High-Temperature Heat Pump Symposium
Copenhagen 29.-30.3.2022

Optimal operation of a conceptional industrial energy system including a high temperature heat pump, thermal energy storage and wind power

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Optimal operation of a conceptional industrial energy system

Introduction

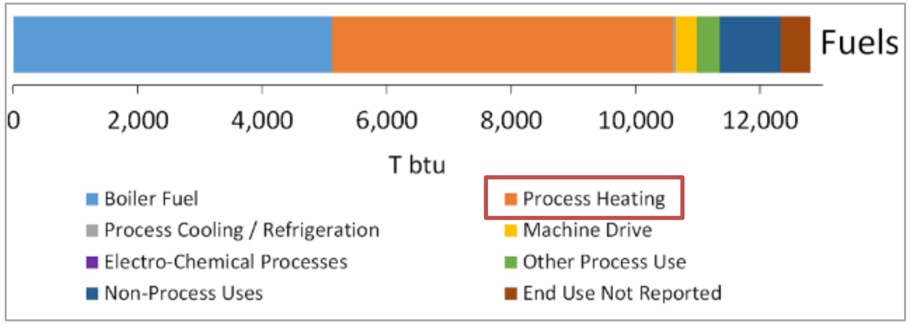
- Currently process heat is provided by combustion based technologies
- Future industrial plants are likely to have onsite renewable energy sources

I. What could an **electrified** industrial energy system look like?

II. How to model **nonlinear** component part load performance efficiently?

III. How to optimally operate the system with **fluctuating input parameters** to minimize CO_2 emissions?

Distribution of energy end-uses in the U.S. manufacturing sector in 2014.



Rissman, J., et al.: „Technologies and policies to decarbonize global industry: Review and assessment of mitigation drivers through 2070”. *Applied Energy*, p. 15, 2020

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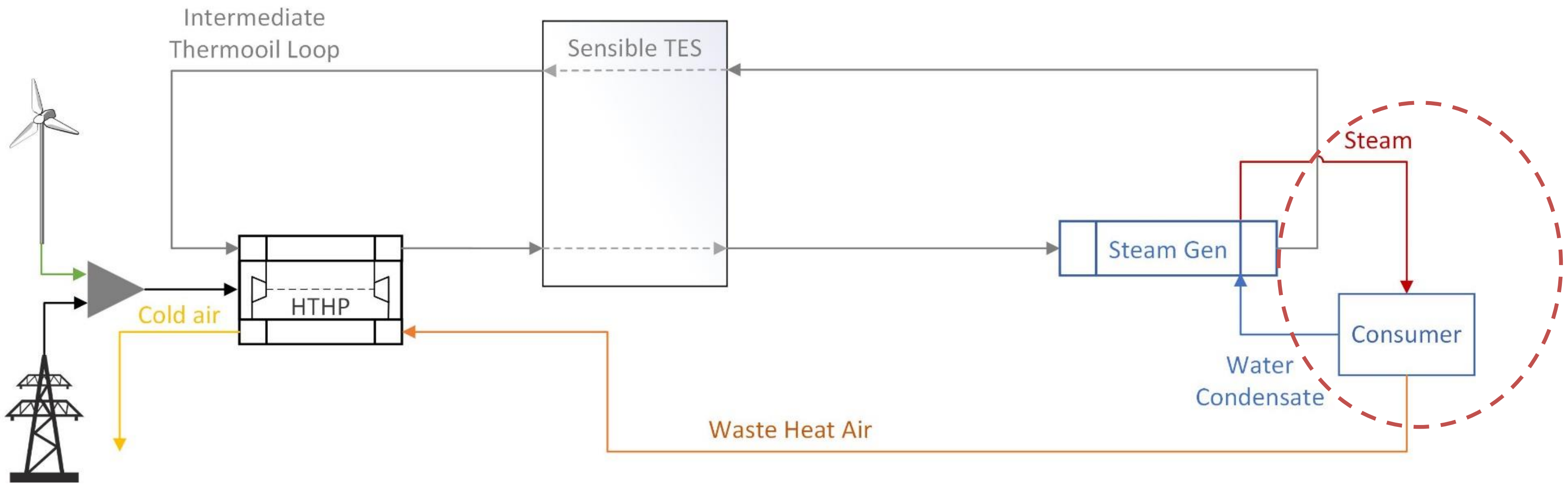
I. What could an electrified industrial energy system look like?



