Utrecht University

Supporting the optimal design and operation of CO_2 capture in industrial facilities with time-resolved models

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Energy System Optimization Workshop, Graz,
27-28 November 2025

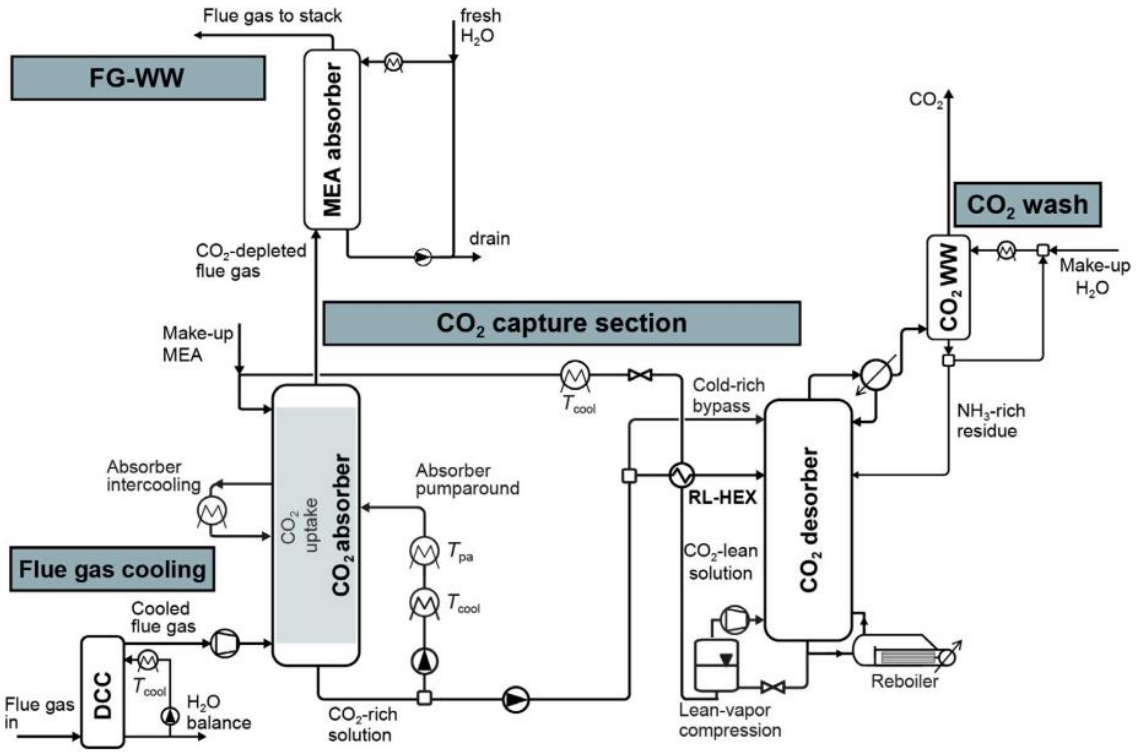
Funded by the European Union. This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101096691.Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

Traditional techno-economic analysis lacks longer temporal resolution

The assessment and design of CCS technologies involve:

- Process simulations
- Techno-economic framework

Under the assumption that the operations and economic framework are **static** or **dynamic with short time horizon**



Source: Weimann, L., Dubbink, G., van der Ham, L., & Gazzani, M. (2023). A thermodynamic-based mixed-integer linear model of post-combustion carbon capture for reliable use in energy system optimisation. *Applied Energy*, *336*. https://doi.org/10.1016/j.apenergy.2023.120738

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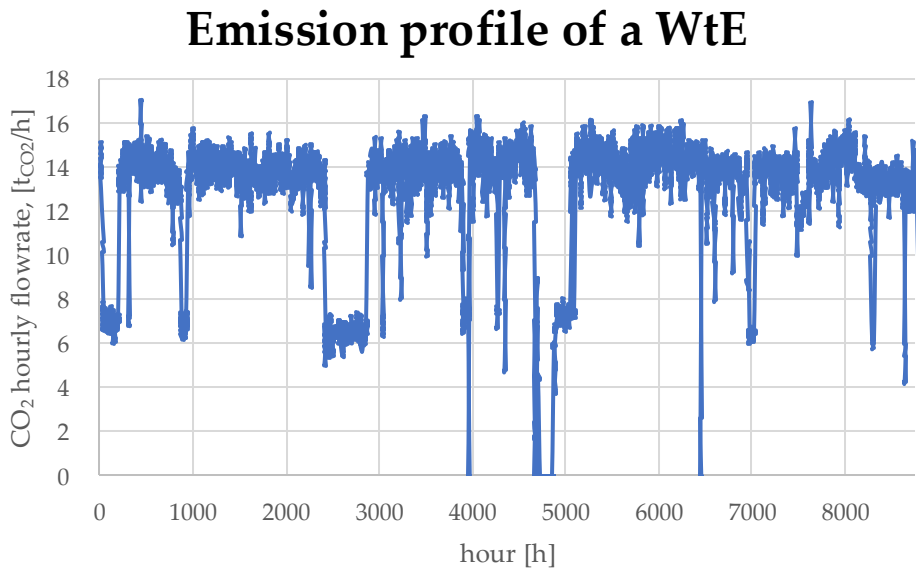
In reality, plants operate under dynamic conditions



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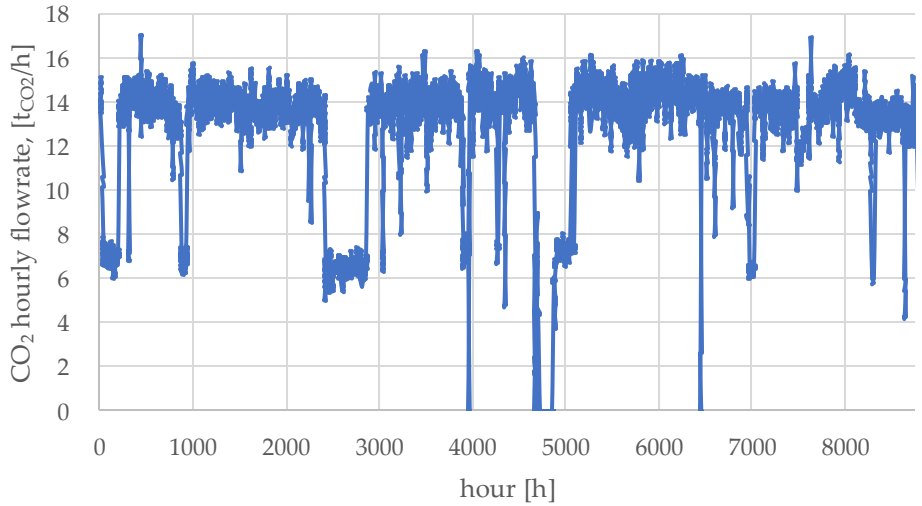
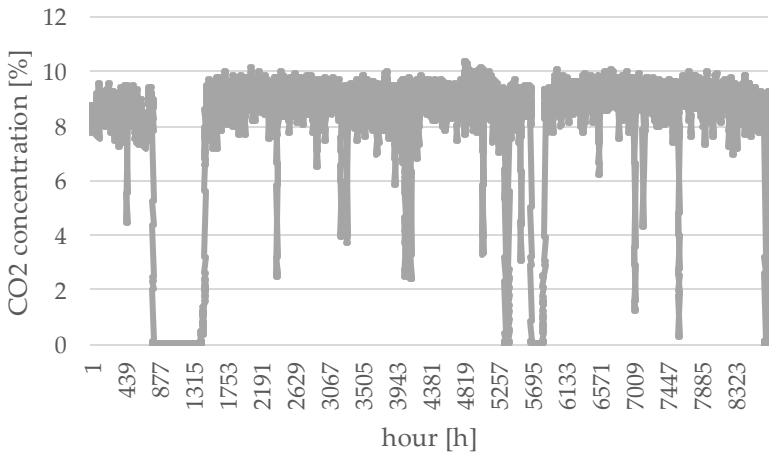
Emission profile of a WtE



CO_2 concentration in a WtE



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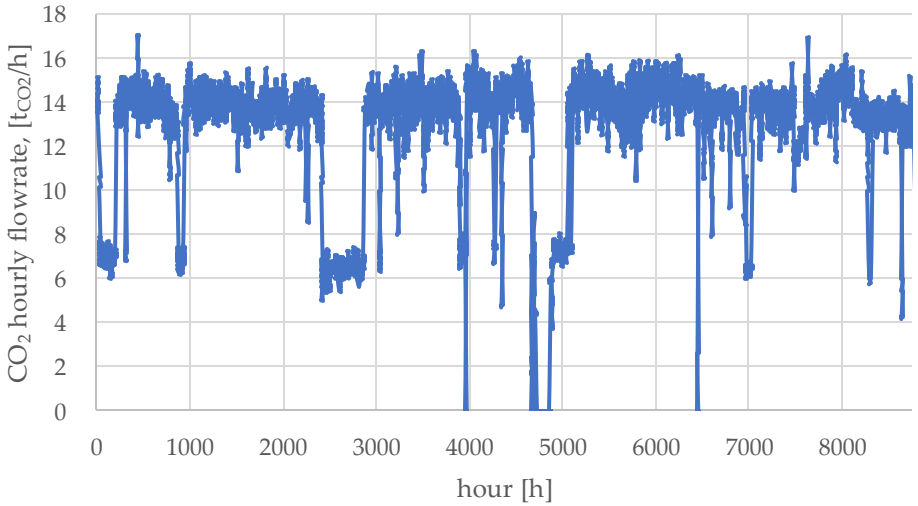
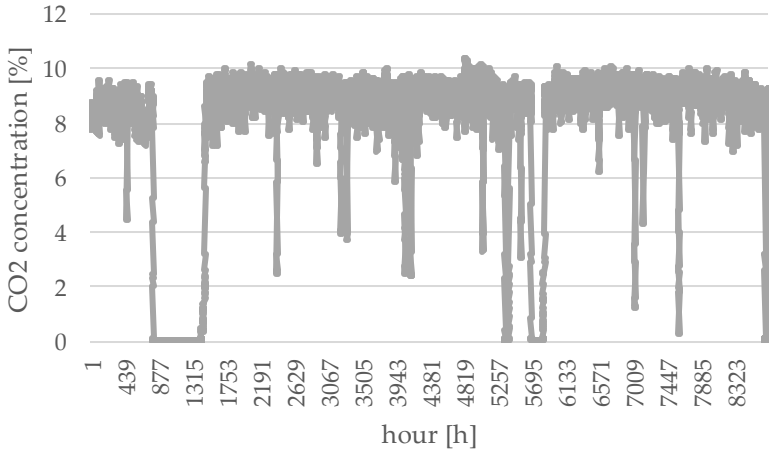
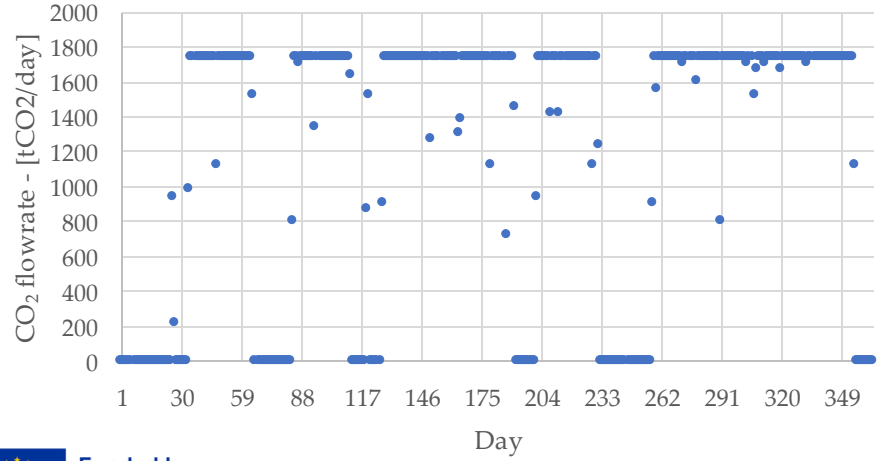


