THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

ENGINEERING
DEPARTMENT OF CHEMICAL AND MATERIALS

AHUORA
CENTRE FOR SMART ENERGY SYSTEMS

Simulation-based examination of hybrid biomass-electric energy systems for demand response and decarbonisation of industrial utilities

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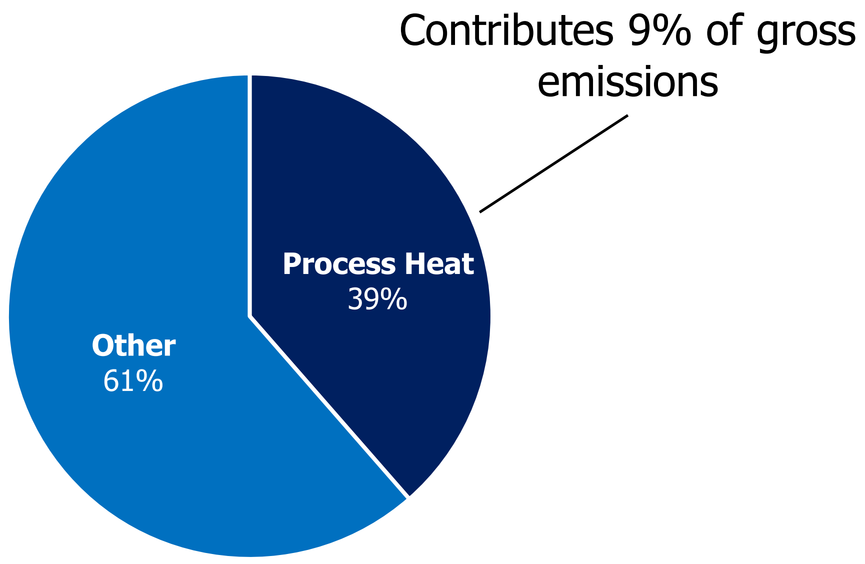
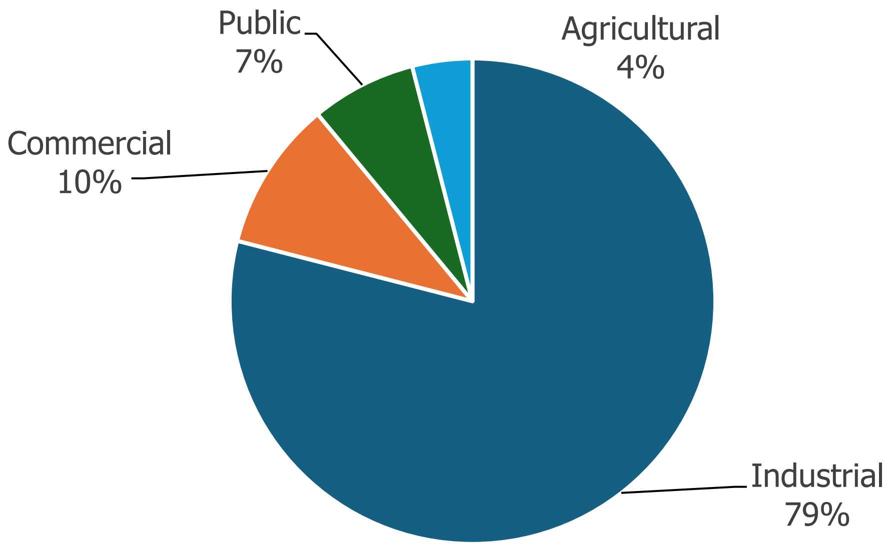
Introduction – Decarbonisation of industry

- Process heat in NZ industries
  - Significant emissions and consumption
- Net zero carbon by 2050?



Energy consumption in New Zealand (EECA, 2020)



Process heat by sector in New Zealand (EECA, 2020)

Industrial energy systems for heat

- Increasing focus on heat pumps
  - Only appropriate for low-grade steam
- Boilers
  - Solid fuel: coal but trend towards biomass
    - Retrofit existing coal boilers or co-fire
  - Gas: not covered in this scope
- Electric boilers

Customised Heat Pump, GEA

Electric boiler

- Electric resistive & electrode types
- Lower cost than solid fuel boilers
- Highly efficient (98-99%)
- Industrial applications:
    - **2019** – Synlait at Dunsandel (12MW)
    - **2021** – Open Country at Awarua (13MW)
    - **2024** – Fonterra at Edendale (20MW)
- Flex option typically,
  not core part of the utility system

