Energy and cost performances baseline of MEA-based CO_2 Capture

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Outline

- Motivation for this study
- System boundaries and case matrix
- Process modelling
- Economic evaluation
- Conclusion and further work

Motivation of this study

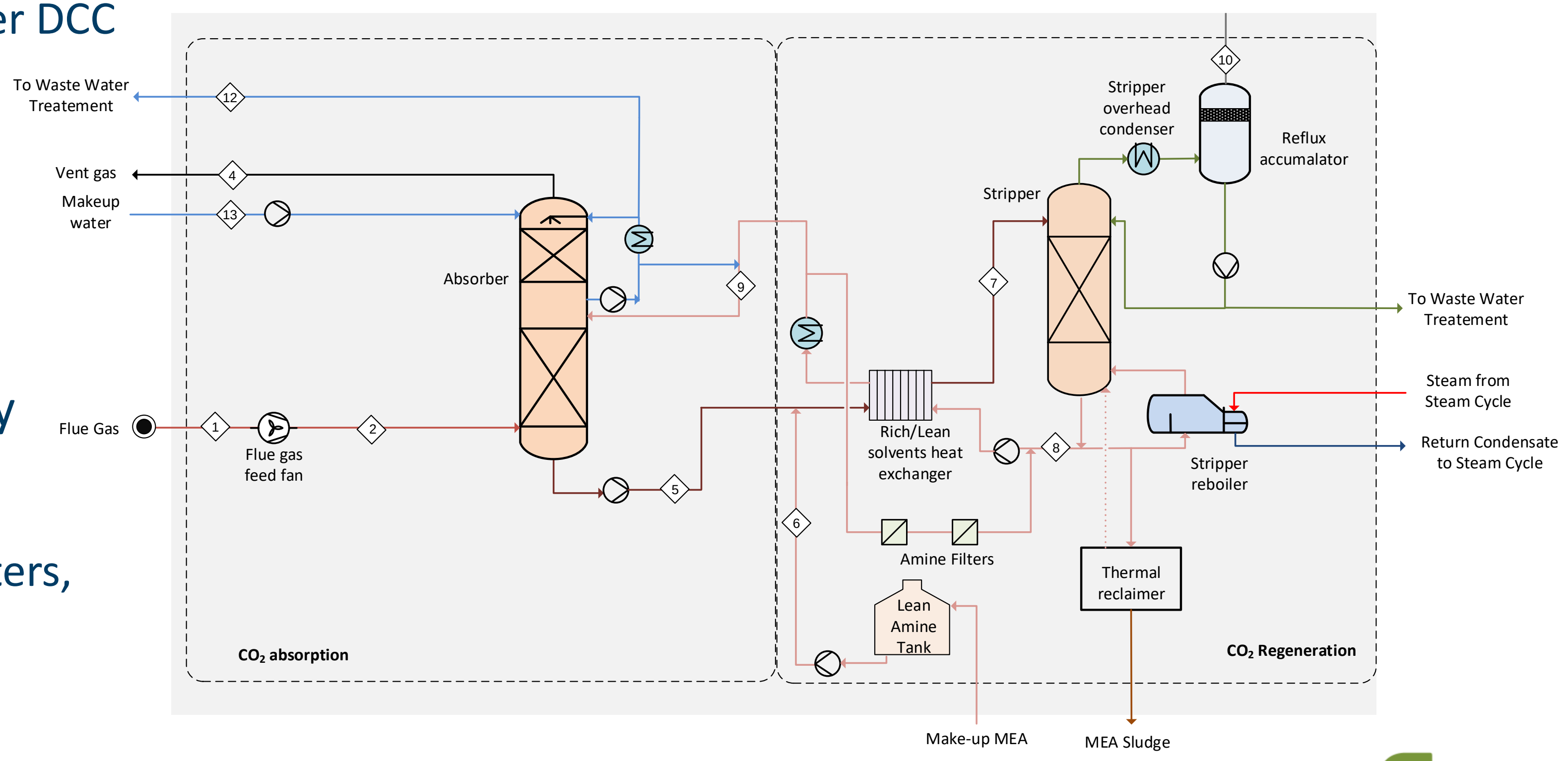
- Benchmarking «novel» capture technologies requires a reference
  - Typically MEA in literature due to large data in open literature

- Inconsistent evaluations from case to case in literature → **Be careful to use literature results**
  - Process configuration
  - Design basis
  - Assumptions for economic evaluation

- Consistent and transparent study over a large range of industrial applications
  - Benchmark for MEA absorption studies
  - Fast performance estimation of specific cases
  - Based on previous experiences with MEA benchmarking in projects : ReCAP, CEMCAP

Process flowsheet

- Direct contact cooler not considered
  - Cooling requirement and transport to DCC very case dependent
  - Feed gas assumed to be saturated after DCC
- CO_2 conditioning excluded
- Additional equipment than commonly considered in literature are included
  - Inventory tanks, thermal reclaimer, filters, etc.