CO_2 concentration in a WtE



Emission profile of a cement plant



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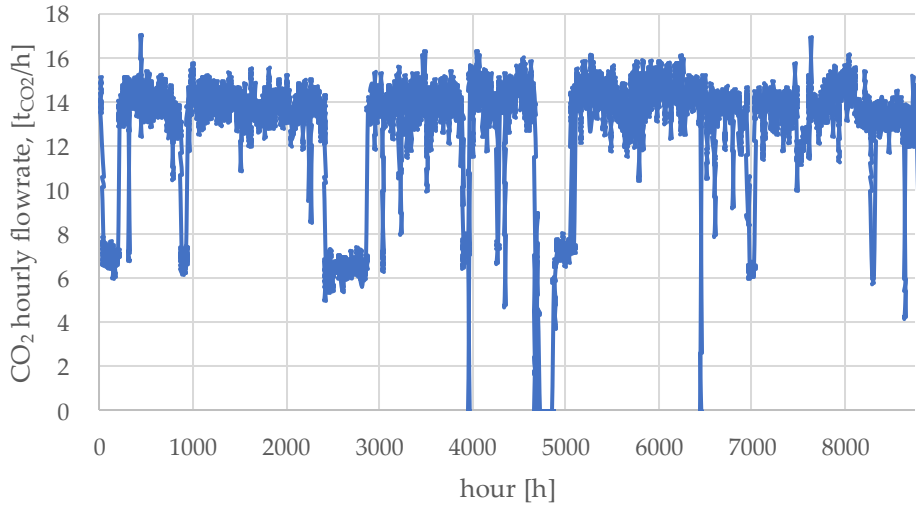
In reality, plants operate under dynamic conditions

Emission profile of a WtE



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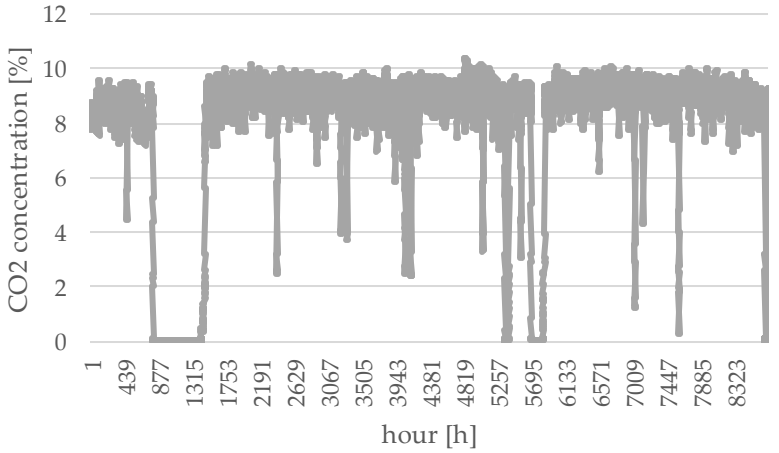

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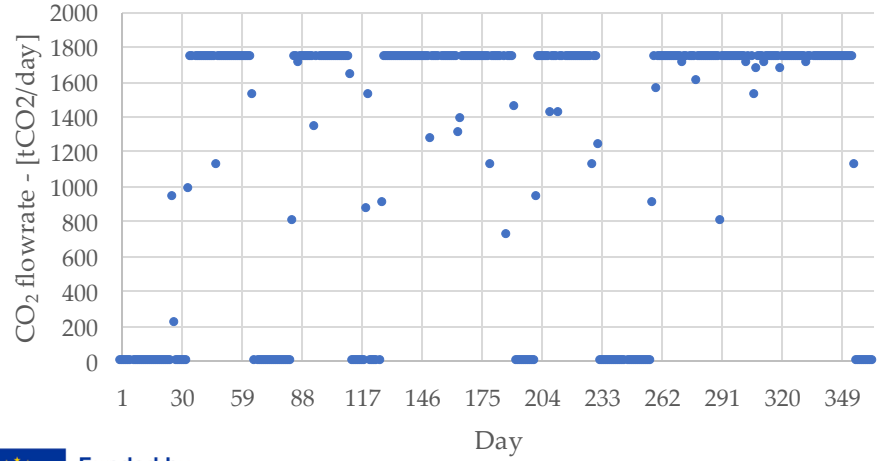
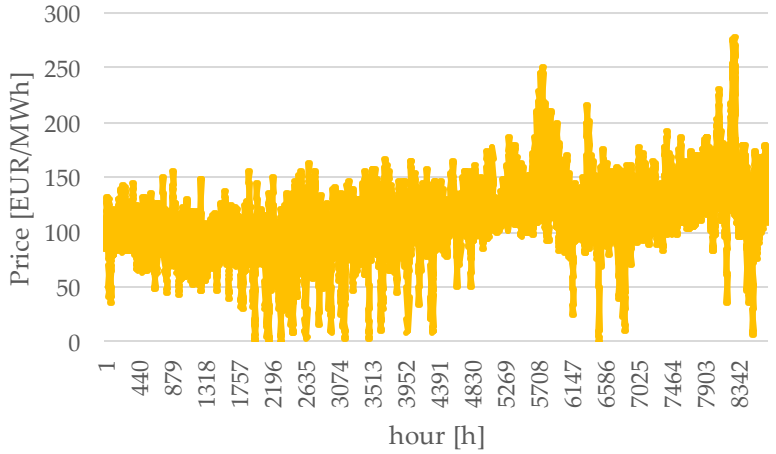


Electricity price



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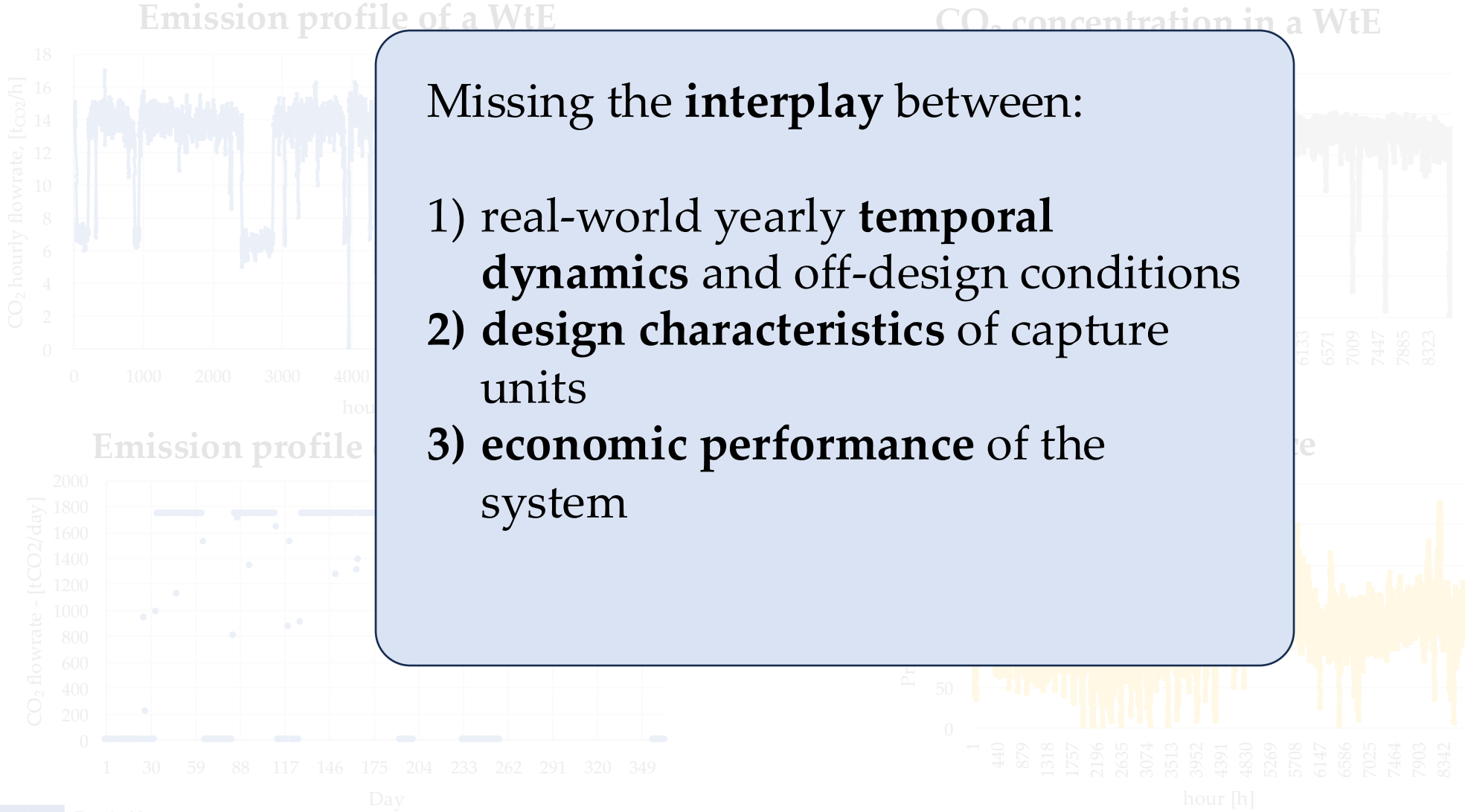
In reality, CCS operates under dynamic conditions



Missing the **interplay** between:

1) real-world yearly **temporal dynamics** and off-design conditions
2) **design characteristics** of capture units
3) **economic performance** of the system

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Can time-resolved models support the assessment of CO_2 capture technologies?

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Overview of the presentation

- Modeling framework
- Capture technologies and industries
- Results
- Conclusions

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Modeling framework - needs

Requirements of the modeling framework:

- handle ~100’000 variables or more for time resolution
- keep the physical fidelity to the process
- Identify optimal design and operating conditions

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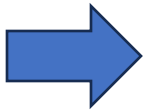

Mixed integer linear programming (MILP)

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Modeling framework - approach

Modeling framework - approach

Process simulations
rate-based in ASPEN
On- and off- design

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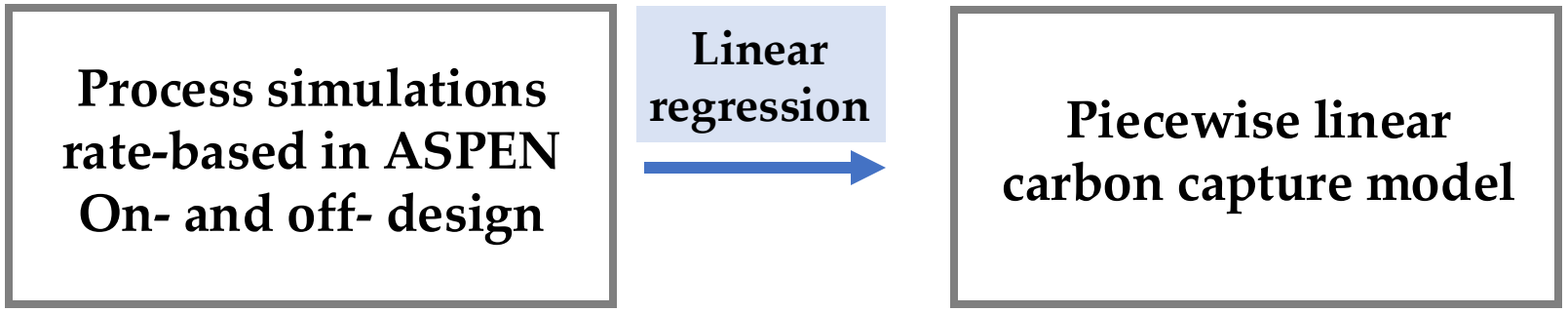
Modeling framework - approach



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Modeling framework - approach

MILP framework – yearly time horizon, hourly resolution

Process simulations rate-based in ASPEN On- and off- design

Linear regression

Piecewise linear carbon capture model

- CO_2 concentration profile
- Real-world industrial production profiles
- Electricty prices
- District heating demand
- Interaction with other technologies (e.g. industrial boilers, heat pumps etc.)

