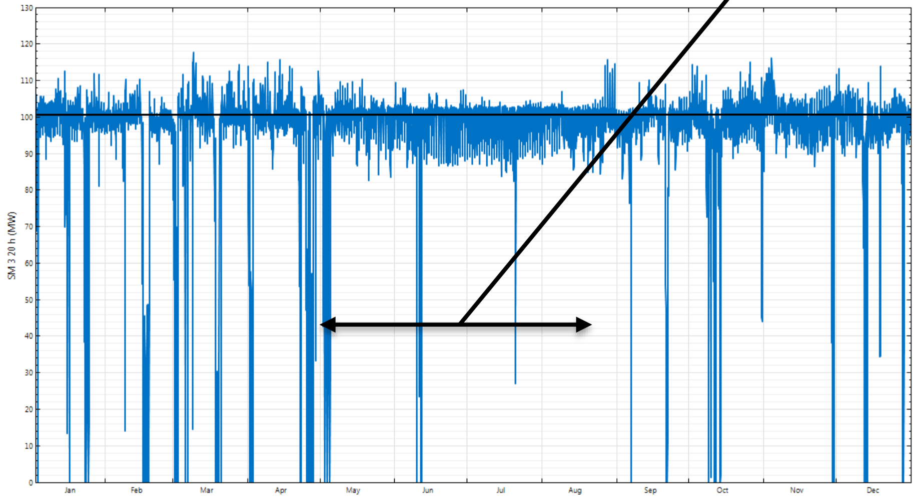
solar field is too small to charge large storage which leads to several turbine stops

