Minimizing Water Consumption of a CSP Plant, by Using an Optimization Algorithm for Cooling Operation

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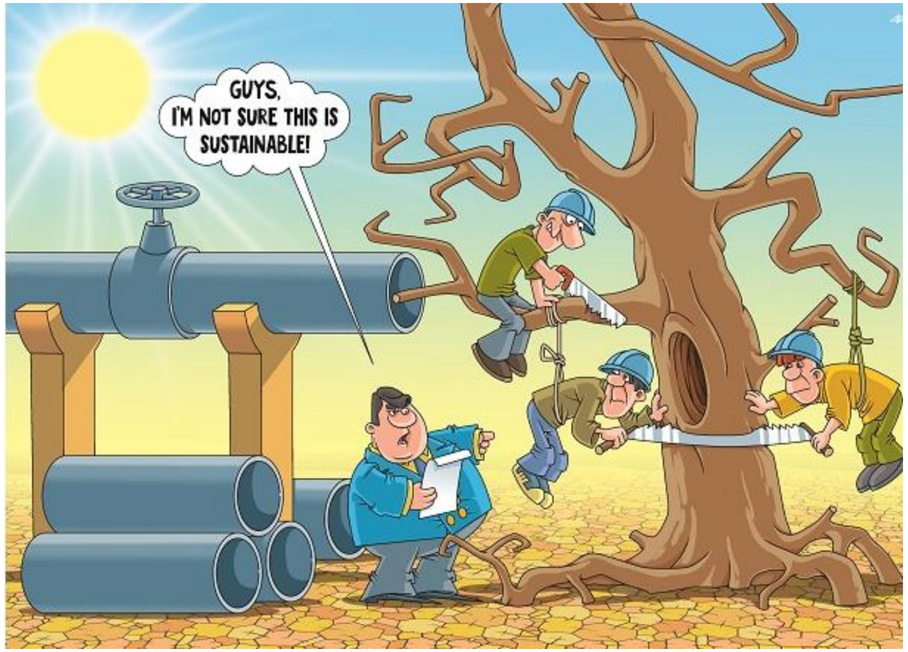
Introduction
complex hybrid cooling systems require optimized operating plans

water – a precious and valuable resource → water often scarce at CSP locations → wet cooling causes over 90% of water consumption → dry cooling → performance loss → hybrid cooling systems combine advantages → cooling system‘s complexity rises → demand for optimized operating plans → **cooling operation optimization**



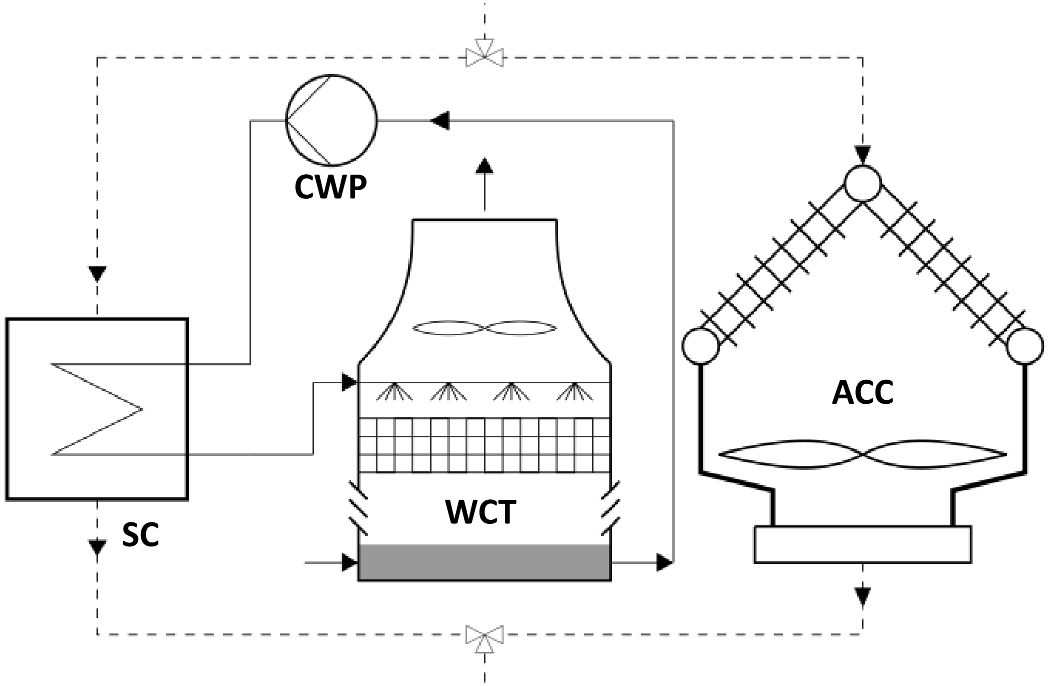
https://www.worldbank.org/en/news/feature/2017/12/14/water-cartoon-calendar-2018.print

