# Spatio-temporal analysis of industrial excess heat as resource for district heating

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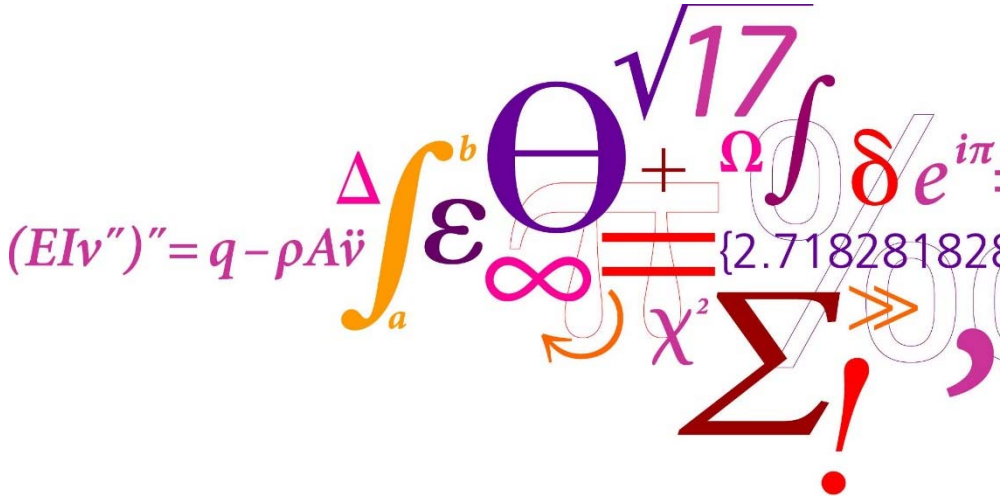
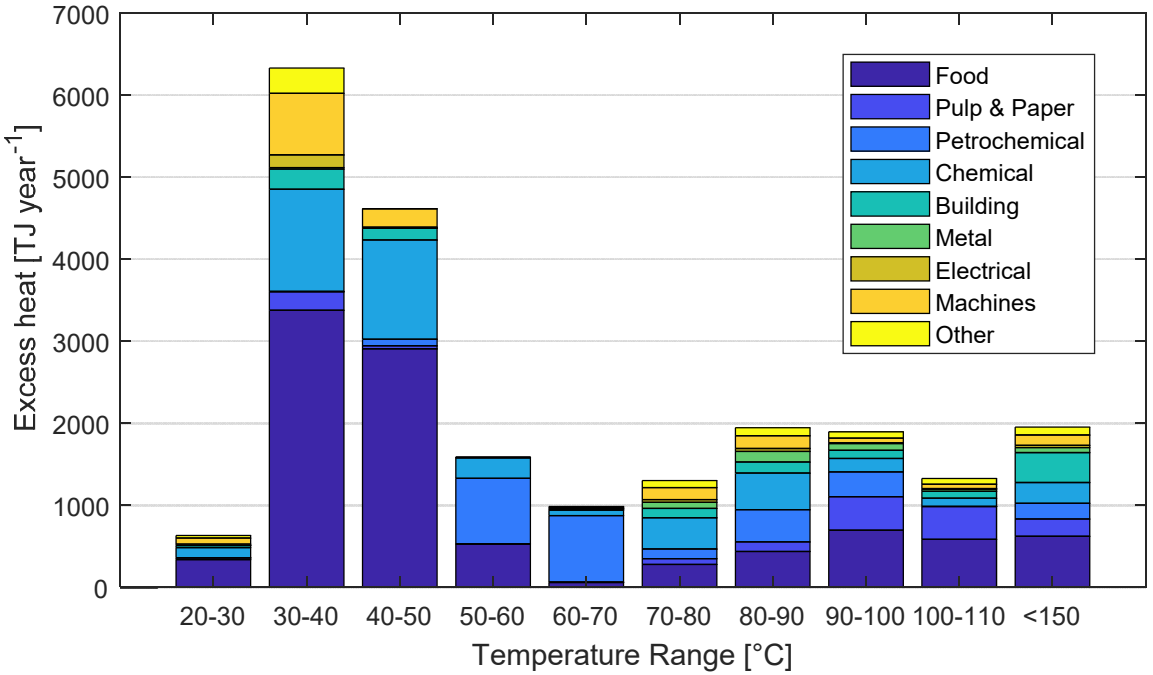


# Introduction

## Industrial excess heat

In Denmark:

- 212 PJ of excess heat per year available of which 23 % from the industry
- 101 PJ of district heat delivered to consumers in 2015 in Denmark




*Bühler F., Nguyen T-V., & Elmegaard B. (2016). Energy and Exergy Analyses of the Danish Industry Sector. Applied Energy, 184, 1447–1459.*

*Bühler F., Petrovic S., Ommen T.S., Holm F.M. & Elmegaard B. (2017). Identification of Excess Heat Utilisation Potential using GIS: Analysis of Case Studies for Denmark. In Proceedings of ECOS 2017.*

# Introduction

**Since 2006:**

- Utility companies have obligation to realize energy saving projects
- Latest agreement: 10.1 PJ/year in the period 2016-2020
- Since 2017: Heat pumps for district heating included

**Objective:**

- Determine potential for using excess heat for district heat
- Determine heating prices for excess heat sources
- Compare and evaluate industrial sectors

**Approach:**

- Spatial analysis
- Thermodynamic analysis
- Temporal patterns
- Economic evaluation