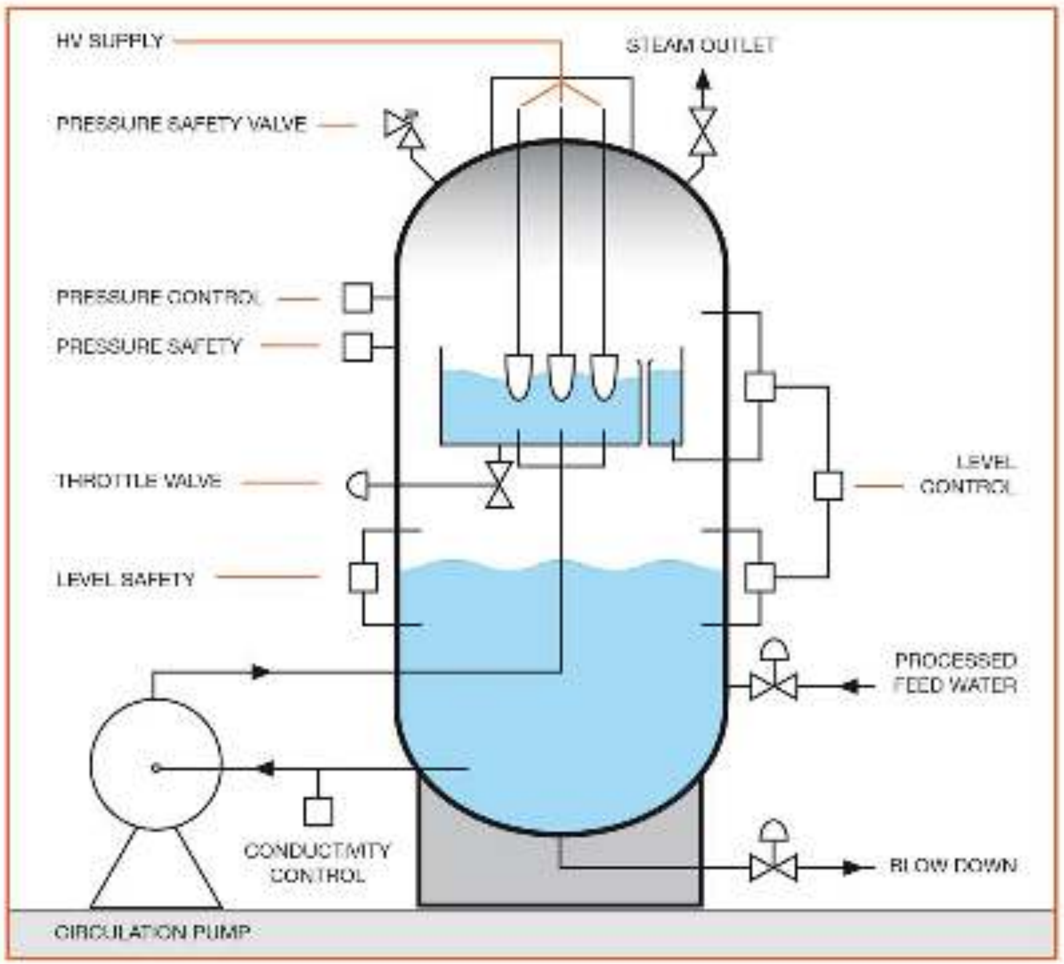
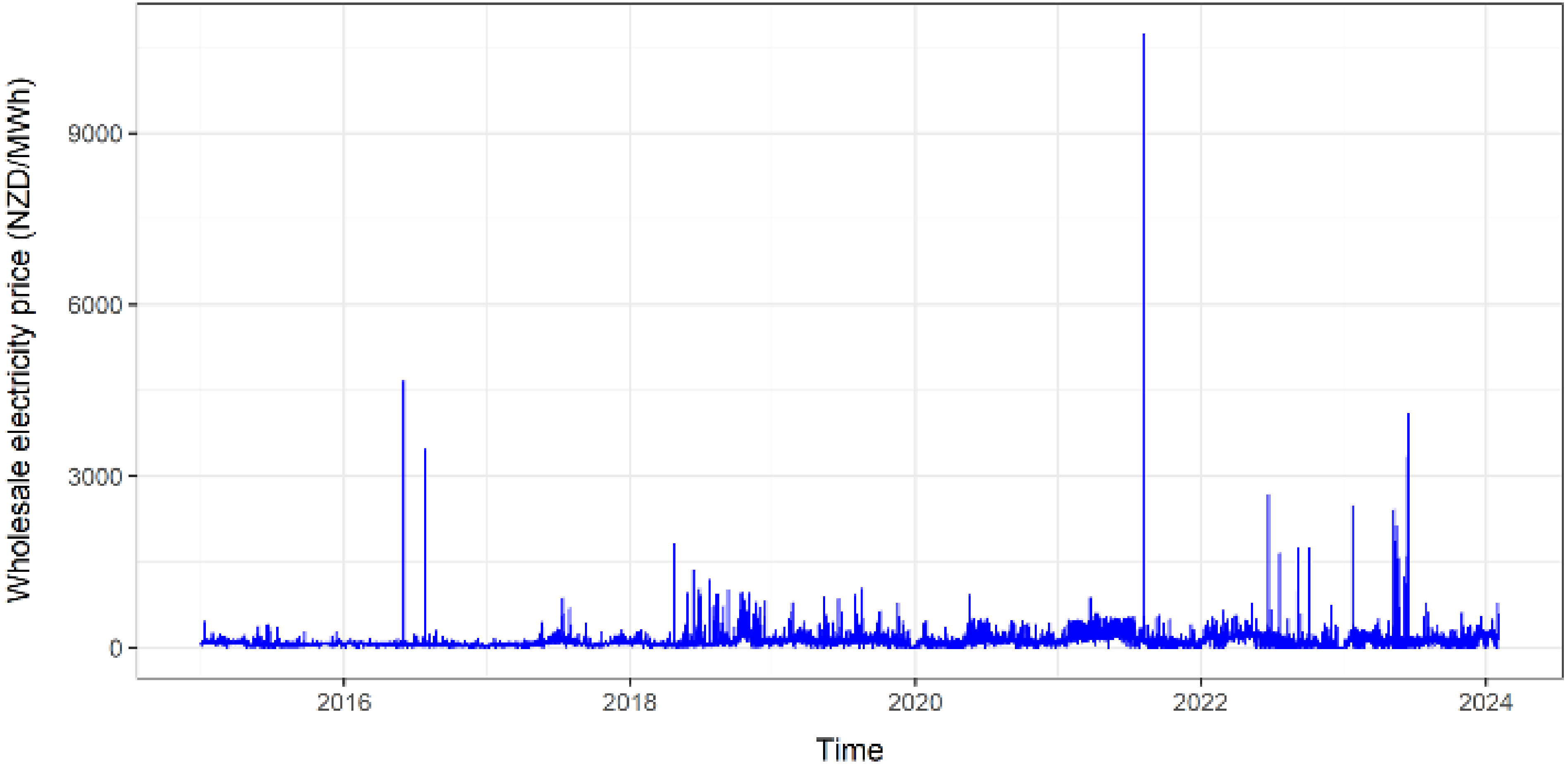


Diagram of electrode boiler (Parat, 2021)

