Potential of Repurposed Cooling Towers for Direct Air Capture in Germany

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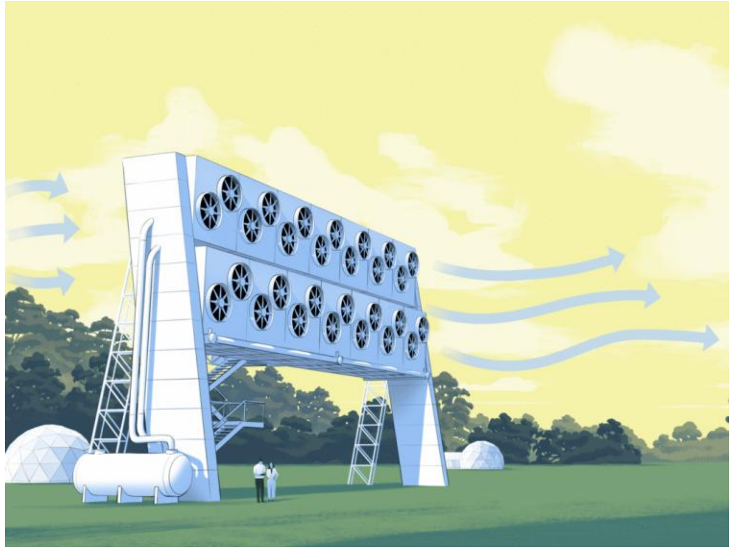
Direct Air Capture

Context

- Direct Air Capture (DAC) as scalable negative emission technology
- Capacity of 90 Mt_{CO2}/a expected in 2030[2]
- Targeted capture cost of 100 – 150 €/t_{CO2}



