Techno-economic Analysis of enhanced Dry Cooling for CSP

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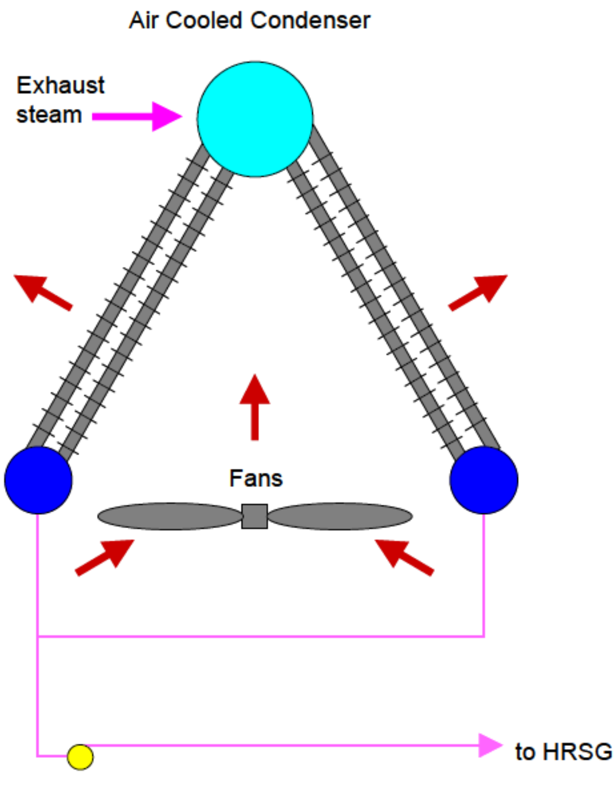
Motivation

- Which factors are important for the site selection of a steam power plant?
  - Proximity to load centers
  - Accessibility and presence of transmission corridors
  - Availability of low-cost fuel
  - Presence of water for cooling purposes

- Low-cost fuel is often available in water scarce regions. Examples:
  - Coal plants located near to coal mines in South Africa
  - CSP! (even if currently evaporation cooling is mostly used)

→ In these cases dry cooling is the only viable option!

Dry Cooling - State of the Art and Improvements



Tawney 2003

- The heat exchange is governed by the dry bulb temperature (T_{DB})
- Strong impact of T_{DB} on cooling efficiency
- No water consumption/withdrawal
- Direct or indirect layout (Heller)
- Different approaches for the improvement of dry cooling:
  - Hybrid-wet cooling
  - Deluge cooling
  - ACC optimized design
  - Optimized dispatch

Methodology

- Simplified model → sensitivity analysis of LEC on key parameters:
  - ACC cooling design (Initial temperature difference)
  - Solar multiple
  - Solar field specific investment cost

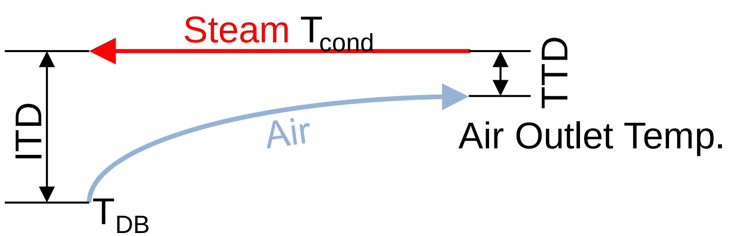
- REMix model → Optimal plant dispatch of a dry cooled CSP plant:
  - Standard dispatch (100 % till complete TES discharge)
  - Optimized dispatch I (constant price)
  - Optimized dispatch II (time-variable price, demand proportional)