Agenda

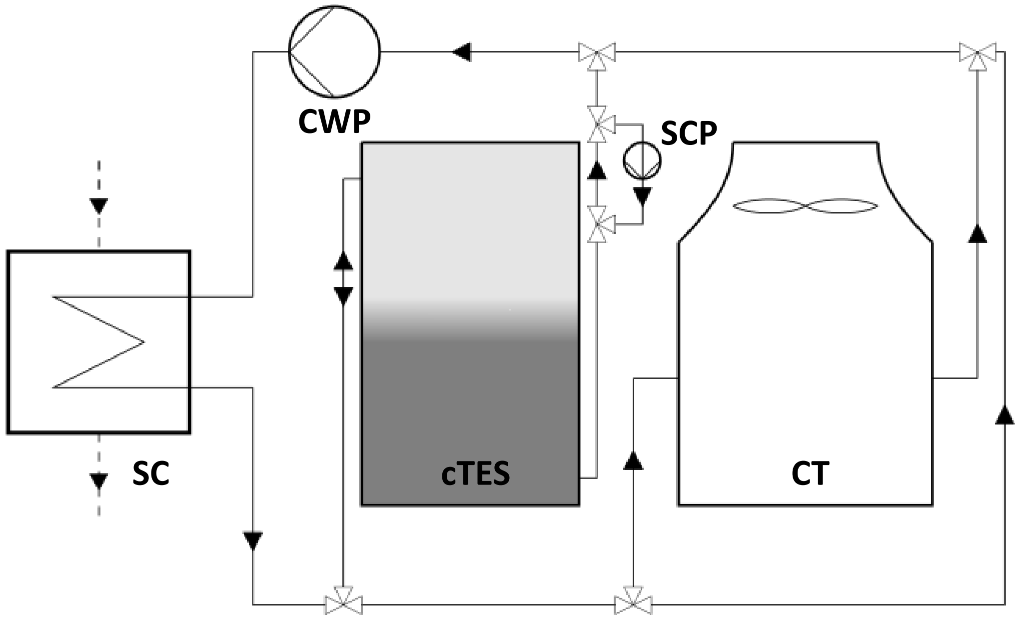
- Hybrid Cooling Systems
- Optimization Problem
- Cooling Operation Optimization Algorithm
- Simulation Results and Discussion
- Conclusion

Hybrid Cooling Systems
cooling systems using multiple cooling mechanisms

ACC and WCT in parallel



WCT or DC in parallel with cTES

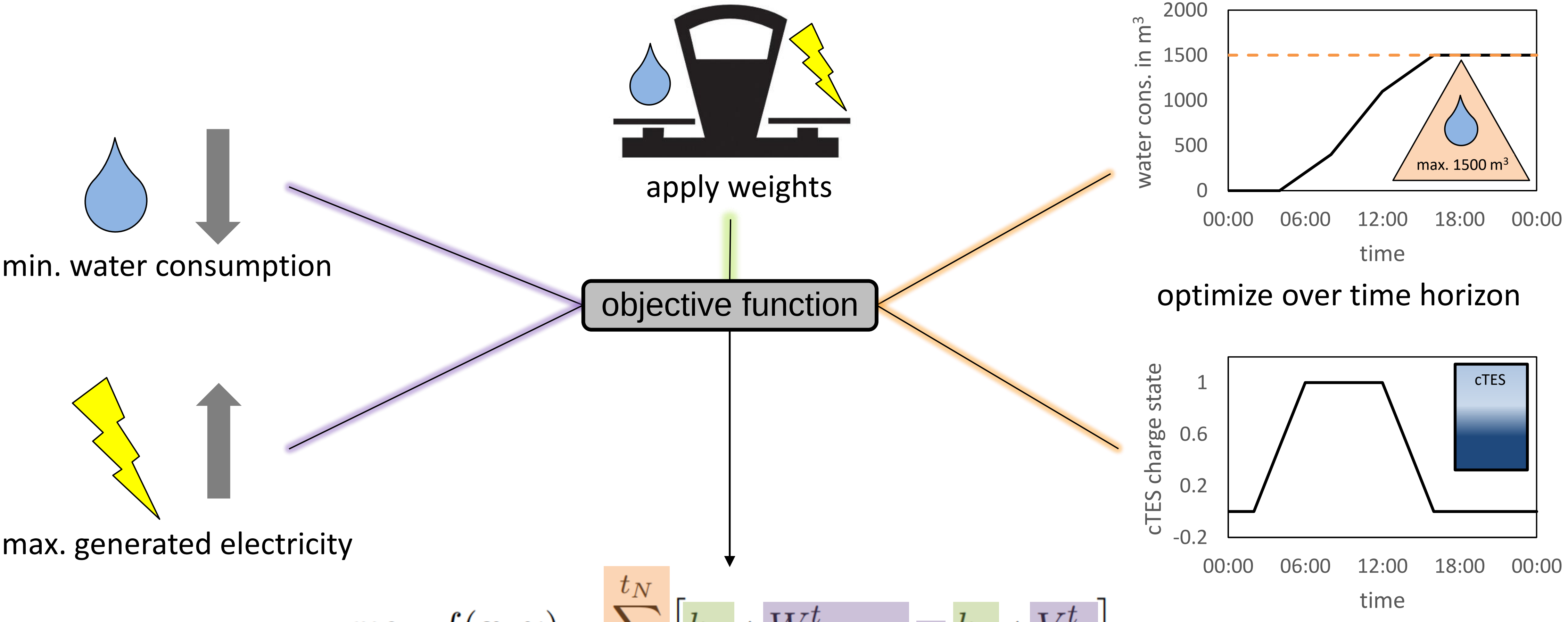


ACC: Air Cooled Condenser
SC: Surface Condenser
WCT: Wet Cooling Tower
DC: Dry Cooler

CT: Cooling Tower
cTES: Cold Thermal Energy Storage
CWP: Cooling Water Pump
SCP: Storage Charging Pump