Reduction of first-of-a-kind hurdles required

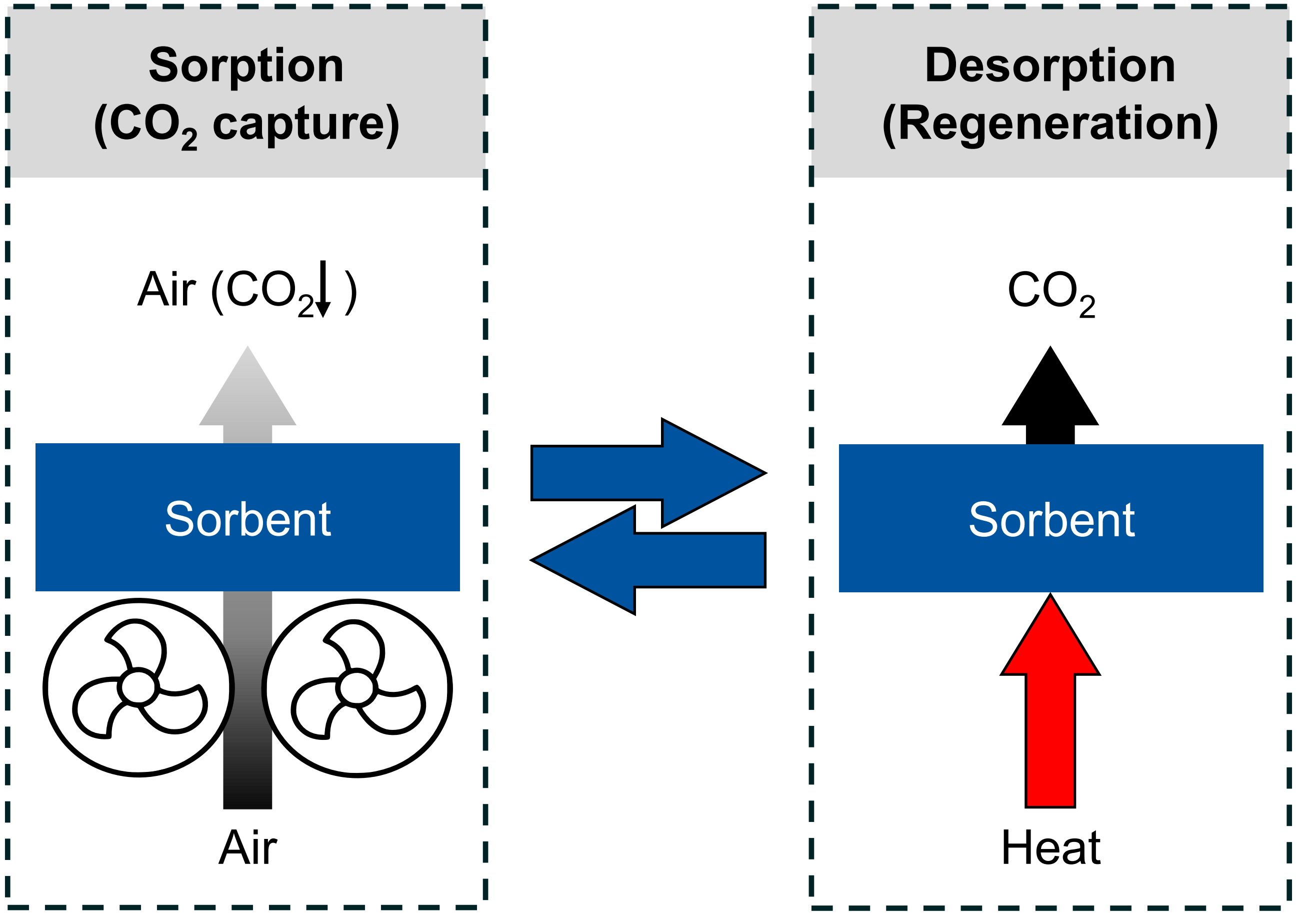
Challenges

- High investment cost due to large capture facilities
- High energy demand due to low CO_2 concentration
- Scale-up hindered by initial investment

Image: TÜV SÜD AG[3]

Sorption-based DAC processes

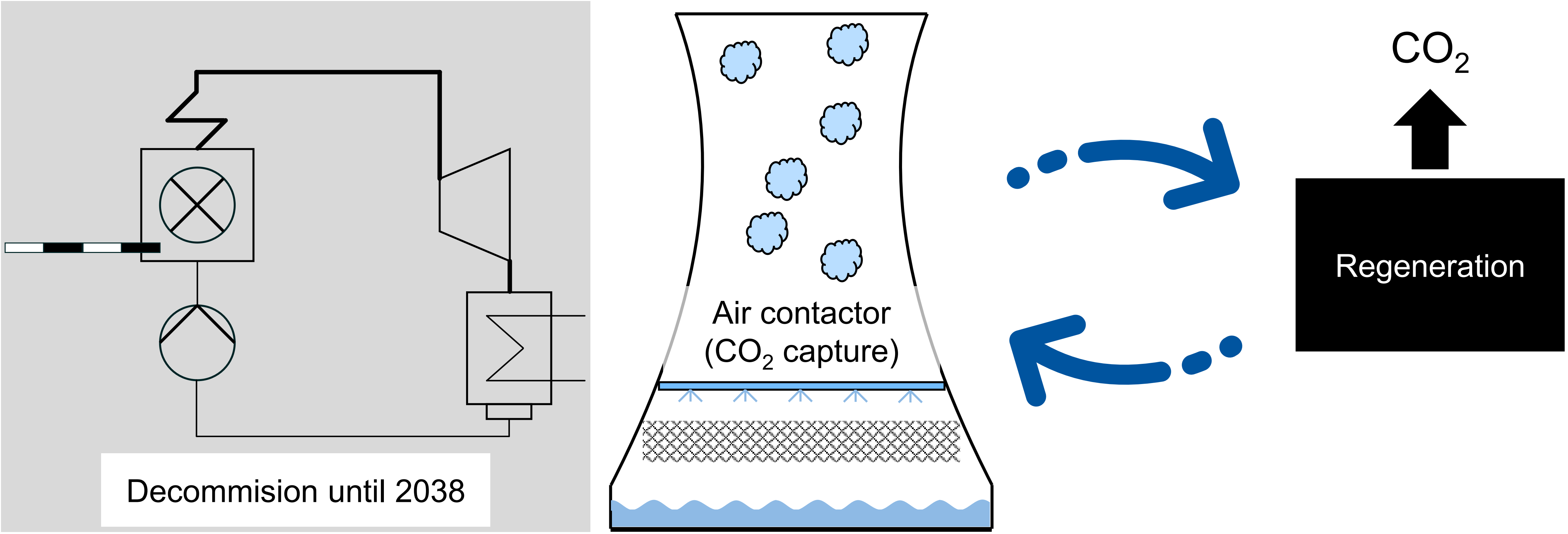
- **Absorption**
  - Liquid sorbent
  - Continuous
- **Adsorption**
  - Solid sorbent
  - Discontinous



- Endothermic
- Major share of energy demand
- Typically heat-driven

For 1 Mt_{CO2}/a: >50 t_{air}/s required due to low CO_2 concentration ~400 ppm

ConTACtFuels – Repurposed cooling towers in DAC plants



ConTACtFuels[4]: Analysis of the techno-economic potential of repurposed power plant infrastructure in DAC