- Constant steam demand (215 °C, 4.5 MW_{th}) of an industrial application

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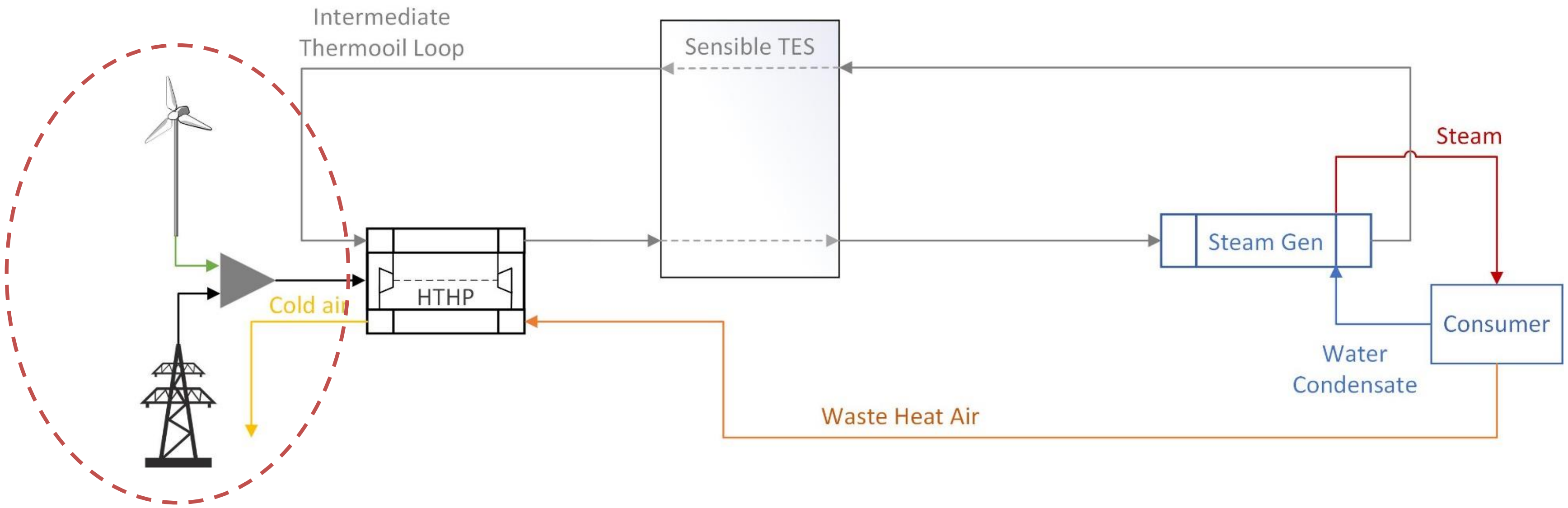

- Constant steam demand (215 °C, 4.5 MW_{th}) of an industrial application
- System is powered by wind turbine & grid electricity

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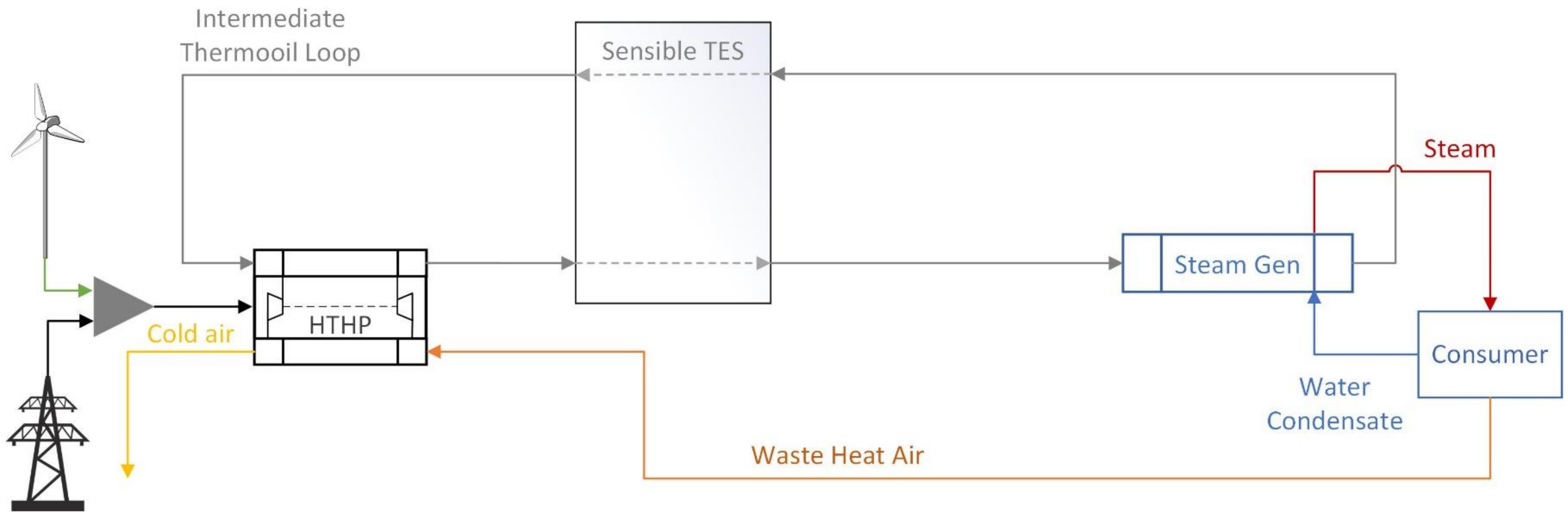