# Method

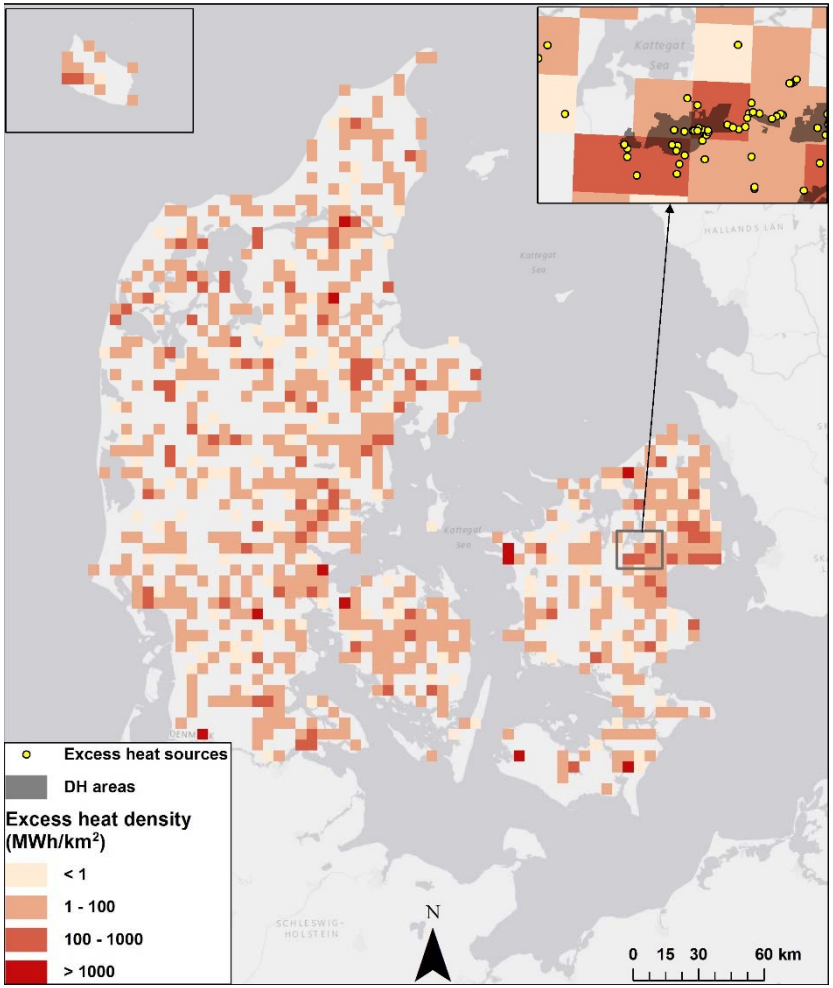
# Method
## Spatial analysis

Excess heat

- 2500 industrial sites with excess heat from thermal processes
- Excess heat distributed on 13 temperature levels

Heating demands

- 250 district heating areas
- Heating demand
- Supply and return temperature
- Distribution efficiency

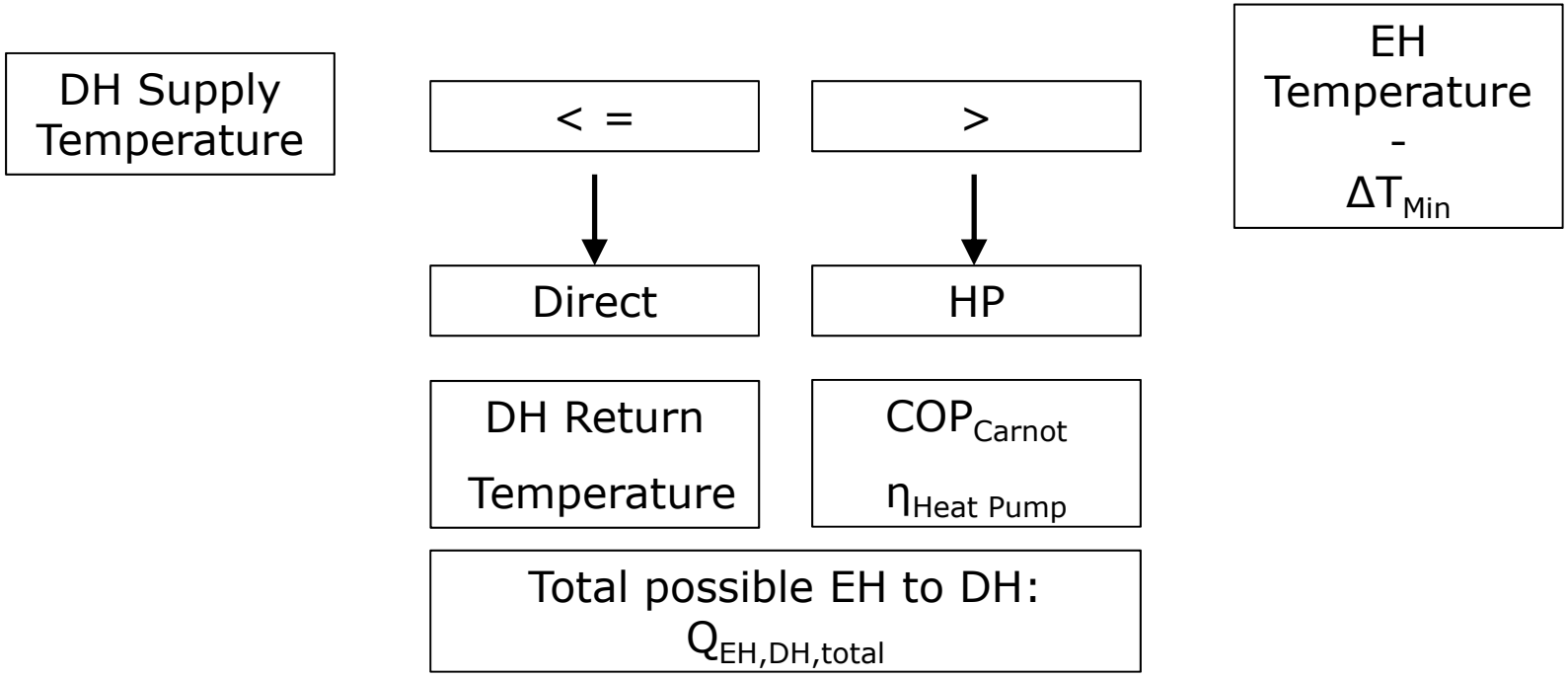



*Bühler. F.. Petrovic. S.. Karlsson. K. B.. & Elmegaard. B. (2017). Industrial excess heat for district heating in Denmark. Applied Energy. 205. 991-1001.*