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Main optimization variables and parameters

Variables

- *Selection*: capture technology
- *Design*: capture unit size
- *Operation*: portion of flue gas treated every hour

Parameters

- CAPEX as function of
  - size
  - design CO_2 concentration
- Energy input as function of
  - CO_2 processed
  - design CO_2 concentration
  - hourly CO_2 concentration

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Capture technologies

Industry

Waste to energy

Cement

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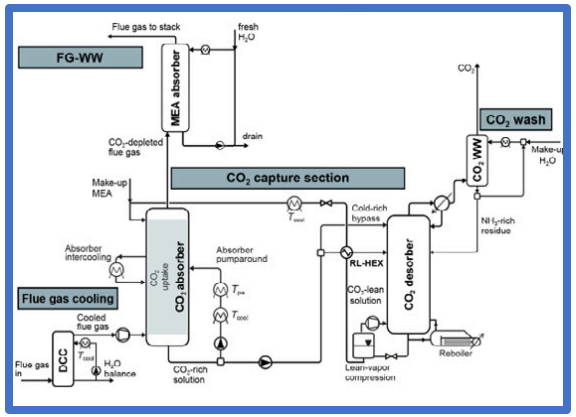
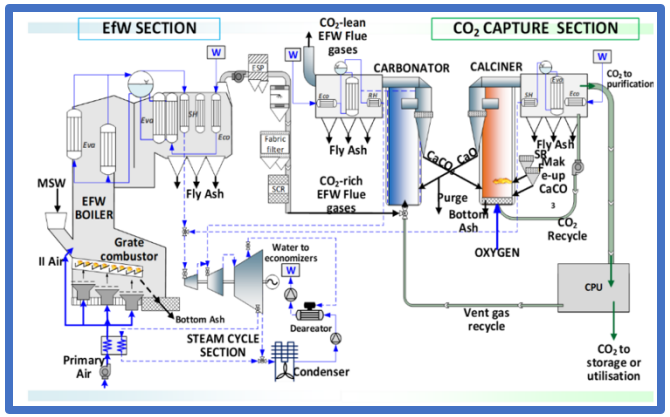


Calcium looping



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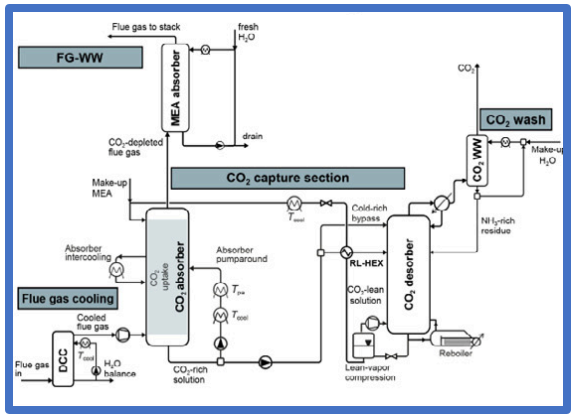

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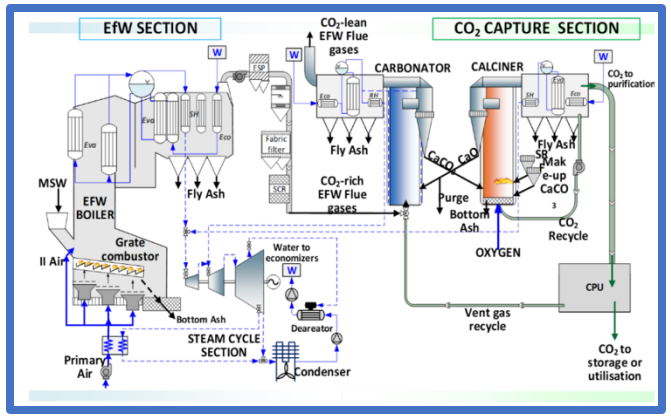

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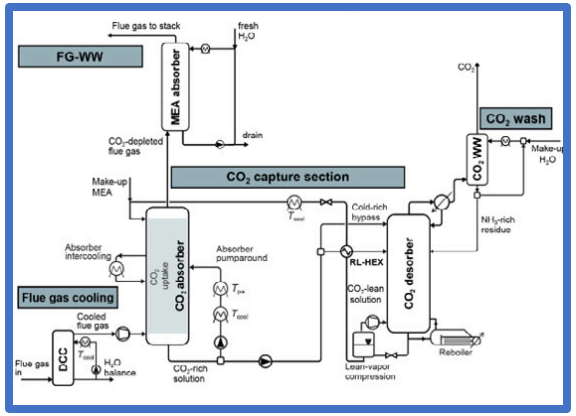

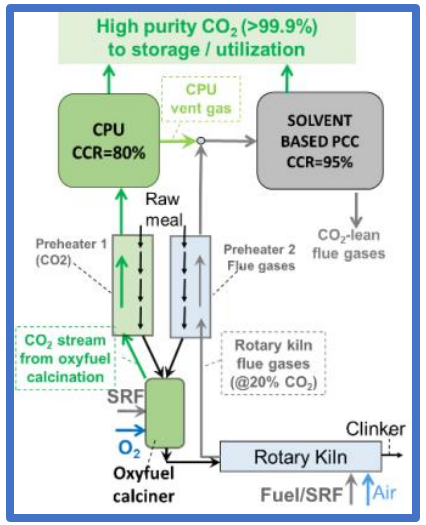

Partial oxyfuel only/ plus PCC

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Capture technologies

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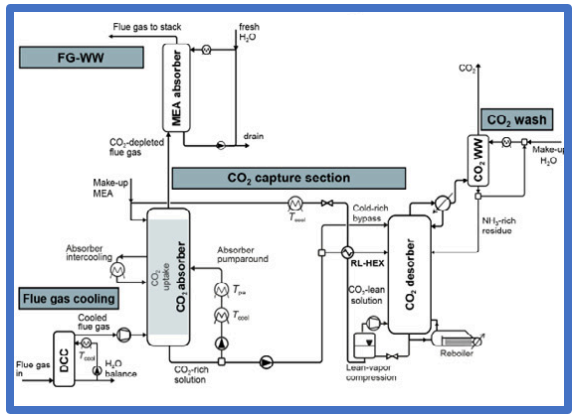

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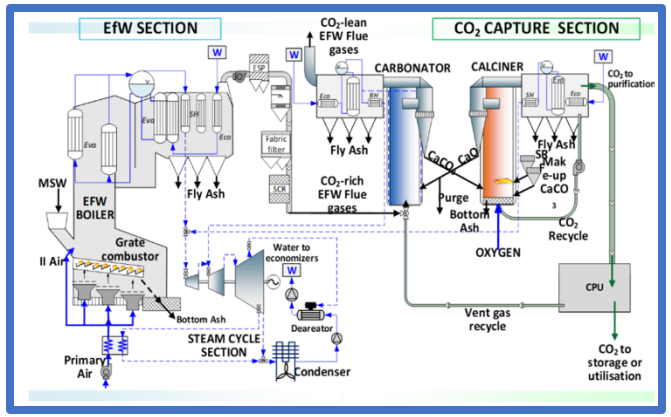

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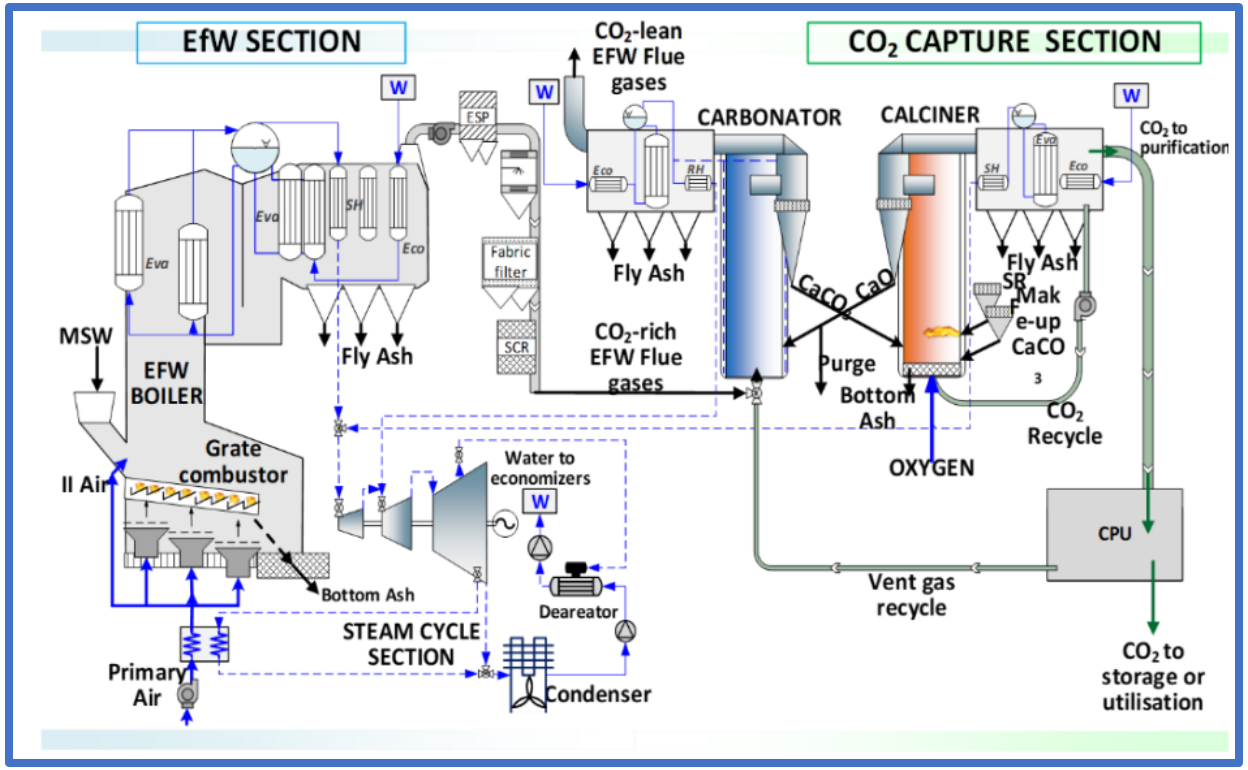
Calcium looping for waste-to-energy



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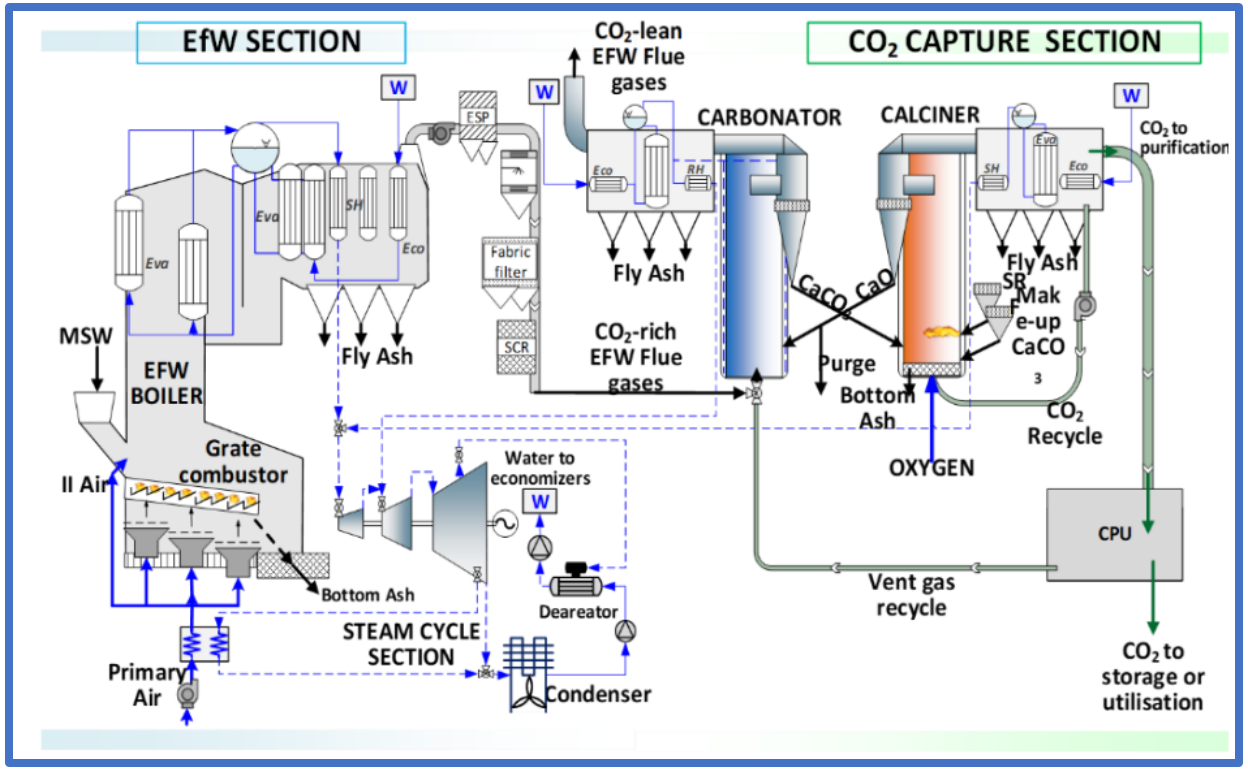
Calcium looping for waste-to-energy