- Constant steam demand (215 °C, 4.5 MW_{th}) of an industrial application
- System is powered by wind turbine & grid electricity
- TES integrated with thermooil loop to control charging and discharging operation
- 75 °C air as heat source for the HTHP

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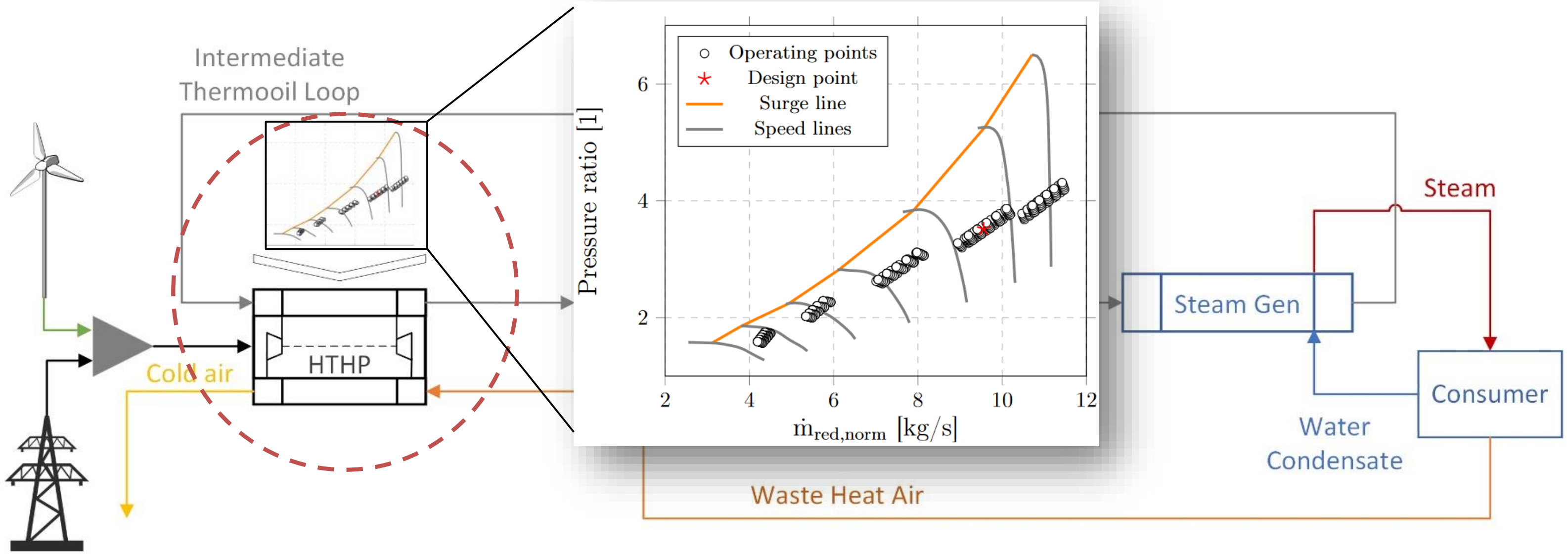
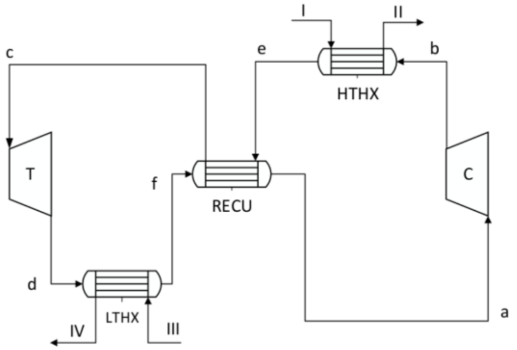
II. How to model nonlinear component part load performance efficiently?