Agenda

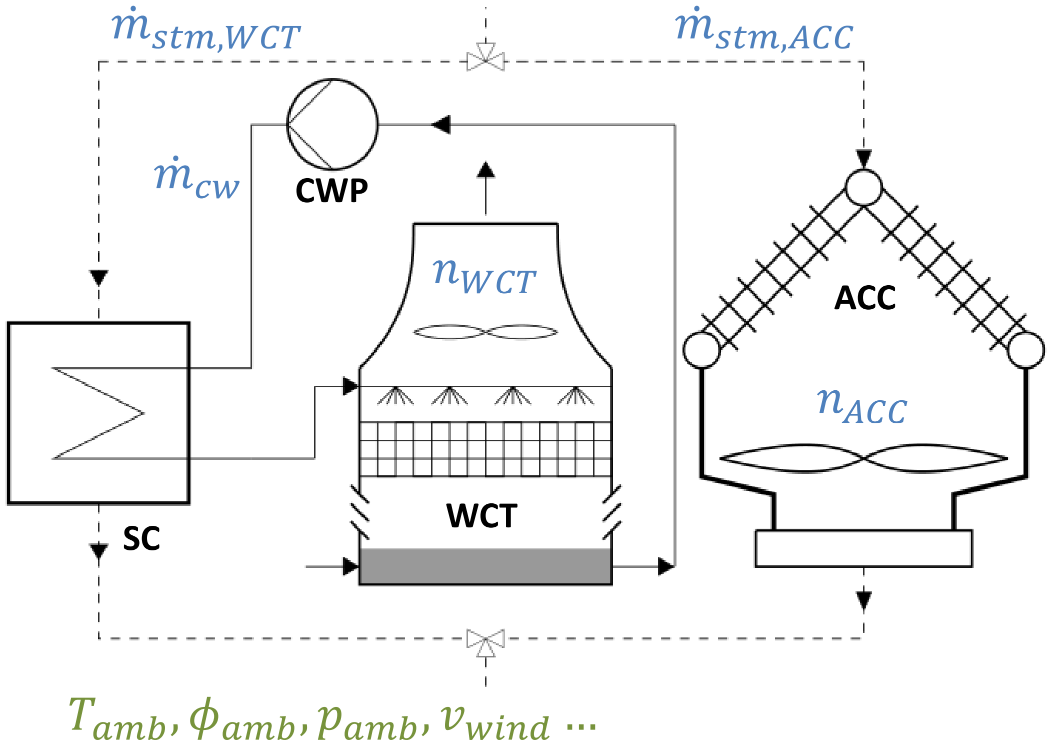
Optimization Problem
minimize water consumption and maximize electrical yield



$$\max_{\boldsymbol{x}} \; f(\boldsymbol{x},\boldsymbol{y}) = \sum_{t=0}^{t_N}\left[k_{el} * W^{t}_{el,netto} - k_{w} * V^{t}_{ew}\right]$$

https://www.schulbilder.org/malvorlage-waage-i16438.html

Optimization Problem
transform search space from manipulative quantities to operating states



transform

operating state 1:
Use ACC 100% and WCT 100%

operating state 2:
Use ACC 100% and WCT 50%

operating state 3:
Use ACC 50% and WCT 50%

operating state 4:
Use ACC only

search space

$$\max_{\boldsymbol{x}} f(\boldsymbol{x}, \boldsymbol{y}) = \sum_{t=0}^{t_N} \left[k_{el} * W_{el,netto}^{t} - k_w * V_{ew}^{t} \right]$$

Optimization Problem
consider equality and inequality constraints in definition of operating states

operating state 1:
Use ACC 100% and WCT 100%

operating state 2:
Use ACC 100% and WCT 50%

operating state 3:
Use ACC 50% and WCT 50%

operating state 4:
Use ACC only

operating state 1:
Use ACC 100% and WCT 100%

if $p_{cond} < p_{cond,min}$ then reduce WCT load

if $p_{cond} > p_{cond,max}$ then reduce Power Block load

⋮

$$a > b$$
$$a = b + c$$

equality and inequality constraints

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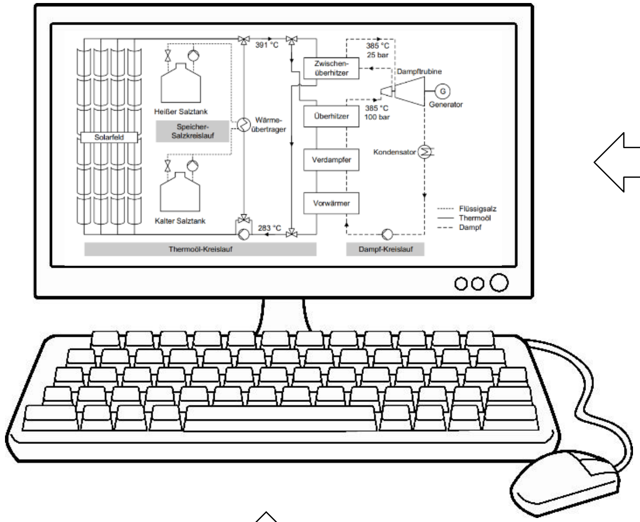
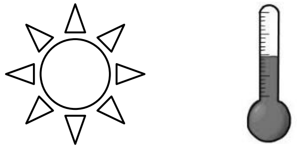
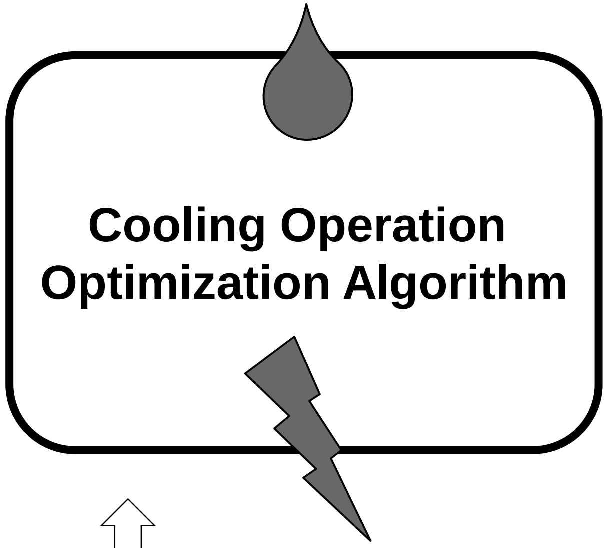
Cooling Operation Optimization Algorithm
optimization algorithm is applicable to a power plant model as black box