We performed **multiple** ASPEN **simulations** of CaL in a WtE facility:

- 3 plant sizes: small, mid, big
- 2 target CO_2 concentrations: 8% and 10%

KPIs: CAPEX, OPEX, net el. production, fuel consumption



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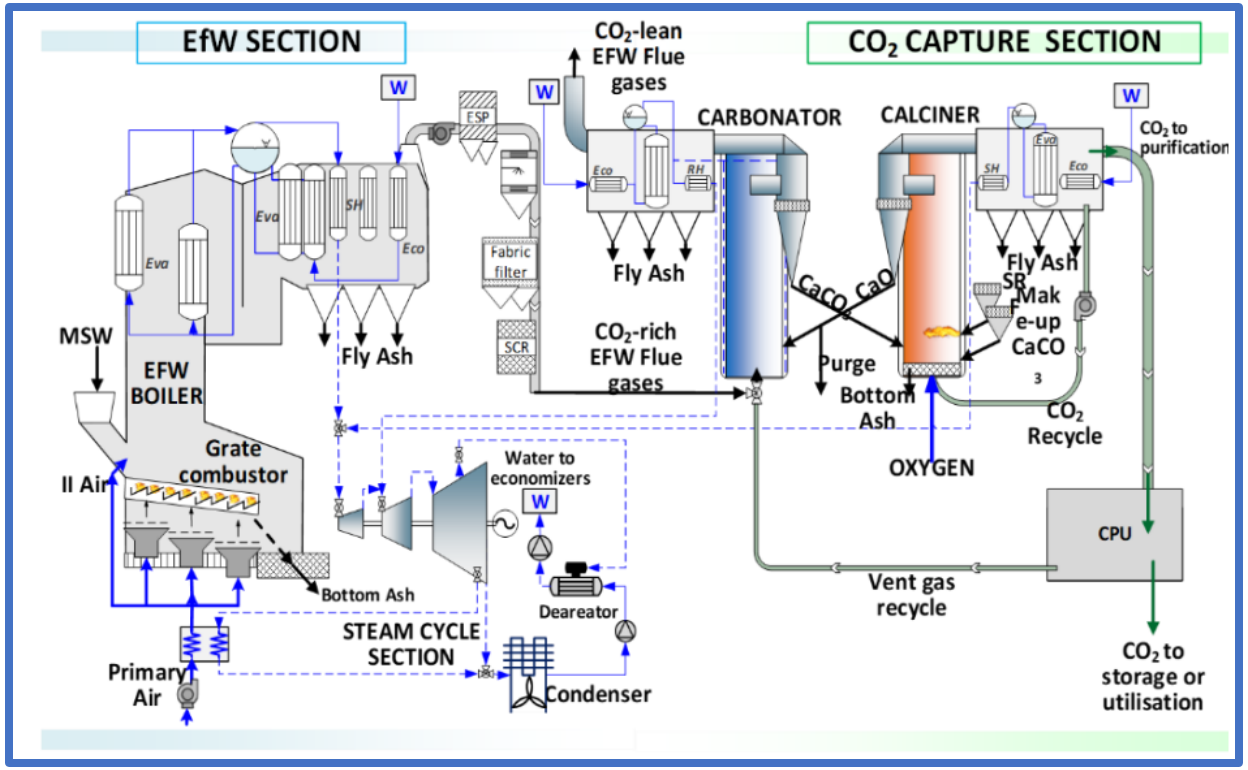
Calcium looping for waste-to-energy

We simulated **off-design** conditions:

- Flowrate variation: ±7% compared to baseline
- CO_2 concentration variation: ±1% compared to baseline



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Capture technologies

Industry

Waste to energy

MEA [1]

Calcium looping

Cement

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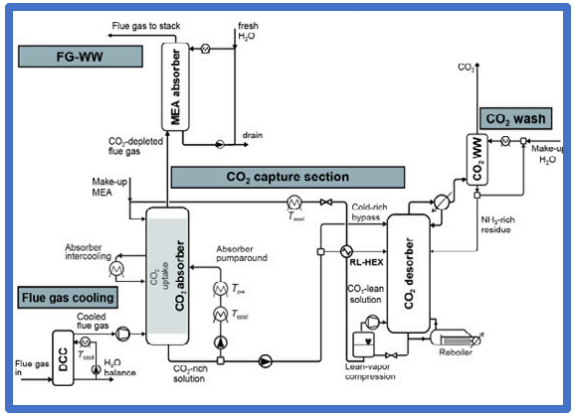

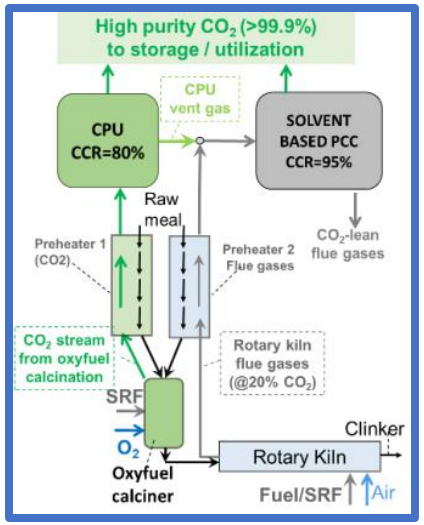

Partial oxyfuel only/ plus PCC

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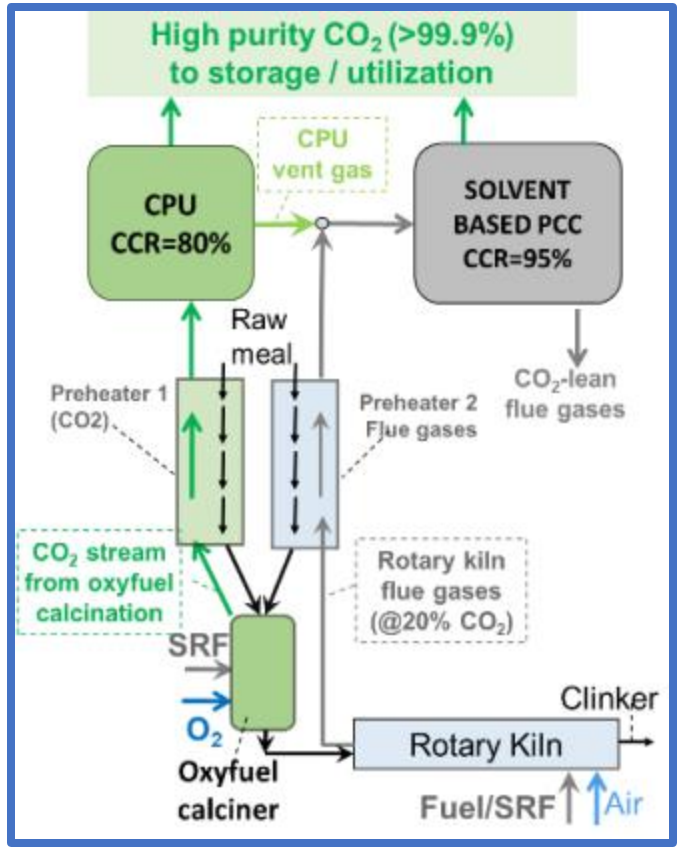
Partial oxyfuel with PCC for cement



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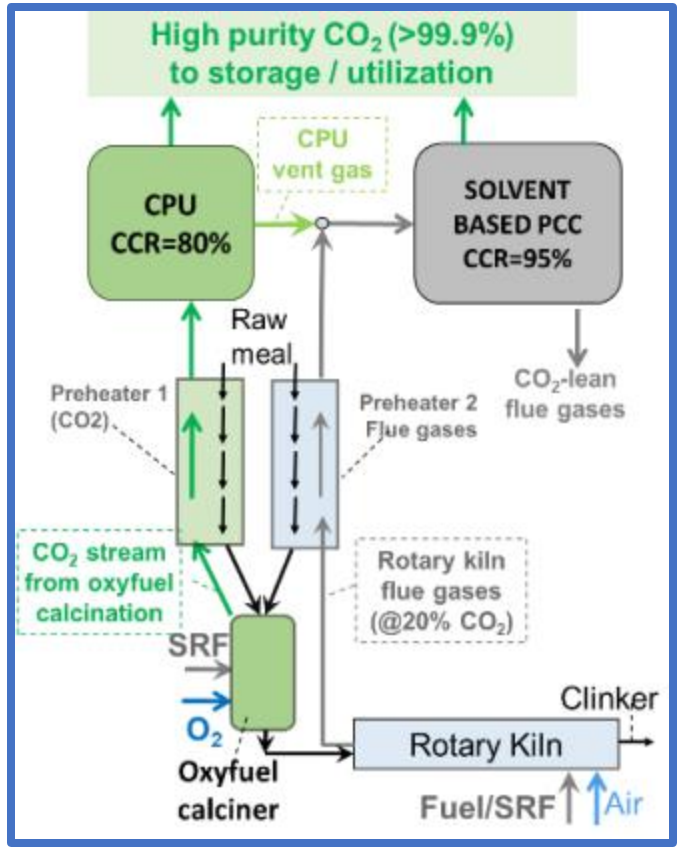
Partial oxyfuel with PCC for cement

We performed **multiple** ASPEN **simulations** of the partial oxyfuel/hybrid oxyfuel+PCC capture options:

- 2 plant sizes: 1800 and 3000 tpd clinker
- Oxyfuel only, oxyfuel with PCC

KPIs: CAPEX, OPEX, el. consumption, extra fuel consumption



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Capture technologies

Industry

Waste to energy

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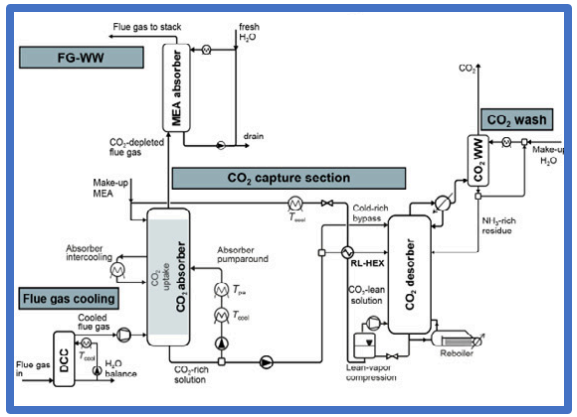