Design-parameters	Value
COP [-]	1.45
P_{el} [MW]	3.2
Pressure ratio [-]	3.5
η_{HP} [%]	56.8





- Recuperated, reverse Brayton Cycle HTHP with air as working medium
- Modelled in process simulation software Ebsilon
  - Compressor part load performance by compressor map
  - Heat Exchanger with constant area & heat transfer coefficient

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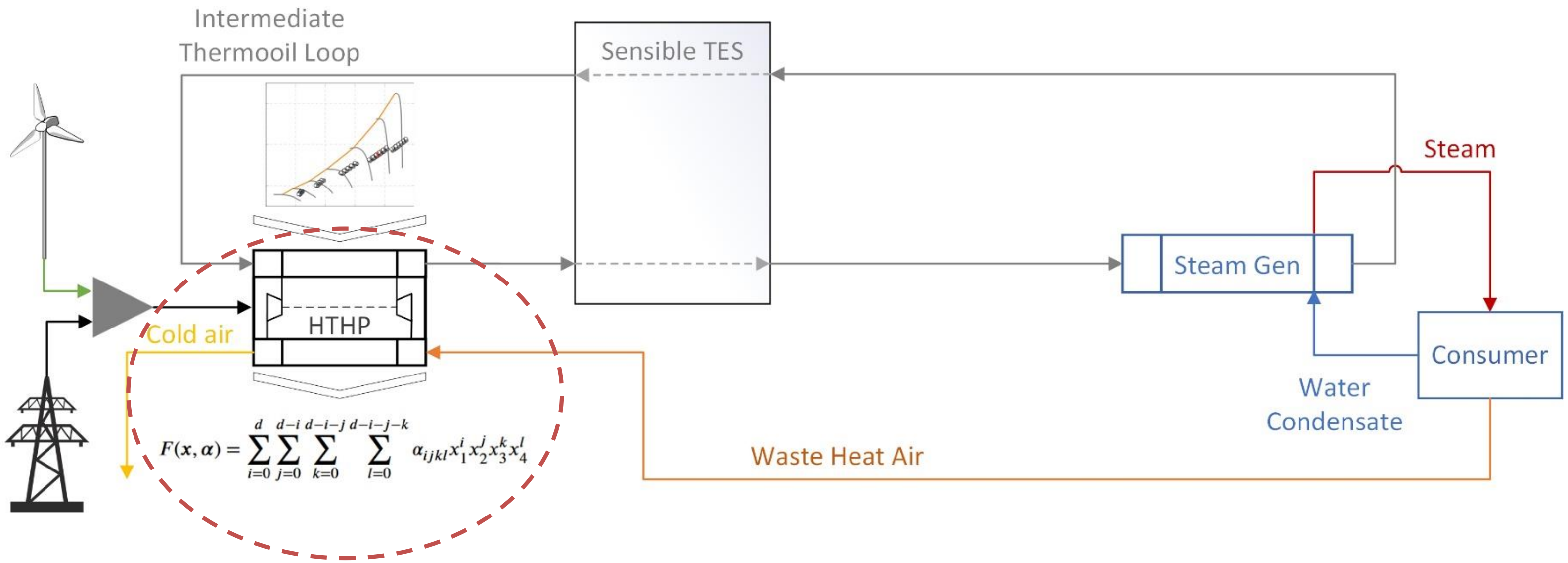
II. How to model nonlinear component part load performance efficiently?

$$P_{el} = F_{HTWP}(T_I, \dot{m}_I, T_{III}, N)$$

$$T_{II} = F_{HTHX}(T_I, \dot{m}_I, T_{III}, N)$$

$$T_{IV} = F_{LTHX}(T_I, \dot{m}_I, T_{III}, N)$$



- Map HTHP operating behaviour into nonlinear algebraic surrogate model by parameter variation