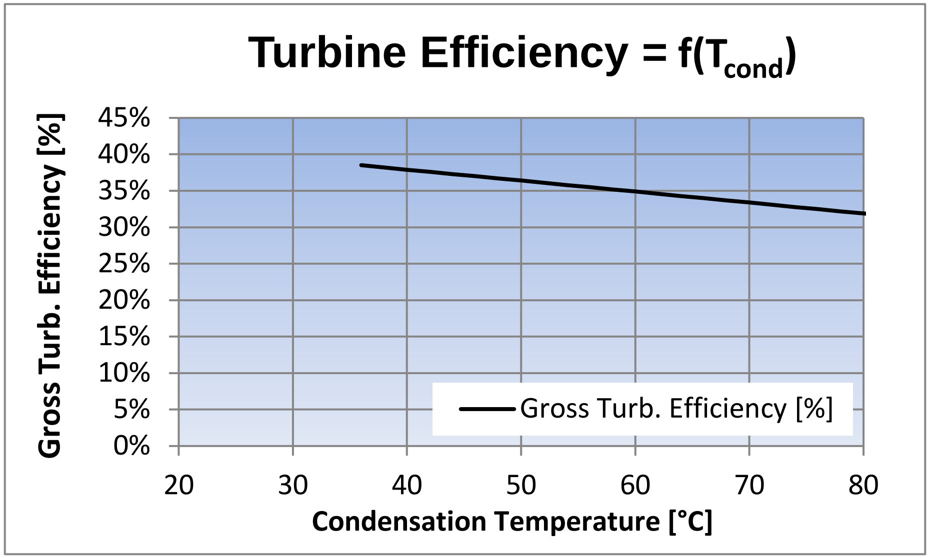
Technical Model

T_{cond} = T_{BD} + ITD

ITD = Initial Temperature Difference

TTD = Terminal Temperature Difference

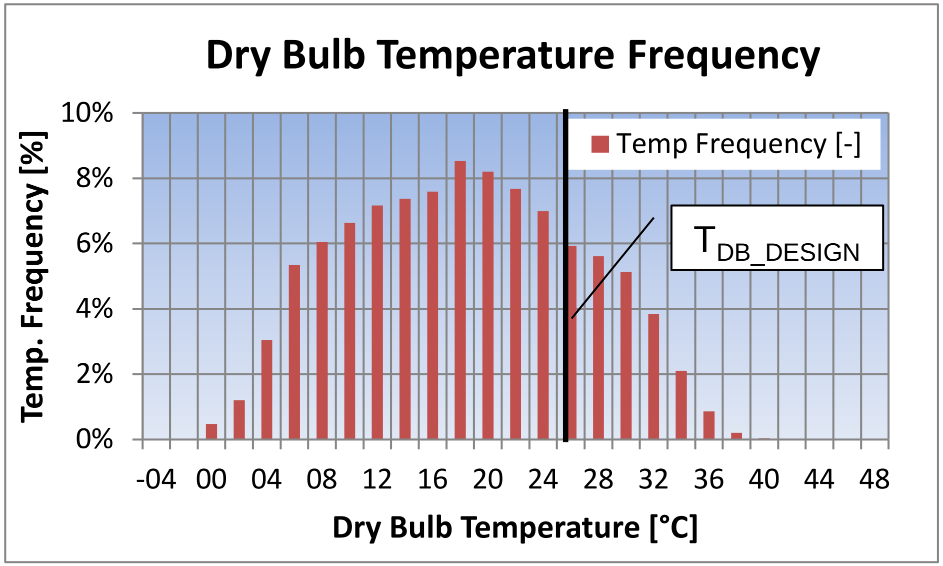


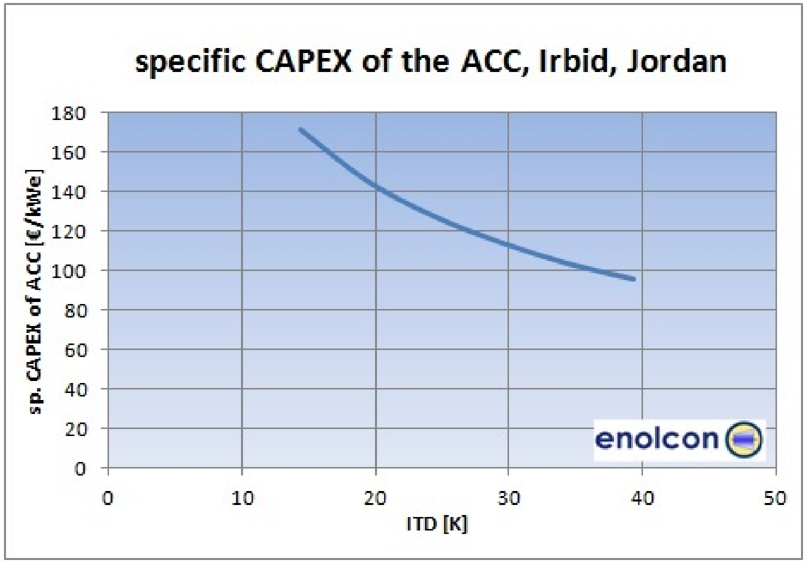


- Assumption: constant ITD, TTD