Case matrix

- 45 cases considered based on combinations of:
  - 5 flue gas mass flow rate (313-3,696 t/h)
  - 9 CO_2 concentration (3.5-30%CO_2)
- For each case
  - Simulation, design, and equipment list
  - Full cost evaluation

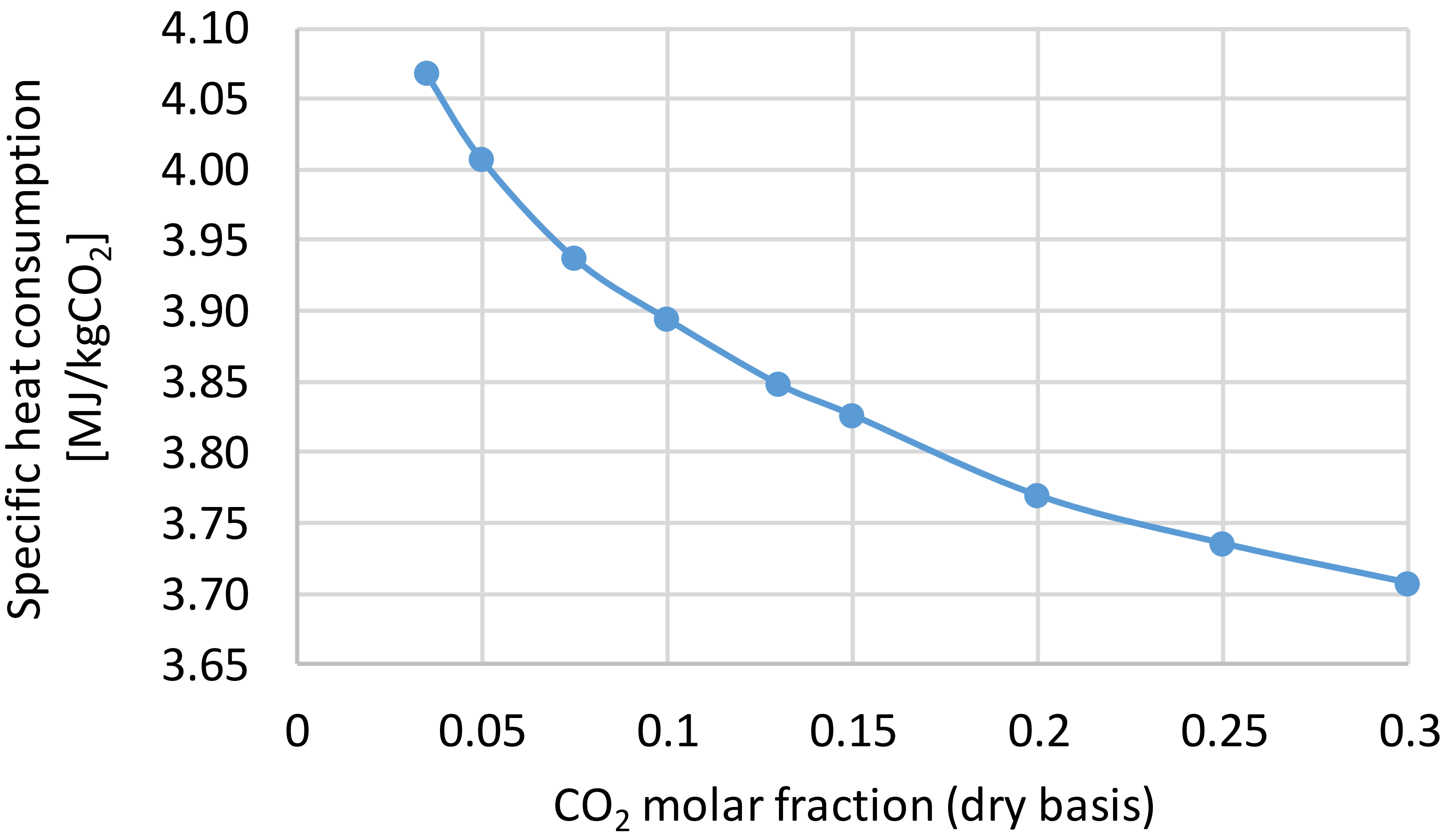
		32 MW offshore GT				1000 MW coal PP
		Flowrate of CO_2-rich gases, t/h				
		313 (vol1)	1159 (vol2)	2004 (vol3)	2850 (vol4)	3696 (vol5)
Gas turbine	CO_2 molar fraction (dry basis): 0.035					
Gas turbine	0.05					
	0.075					
	0.10					
Coal-fired	0.13					
Coal-fired	0.15					
Cement	0.20					
Cement	0.25					
Steel	0.30					