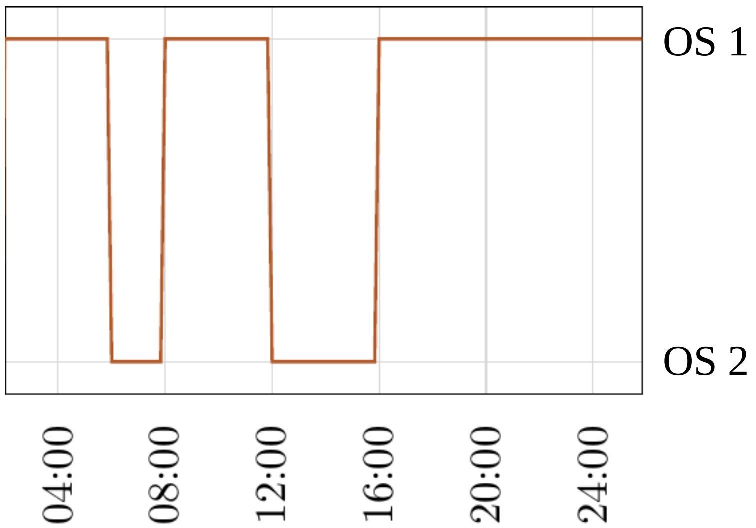




operating state 1

operating state 2

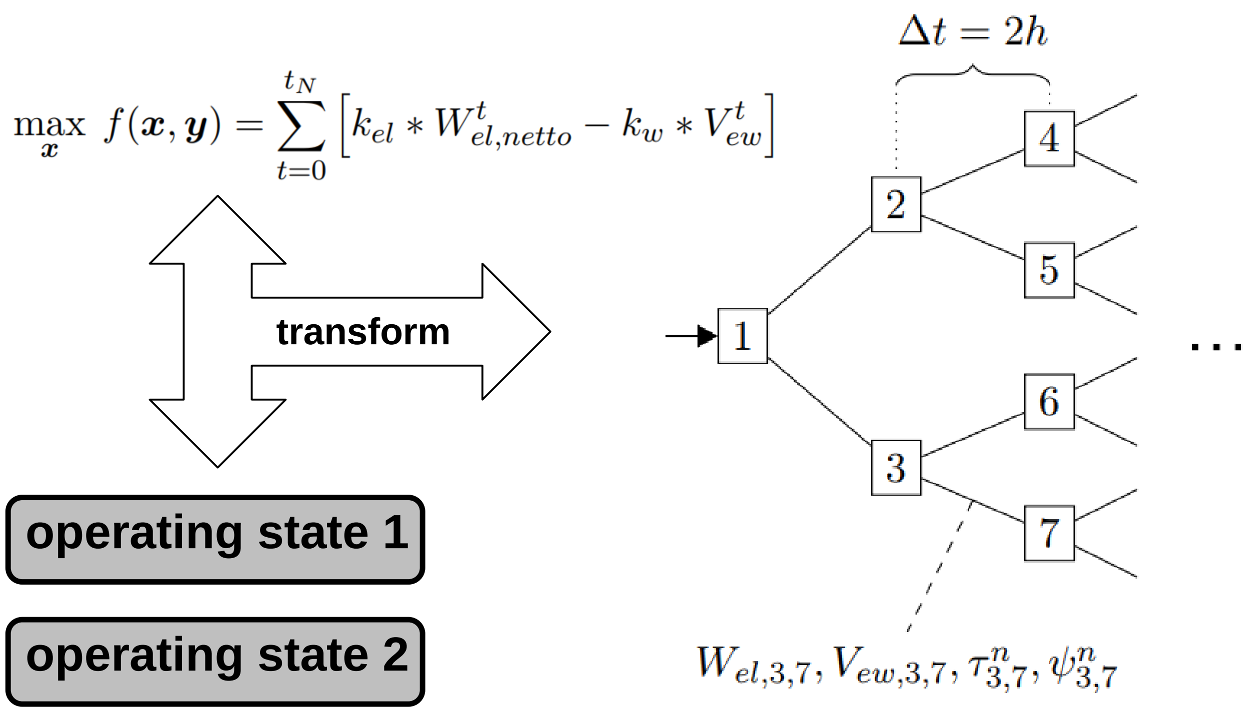
optimized operating plan

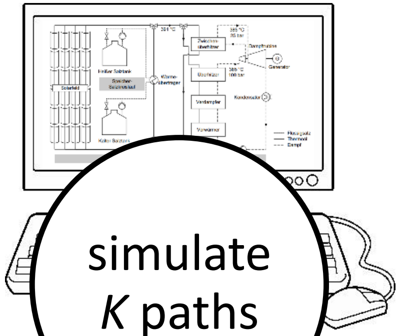


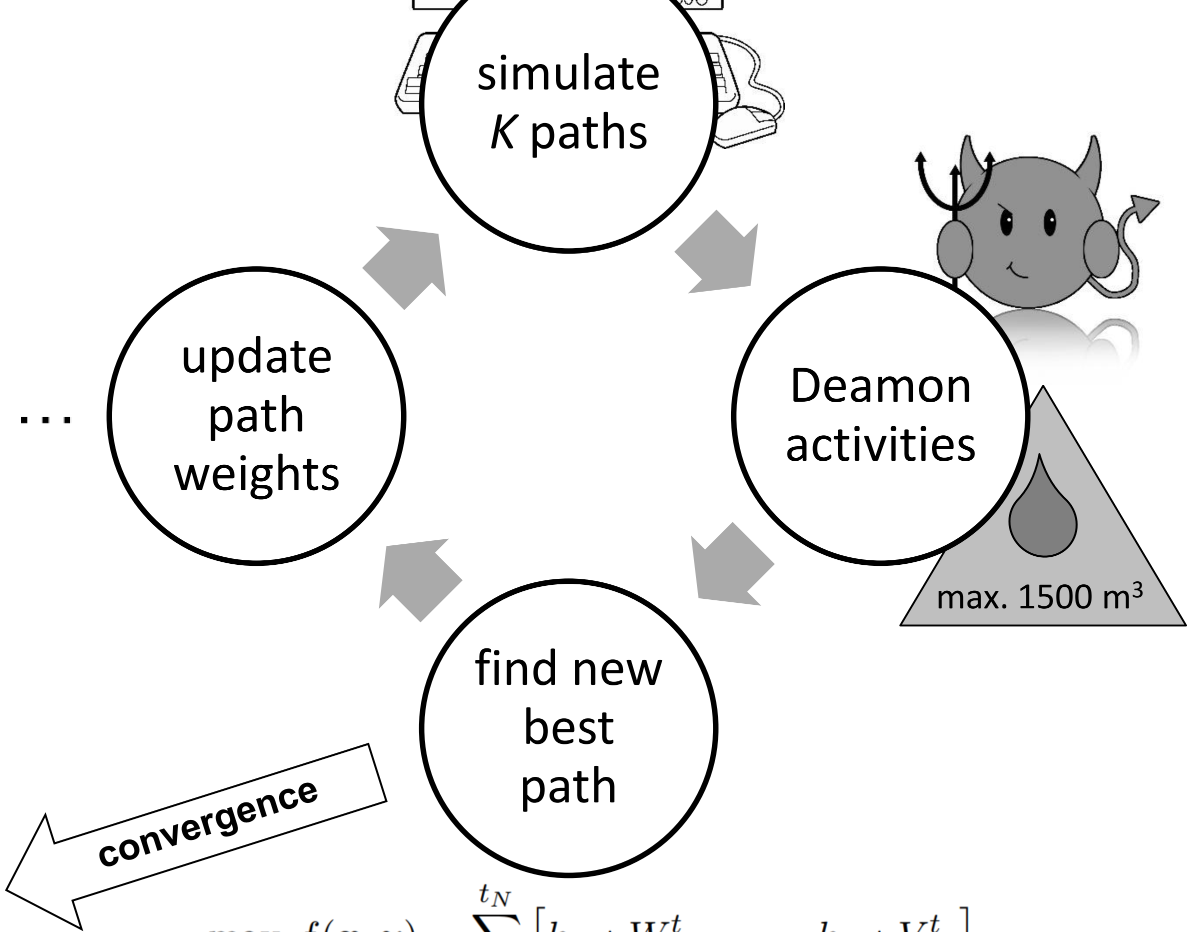
https://paintingvalley.com/sketches/desktop-computer-sketch-10.png
https://www.drawingnow.com/file/videos/image/how-to-draw-a-thermometer.jpg

Cooling Operation Optimization Algorithm development of an *Ant Colony Optimization* variant