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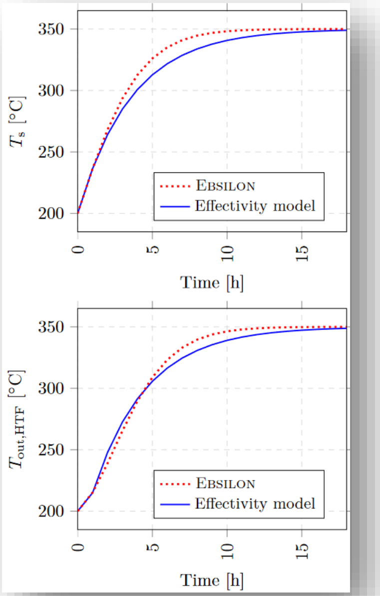

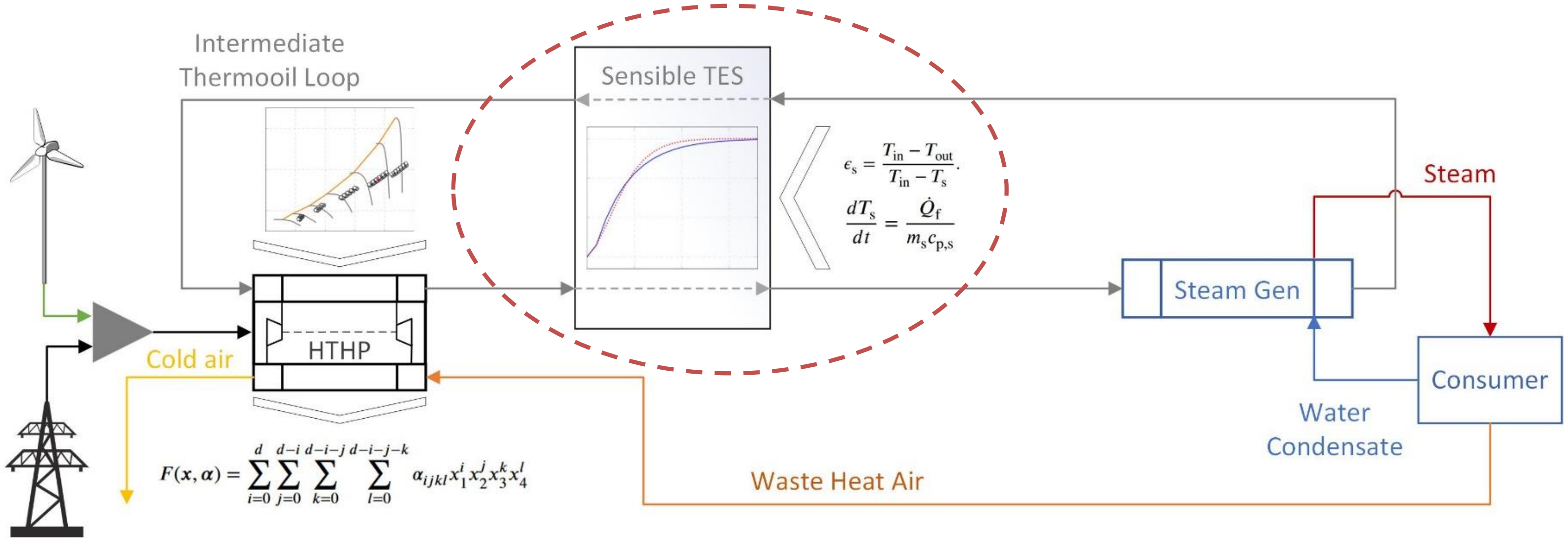

- Sensible Thermal Energy Storage based on EnergyNest Concrete Storage
- Simple TES model based on the effectiveness of heat transfer
- Uniform storage temperature