# Method
## Thermodynamic analysis

Excess heat above 60°C -> gas -> $\Delta T_{Min}$ = 10 K

Excess heat below 60°C -> liquid -> $\Delta T_{Min}$ = 5 K

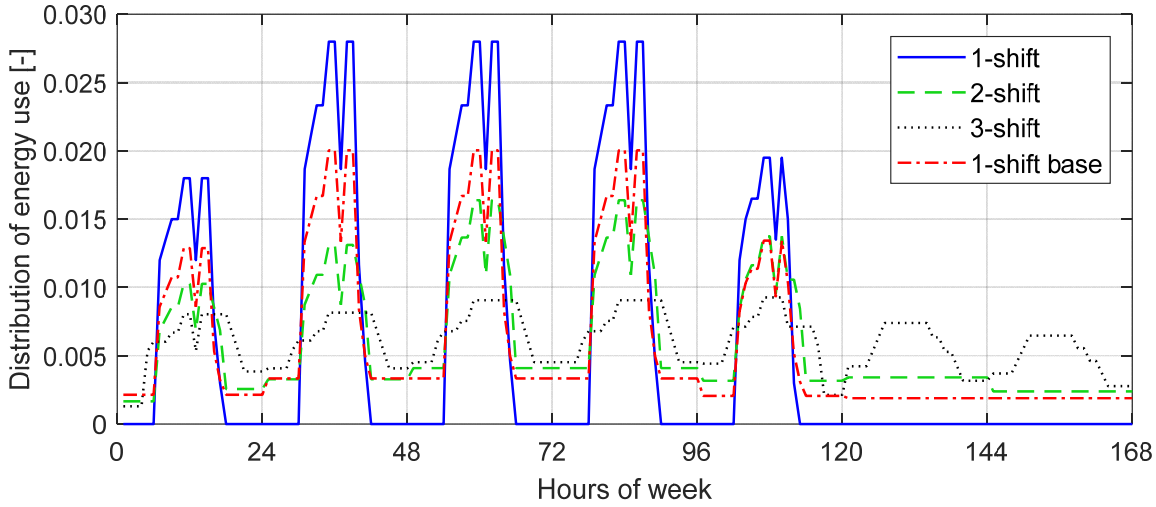


# Method

## Temporal analysis

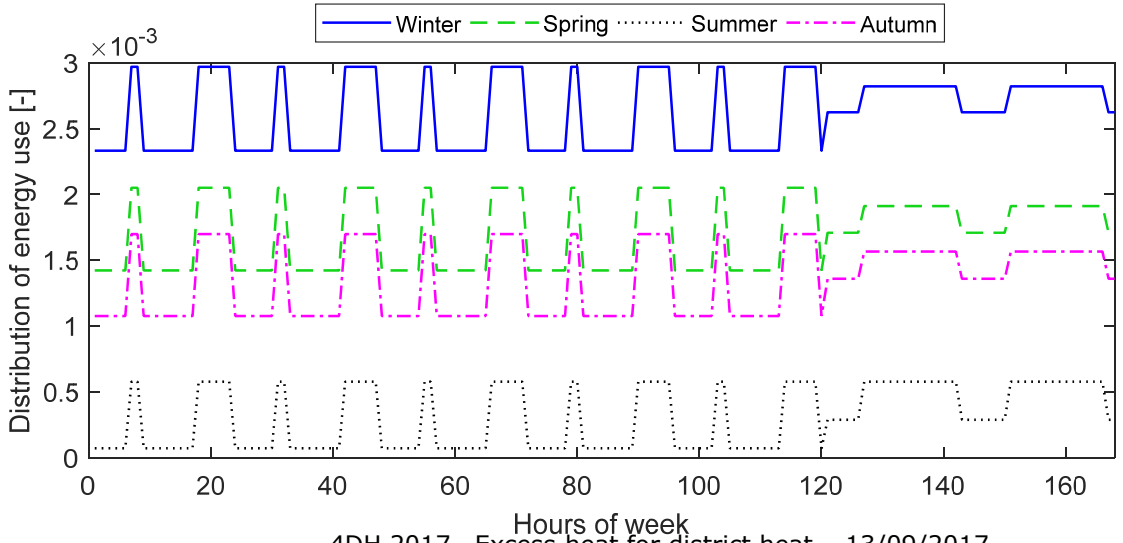
### Industry profiles

- Number of shifts partly determined by number of employees
- Seasonal variation for different industries