Calcium looping

Cement

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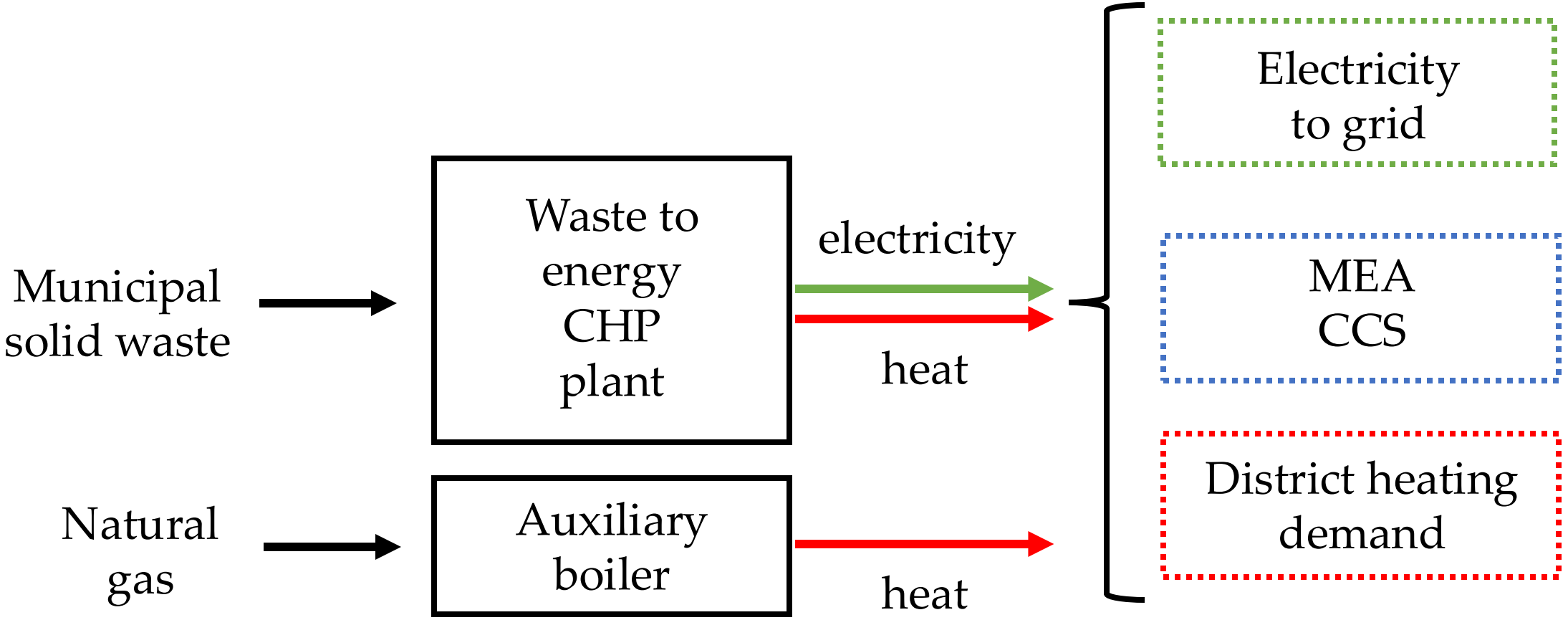
Application to a combined heat and power WtE with MEA



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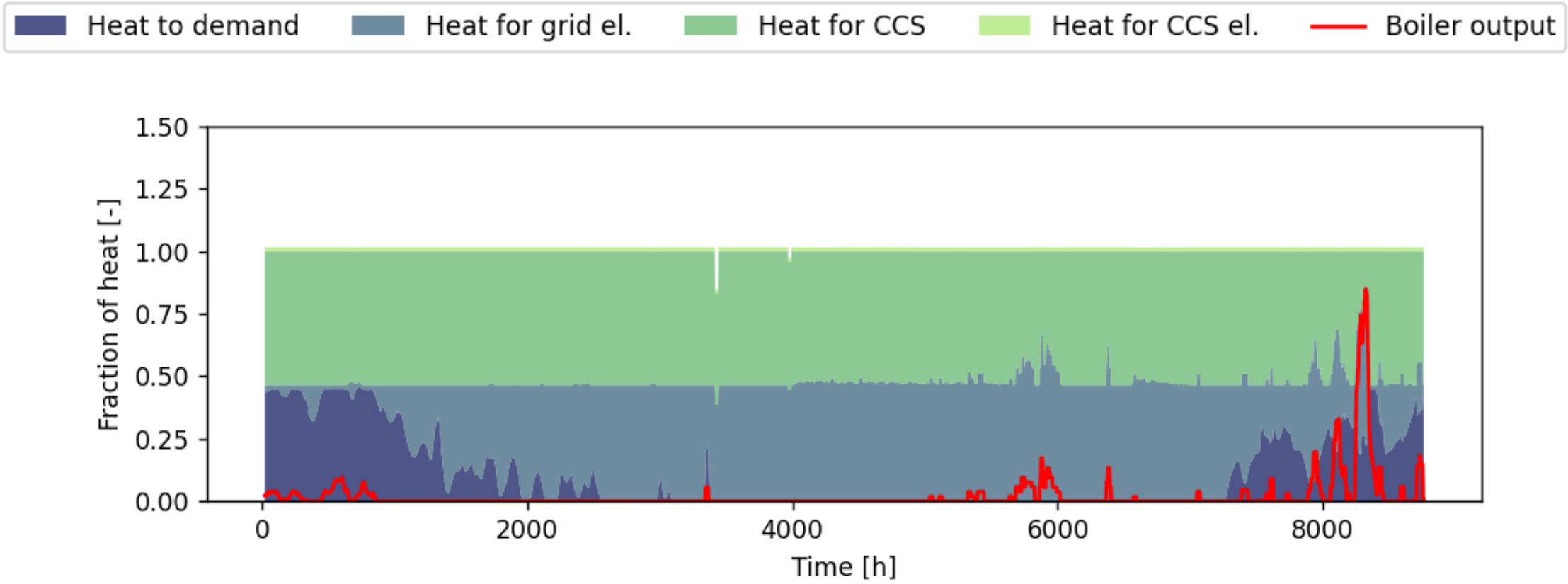
Optimal heat usage in the WtE throughout the year…



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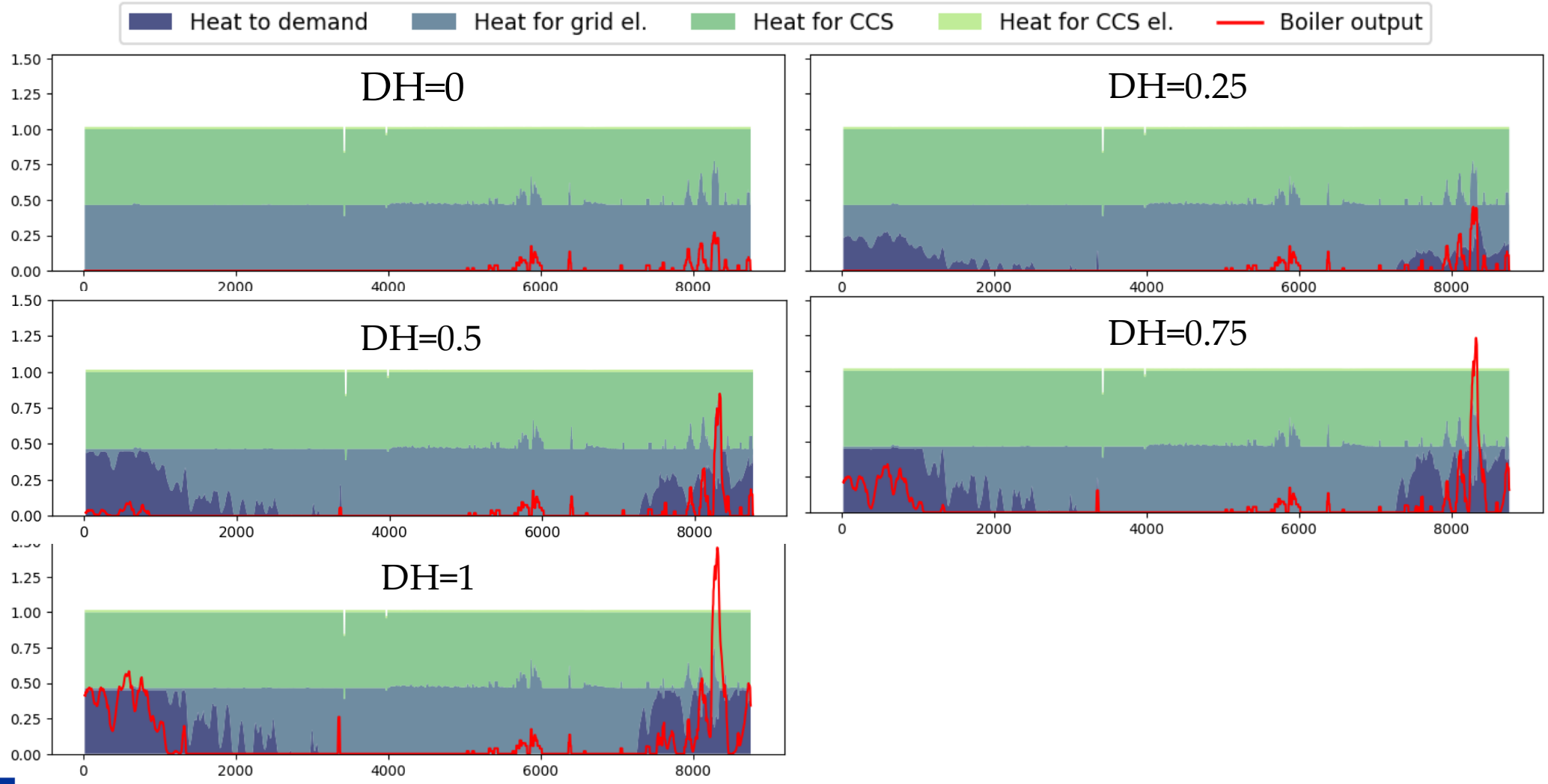
…with increasing district heating (DH) demand



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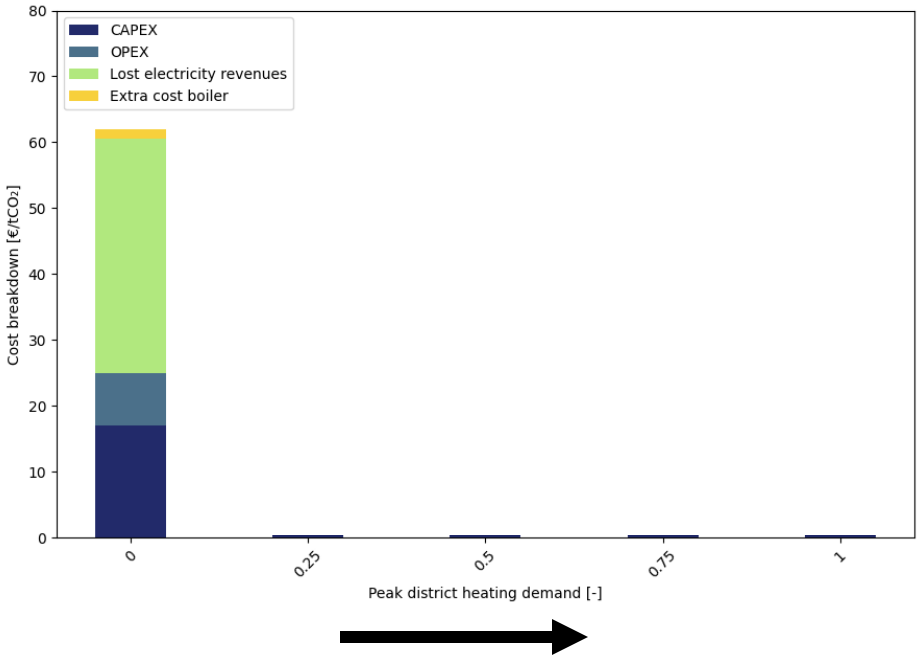
Impact of increasing DH demand on MEA costs