$$\max_{\boldsymbol{x}} \; f(\boldsymbol{x},\boldsymbol{y}) = \sum_{t=0}^{t_N} \left[k_{el} * W^t_{el,netto} - k_w * V^t_{ew} \right]$$







optimized operating plan

$$\max_{\boldsymbol{x}} \; f(\boldsymbol{x},\boldsymbol{y}) = \sum_{t=0}^{t_N} \left[k_{el} * W^t_{el,netto} - k_w * V^t_{ew} \right]$$

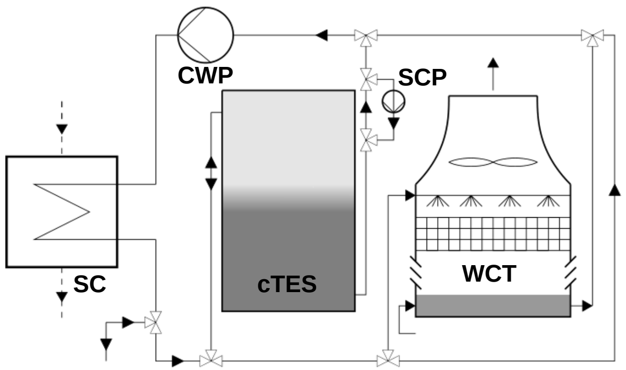
http://cliparts.co/cartoon-devil-pictures