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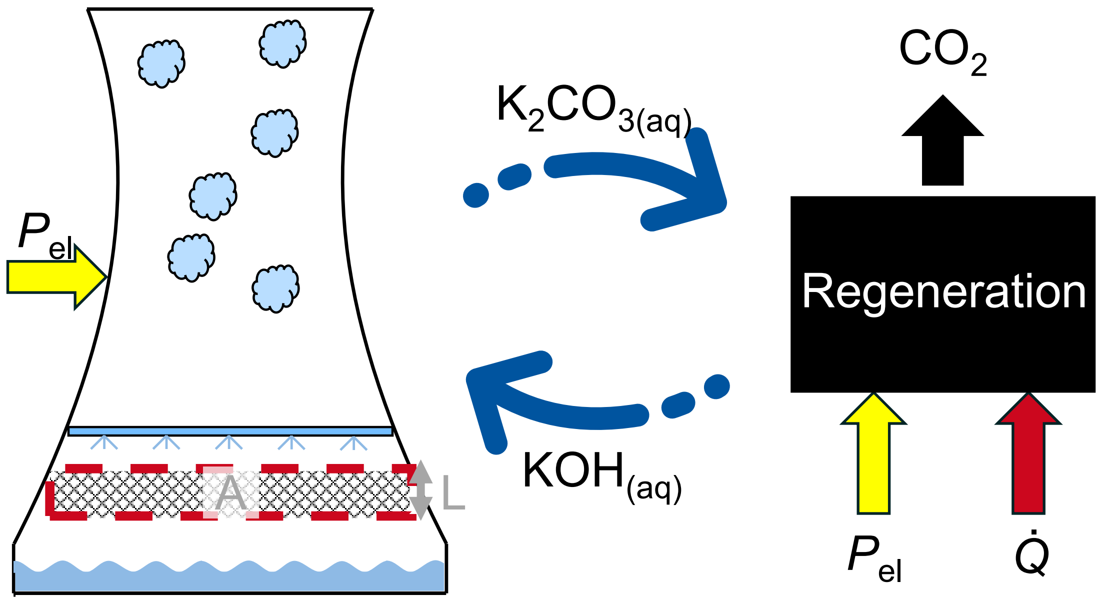
Techno-economic assessment

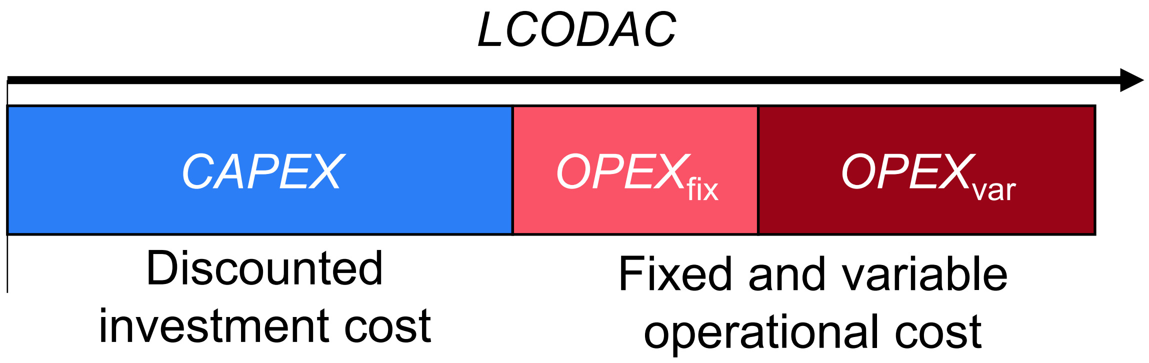
Thermodynamic approach

- 1D air contactor model
  - Analysing mass transfer and electricity demands
  - ➢ Assessing cooling tower geometries
- Regeneration: black-box model
- Case study: KOH-based process[5]