$$Q_{cond} = A \cdot U \cdot LMTD = A \cdot U \cdot \frac{ITD - TTD}{\log\left(\frac{ITD}{TTD}\right)}$$

Design Point Specifications and Investment Cost



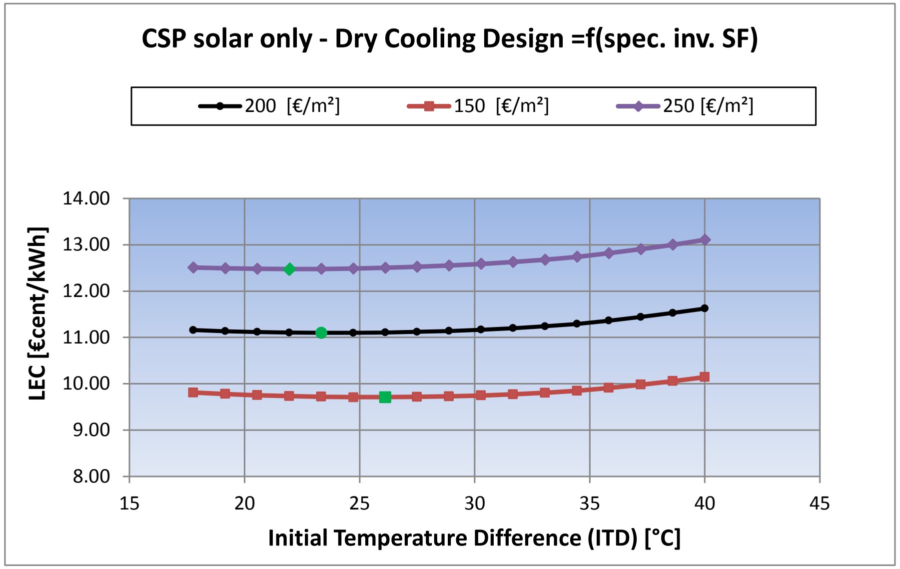


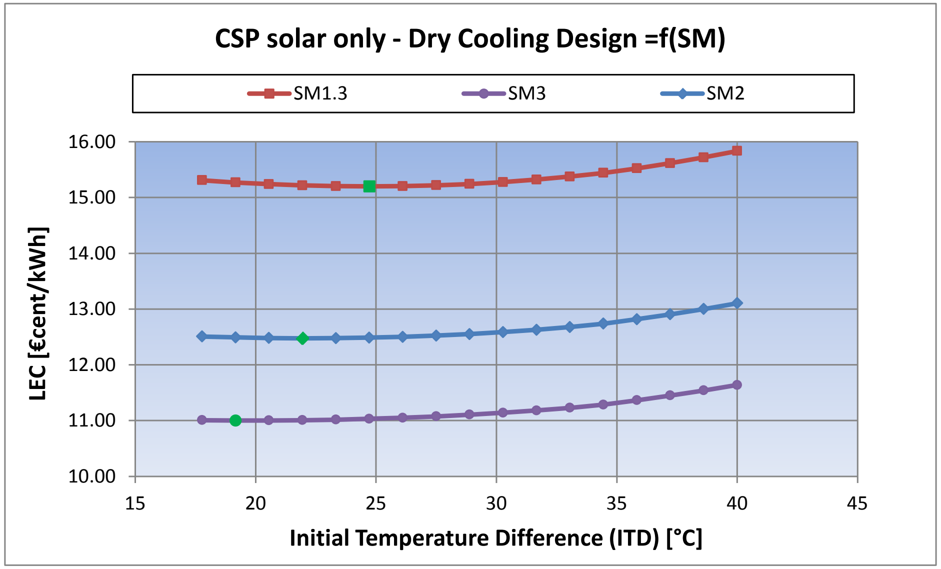
- Assumption: design point specifications have been set for the 20 % percentile of the annual temperature