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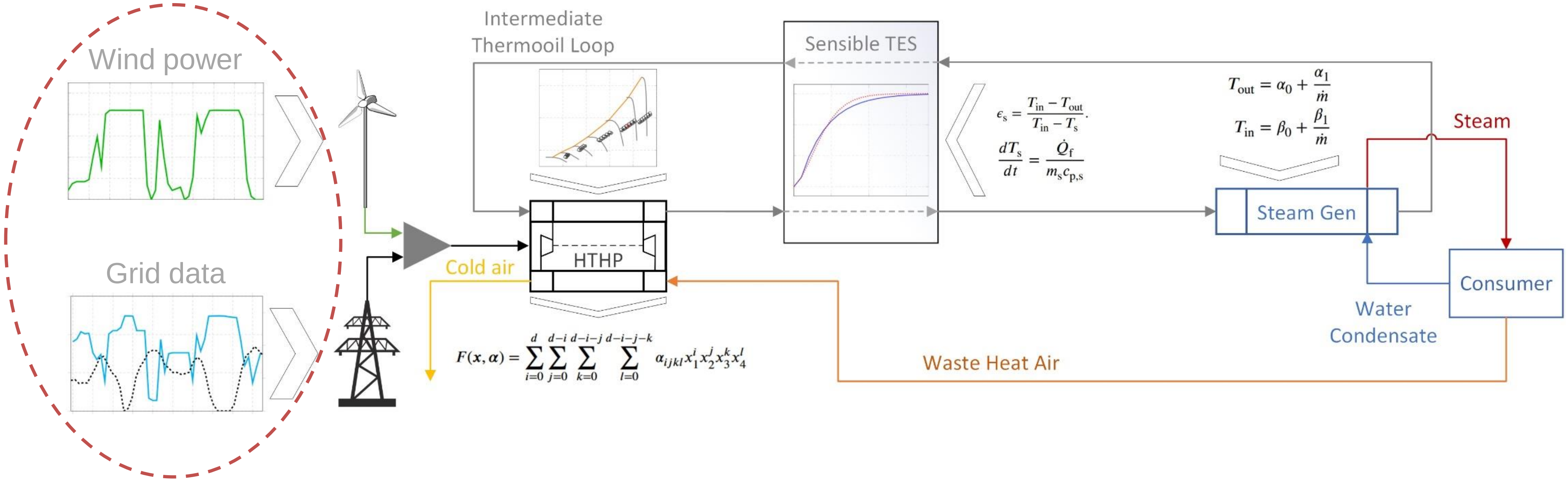

- Hourly historical data for:
  - Wind speeds
  - Electricity price
  - Grid emission factor

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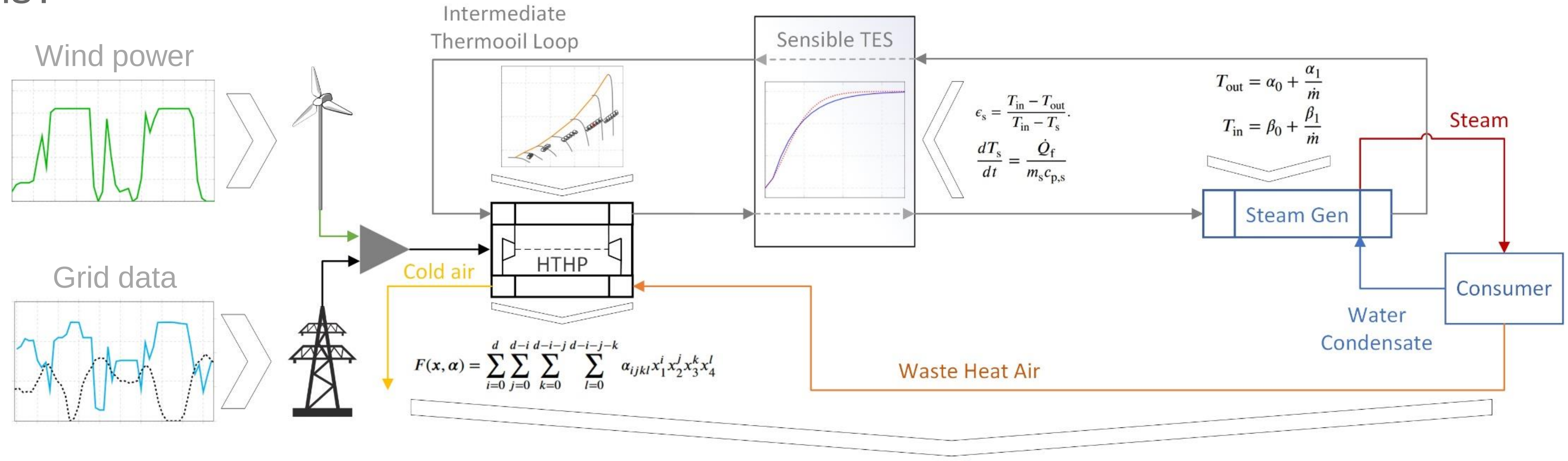
III. How to optimally operate the system with fluctuating input parameters to minimize CO2 emissions?