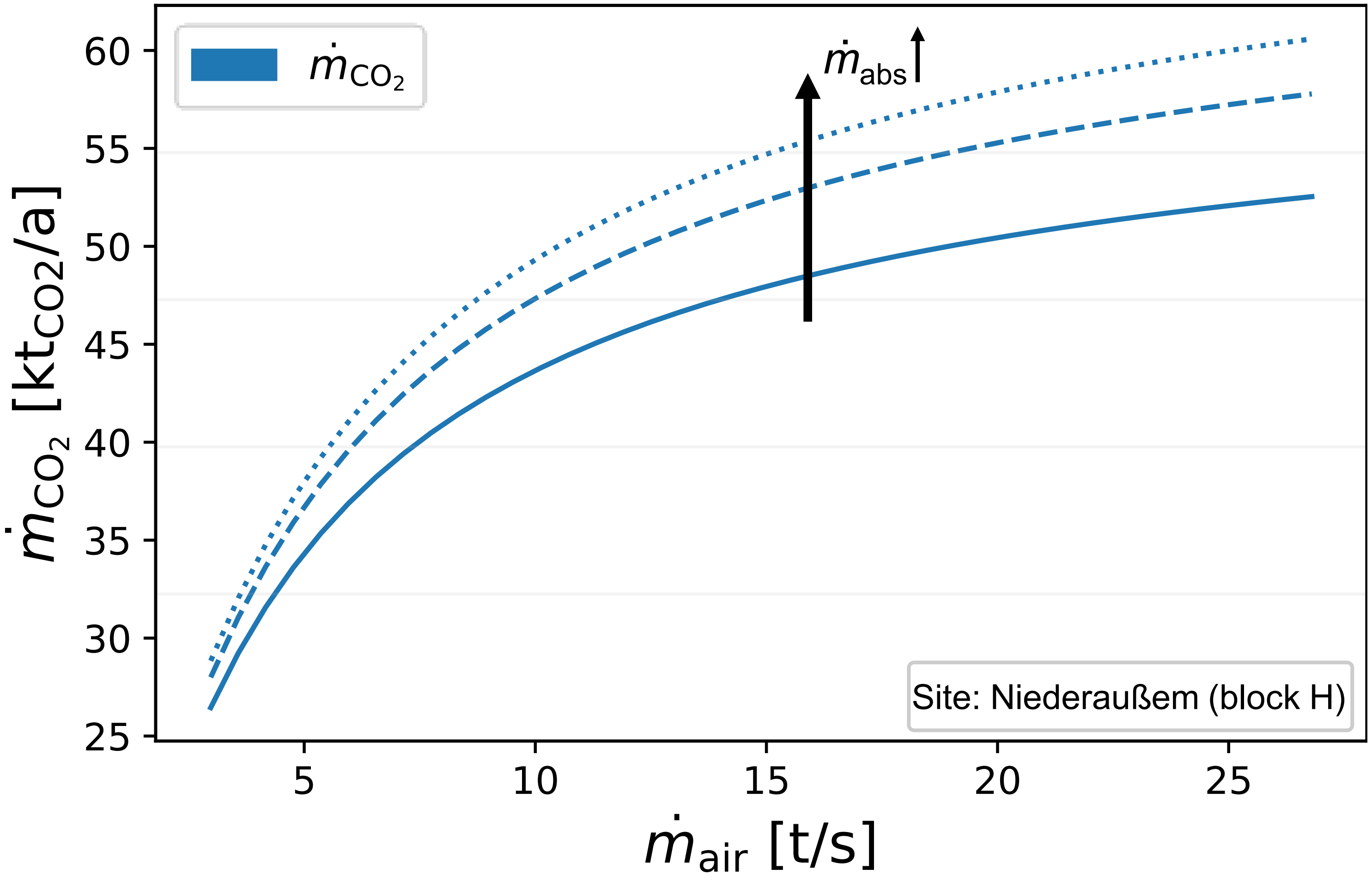
Techno-economic approach

- Assessment of Levelized Cost of Direct Air Capture (*LCODAC)*
  - Capture cost (€/t_{CO2}) at a *net present value* of zero
  - Investment cost reduction by repurposed cooling tower
  - Variation of lifetime: 10 – 25 years
- ➢ Comparison with new DAC plant (25 year lifetime)



KOH: Potassium hydroxide | K_2CO_3: Potassium carbonate | P_{el}: electrical power | $\dot{Q}$: Heat flow | *CAPEX*: capital expenditure | *OPEX*: operational expenditures

