MODELLING DISTRICT HEATING AND
ITS ROLE IN A DECARBONISED ENERGY
SYSTEM

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• Higher renewable deployment requires more flexibility in the grid
• Electrified heating couples heat and power sectors
• District Heating (DH) can facilitate large scale Thermal Energy Storage (TES)
• How is DH with heat pumps (HP) and TES designed to minimise operating costs?
• How may widespread DH deployment contribute to flexibility?
• How is DH with Heat Pumps designed to minimise operating costs?
• How may widespread DH deployment contribute to flexibility?
• Supply and demand linked through weather data
Heat Demand Modelling

• Model high spatiotemporal resolution heat demand – hourly at local level
• Heat demand density threshold to filter areas suitable for DH deployment
• Domestic (11) and nondomestic archetypes (12)
• Census data on local level domestic building type distribution
  And CaRB2\(^1\) data for nondomestic
• Custom thermal model using Met Office data for 11 weather regions
• Occupancy profiles derived from hourly gas consumption data
• Calibrated total local demand with annual gas consumption data
• Hourly total heat demand - Input for national electricity scenarios
• Hourly urban heat demand – input for DH analysis
Electricity Dispatch and Cost Model

- Electricity dispatch model + cost model
- Scaled historic demand data + heating + others
- Renewable generation extrapolated from Renewables Ninja$^{[2,3]}$ capacity factors
- Storage and Dispatchable generation are assumed to be the primary grid balancing methods
- Grid (battery) Storage is used only to store surplus renewable generation
- Assumed merit order of carbon intensity
- Adapted National Grid net-zero scenario (CT) that included high DH deployment
- Calculated hourly marginal costs of electricity dispatch from renewable generators and grid storage
- Costs are converted to end user prices with transmission and distribution losses and charges added on
Adapted National Grid net-zero scenario (CT) that included high heat electrification and DH deployment.
Modellled supply and demand to produce hourly electricity costs.
**District Heating Model**

- District heating model
- 70°C flow temperature
- Variable return temperatures
- Dynamic distribution losses based on ambient temperature
- Thermal plant consisting of HP and tank TES
- Ground source HP
- Modelled dynamic COPs – ground temperatures
- TES - thermal losses based on ambient temperature
- 3 operating modes
- Penalty equivalent to COP = 1 (resistance heaters)

**Operating Modes**

1. The HP is off, the heat load is met entirely by discharge from the TES.

2. The HP is on and covers the entire heat load.

3. The HP is at full capacity using the residual spare capacity to charge the TES.
Operating Algorithms

- Attempted heuristic algorithms – fast exploration
- All simulations use a 50 GWh_{th} annual demand DHN and peak size HP
- MPC operational control algorithm
- Dynamic programming – Prodyn\(^3\)
- Finite lookahead time horizon
- Input: demand and cost time series
- Compared TES as percentage of annual demand

<table>
<thead>
<tr>
<th>TES % of Annual Demand</th>
<th>Hours of peak demand stored</th>
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<tbody>
<tr>
<td>0.1%</td>
<td>1</td>
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<tr>
<td>0.2%</td>
<td>2</td>
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<tr>
<td>0.5%</td>
<td>10</td>
</tr>
<tr>
<td>1.0%</td>
<td>20</td>
</tr>
<tr>
<td>2.0%</td>
<td>40</td>
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HP capital causes costs to rise beyond 100%
Annual Results

- Thermal Energy Storage capacity rapidly reduces electricity import costs
- But slightly increases total electricity demand due to thermal losses
- Minimum costs varies by year
- Dependent on seasonal conditions
- Minimum is reached between 1-2% TES in all years except 2010-2011
District Heating Costs

- District heating costs per unit of heat delivered are minimum at 1.3% TES
- In a scenario with high offshore wind and heat electrification
- TES is only fraction of total costs
- TES with optimised operation achieves a 12% reduction in the cost of heat
- TES costs not inclusive of land costs

Break down of cost of heat from DH

Using medium cost ranges
DH and Electricity Grid Conclusions

- A DH deployment of 10% of national heat demand results in:
  - 12% decrease in annual demand
  - 17% reduction of peak demands
- The addition of grid storage eliminates over 750 deficit hours (blue line)
- For 2010 weather year, TES displaces **107 GWh<sub>e</sub>** of grid storage (dashed)
- Other years exhibited a smaller level of displacement between **34-53 GWh<sub>e</sub>**.
- Benefit of TES highly condition-dependent;
  - From **20%** of the “thermal storage electrical equivalent”
  - to just over **5%** in a mild year.
- 53 GWh<sub>e</sub> Li-ion is worth **£18 billion**
  - 1 GWh<sub>th</sub> of TES - **£4.5 million** potentially displaces up to
  - 0.2 GWh<sub>e</sub> of Li-ion valued at **£67.4 million**
- But a 10% DH deployment would require an estimated **£52 billion** capital expenditure on infrastructure
THANK YOU

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Publications
Siddiqui, S., Macadam, J., Barrett, M., 2021. The operation of district heating with heat pumps and thermal energy storage in a zero-emission scenario. Energy Reports.

References