Time-resolved analysis

Cost of capture



Increasing DH demand

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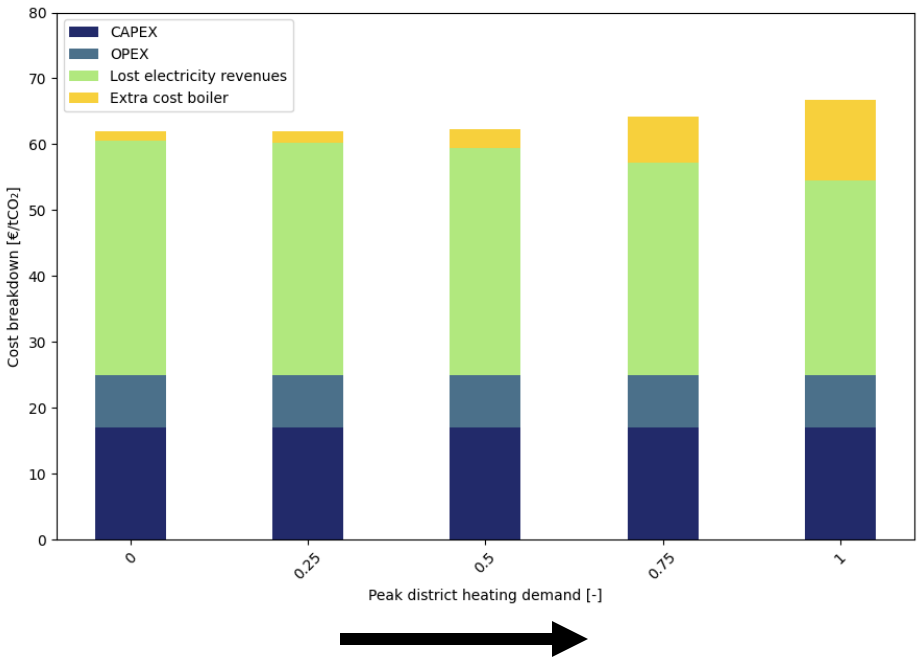
Assessing the opportunity cost of MEA in WtE

Time-resolved analysis

Cost of capture



Increasing DH demand

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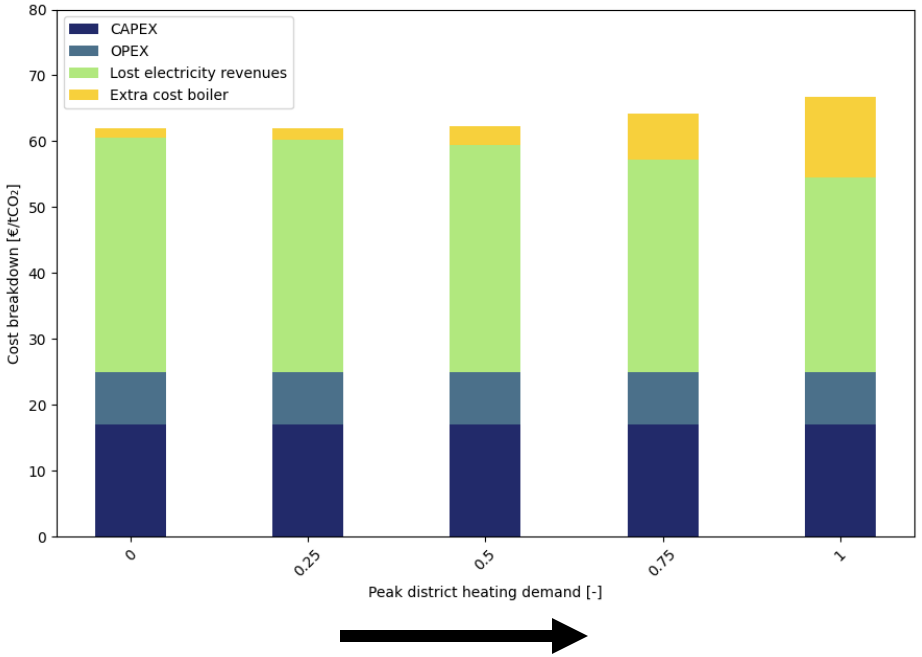
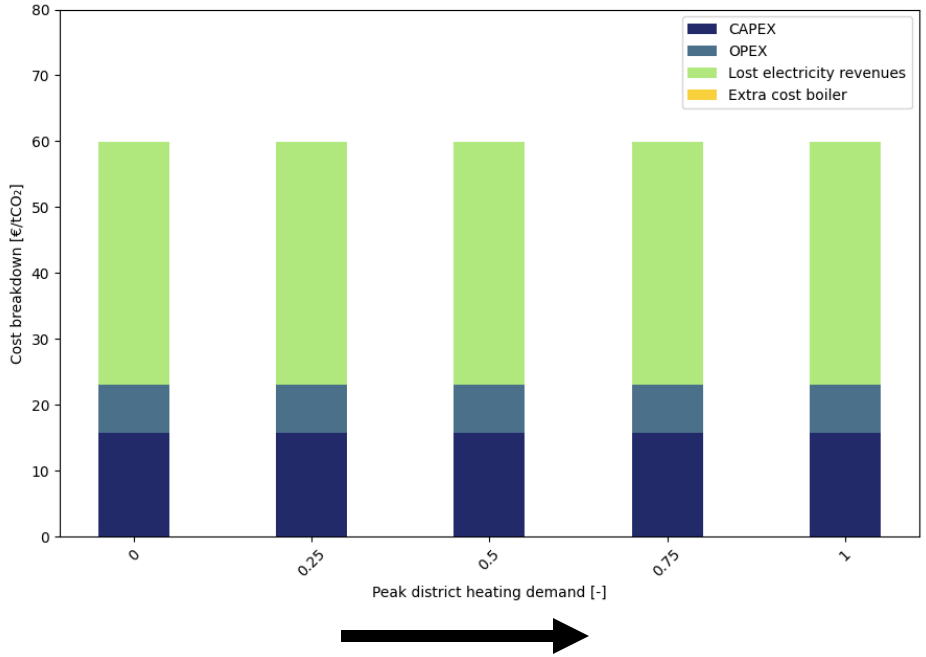


Increasing DH demand

Static analysis

Cost of capture



Increasing DH demand

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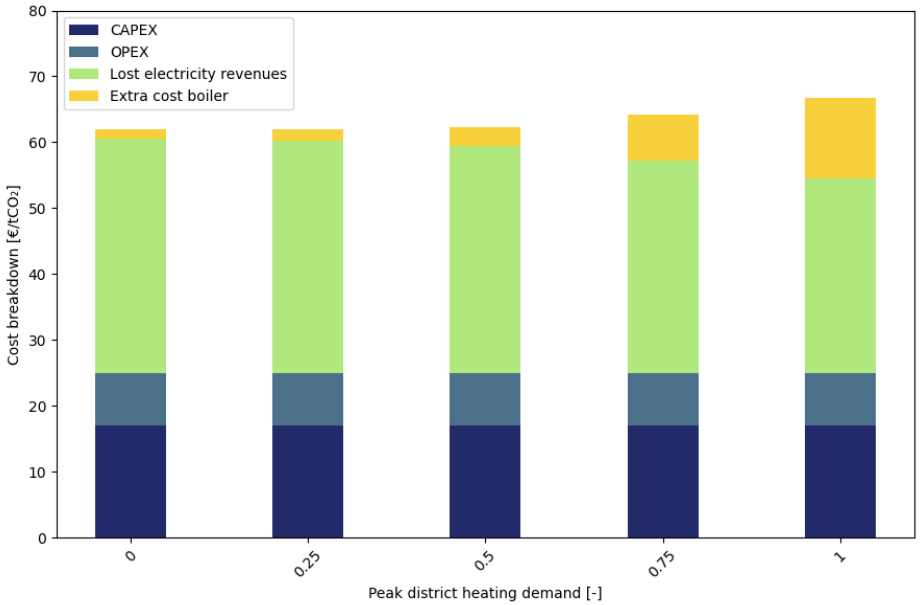
Assessing the opportunity cost of MEA in WtE

Time-resolved analysis

Cost of capture

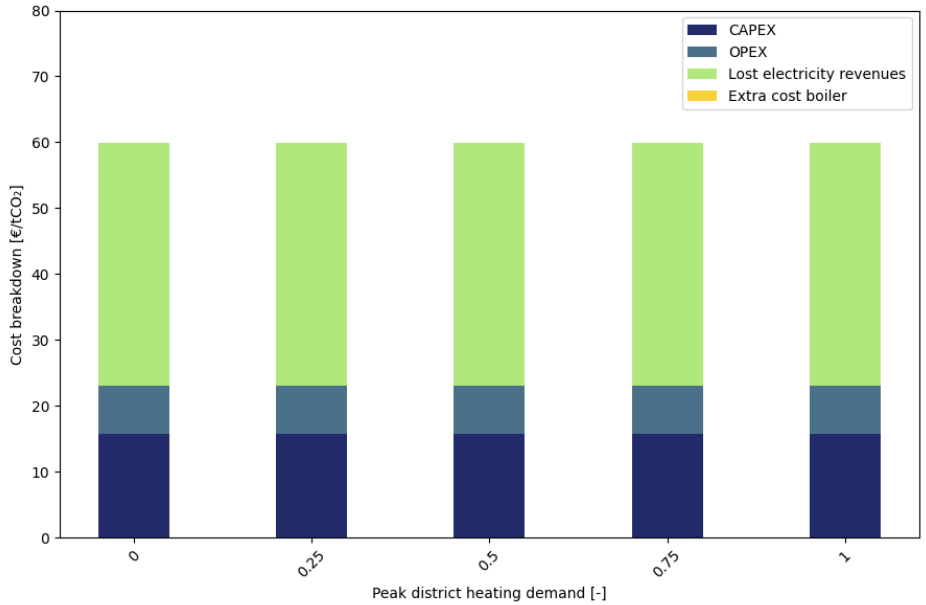


Increasing DH demand

Optimal CCS **size**: 88%

Static analysis

Cost of capture



Increasing DH demand

Optimal CCS **size**: 100%

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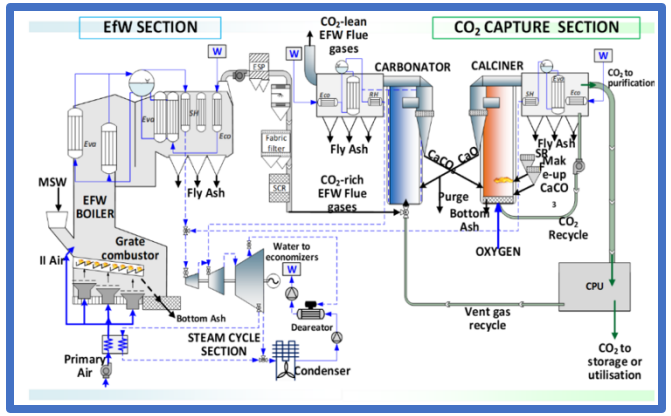
Capture technologies

Industry

Waste to energy

MEA [1]

Calcium looping



Cement

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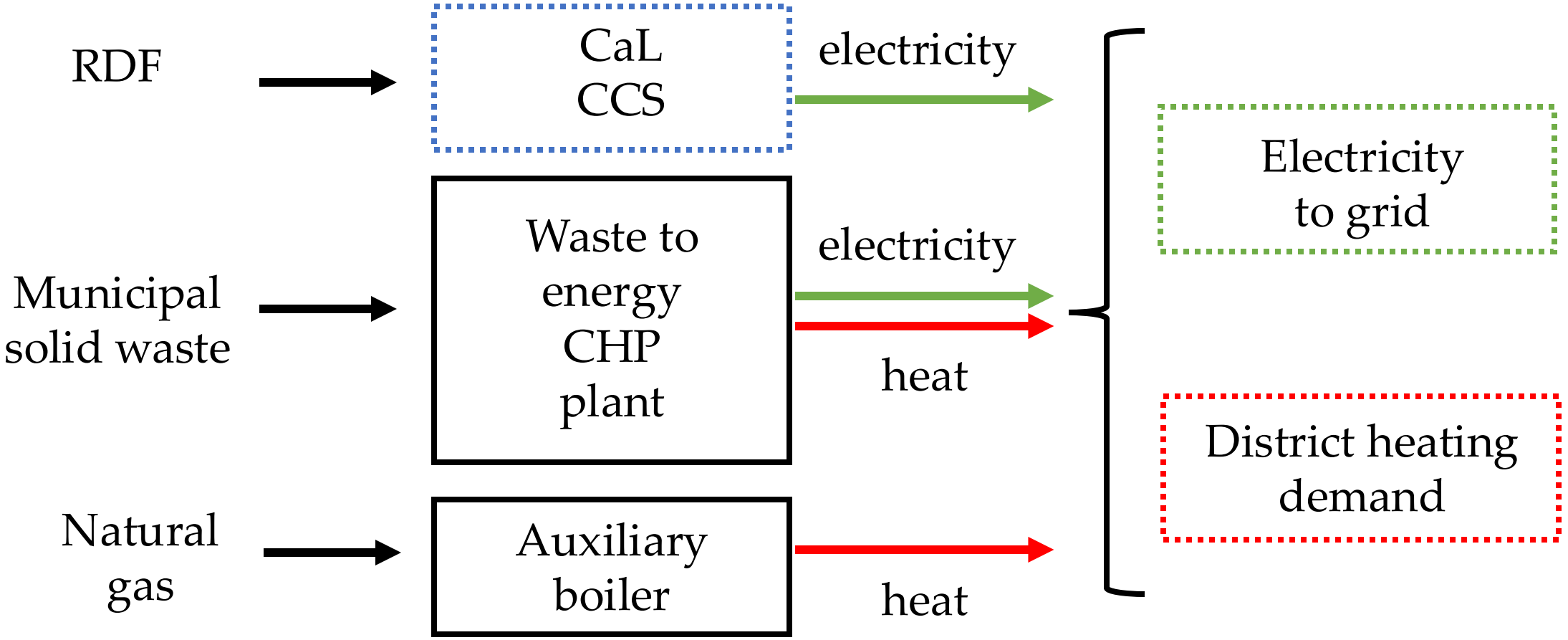
Application to a combined heat and power WtE with calcium looping