Electrification risk

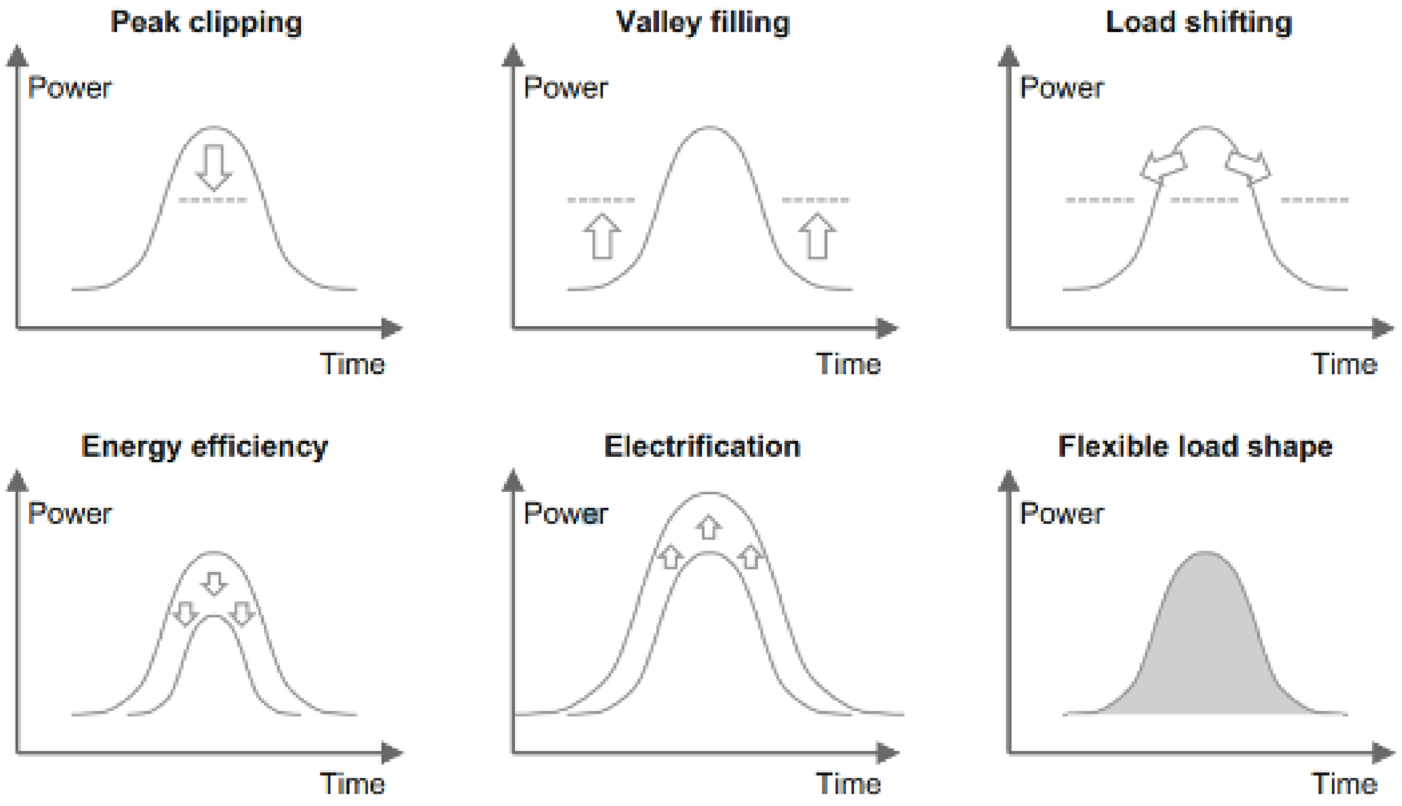
Wholesale electricity spot price across New Zealand from 2015-2023



Demand response

- Alter the energy consumption, generally through manipulating the process operations

- Challenging since some industrial processes cannot necessarily just stop processing



Demand shaping approaches (Beier, 2016)

Hybrid system

- Best of both worlds?
- Balance between the two to meet the site's needs
- Electricity contracts and hedging can also help with this

Electric boiler (EB)

- High efficiency (98-99%)
- Demand response with grid when advantageous

Biomass boiler (BB)

- On-site secure supply
- Provides stability, mitigating electricity market volatility

Outlines of this work & presentation

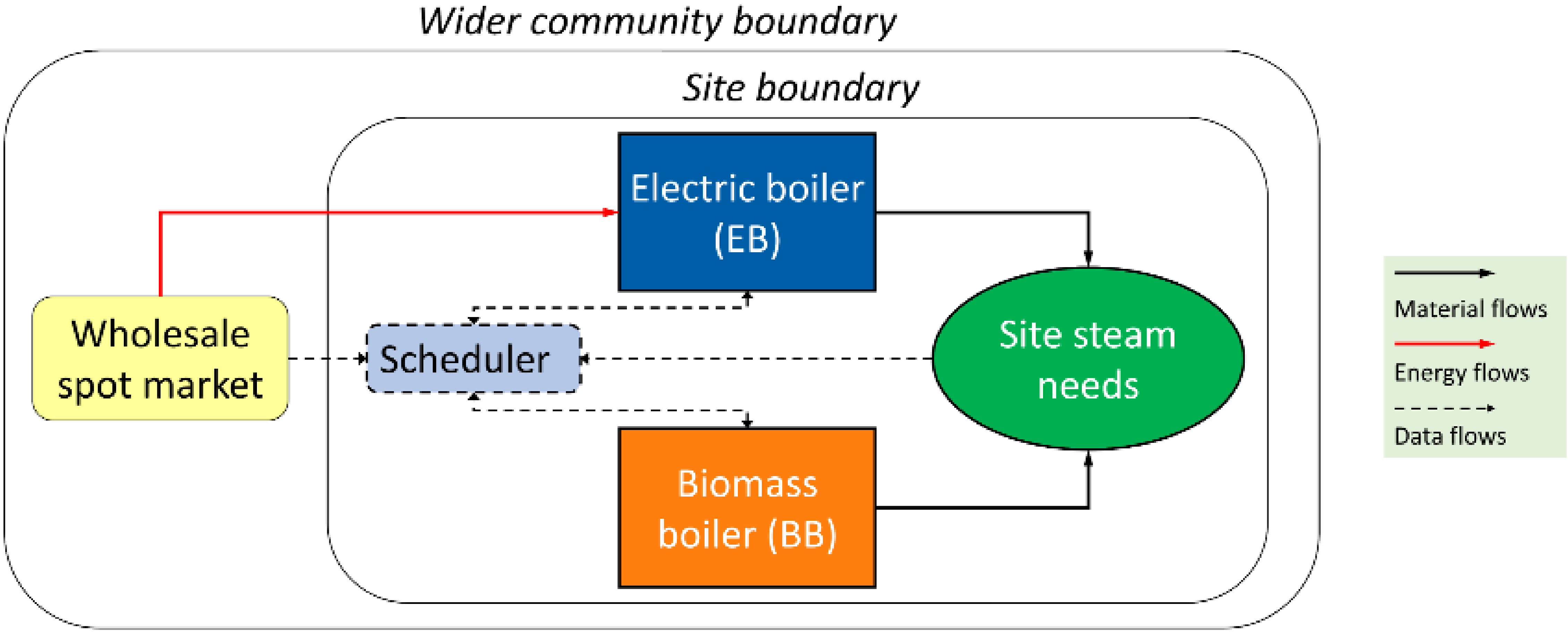
- Hybrid biomass-electric system model
  - Sizing, technoeconomic assessment, environmental impacts

- Characterisation and forecasting of wholesale electricity market
  - Value of forecast, *Monte Carlo*

- Evaluating the value of energy flexibility options
  - Storage, heat pumps, solar