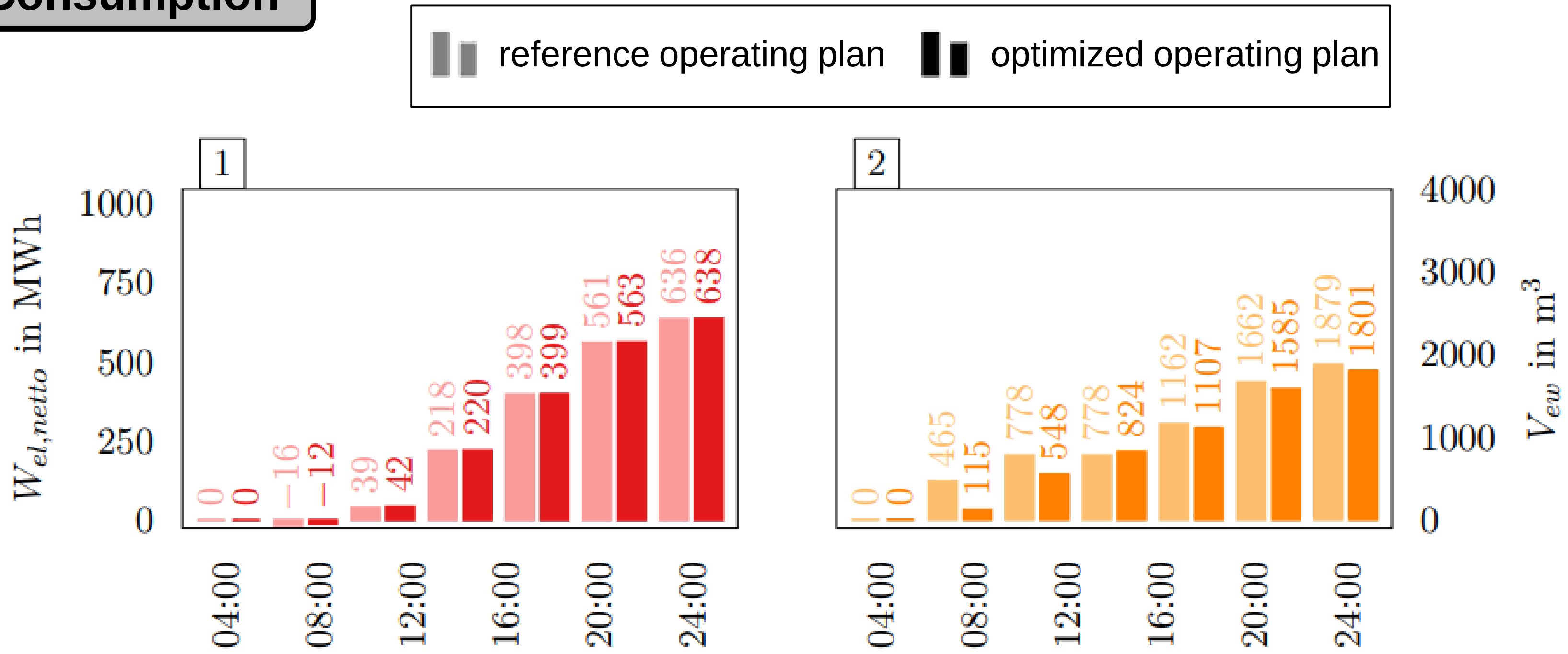
Agenda

Simulation Results and Discussion
cooling optimizer finds a better solution

Electrical Yield and Water Consumption

- 50 MW Parabolic Trough Power Plant
- South Spain
- late summer day
- over 16 000 000 possible operating plans

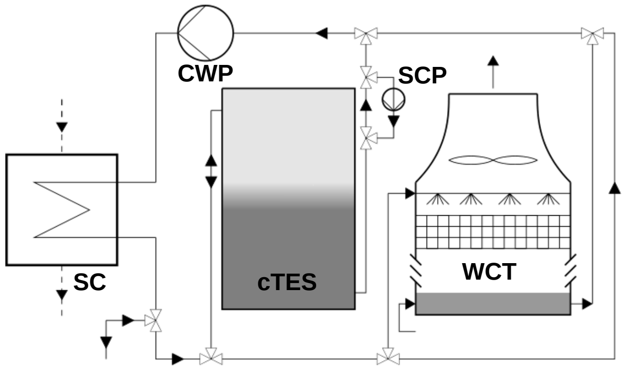




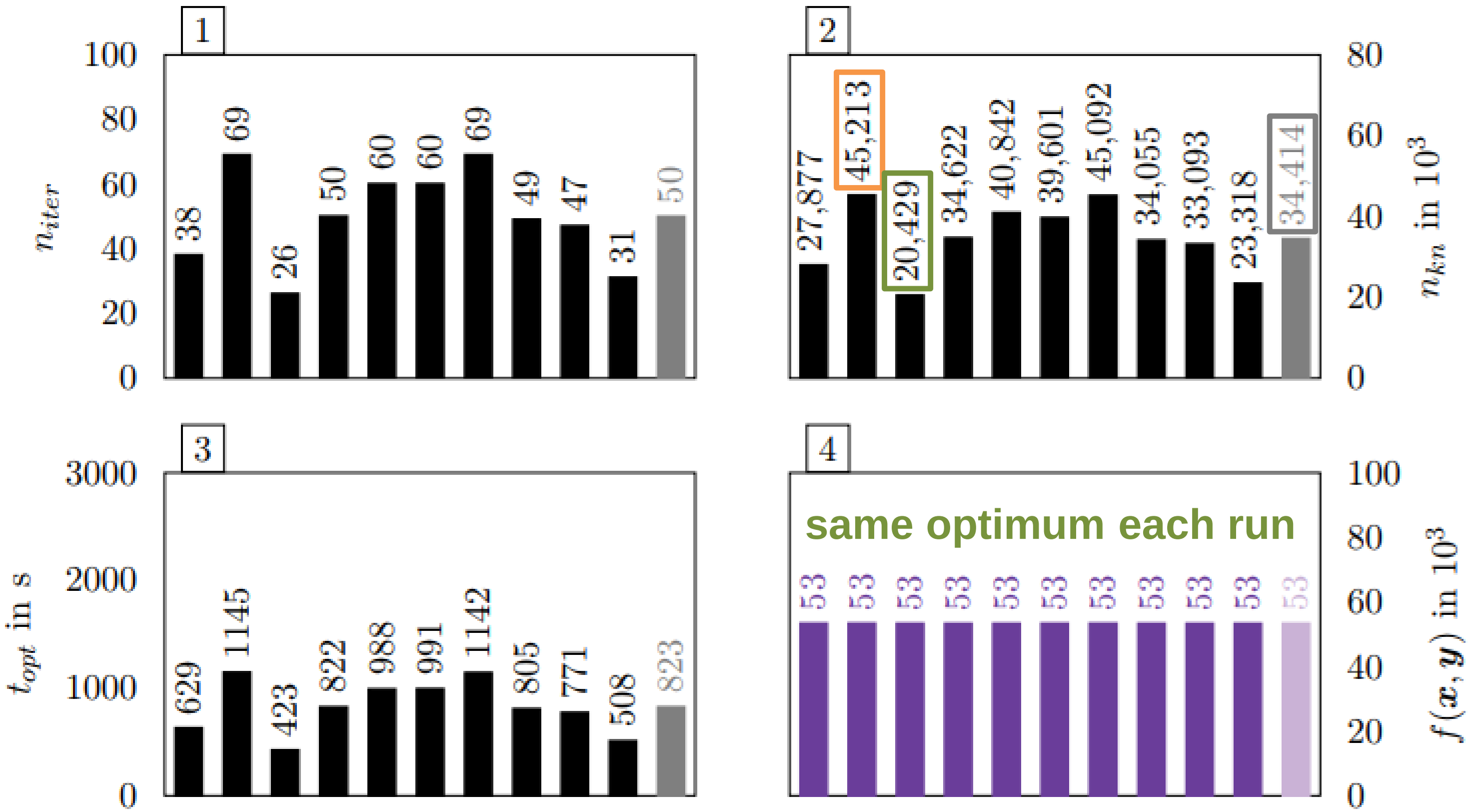
Simulation Results and Discussion
cooling optimizer finds the same optimum every optimization run