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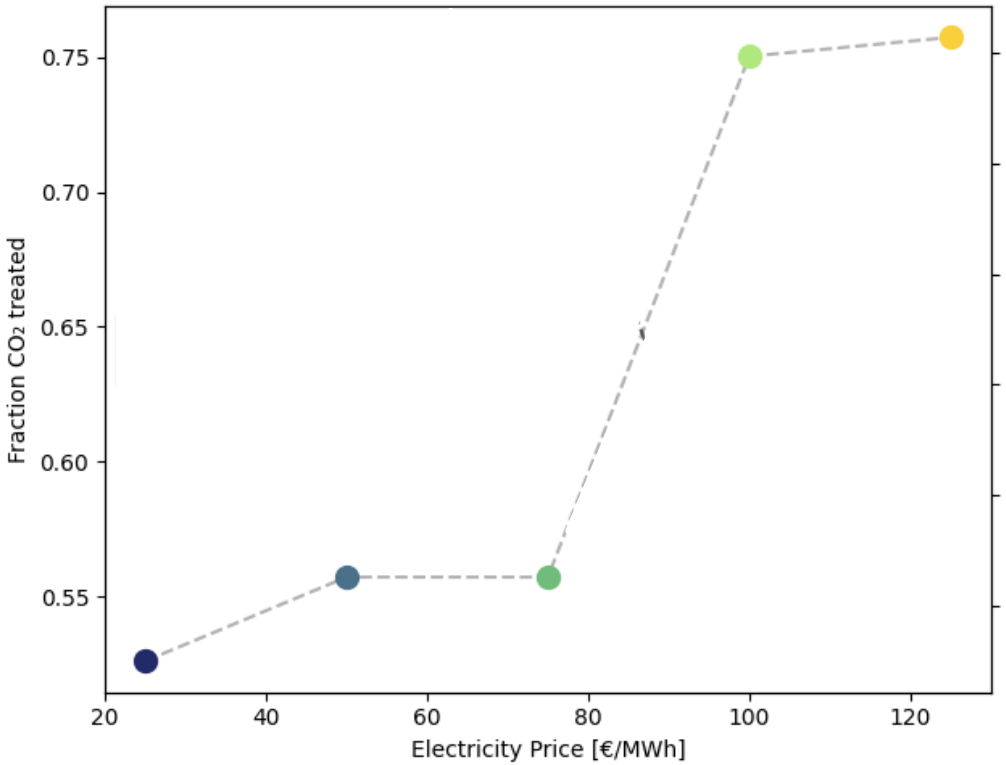
Calcium looping in WtE with varying el. prices

Optimal CaL size
(fraction of peak)



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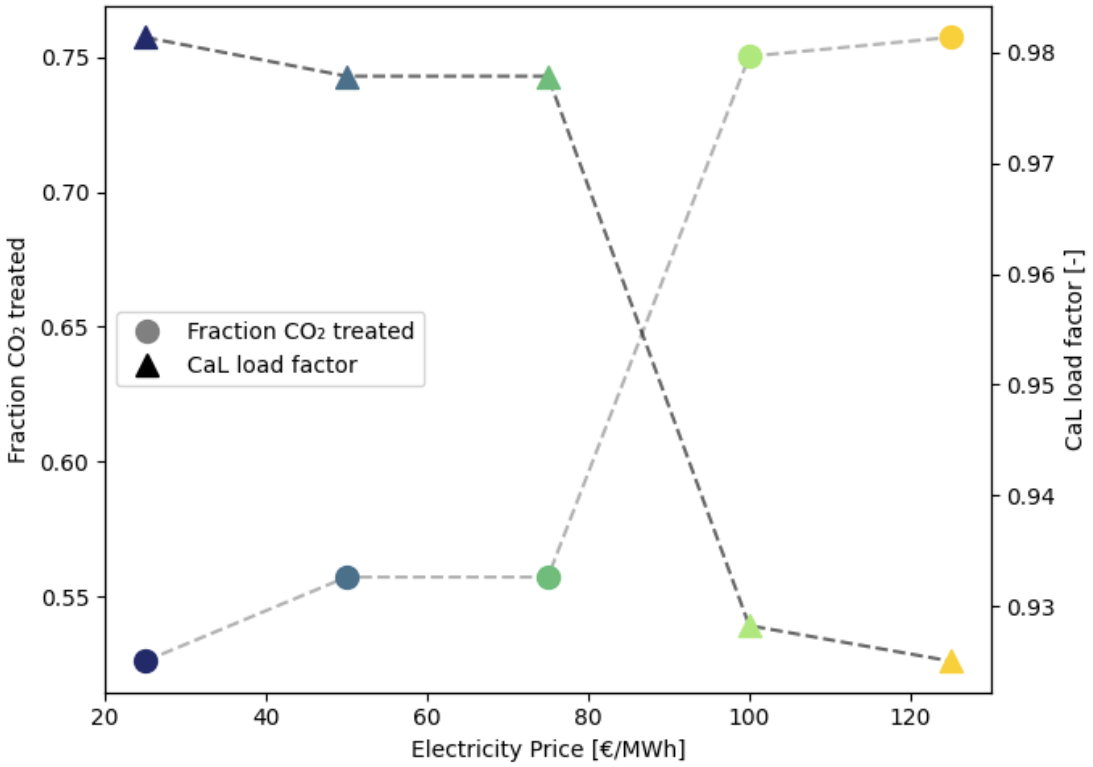
Calcium looping in WtE with varying el. prices

Optimal CaL size
(fraction of peak)



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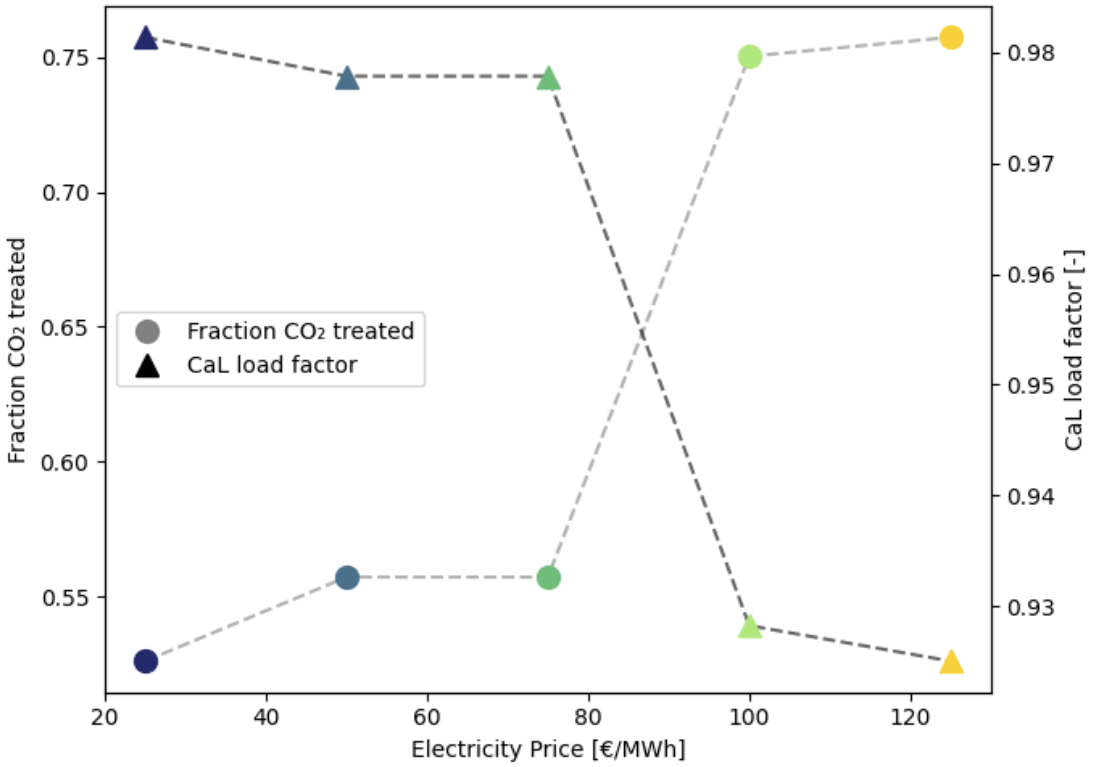
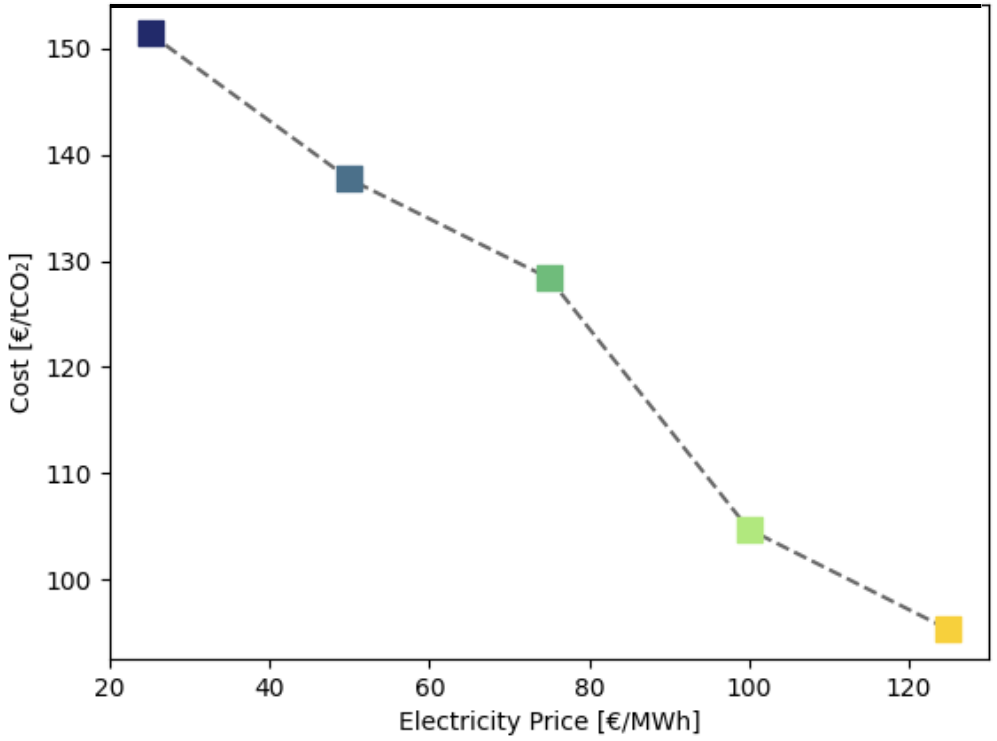
Calcium looping in WtE with varying el. prices

Optimal CaL size
(fraction of peak)



Cost of capture



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Conclusions

- The impact of the time-resolution changes with the industry and the characteristics of the plant
- Time-resolved models support the assessment of capture technologies in **technology selection**, **design** and **operation**
- They help **quantifying trade-offs** and improving the **economics** of the system

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Any questions?