- *Improved demand response of hybrid system, using reinforcement learning*

Hybrid system concept

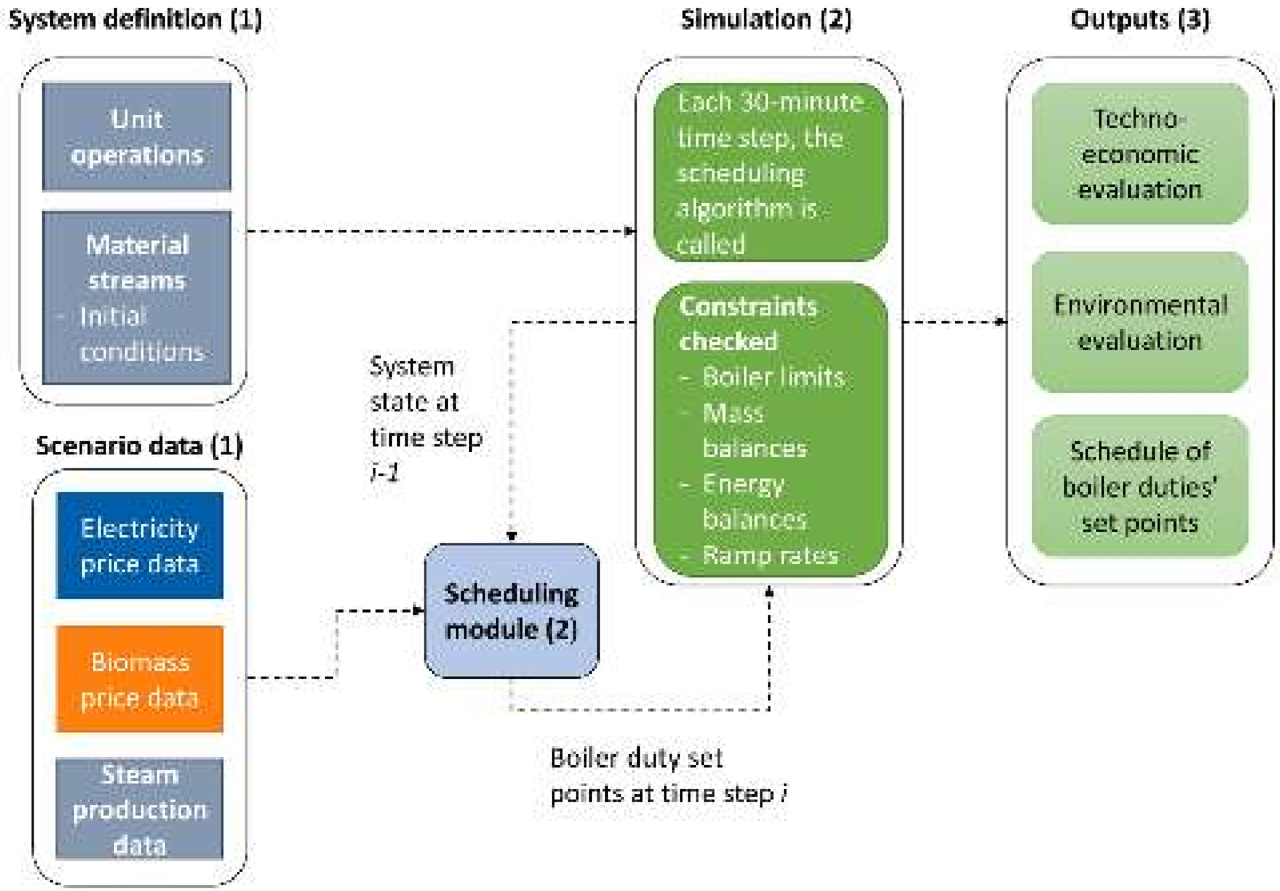


Simulation model

- Python
- Basic thermodynamics
- 30-minute time steps 'dynamics'
- Scheduling rule

$$EB\ duty_{t+1} = EB\ duty_t \ \pm 0.7 EB\ duty_{max}$$

- Biomass price = $90/MWh
- Run time: 3-4 seconds to simulate ~1 year
- Case study