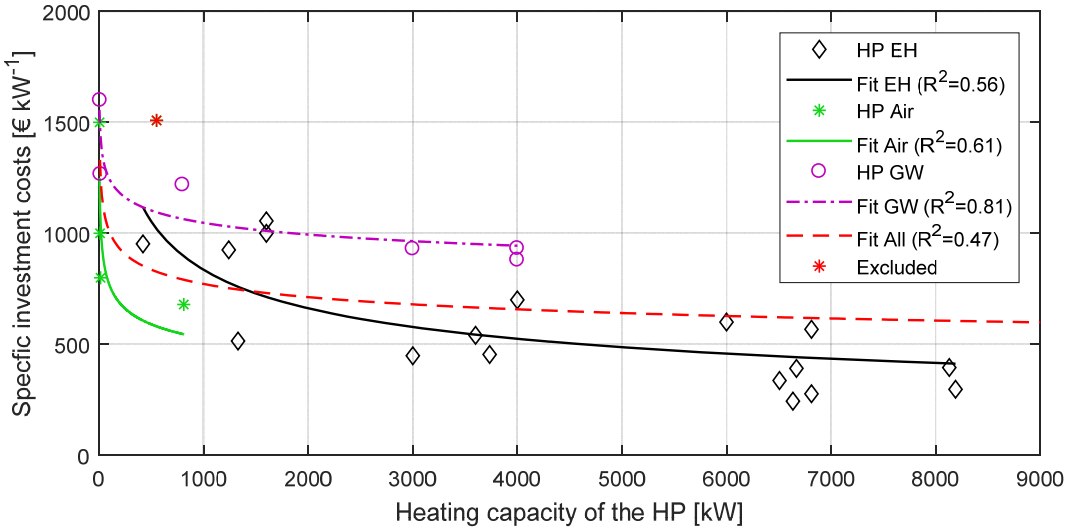

### District heating profiles

- Residential, office, recreational and culture
- Share of DH consumers for each DH area
- Four seasons



# Method
## Economic analysis

- Investment costs for *heat pump* based on installed HP systems in Denmark
- *Heat exchanger* cost estimation based on required heat transfer area
- Connection of EH and DH with *pipes* as a function of required capacity
- *Storage* costs divided into:
  - Vessels (<150 m³)
  - Tanks (<5000 m³)
  - Water pits




Evaluation and comparison based on heating price over a 20 year time span:

$$C_H = \left( CRF \times I + \frac{\sum_{n=1}^{n} C_{f,OM,n} + C_{v,OM,n}}{n} \right) \frac{1}{Q_{DH}}$$

# Results

# Results
## I. Temporal & thermodynamic analysis

| | $S_{Demand}$ [%] | $S_{Storage}$ [%] | $S_{HP}$ [%] | $COP$ [-] |
|---|---|---|---|---|
| Gravel & stone | 87.5 | 7.0 | 57.5 | 4.9 |
| Oil Refineries | 77.9 | 21.8 | 82.8 | 5.5 |
| Food | 99.9 | 6.3 | 28.1 | 4.8 |
| Sugar | 100.0 | 0.9 | 29.9 | 2.6 |
| Wood, pulp & paper | 100.0 | 8.6 | 0.3 | 4.2 |
| Chemical & pharma | 92.5 | 9.6 | 30.0 | 3.9 |
| Cement & bricks | 94.8 | 31.1 | 13.3 | 4.3 |
| Concrete products | 100.0 | 1.6 | 18.5 | 6.3 |
| Asphalt | 98.6 | 5.9 | 33.0 | 7.7 |
| Metal | 75.0 | 6.4 | 6.4 | 4.6 |
| Metal products | 99.9 | 0.4 | 8.5 | 4.3 |

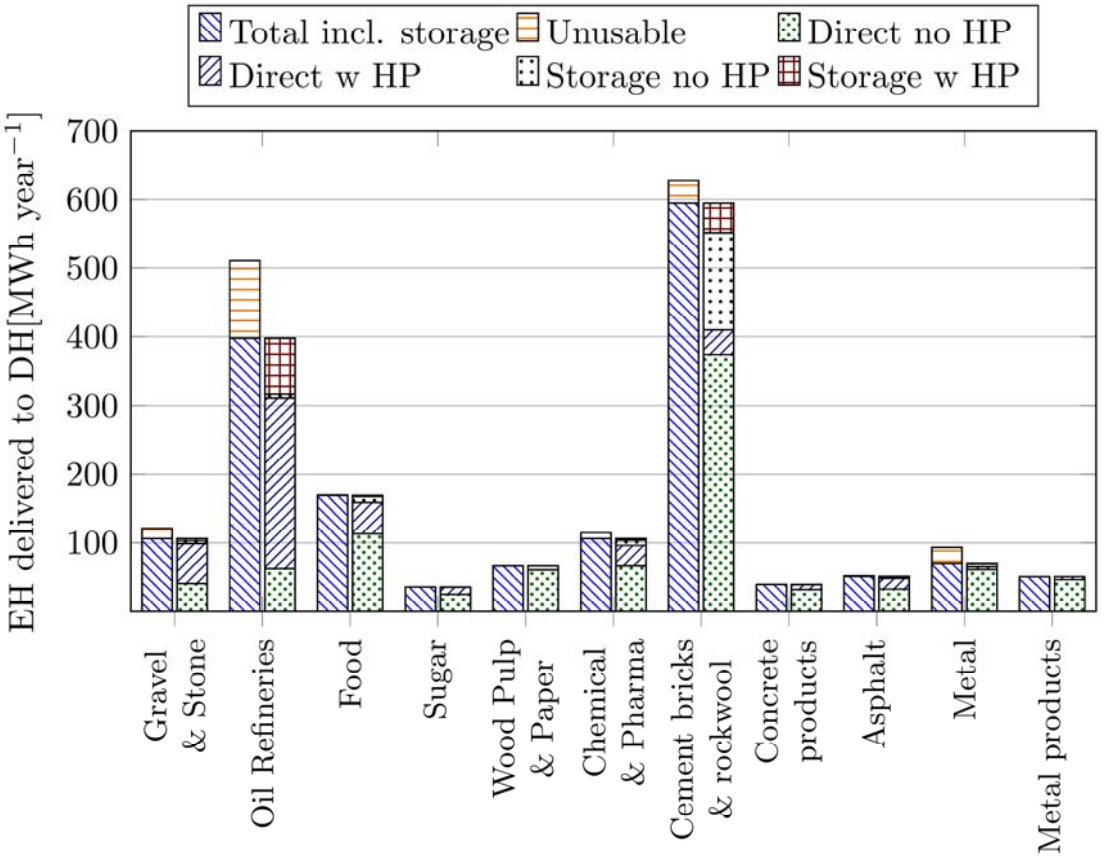
$$S_{Demand} = \frac{Q_{DH}}{Q_{EH,total}} \times 100\%$$