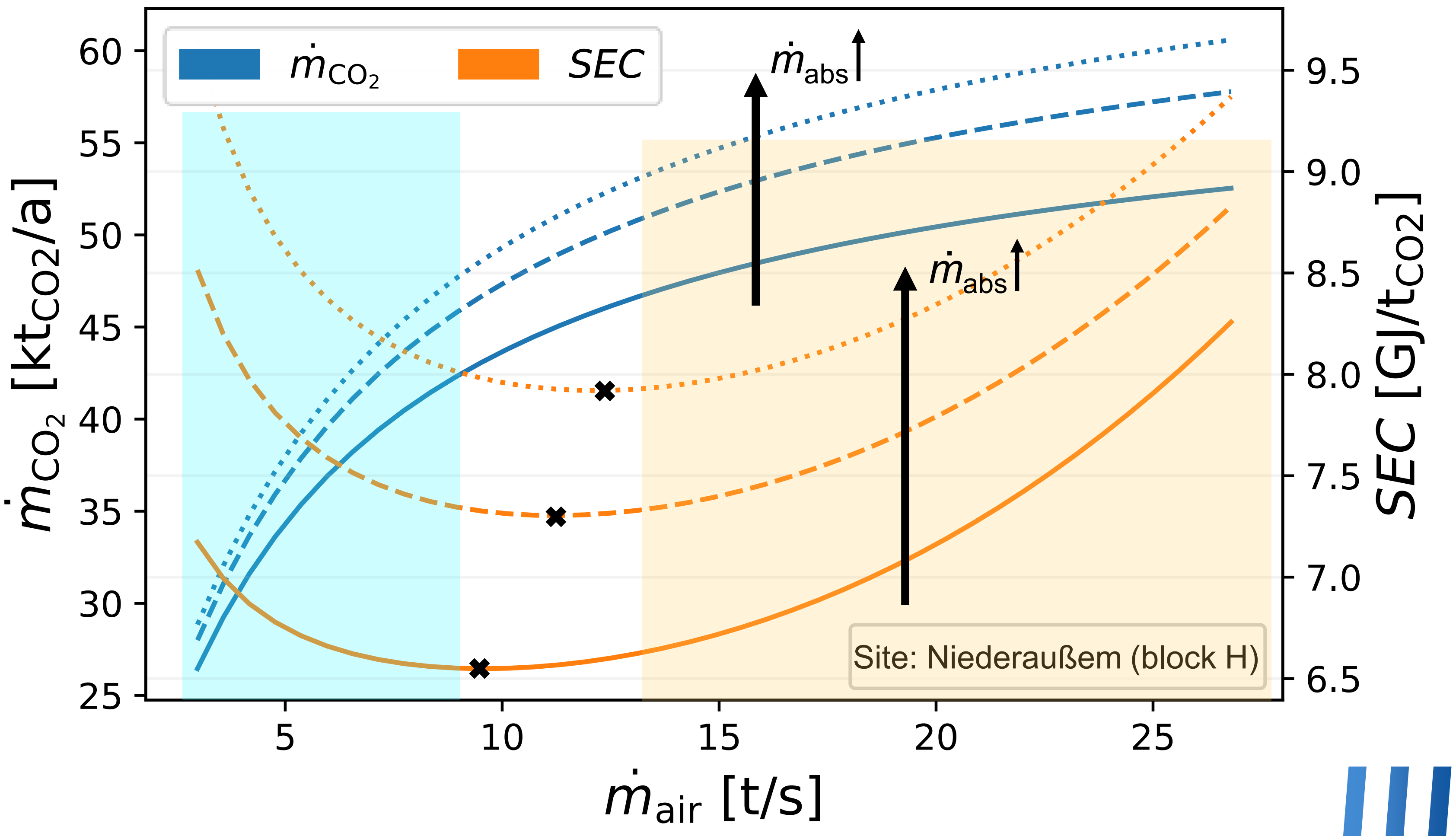
Technical results



- Annular capture capacity profits from increasing mass flows

SEC: specific energy consumption | $\dot{m}_{CO2}$: annular CO_2 capture capacity | $\dot{m}_{air}$: Air mass flow | $\dot{m}_{abs}$: Absorbent mass flow

Technical results



- Annular capture capacity profits from increasing mass flows
- Two effects on *SEC* with increasing air mass flow
  - Decreasing *SEC* at low $\dot{m}_{air}$ due to sharp increase in $\dot{m}_{CO2}$
  - Increase in *SEC* at high $\dot{m}_{air}$ due to fan energy demand
- Minimum *SEC* location depends on $\dot{m}_{abs}$

Trade-off: Captured CO_2 vs. energy demand

SEC: specific energy consumption | $\dot{m}_{CO2}$: annular CO_2 capture capacity | $\dot{m}_{air}$: Air mass flow | $\dot{m}_{abs}$: Absorbent mass flow