Design basis & assumptions

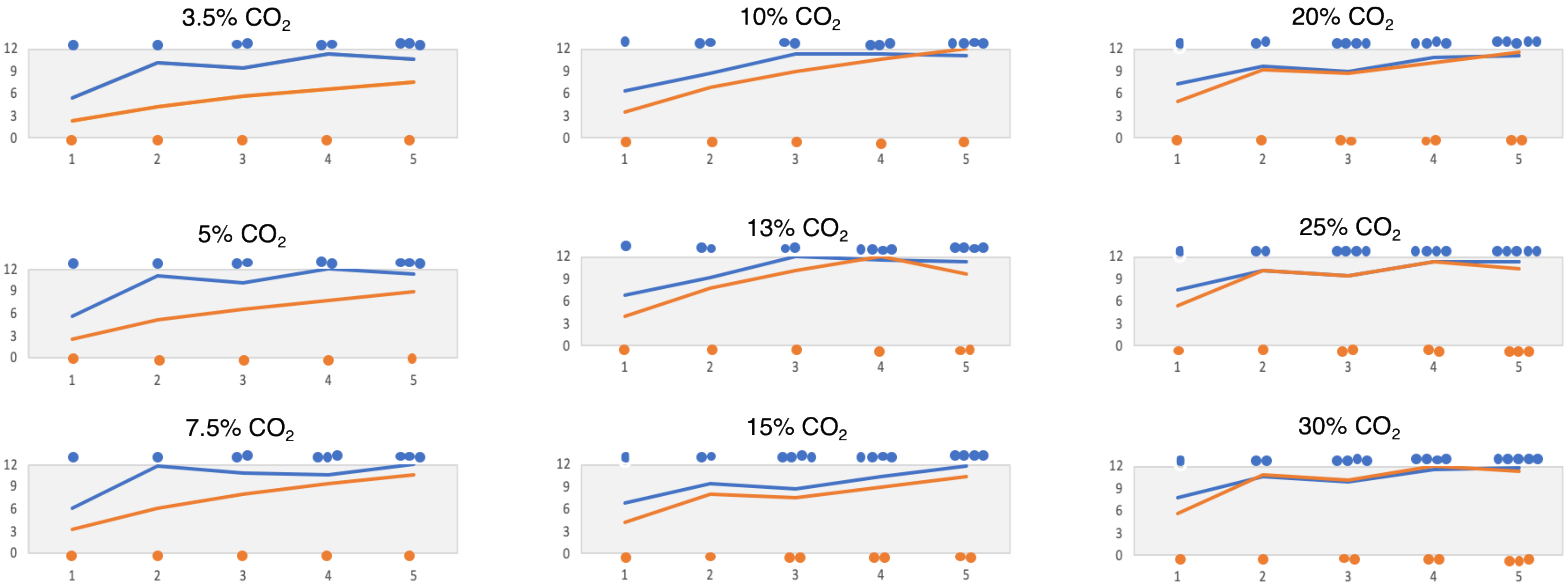
Capture rate [%]	90
Feed composition (dry basis)	N_2-CO_2 binary mixture
Temperature of flue gas feed [^oC]	35
Absorber pressure [bara]	1.1
Stripper pressure [bara]	1.8
Maximum column diameter [m]	12
Minimum temperature difference for heat exchange [^oC]	10
Lean loading	0.18
MEA mass fraction in lean solvent	0.3

Process modelling results – Specific Reboiler Duty

- SRD varies between 3.7 and 4.08 MJ/kgCO_2 depending on the molar concentration
- Values consistent with recent CO_2 capture studies