$$S_{Storage} = \frac{Q_{DH,storage}}{Q_{DH}} \times 100\%$$

$$S_{HP} = \frac{Q_{DH,HP}}{Q_{DH}} \times 100\%$$

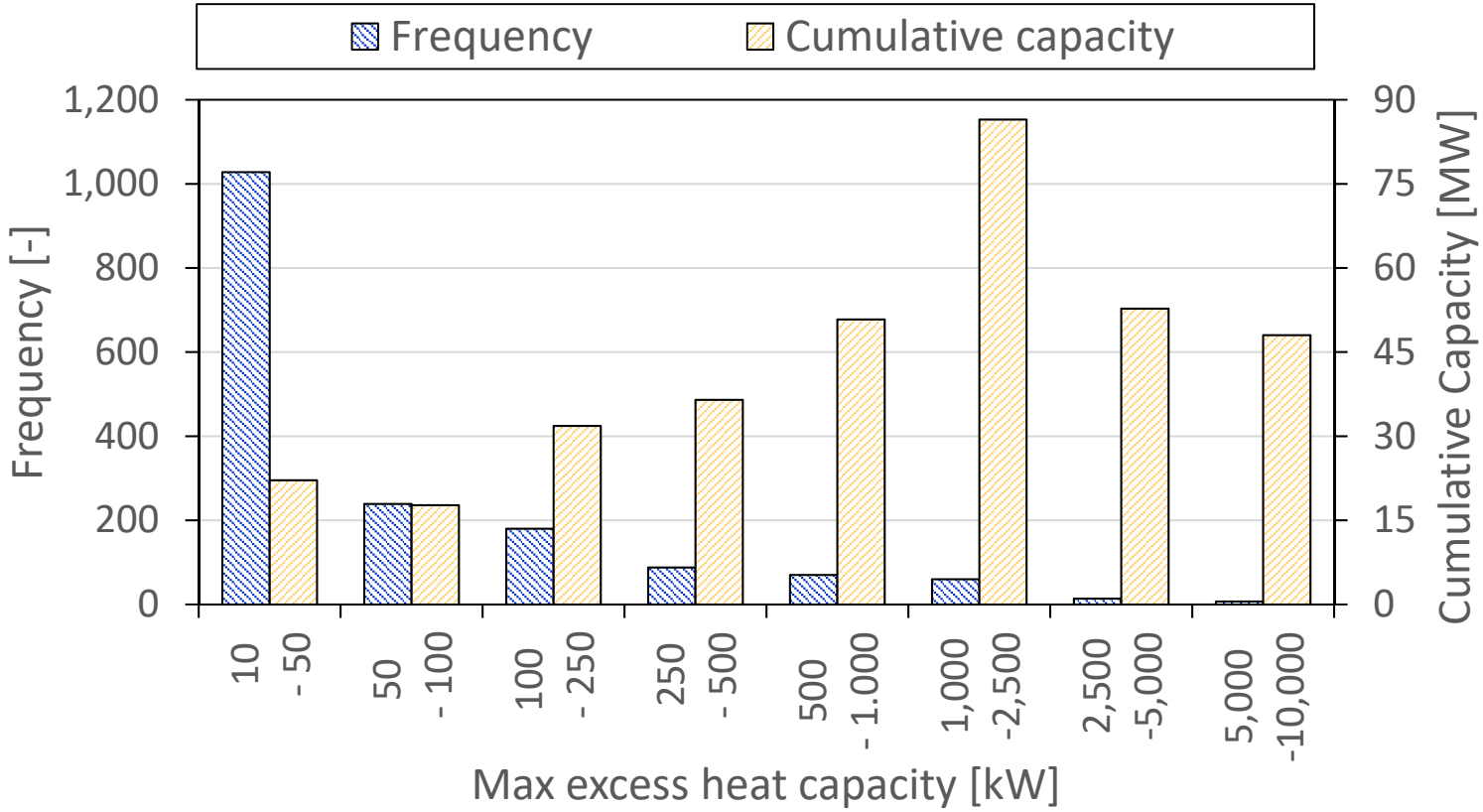
$$COP = \frac{Q_{DH,HP}}{P_{HP}}$$

# Results
## II. Temporal & thermodynamic analysis



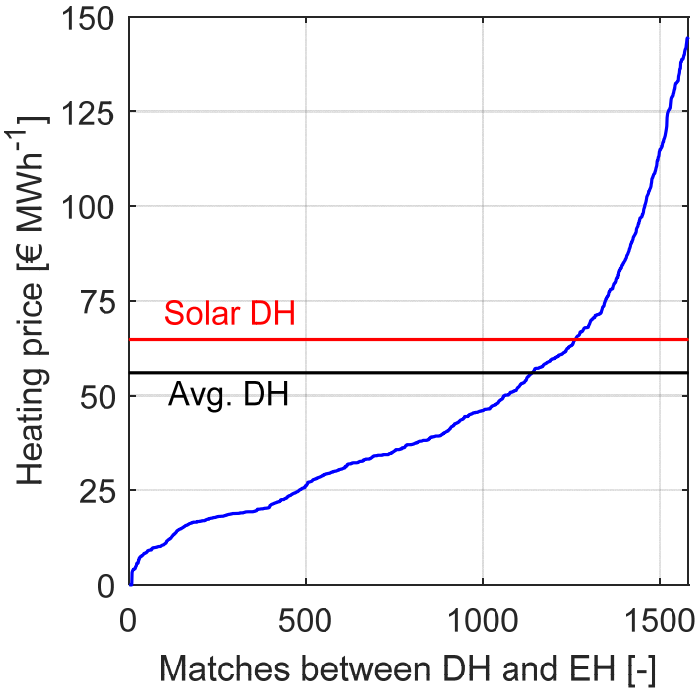

- Unusable EH due to lack of demand
- Direct utilization supply from storage

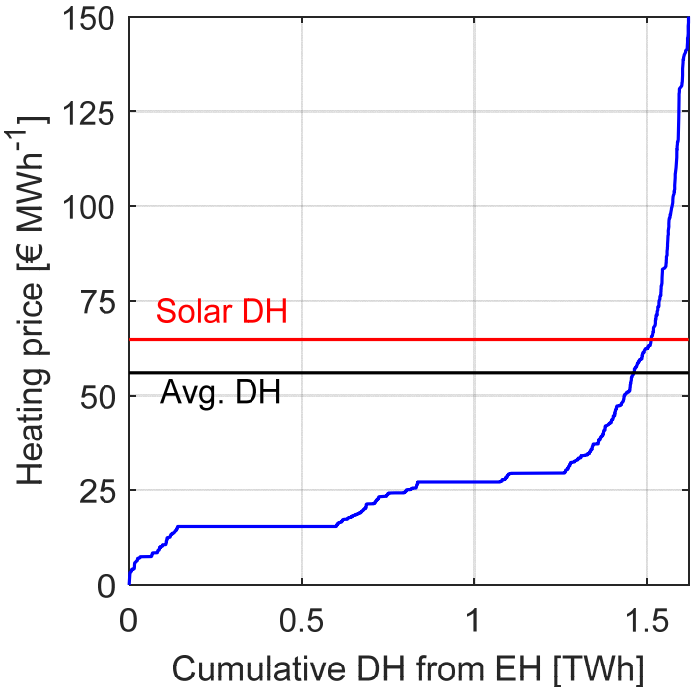