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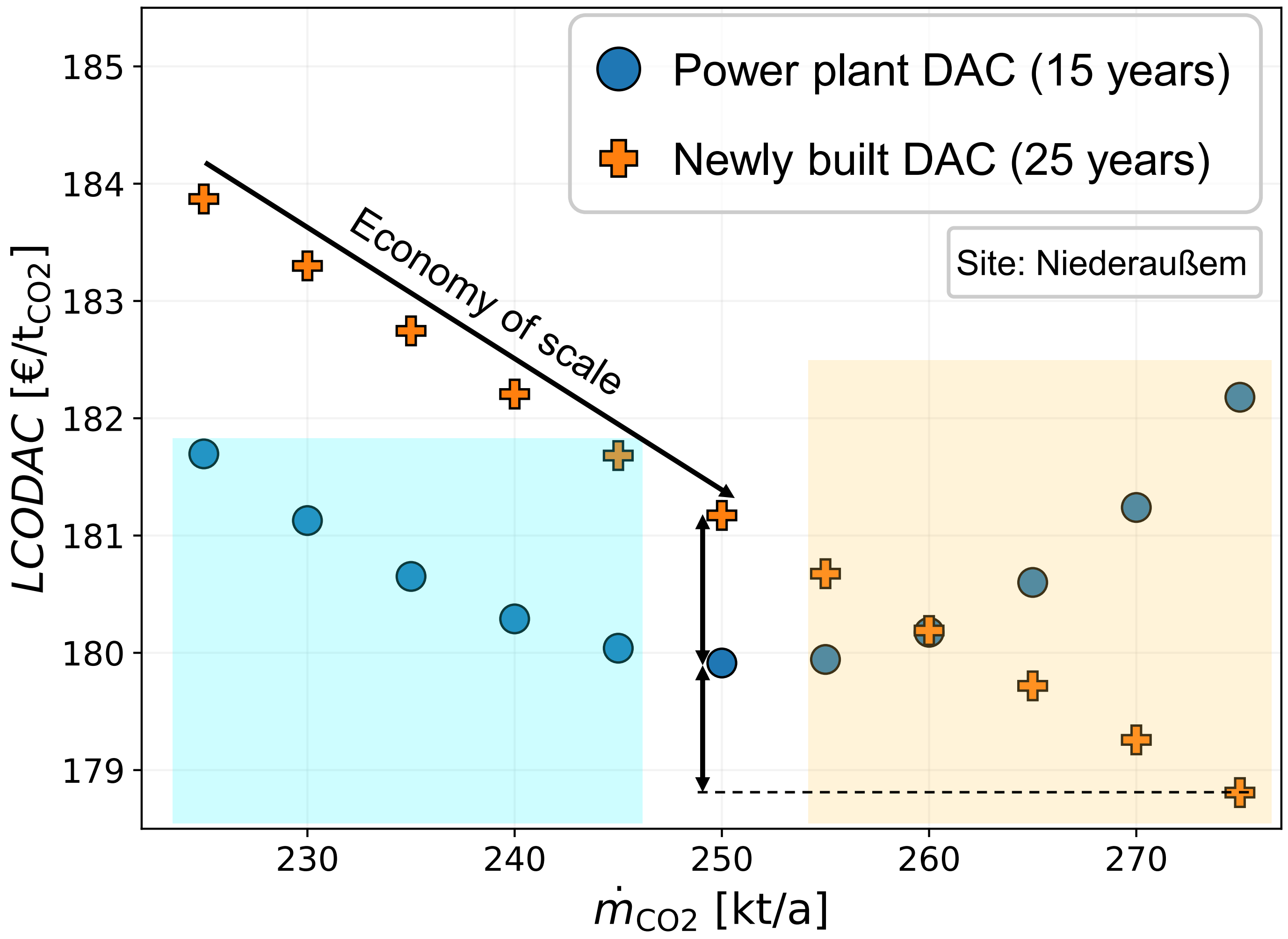
Techno-economic results - Niederaußem