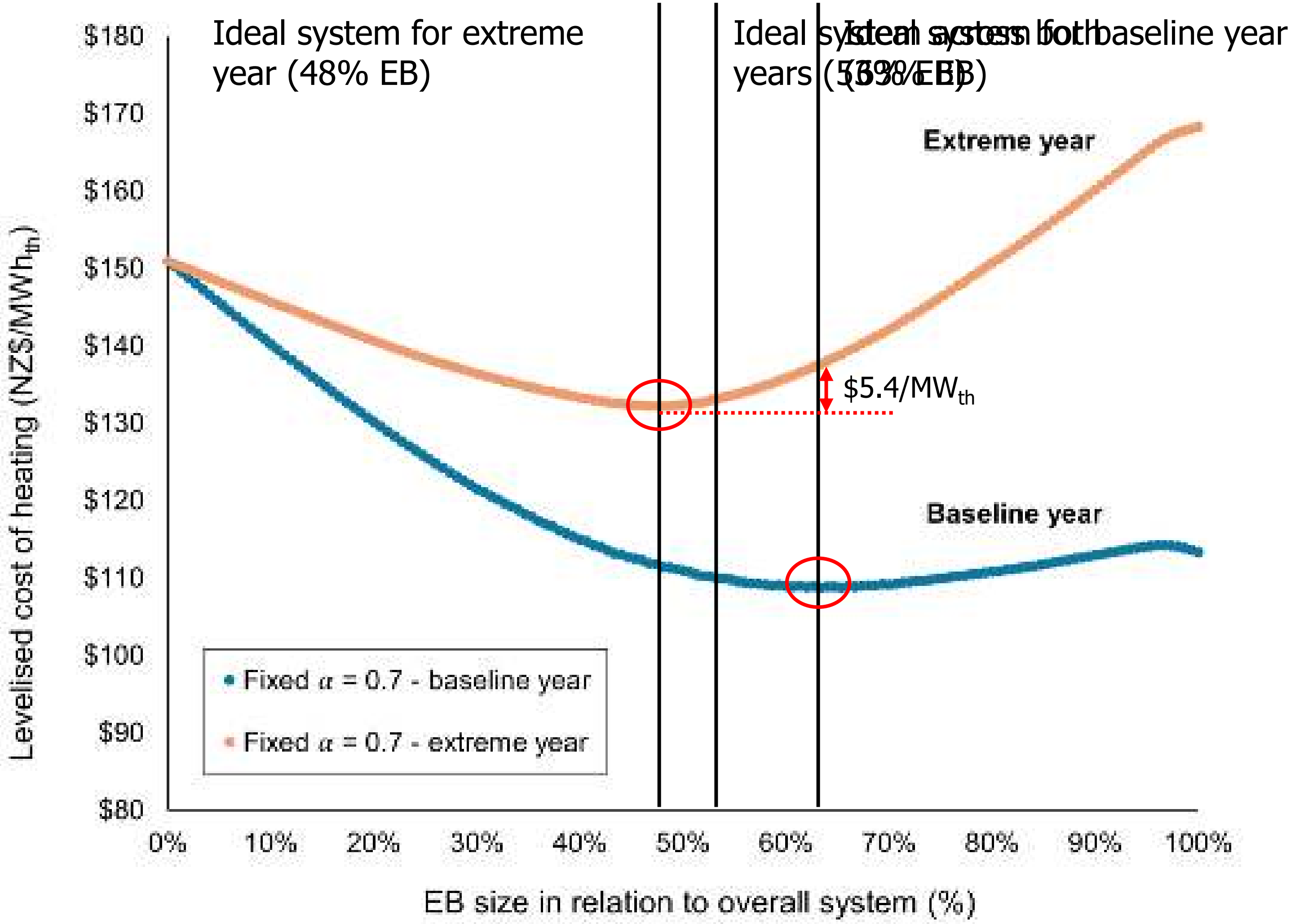


Simulation scenarios

- **Aims**
  - What’s the best size combination of EB and BB?
  - How does that change with different years?
    - **2022-23** = “baseline” year
    - **2021-22** = "extreme” year
  - Considering both economic and environmental assessment criteria
- Levelized cost of heating (LCOH):

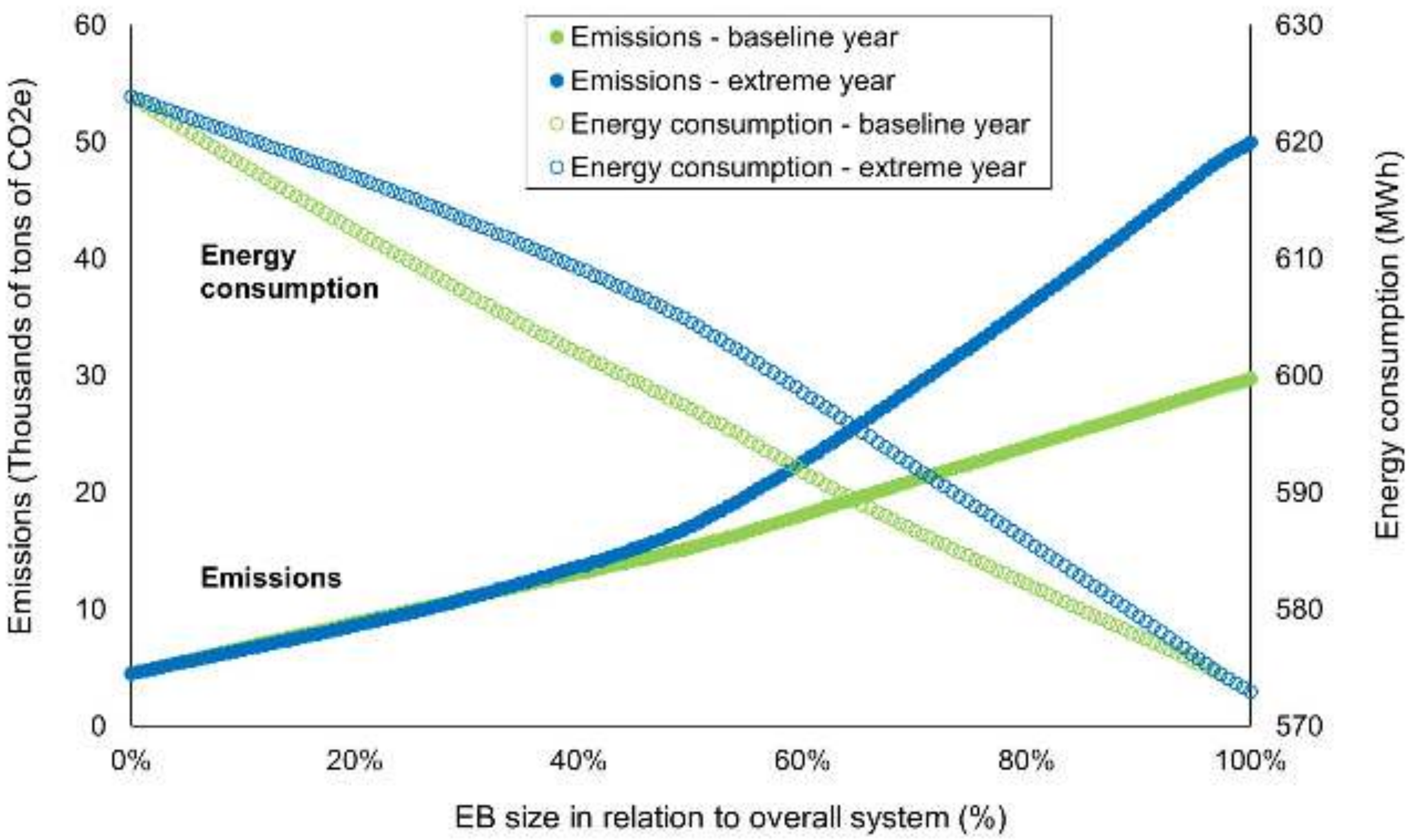
$$LCOH = \frac{aCAPEX + O\&M + Energy\ costs}{Heat\ delivered}$$