# Results
## III. Temporal & thermodynamic analysis



# Results

## I. Economic analysis




Marginal DH price[1] [Euro MWh$^{-1}$]

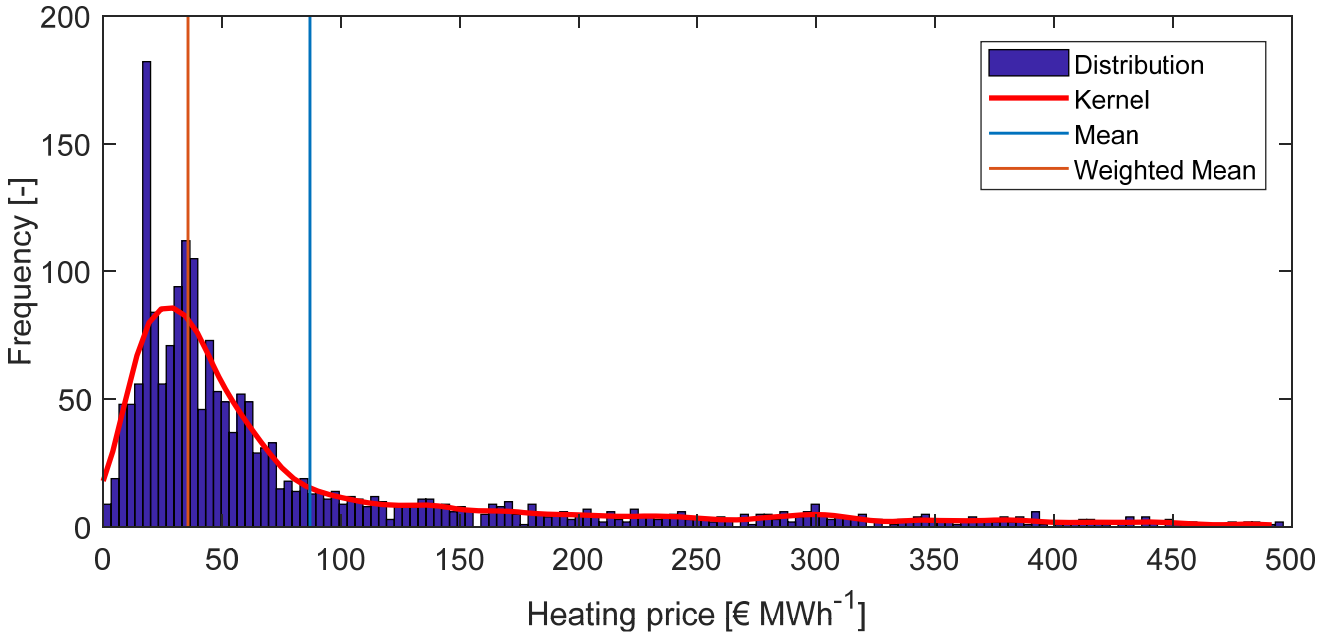
| | 2020 | 2025 | 2035 | 2050 |
|---|---|---|---|---|
| Min | 27.7 | 29.2 | 32.6 | 40.4 |
| Max | 38.4 | 42.8 | 45.7 | 49.6 |

Solar DH price with 100 % of heating demand covered[2]

[1] Ea Energianalyse (2014). Fjernvarmeanalyse – bilagsrapport.

[2] Energistyrelsen (2015). Technology Data for Energy Plants.