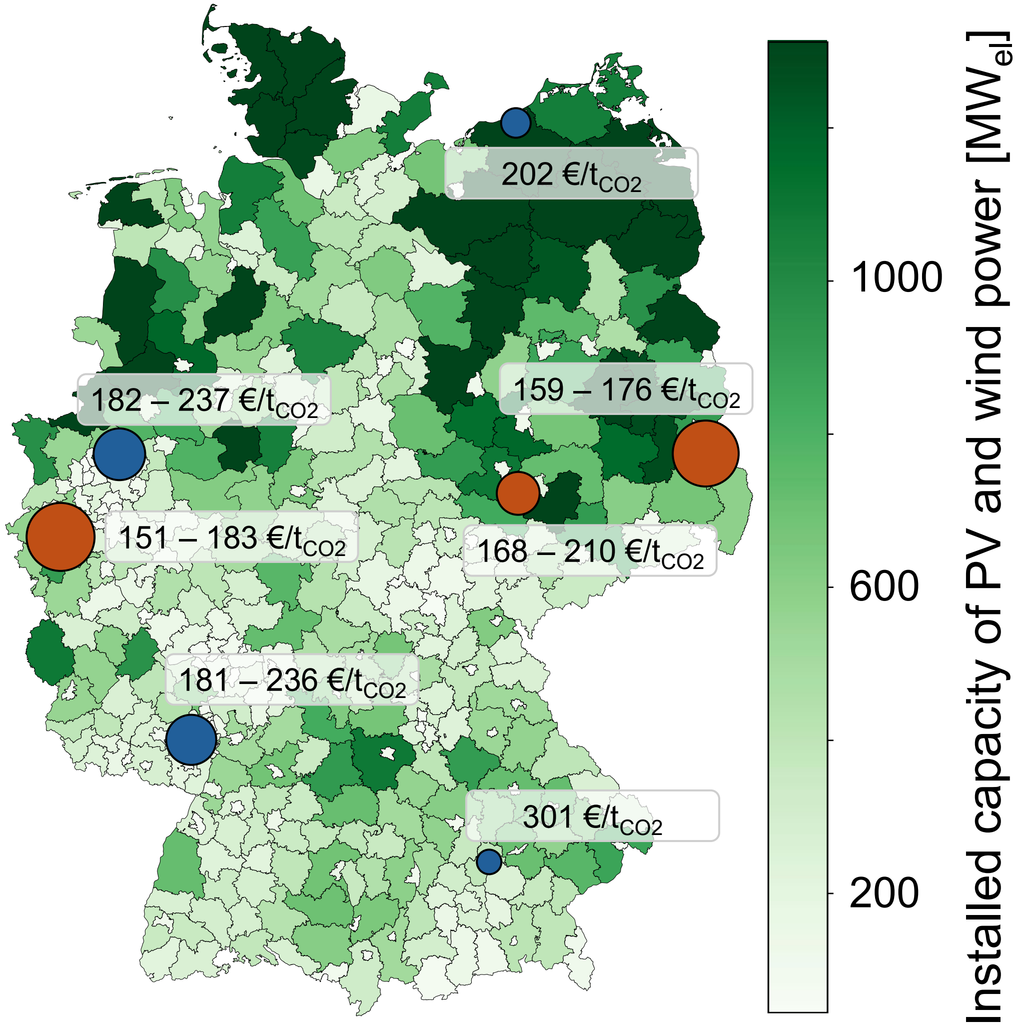


- Investment cost decrease with annular capacity
- Trade-off for power plant DAC:
  - Economy of scale & decreasing *SEC*
  - Increasing *SEC* due to increasing fan and pump energy demand
- Cost reduction depending on lifetimes and design of newly built DAC plant

Minimum *LCODAC* define design of the power plant DAC plant

LCODAC: Levelized Cost of Direct Air Capture | $\dot{m}_{CO2}$: annular CO_2 capture capacity | *SEC:* specific energy consumption

Techno-economic results - Germany



$\dot{m}_{CO2}$ [kt/a]