→ Inability to maintain design output during the hottest hours of the year

- A trade-off exists between CAPEX, power block efficiency and annual yield!

Sensitivity of LEC on key Parameters





- In the case of elevate investment cost, a highly efficient cooling has to be preferred
- The same applies to conventional power plants with high fuel costs!

- High SM (i.e. high plant operating hours) requires high efficiency for more quick amortization of elevate investment cost

Assumptions: SM1.3 w/o TES / SM2 7.5 h TES / SM3 12 h TES

REMix – Analyzed cases

- 100 MW_{el_net} CSP "Andasol-like", solar-only operation, dry cooling
- SM 1.4; 7.5 h TES (not optimized; high dispatch flexibility)
- 3 sites in Jordan

Parameter	Unit	Kerak	Irbid	Aqaba
Latitude	°	31.18	32.55	29.52
Longitude	°	35.70	35.85	35.00
DNI	kWh/m²/y	2,545	2,537	2,371
T_{DB_AVG}	°C	17.0	17.6	24.9
$T_{DB\_80\_\%}$	°C	25.1	24.7	32.5

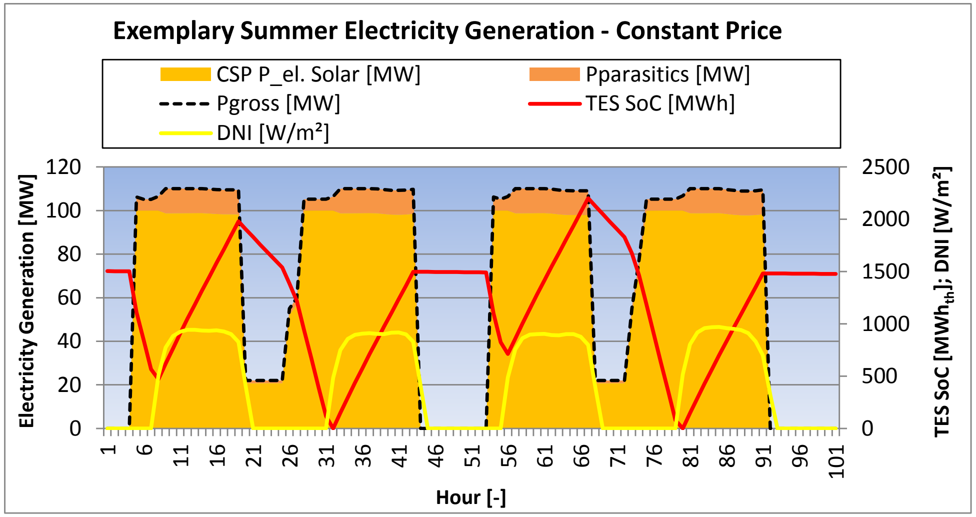
- Hourly simulation with the optimizing tool REMix
- 3 operation strategies:
  - Standard dispatch → used as reference
  - Optimized dispatch I (constant price)
  - Optimized dispatch II (time-variable price, demand proportional)