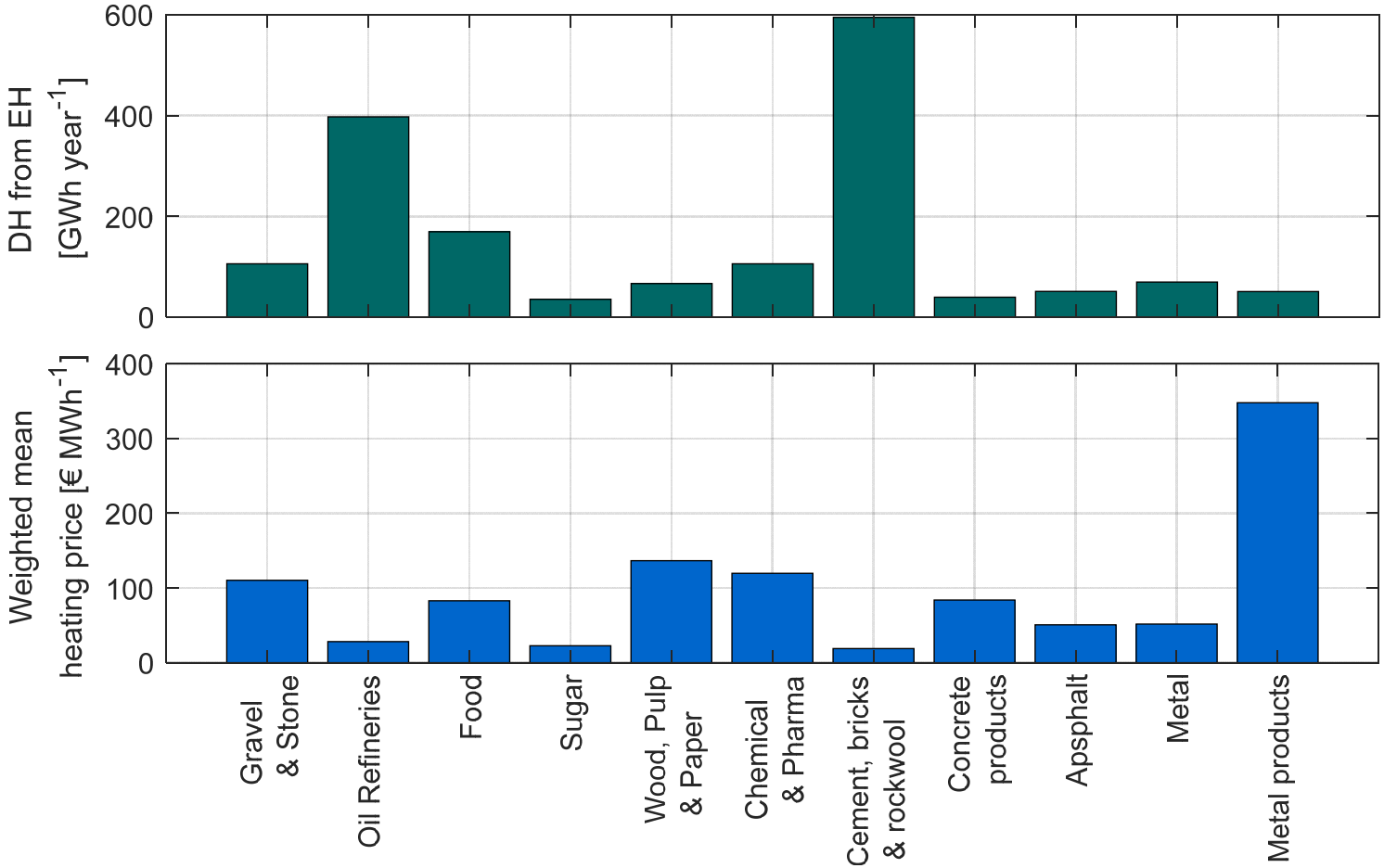
# Results
## II. Economic analysis



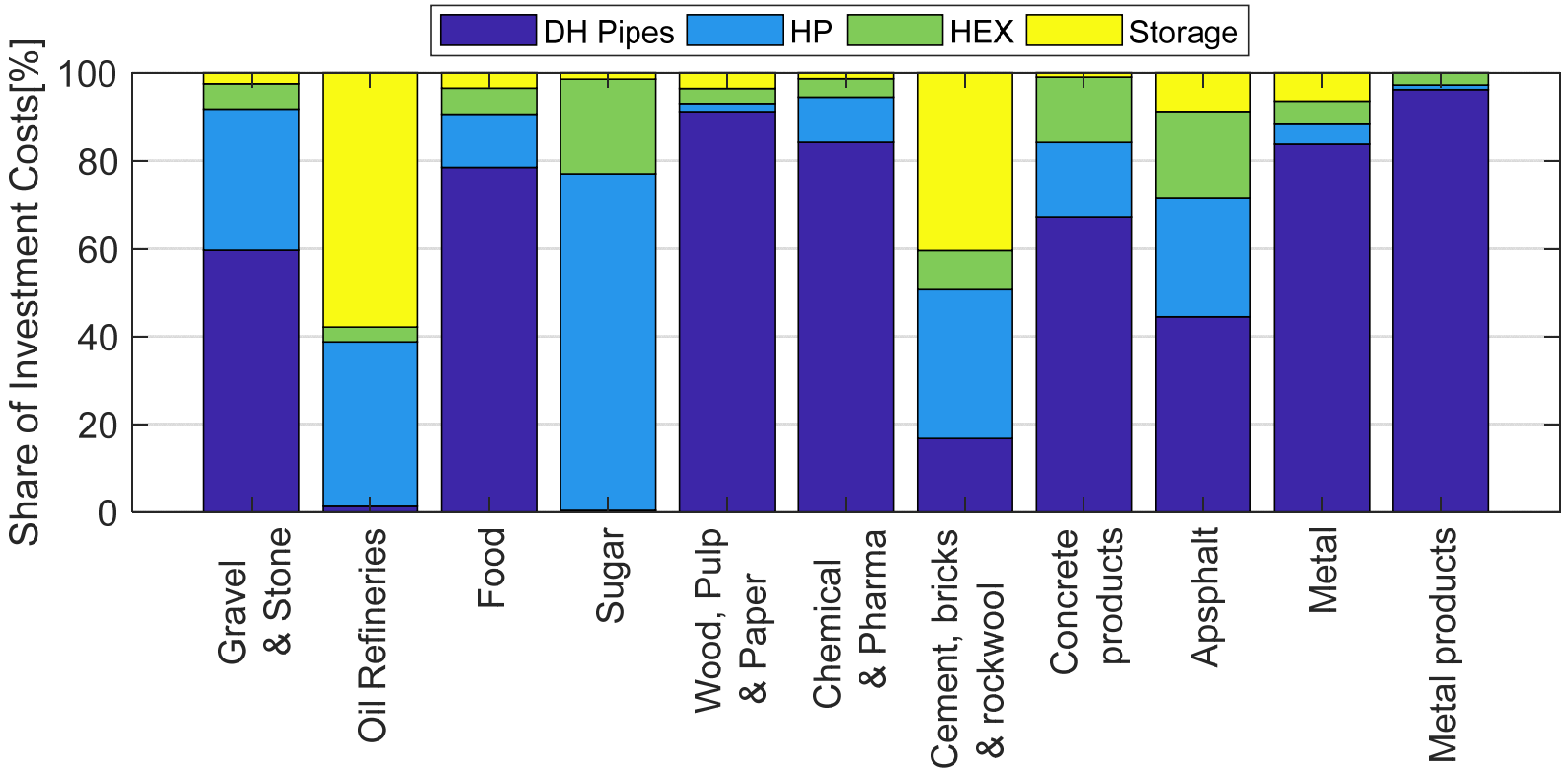

Mean heating price: 87.0 € $MWh^{-1}$

Weighted mean heating price: 35.6 € $MWh^{-1}$

# Results
## III. Economic analysis



# Results
## IV. Economic analysis



# Conclusion

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- Food and building material industry
  - Good temporal match (small storages)
  - Close to DH networks (small share of costs for Piping)
  - Good EH properties (small share of  HP required)

- Heating prices of EH can be low (35.6 € $MWh^{-1}$)