Repeated Optimization Runs

- 50 MW Parabolic Trough Power Plant
- South Spain
- late summer day
- over 16 000 000 possible operating plans



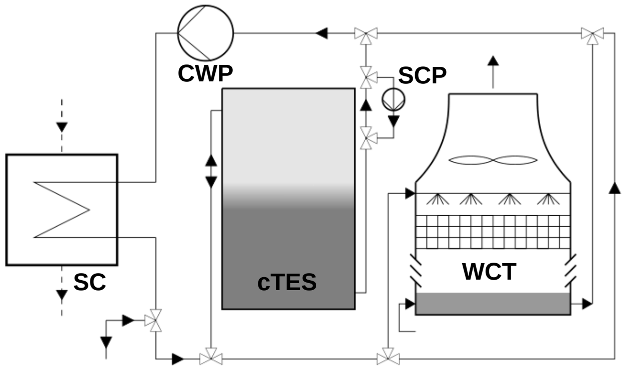
$k_{el} = 0,1\ ^1/_{kWh}$ $F_{el} = 1$ $k_w = 5\ ^1/_{m^3}$ $t_N = 24h$ $\Delta t = 1h$ $K = 64$

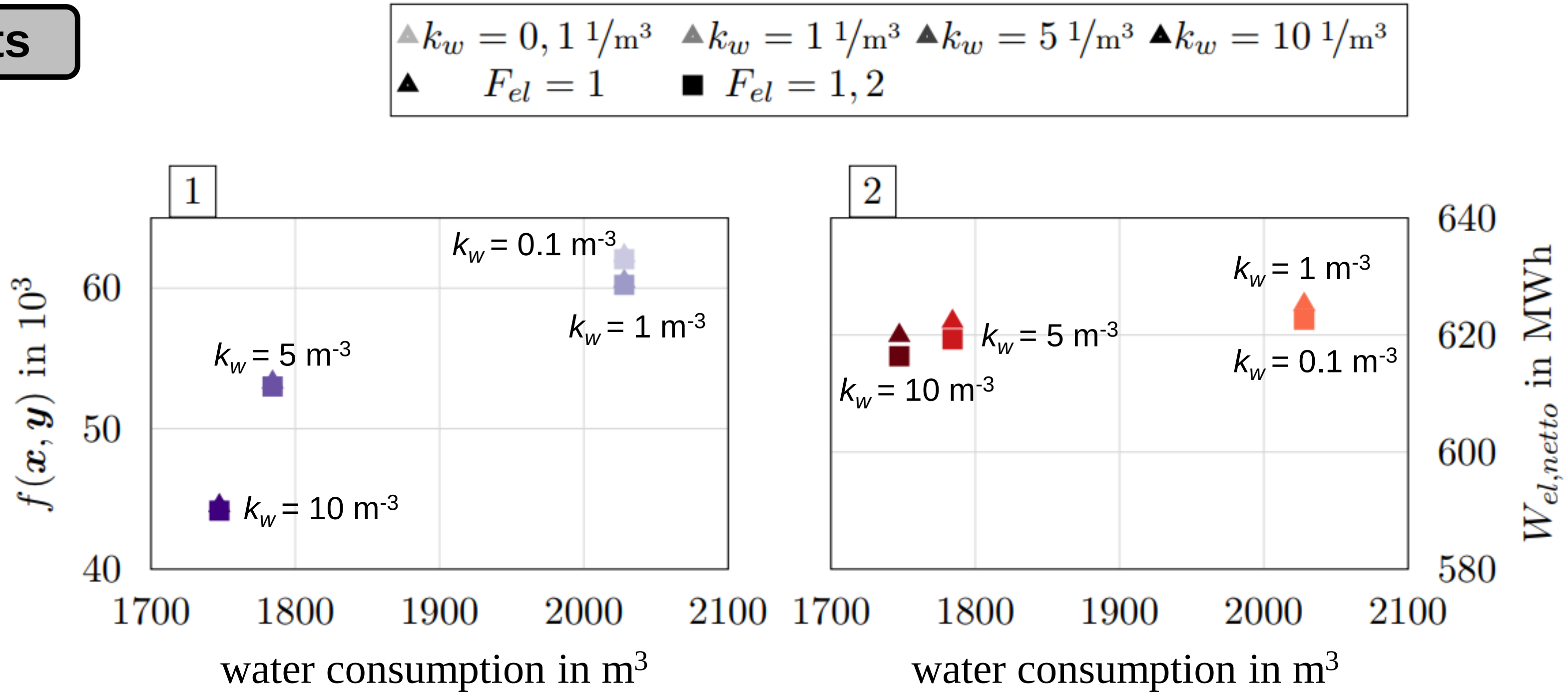


Simulation Results and Discussion
cooling optimizer is sensitive to water and electricity weights

Parameter Variation of Weights

- 50 MW Parabolic Trough Power Plant
- South Spain
- late summer day
- over 16 000 000 possible operating plans