Results - technoeconomic

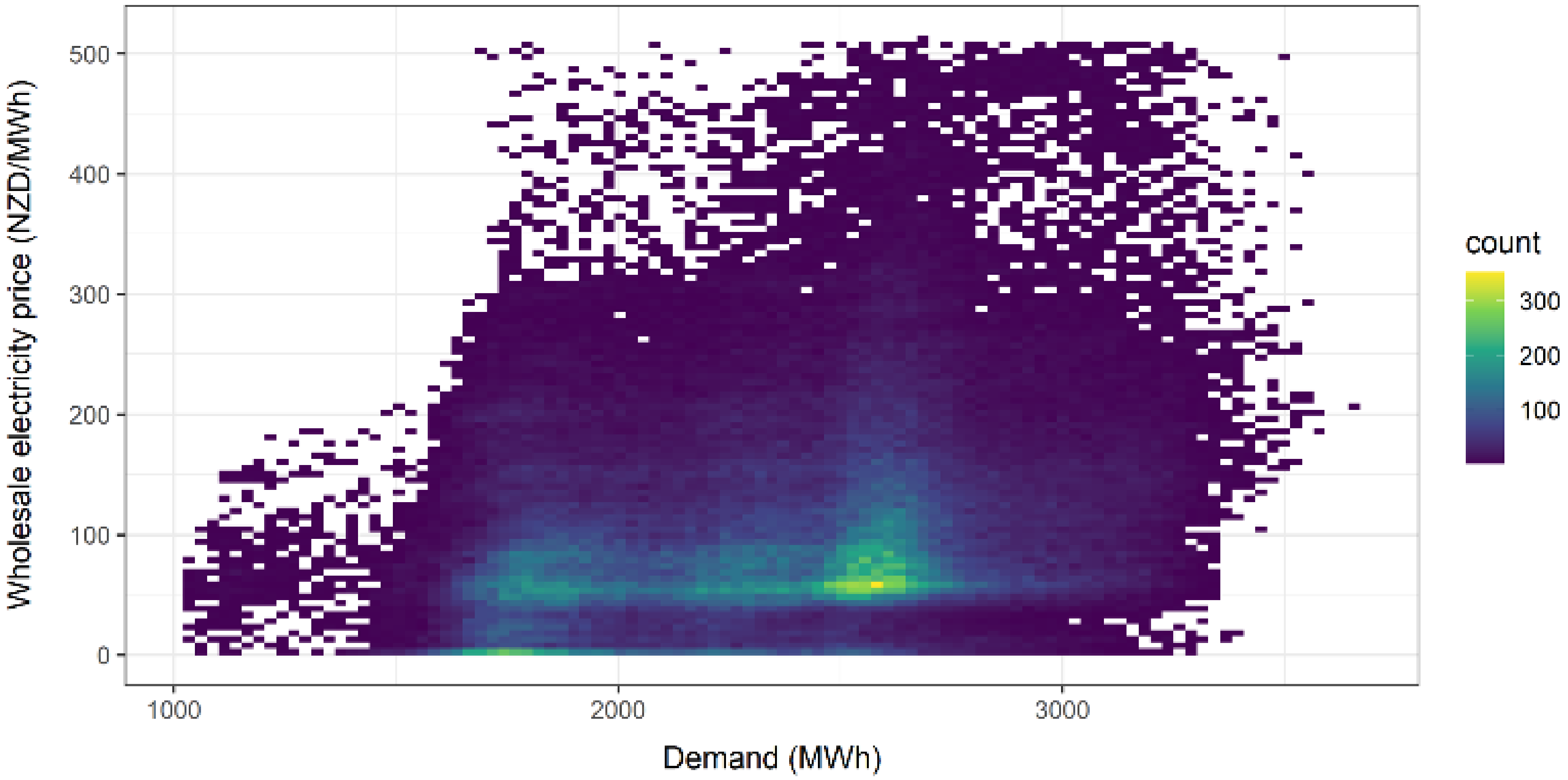


	LCOH in baseline year compared to ideal for that year	LCOH in extreme year compared to ideal for that year
Ideal for baseline	-	4.1% greater ($5.4/MWh$_{th}$)
Ideal for extreme	2.4% greater ($2.6/MWh$_{th}$)	-
Ideal across both years	0.68% greater ($0.9/MWh$_{th}$)	1.08% greater ($1.2/MWh$_{th}$)