15.0 679.0

- Lignite
- Hard coal

Supportive information

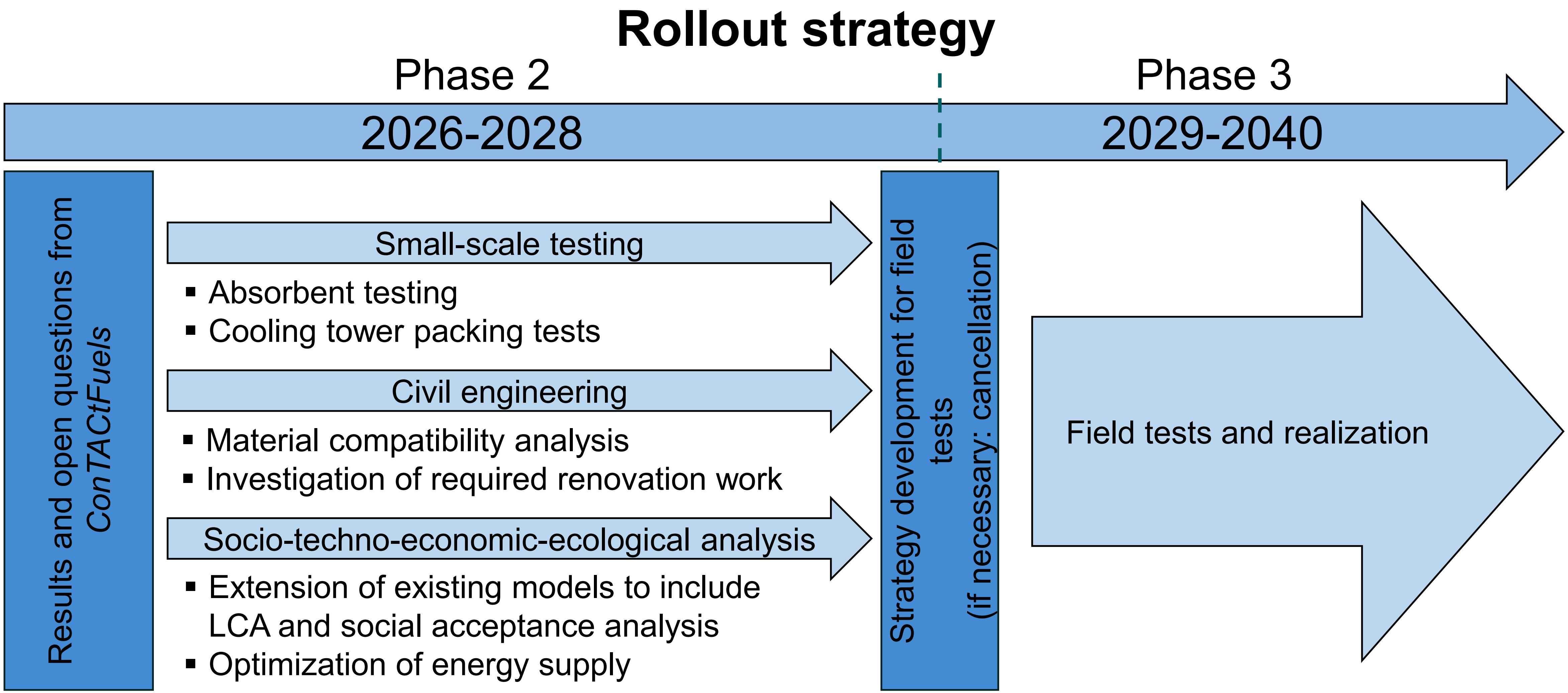
- Clustered plant sites
  - Proximity and coal type
  - Cost range depicts different sites' *LCODAC*
- Lifetime: 25 years

- 2.3 Mt_{CO2}/a of total annular capacity in Germany
- Highest potential for lignite regions
  - Annular capacity of 1.5 Mt_{CO2}/a
  - Cost reduction up to 14 %
- Site-depending potential for hard coal-fired sites
- Renewable energy supply crucial future research question

Considerable DAC potential for Germany

PV: photovoltaic | $\dot{m}_{CO2}$: annular CO_2 capture capacity

Route to a potential application



Summary and conclusion
Key Takeaways

Motivation	1	NET:	Negative emission demand in future energy systems
		DAC:	Scalable option with high initial investment
Methodology	2	Technical:	Case study with KOH-based process
		Techno-economic:	*LCODAC* analysis with repurposed cooling tower capture unit
Theoretical potential	3	Individual site:	Potential depending on cooling tower lifetime in DAC plant
		Germany:	German-wide potential of 2.3 Mt_{CO2}/a
Rollout	4	Phase 2:	Uncertainty reduction with lab-scale investigations
		Phase 3:	Transition to field tests in power plant cooling towers

NET: Negative emission technologies | KOH: potassium hydroxide | *LCODAC*: Levelized Cost of Direct Air Capture

Thank you for your attention!

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[2] International Energy Agency (2022): “Direct Air Capture – A key technology for net zero”

[3] TÜV SÜD AG: “FILTER GEGEN KLIMAWANDEL”, URL: https://abouttrust.tuvsud.com/sustainability/filtergegenklimawandel/

[4] Wirsum und Sager (2025): „CO2-Abscheidung aus Luft für die Brennstoff-Synthese unter Nutzung der bestehenden Kraftwerksinfrastruktur (ConTACtFuels)“, https://doi.org/10.34657/26242

[5] Kiani et al. (2022): “Direct Air Capture of CO2 using Amine-based Capture Technology”, SSRN Electronic Journal