Process modelling results – Column design and sizing



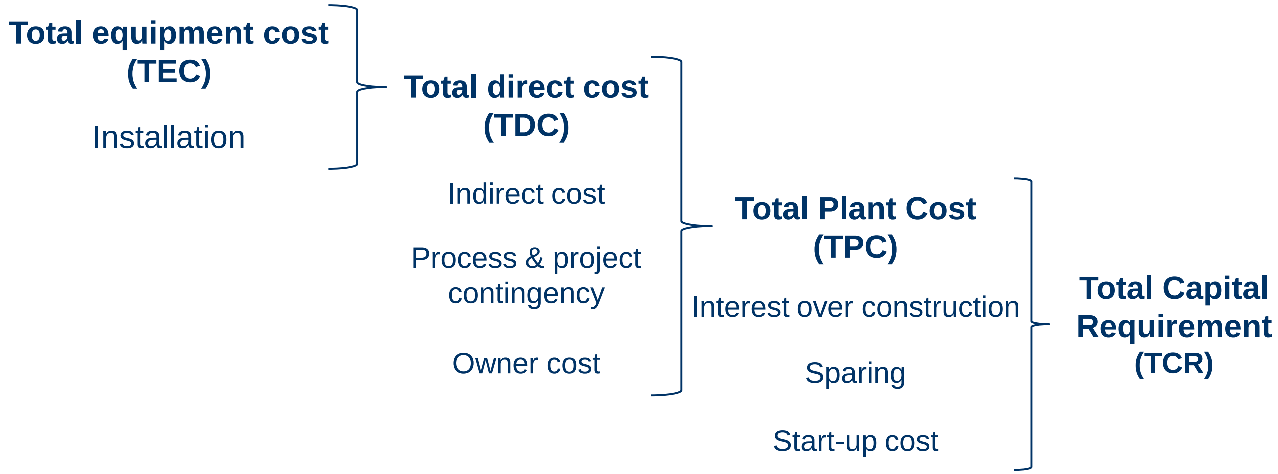
Legend:

Y-axis: Diameter (m) — Absorber diameter — Regenerator diameter

X-axis: Volume (1-5) — Number of absorbers — Number of regenerators

Cost evaluation methodology

- Investment costs
  - Equipment characteristics based on simulation and design margins and limitations
  - Equipment and direct cost assessed with Aspen Process Economic Analyzer
  - Cost escalation to TCR based on well established and transparent approaches from CEMCAP & IEAGHG



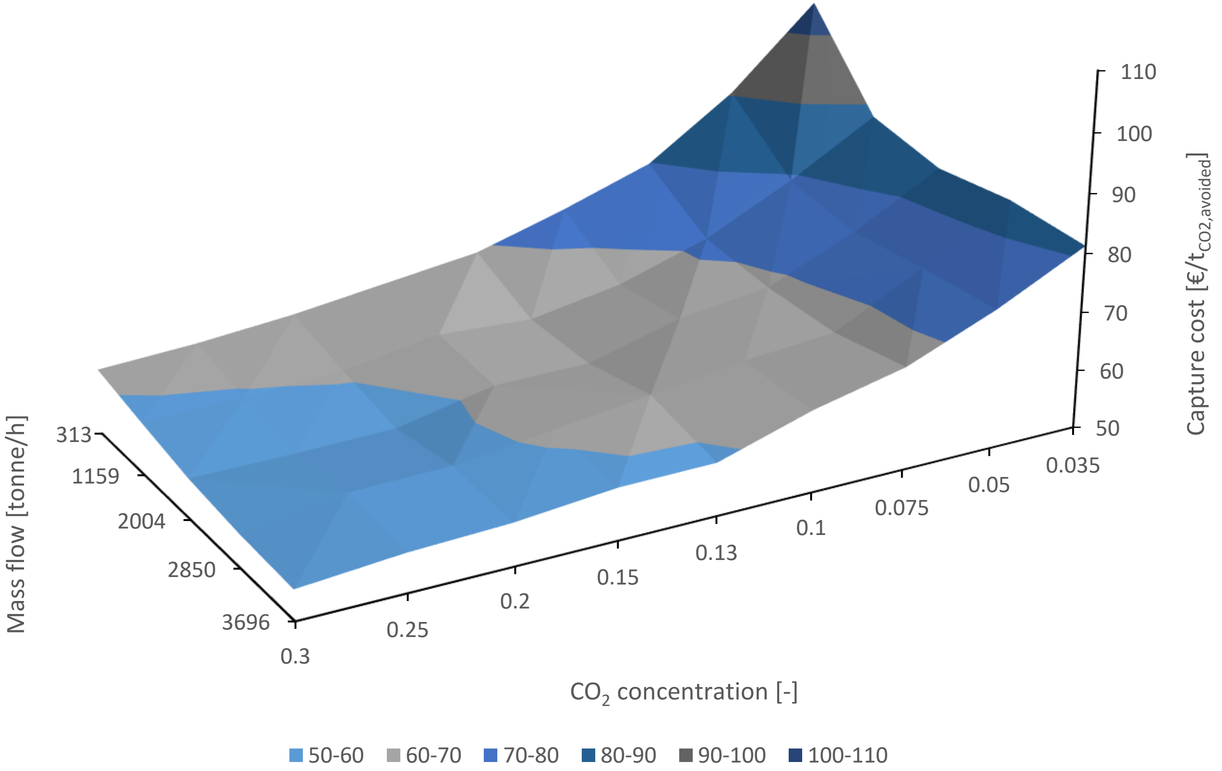
- Operating costs
  - Equipment characteristics based on simulation and design margins and limitations
  - Fixed: Maintenance, insurance, labour
  - Variable: Steam, power, MEA, process and cooling waters
    - Base case: Steam from natural gas boiler
      - Cost: 25.6 €/$MW_{th}h$
      - Climate impact: 0.21 $t_{CO2}/MW_{th}h$