Luca Bertoni

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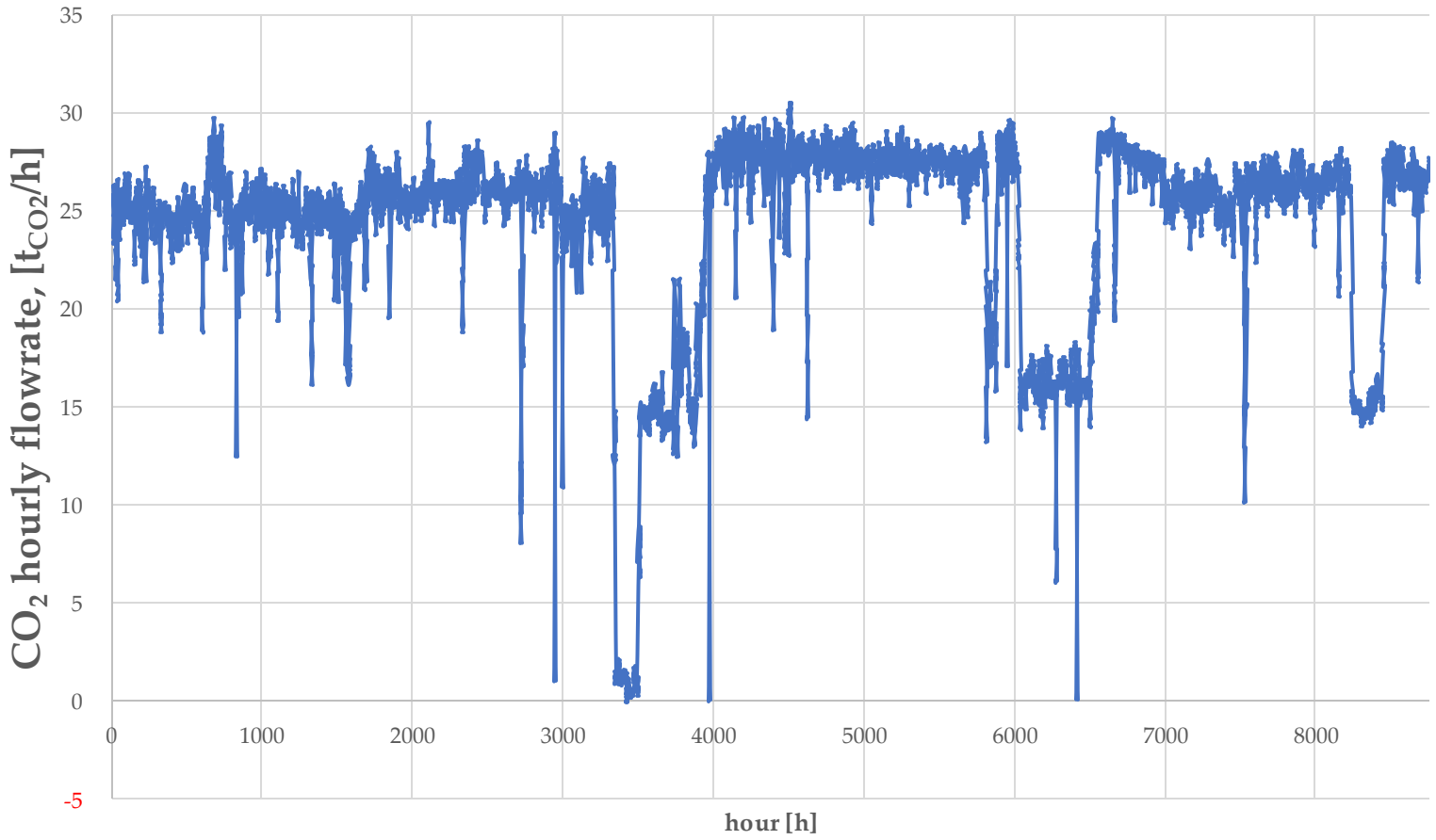
WtE profile



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Cement plants: capture technology selection

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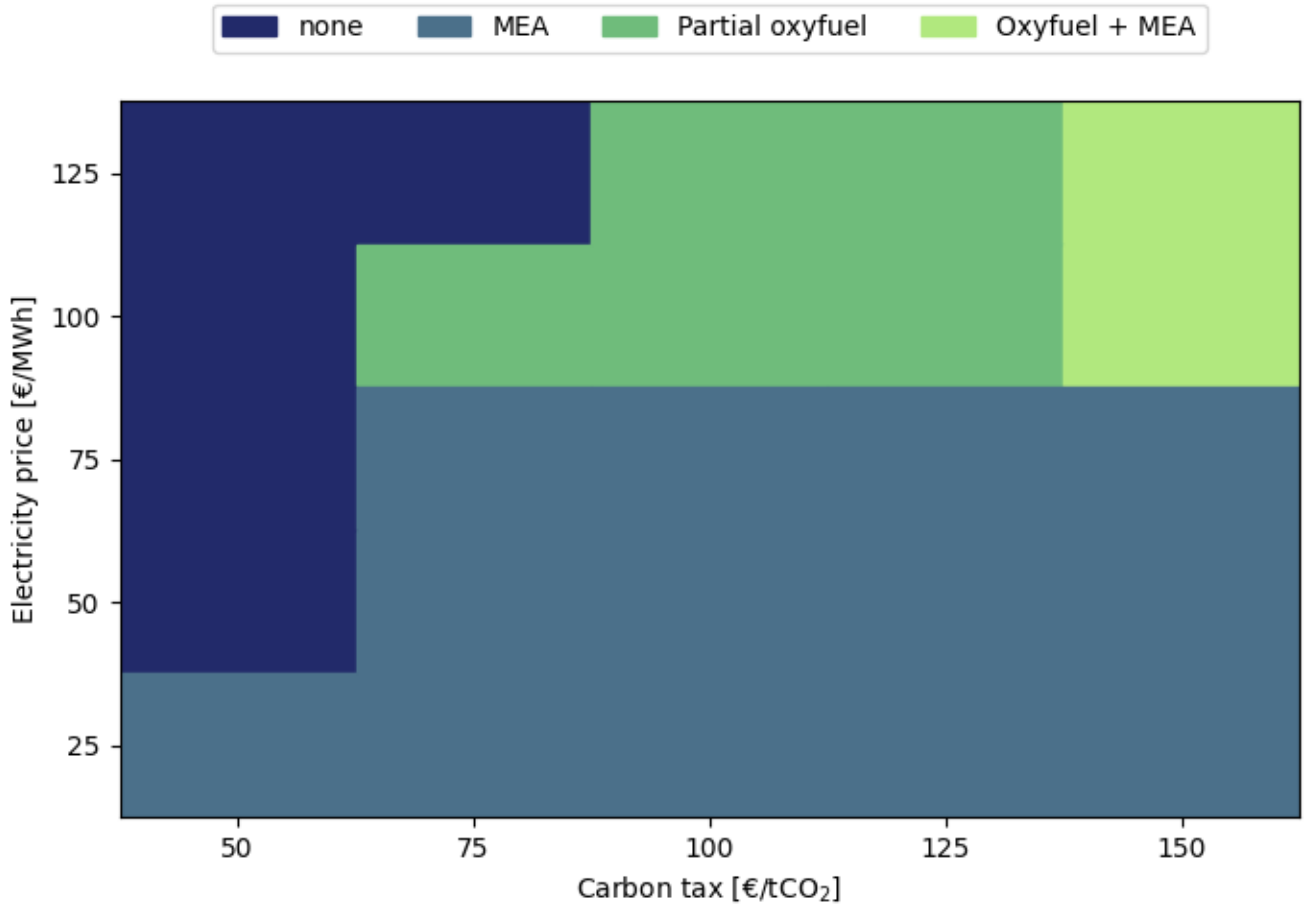
Cement plants: capture technology selection



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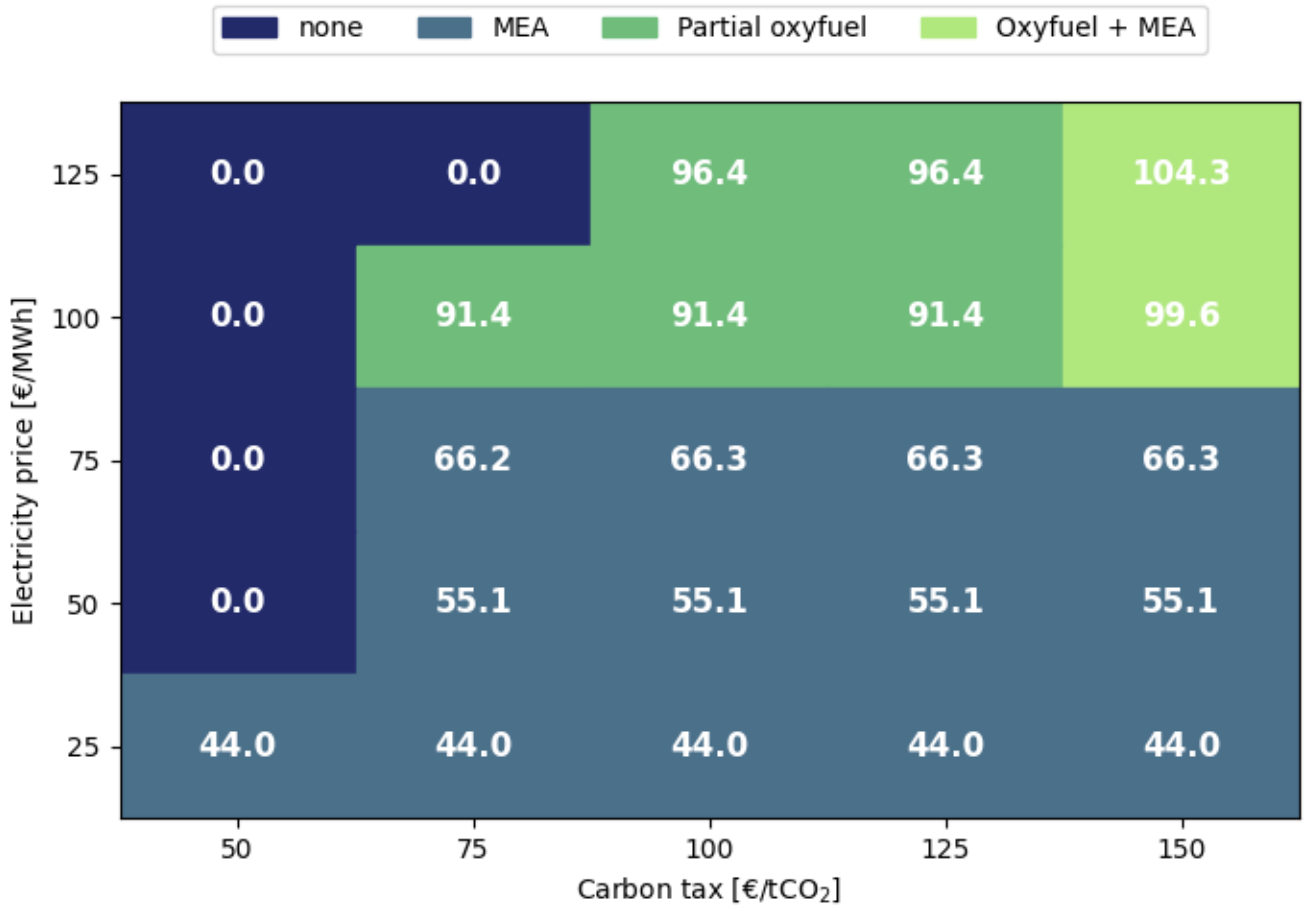
Cement plants: capture technology selection



Cost of capture in EUR/tCO_2

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Capture technologies

Industry

Waste to energy	MEA [1]	Calcium looping
Cement	MEA [1]	Partial oxyfuel only/ plus MEA

[1]: Weimann, L., Dubbink, G., van der Ham, L., & Gazzani, M. (2023). A thermodynamic-based mixed-integer linear model of post-combustion carbon capture for reliable use in energy system optimisation. *Applied Energy*, *336*. https://doi.org/10.1016/j.apenergy.2023.120738

HERCCULES full CCUS chain demonstration

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