→ **decreasing water consumption with increasing weight of water**

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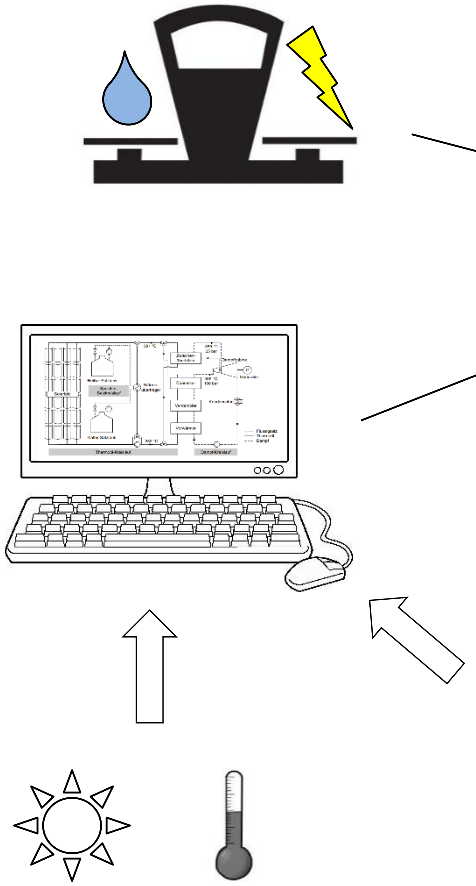
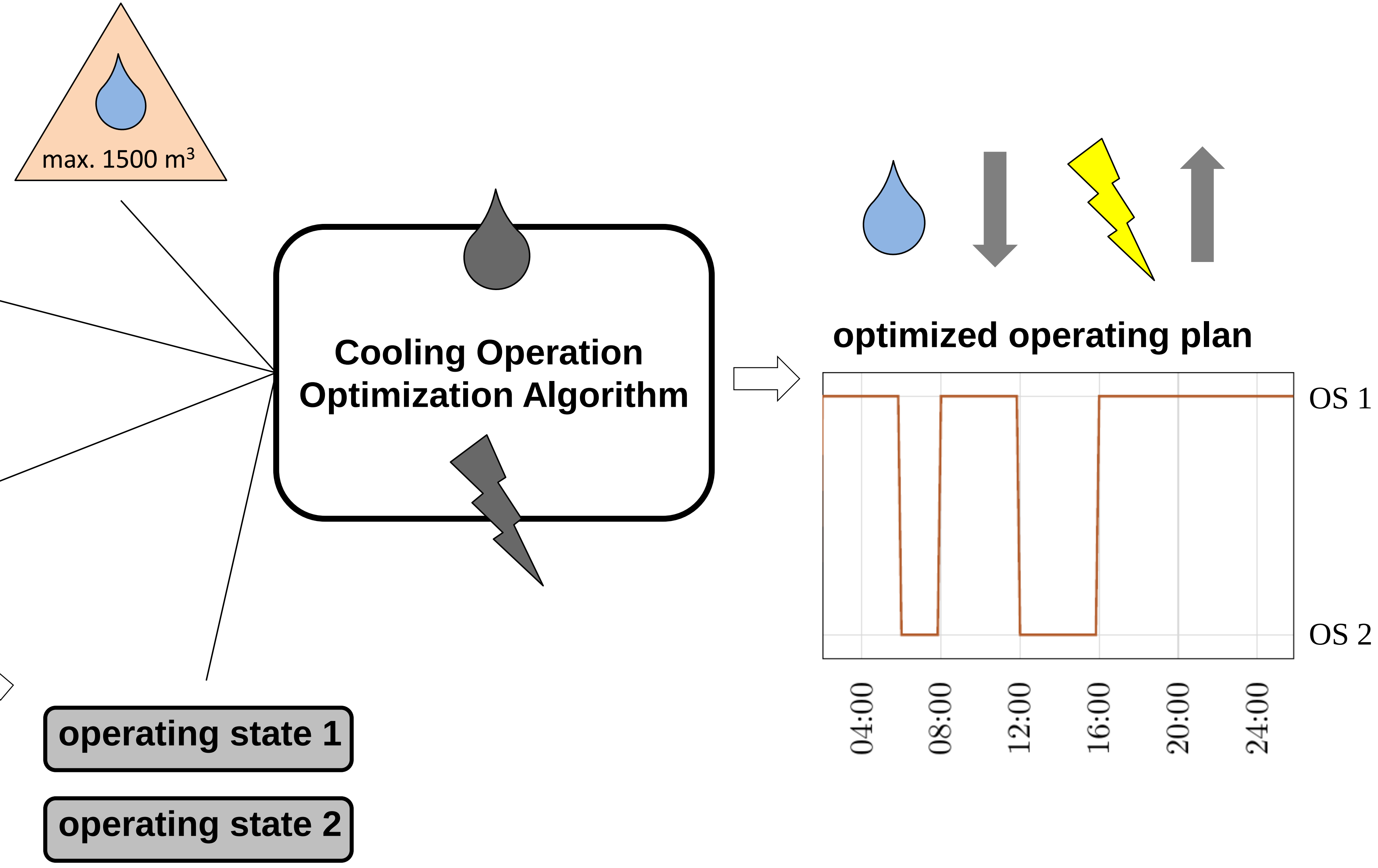
Conclusion




max. 1500 m³
Cooling Operation Optimization Algorithm
optimized operating plan
OS 1
OS 2
04:00
08:00
12:00
16:00
20:00
24:00
operating state 1
operating state 2

Sources

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- Igor Nedelkovski, Ilios Vilos und Tale Geramitcioski. „Method for Optimal Control of Power Plant Cooling System.". Jan. 2005
- Tobias Hirsch et. al. „Solarthermische Stromerzeugung". In: *Erneuerbare Energien: Systemtechnik · Wirtschaftlichkeit · Umweltaspekte*. Issued by Martin Kaltschmitt, Wolfgang Streicher and Andreas Wiese. Berlin, Heidelberg: Springer Berlin Heidelberg, 2020, p. 995–1066. isbn: 978-3-662-61190-6. doi: 10.1007/978-3-662-61190-6_11. url: https://doi.org/10.1007/978-3-662-61190-6_11.
- Matthias Loevenich. "Entwicklung eines Einsatz- und Betriebsoptimierers für ein hybrides Kühlsystem mit Kältespeicher zur Wassereinsparung und Ertragssteigerung in einem CSP-Kraftwerk". June 2021

Thank you for your attention!

Q&A

„Essentially, all models are wrong but some are useful.“
George E. P. Box

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