- KPI

$$CO_2 \text{ avoidance cost} = \frac{\text{Annualised TCR} + \text{Annual OPEX}}{\text{Annual } CO_2 \text{ emissions avoided}}$$

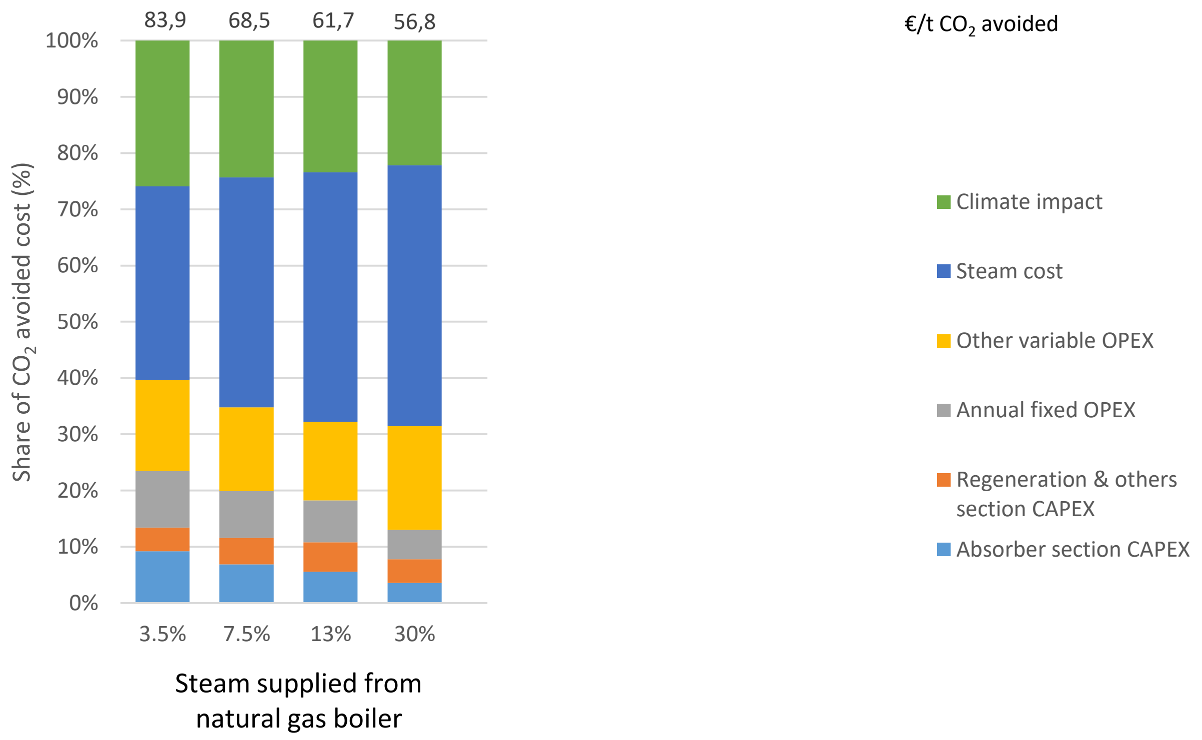
Impact of scale and flue gas CO_2 concentration