$$T_{out} = \alpha_0 + \frac{\alpha_1}{\dot{m}}$$

$$T_{in} = \beta_0 + \frac{\beta_1}{\dot{m}}$$

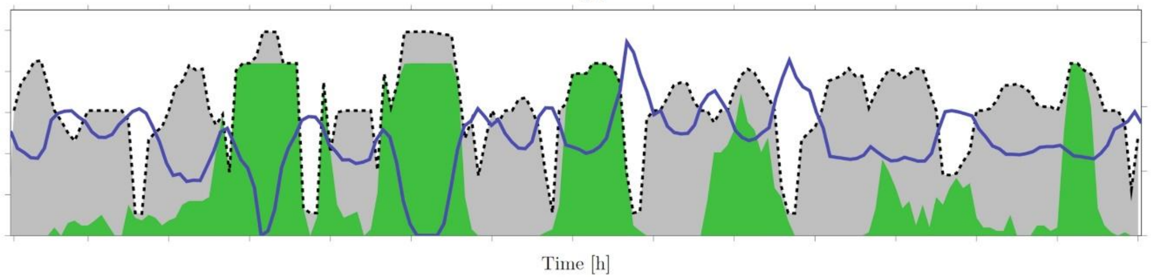
$$\epsilon_s = \frac{T_{in} - T_{out}}{T_{in} - T_s}.$$

$$\frac{dT_s}{dt} = \frac{\dot{Q}_f}{m_s c_{p,s}}$$

$$F(x, \alpha) = \sum_{i=0}^{d} \sum_{j=0}^{d-i} \sum_{k=0}^{d-i-j} \sum_{l=0}^{d-i-j-k} \alpha_{ijkl} x_1^i x_2^j x_3^k x_4^l$$

$$\min\ J(P_{grid}) = \sum_{k=1}^{n} C\left(P_{grid}^k\right) \Delta t$$

- Optimization for 168 hour time frame
- Data from Week 31, 2020



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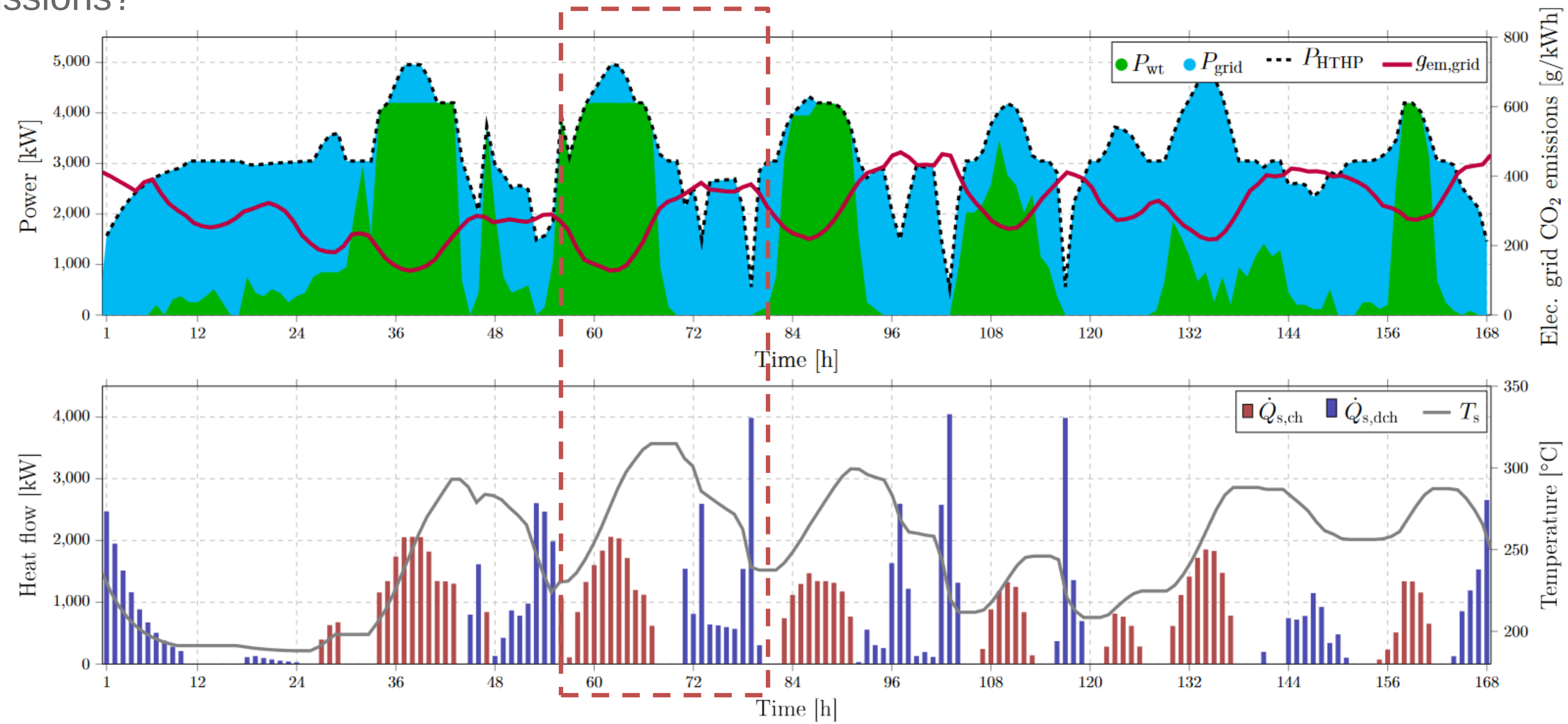