less turbine stops due to additional PV

CSP – SM 3, 20 h TES



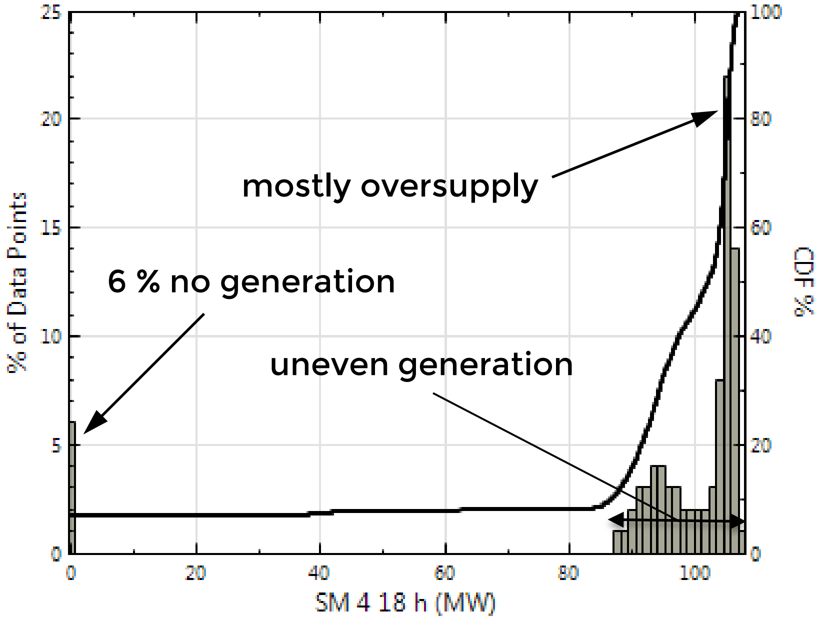
CSP/PV – SM 3, 20 h TES



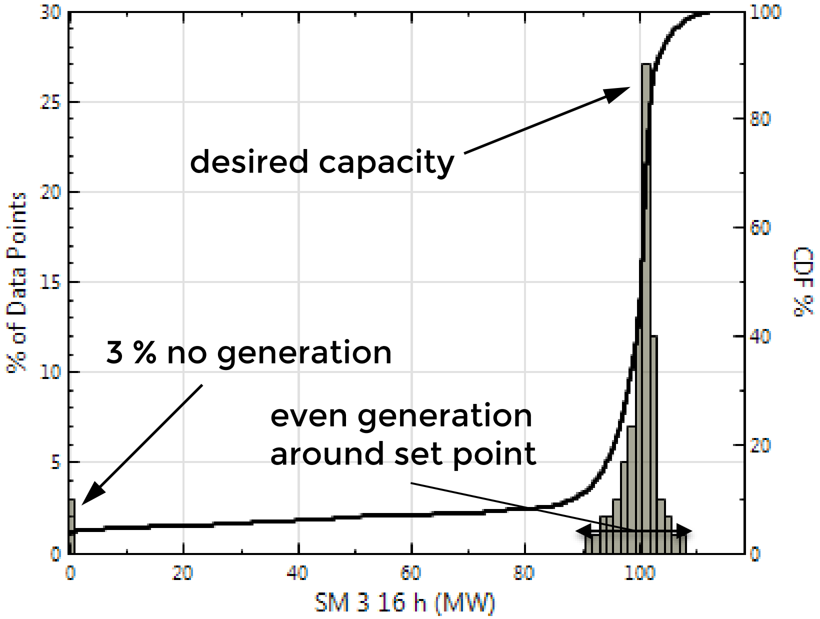
CSP vs. CSP/PV

Probability distribution

CSP
SM 4, 18 h TES



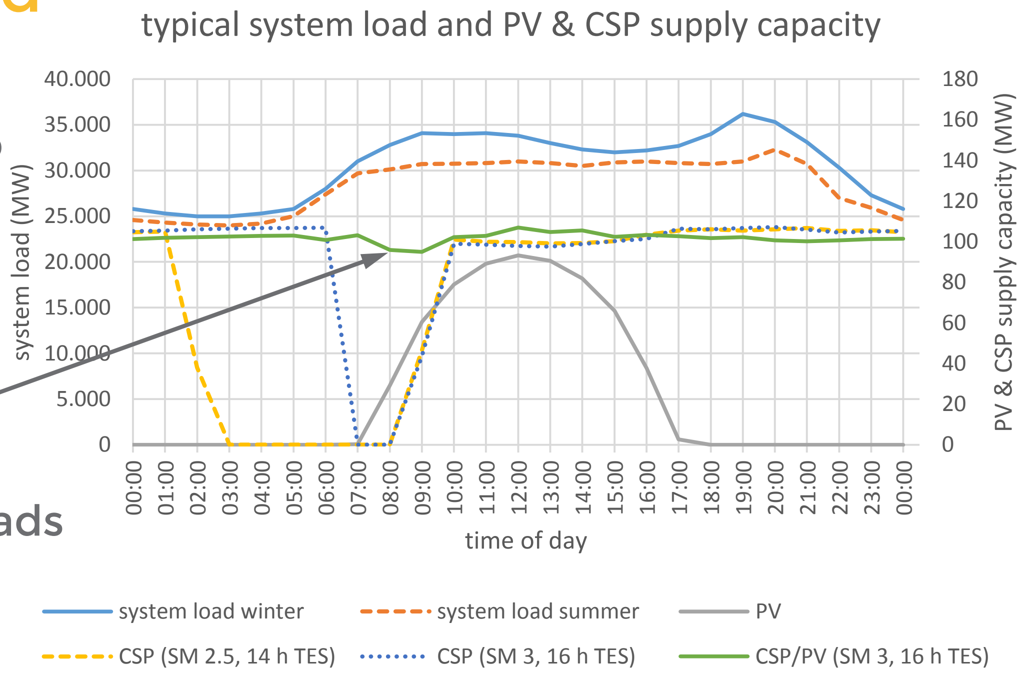
CSP/PV
SM 3, 16 h TES



Conclusion

PV enhanced CSP plants can provide base load capacity for the SA grid

- Higher electricity yields compared to standalone CSP
- High capacity factors (>90 %)
- Reduced system size and therefore costs
- **Constant power output for base load generation**
- Improved control strategy leads to even better results



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Thank you for your attention!

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