- With smaller scale and decreasing concentration of CO_2 in flue gas, the capture cost increases rapidly
- Economies of scale become more pronounced at flue gas CO_2 concentrations below 7.5%
- The effect of scale becomes less pronounced at CO_2 concentrations above 20%



Breakdown of CO_2 avoidance cost

- Breakdown of CO_2 avoidance cost exemplified for a constant flue gas mass flow with varying CO_2 concentration
  - ➢ Cost of steam and other variable costs become more dominant at higher CO_2 concentrations while CAPEX share decreases



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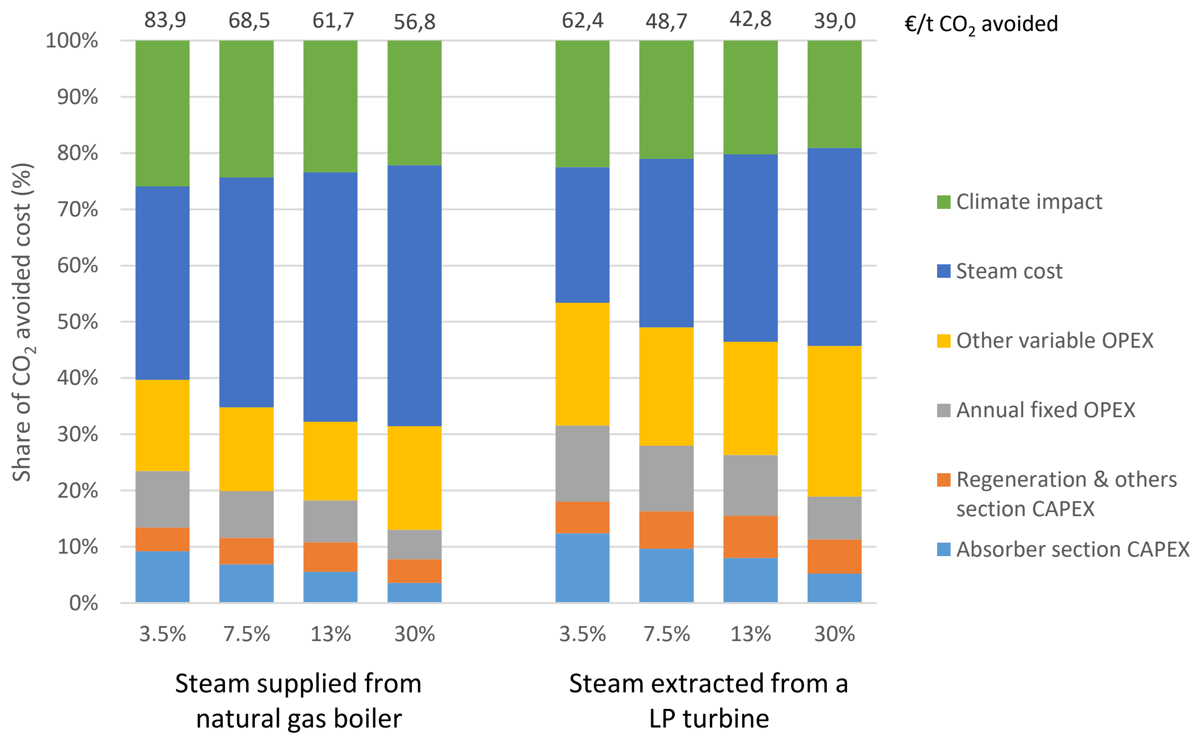
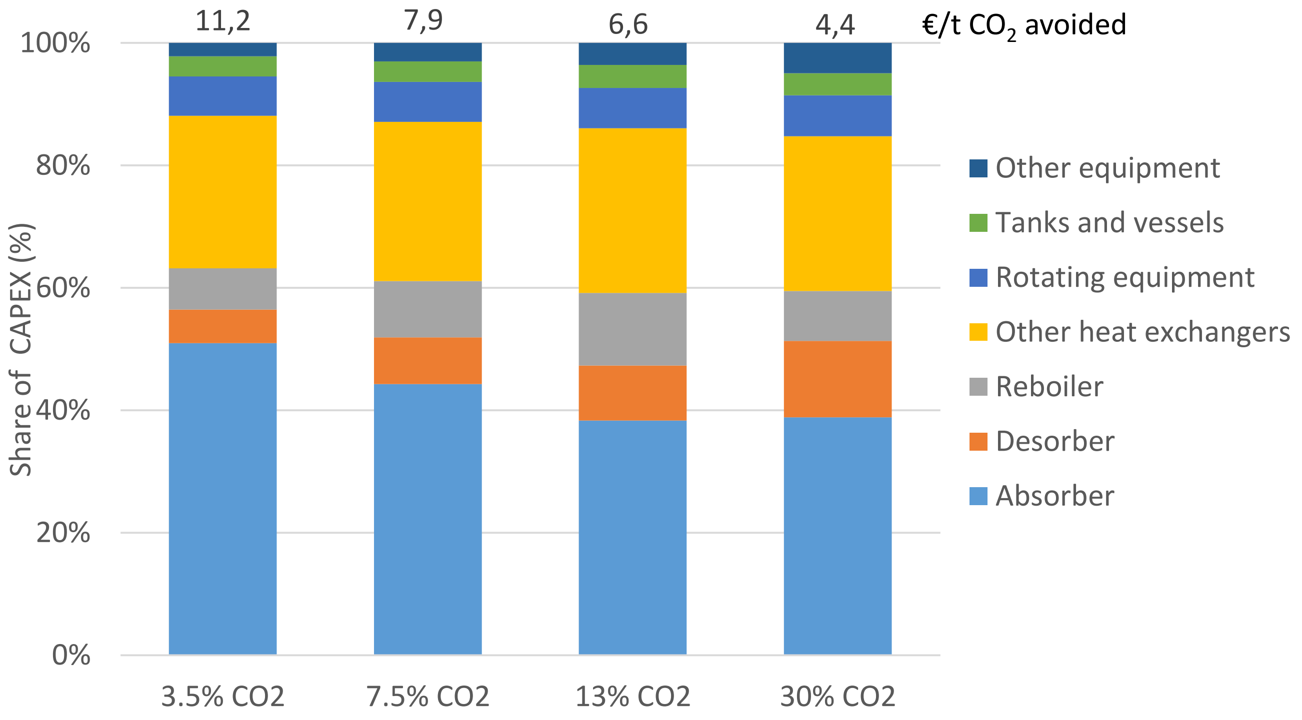