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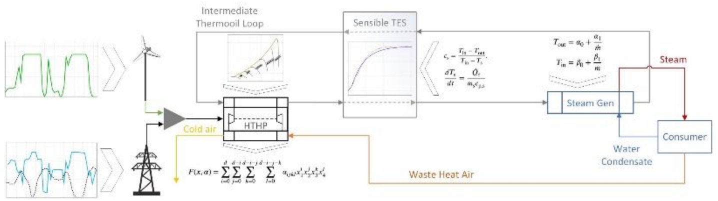
Conclusions

- A conceptual industrial energy system based on a hybrid electricity source was introduced
- Nonlinear HTHP part load behavior can be mapped into algebraic surrogate models
- Optimal operation and TES show a high potential to reduce the CO_2 emissions
- Basis for many future research topics: e.g. online optimization, design optimization, process integration



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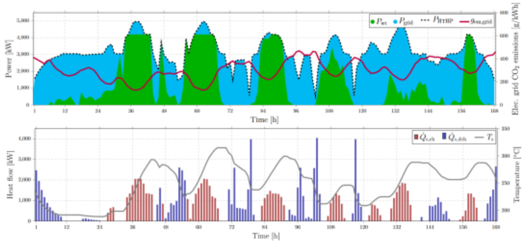

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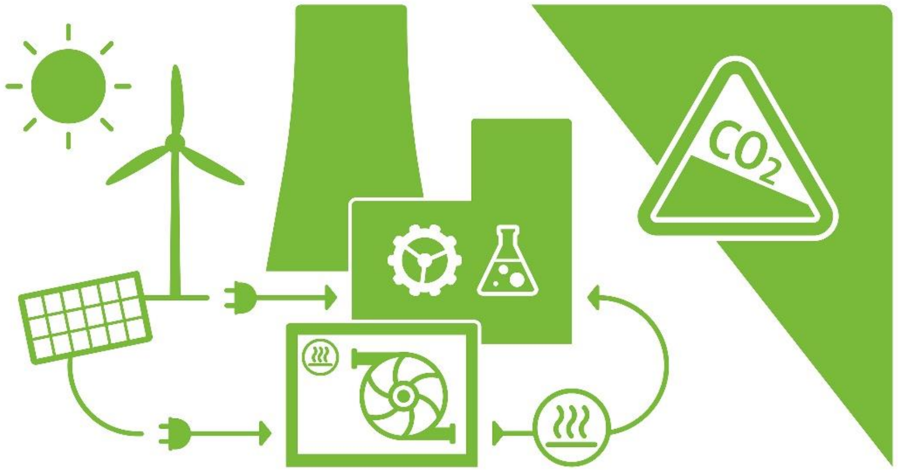
Questions?



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