REMix - Results

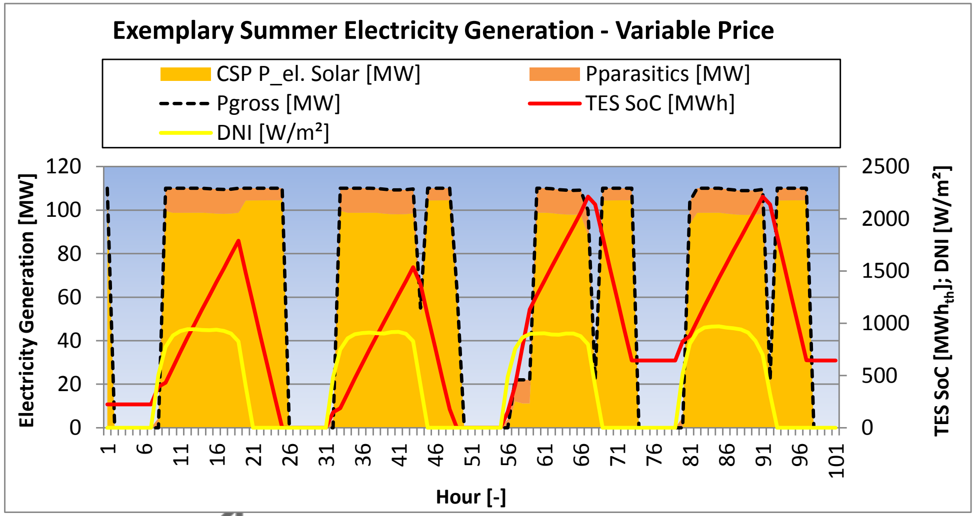
Parameter	Unit	Kerak			Irbid			Aqaba		
Operation Strategy	-	Standard Operation	Optimized Dispatch + Fixed Price	Optimized Dispatch + Variable Price	Standard Operation	Optimized Dispatch + Fixed Price	Optimized Dispatch + Variable Price	Standard Operation	Optimized Dispatch + Fixed Price	Optimized Dispatch + Variable Price
Q_{SF}	[GWh_{th}]	1180.4	1180.4	1180.4	[illegible]	[illegible]	254.4	1192.4	1192.4	1192.4
n start-up - PB	[-]	348 →	303	303	[illegible]	[illegible]	337	358	342	301
P_{EL_GROSS}	[GWh/y]	419.0	427.8	421.4	444.5	459.3	451.7	409.3	418.0	402.0
P_{EL_NET}	[GWh/y]	383.5	391.6	385.9	407.0	420.5	411.9	373.3	381.1	367.3
Plant Parasitics	[GWh/y]	35.4	36.2	37.6	37.4	38.9	39.8	35.9	36.9	37.4
η_{GROSS} - PB	[%]	36.5%	36.8%	36.3%	36.6%	36.9%	35.8%	35.3%	35.4%	35.2%
η_{NET} - PB	[%]	33.5%	33.8%	33.1%	33.5%	33.9%	32.3%	32.3%	32.4%	32.0%
Δ LEC	[%]	0.0% →	-2.0%	3.6%	0.0%	-3.2%	-1.1%	0.0%	-2.0% →	7.1%

Minimization of PB start-up procedures

REMix – Results Analysis



- In the case of constant feed-in price:
  - Minimization of the number of start-ups
  - Max. production in the early morning hours (lower T_{DB})



- In the case of time-variable price, the impact of the temperature seems to play a secondary role in the optimization strategy

Conclusions

- Air cooled condensers will be the preferred option for large-scale introduction of CSP in water-scarce and DNI-rich regions

- The optimal ACC design results from a technical-economic trade-off between turbine efficiency and investment cost; In CSP plants, highly efficient ACC are required for high SM/TES and high specific CAPEX

- Ca. 2 % LEC reduction can be reached in dry cooled CSP plant by partial plant commitment shifting towards night hours

- In the case of demand-driven plant commitment, slightly higher feed-in tariffs should be introduced. However, in this case CSP would be able to displace the most expensive plants during peak periods.

Thank you
for your attention!

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