Breakdown of CAPEX

- Breakdown of CAPEX exemplified for a constant flue gas mass flow with varying CO_2 concentration

- The absorber is the largest single equipment in terms of CAPEX
  - The absorber share of CAPEX decreases with increasing CO_2 concentration in the flue gas
  - Absorber size is similar between cases while the amount of CO_2 avoided increases with CO_2 concentration



Steam supply scenarios

	Cost	Climate impact	Cost compared to reference	Climate impact compared to reference
Steam supply scenario	**€/MW_{th}h**	**$tCO_2/MW_{th}h$**	**-**	**-**
Natural gas boiler - reference	25,6	0,21	1,0	1,0
Steam extraction from an LP Turbine	13,3	0,18	0,5	0,9
Coal CHP plant	22,0	0,46	0,9	2,2
Steam produced from waste heat from process	6,8	0	0,3	0,0
Electric boiler - EU	64,4	0,31	2,5	1,5
Electric boiler - Norway	33,3	0,01	1,3	0,1

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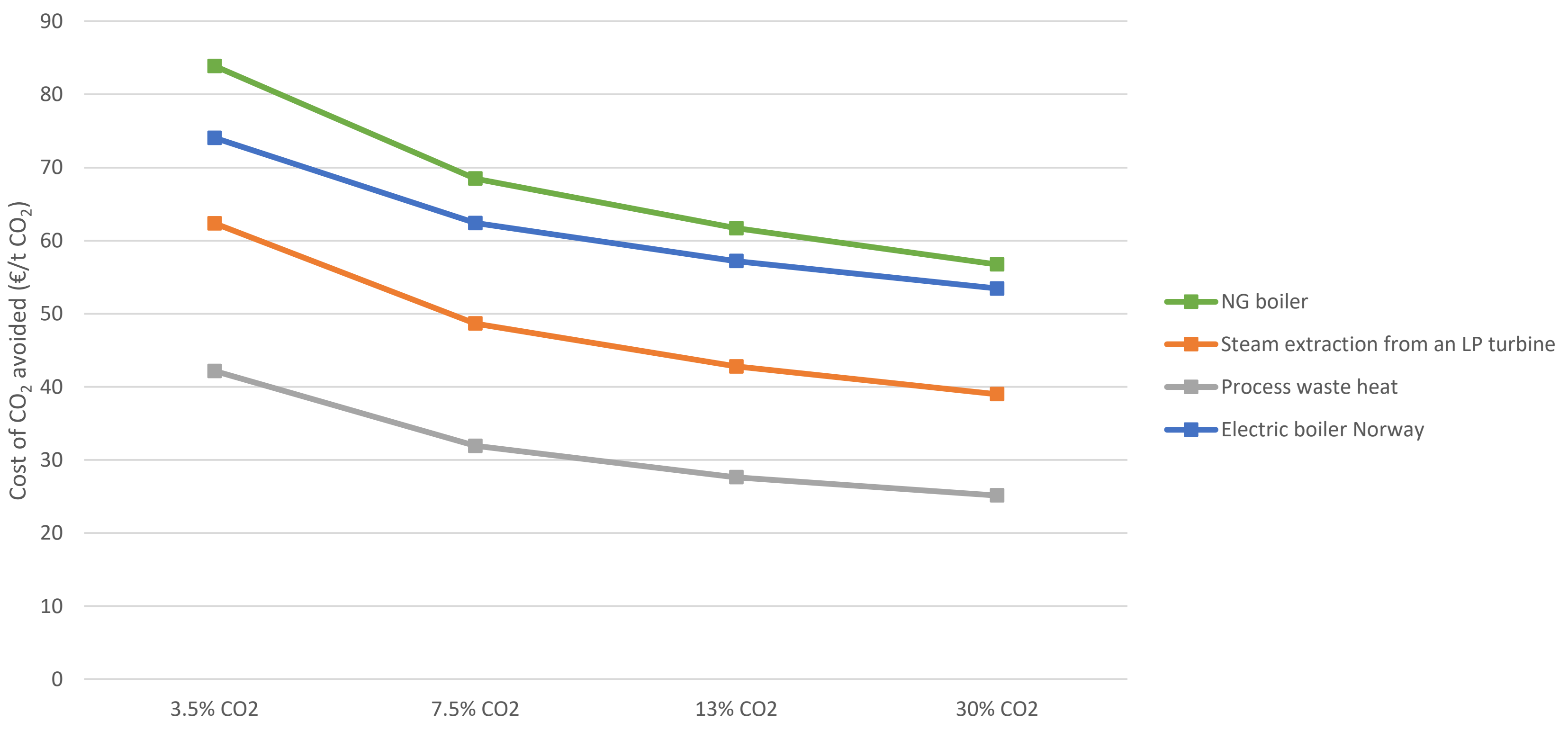
Impact of steam supply

- The source of steam and its climate impact, together with the direct cost of steam has a strong impact on the CO_2 avoidance cost
- The choice of steam supply strategy is highly site-specific, e.g. availability of waste heat/steam in upstream process or nearby industry, local/regional el grid characteristics etc.

Constant flue gas mass flow of 2004 tonne/h



Conclusions and future work

- Performances evaluation of MEA absorption over a large range of industrial applications (composition and size)
  - Consistent and transparent study
  - Based on previous project experiences
  - Detailed evaluation of each case considered
  - Aim to be used as basis for fast performances estimation of MEA benchmark in future studies
- Observed trends
  - Column size limitations can have significant impact on the plant design and limit scale benefits
  - Cost in €/t decreases as CO_2 concentration and size increase
  - Absorber and desorber represents around 50% of the CAPEX
  - Steam consumption is often the main cost contributor
  - Steam production method is key and impacts the CO_2 avoidance cost in two ways: steam cost and climate impact

Conclusions and future work

- Further work
  - ➢ Perform additional cases evaluation in relevant "areas"
    - ❑ Smaller volumes for high-purity sources
    - ❑ Larger volumes for low-purity sources
  - ➢ More precise evaluation on water balances
  - ➢ Document and make results widely available

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NORWEGIAN CCS RESEARCH CENTRE

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