Results - environmental

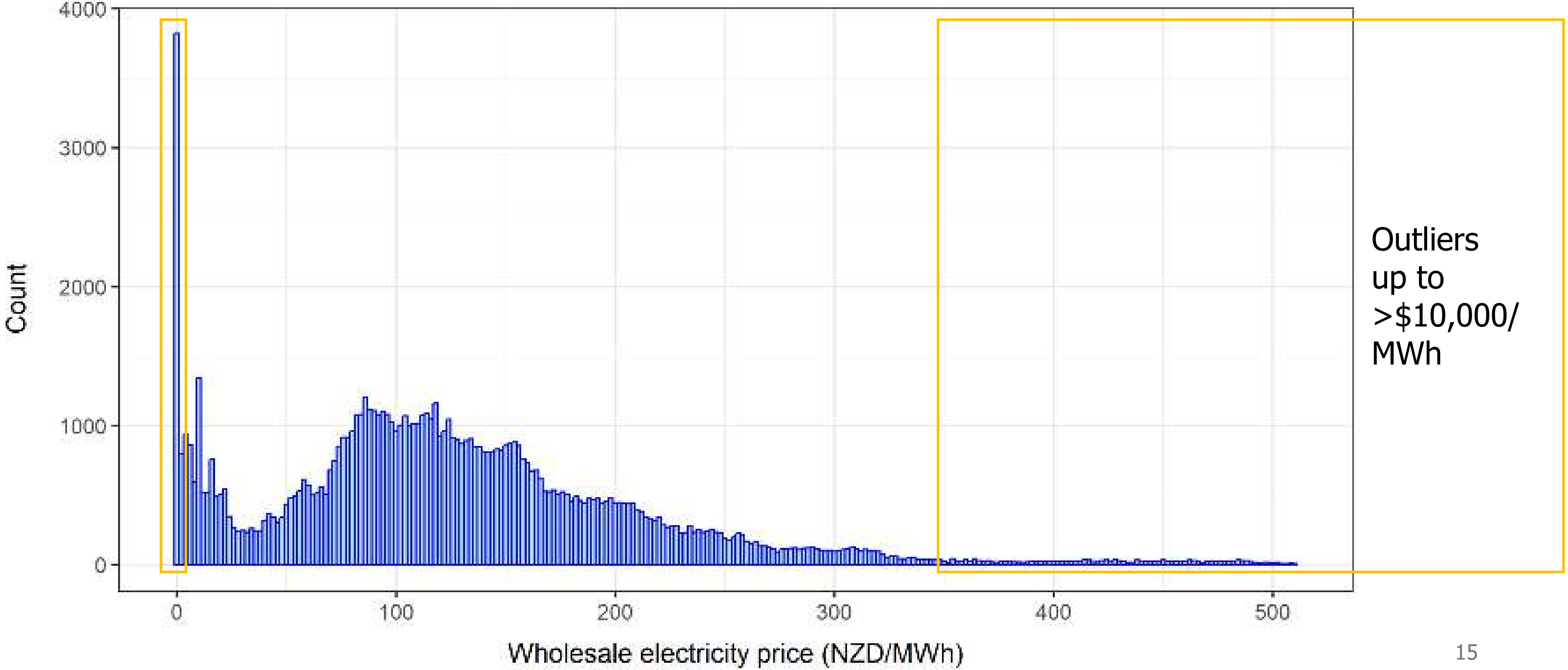


Electricity market



Exploitation and mitigation

Histogram of filtered price data (99.7%) for NZ 2019-2023

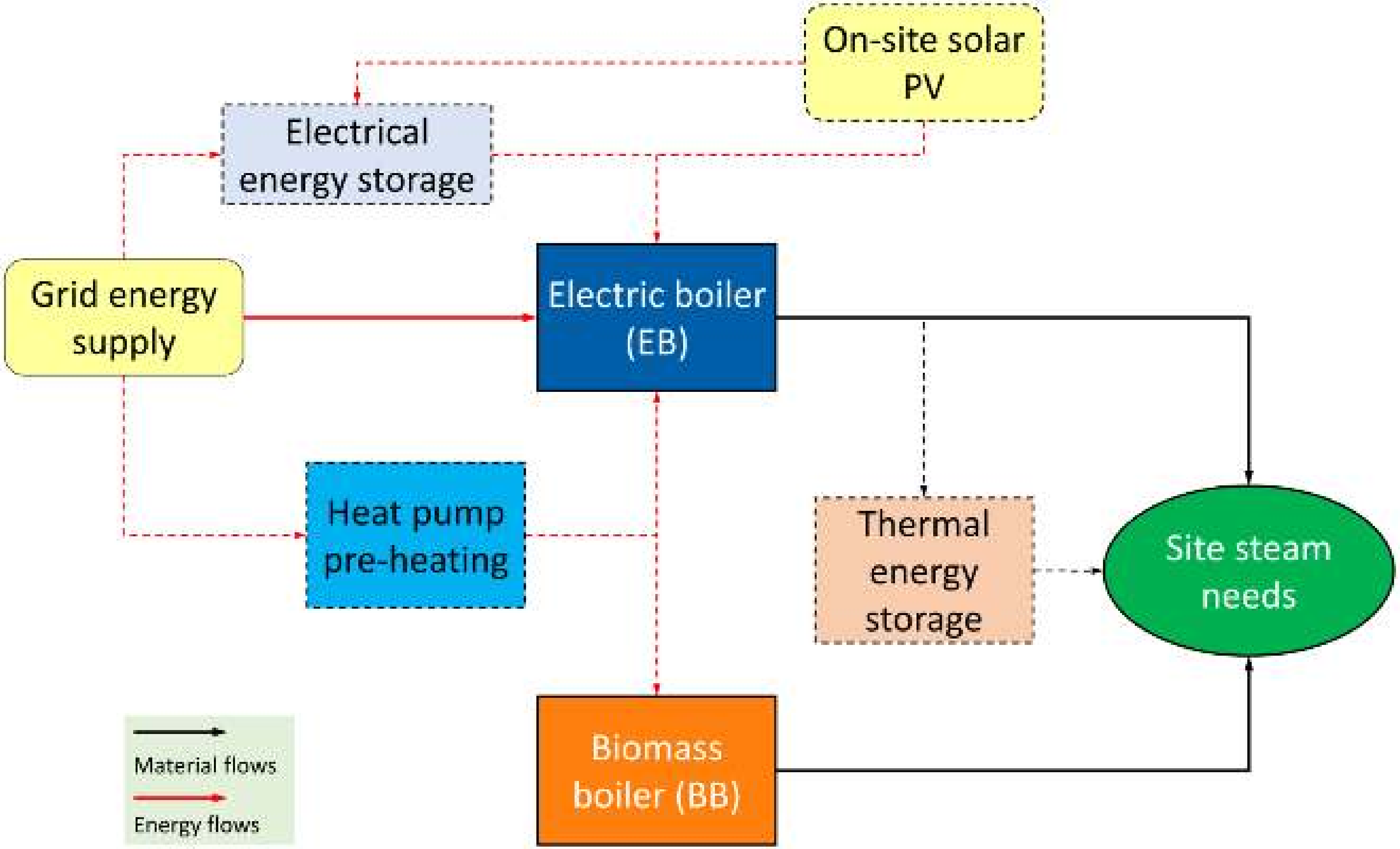


Outliers up to >$10,000/ MWh

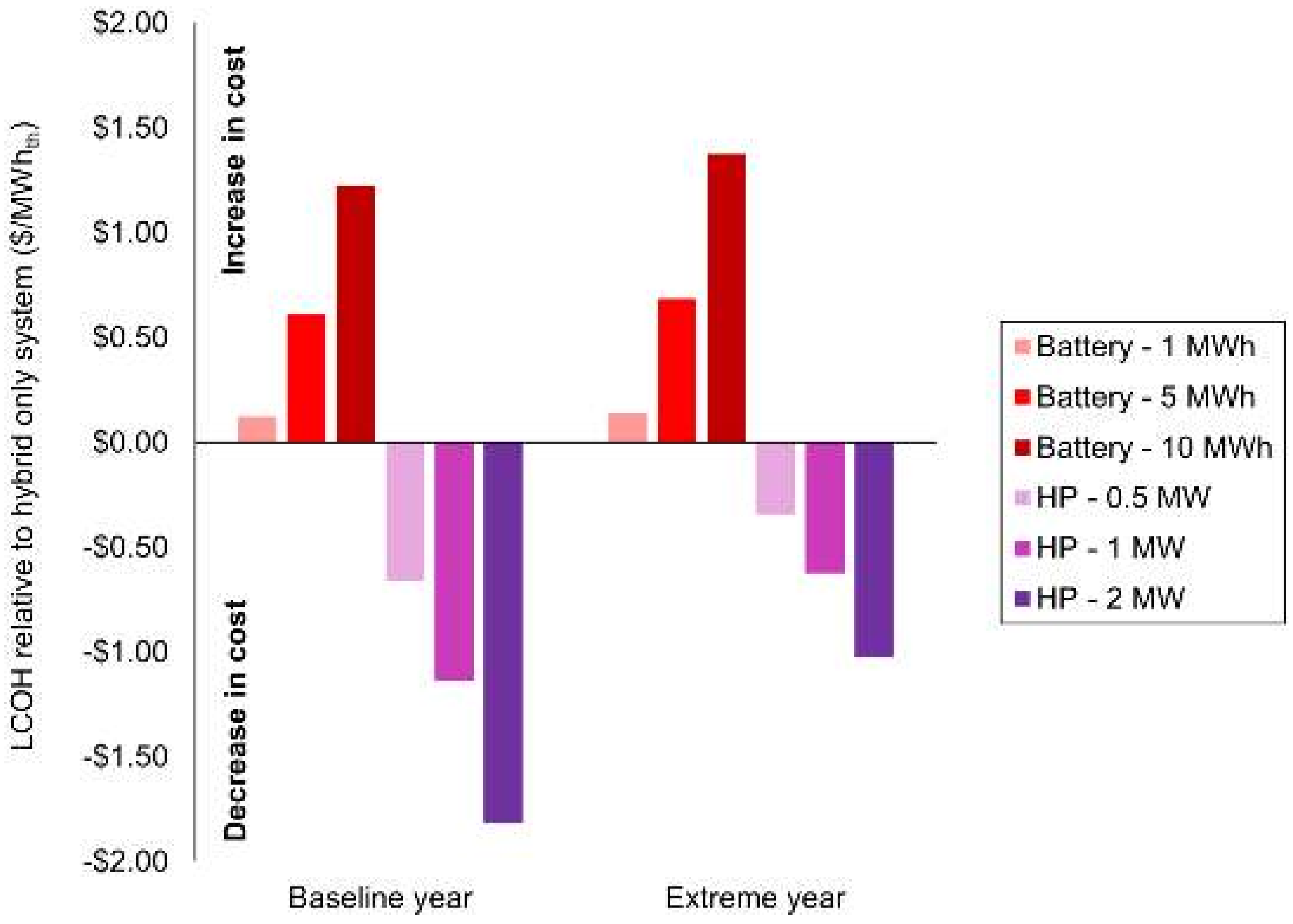
Flexibility options

- ~~Thermal energy storage (Steam accumulator~~)
  - Generate extra steam when electricity price is low and store this
- Electrical energy storage (Battery)
  - Store energy when electricity price is low
- Heat pump
  - Pre-heat and maximise usage when price is low
- On-site solar (PV)
  - Site-specific energy supply
  - With and without a battery

Flexibility options

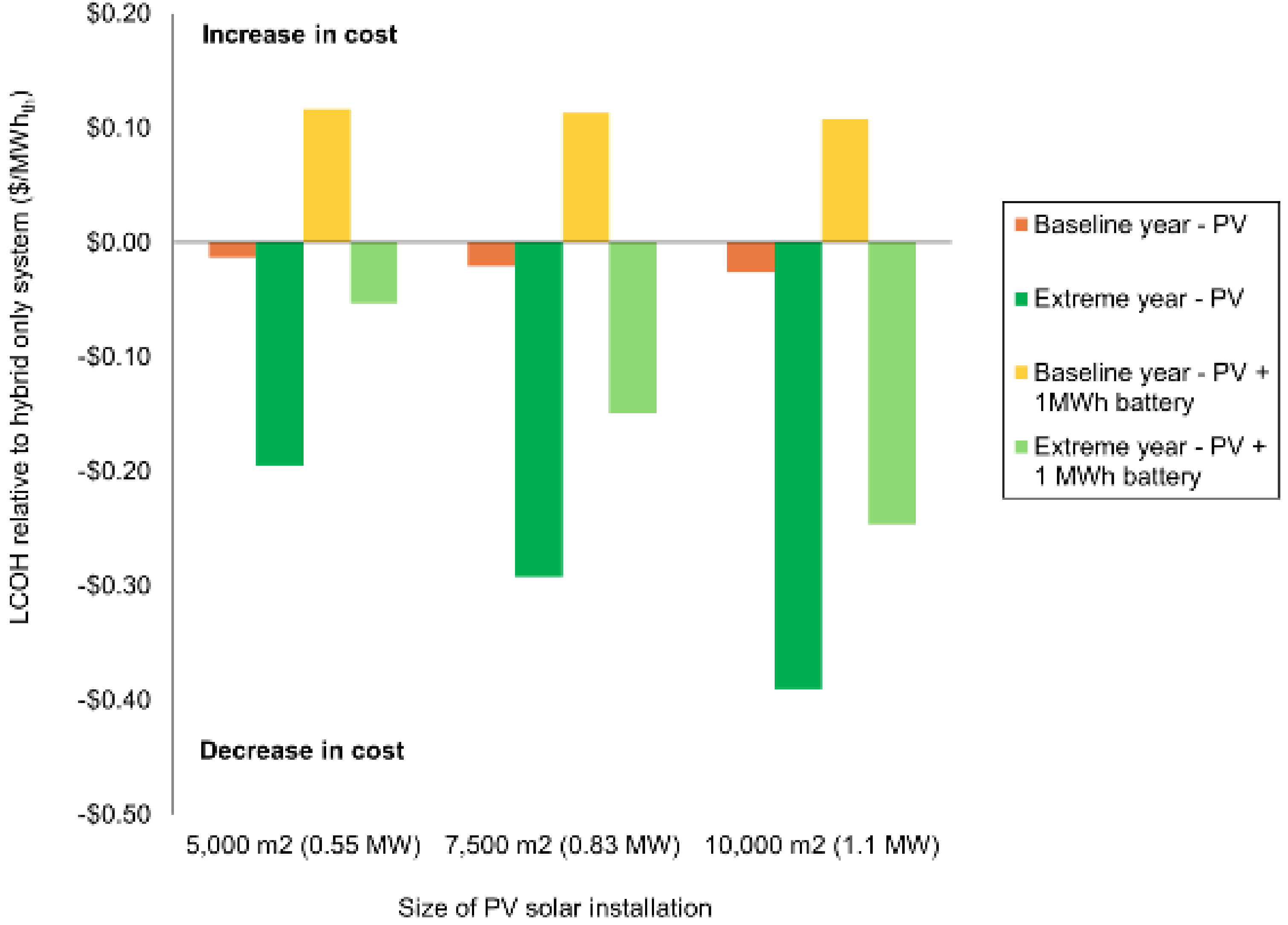


Results – battery and heat pump



- Batteries have a very high capital cost, which is not compensated for by performance
- Heat pump good across both years

Results – on-site solar



- Not enough energy yield for the scale of the site, barely economic
- However, more valuable in years where electricity prices are higher and more volatile
- PV makes battery more feasible

Summary/Conclusions

- Simulation tool built to evaluate flexible energy systems
- Hybrid systems very effective with best configuration being 53% EB and 47% BB
- Increasing electricity usage not good for emissions with current grid generation mix
- HP great
- Solar PV barely economic for large scale industrial electricity users
- Batteries not cost-effective alone, but fine when paired with PV

Work not covered in this presentation

- Wholesale electricity price characterisation and poor quality forecasting
- Oversizing the utility system for the site’s heat demand
- Loading-efficiency curves for boilers
- More demand response and doing this without a forecast

WIP and further work

- Monte Carlo simulations to explore uncertainty of electricity price and resiliency of energy systems
- Smarter scheduling via reinforcement learning
- Policy or demand response incentives?
- Decision support systems?

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Supplementary - parameters

- CAPEX and OPEX costs
- Efficiencies
- Emissions factors

$$a = \frac{(1+r)^n \times r}{(1+r)^n - 1}$$