  - EH is not free compared to Solar
  - Ownership model will influence real costs
  - Perceived risk of investment & cost of financing

- Future work and additional considerations
  - Private-economic analysis (taxes, subsidies, excess heat price)
  - Prioritization of other heat sources

# Thank you for you attention!

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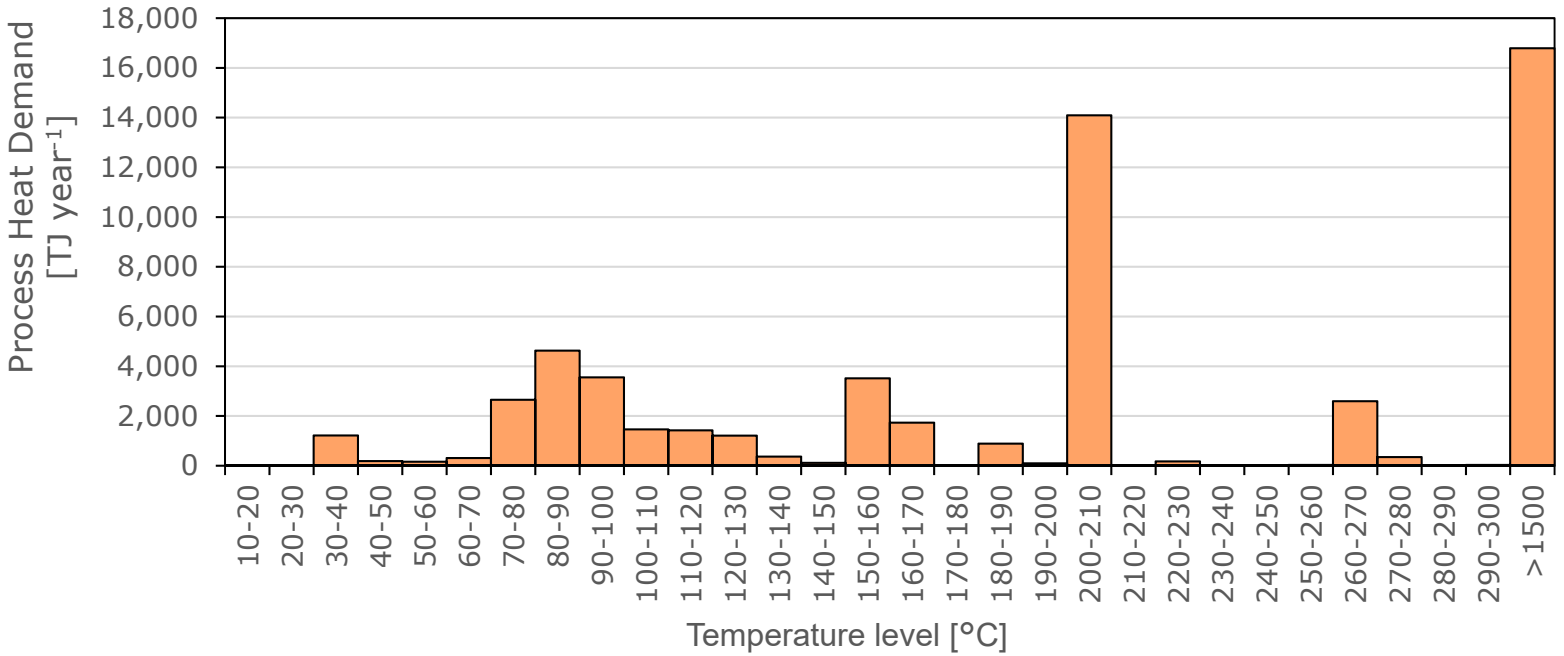
# Process heat in Denmark

Total process heating demand in Denmark in the temperature interval from 10 °C to 1500°C fro selected industries.

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