

Decarbonising the Residential Heating in the North of Tyne (NoT)

Integrating Social Interventions and Low-Carbon Technologies

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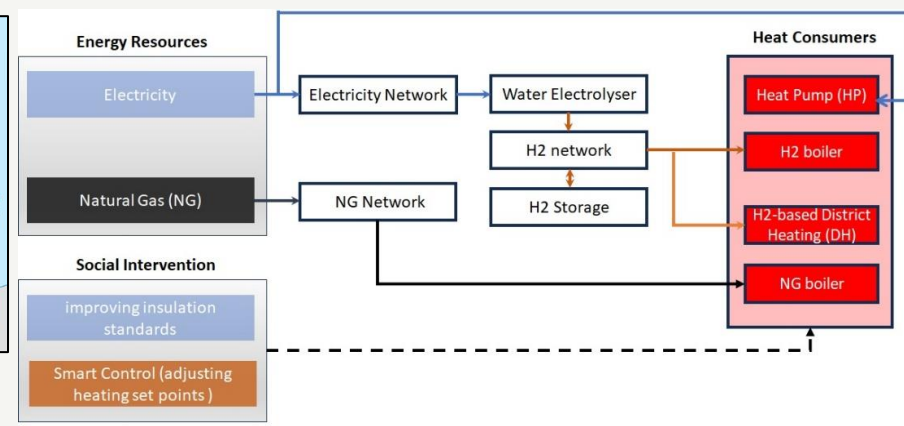
Heat Decarbonisation: North of Tyne (NoT)

Objective:

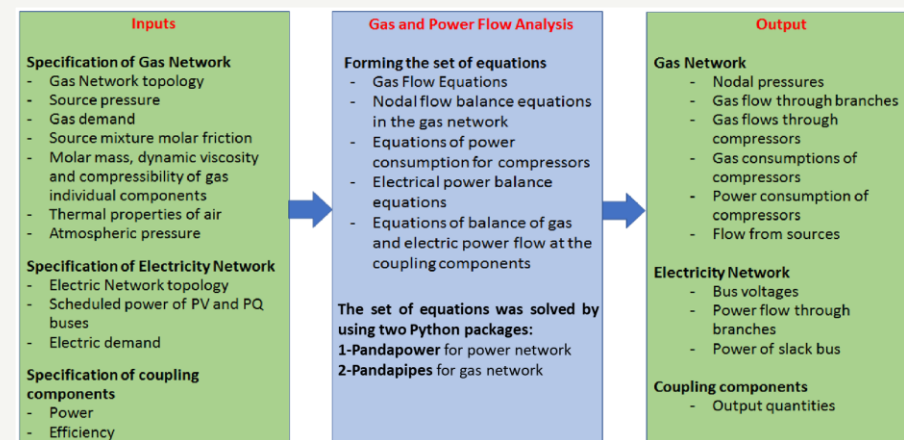
Assessment of the impacts of social and technical interventions for the decarbonisation of residential heating on the electricity and gas systems in the North of Tyne (NoT) region.

Key Questions:

1. What are the impacts of social and technical interventions on system performance?
2. What is the economic dispatch and associated CO2 emissions of the heating interventions?
3. What are the impacts heat pumps and hydrogen boilers at different intervention levels?
4. What are the impacts of the combined interventions of heat pumps and hydrogen boilers?
5. What is economic plan of one-day heating interventions for the years 2025-2050?
6. What is the plan for combined heat pumps and hydrogen boilers with CCS over 2025-2050?
7. What are the requirements/impacts for hydrogen blending into the existing gas network?



High-level diagram of resources-technology model

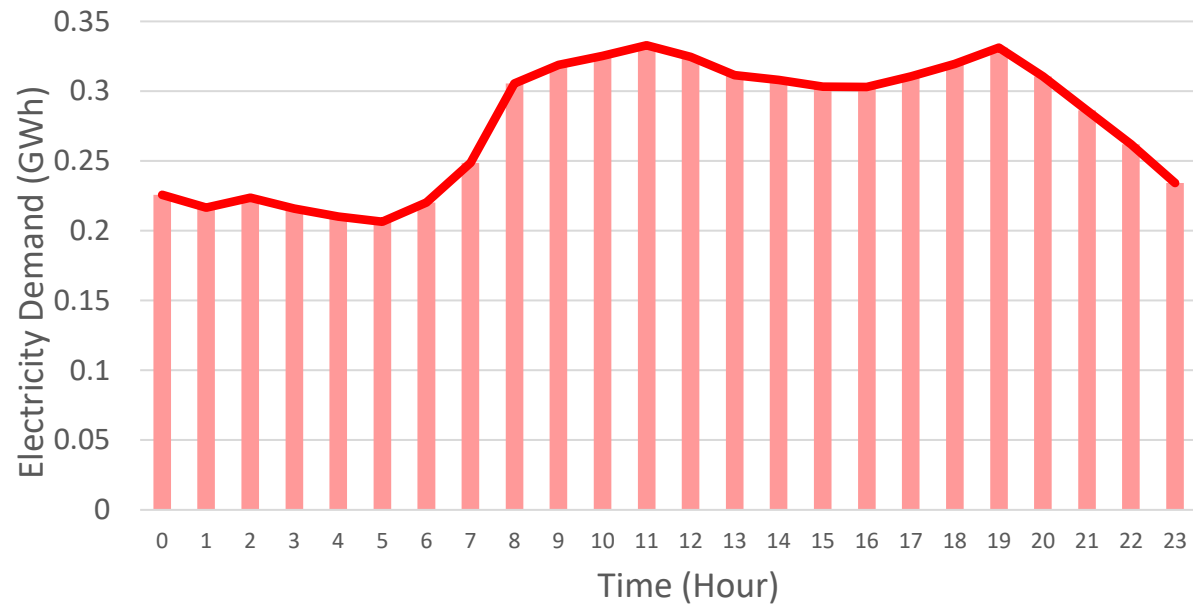


Schematic Diagram of Modelling

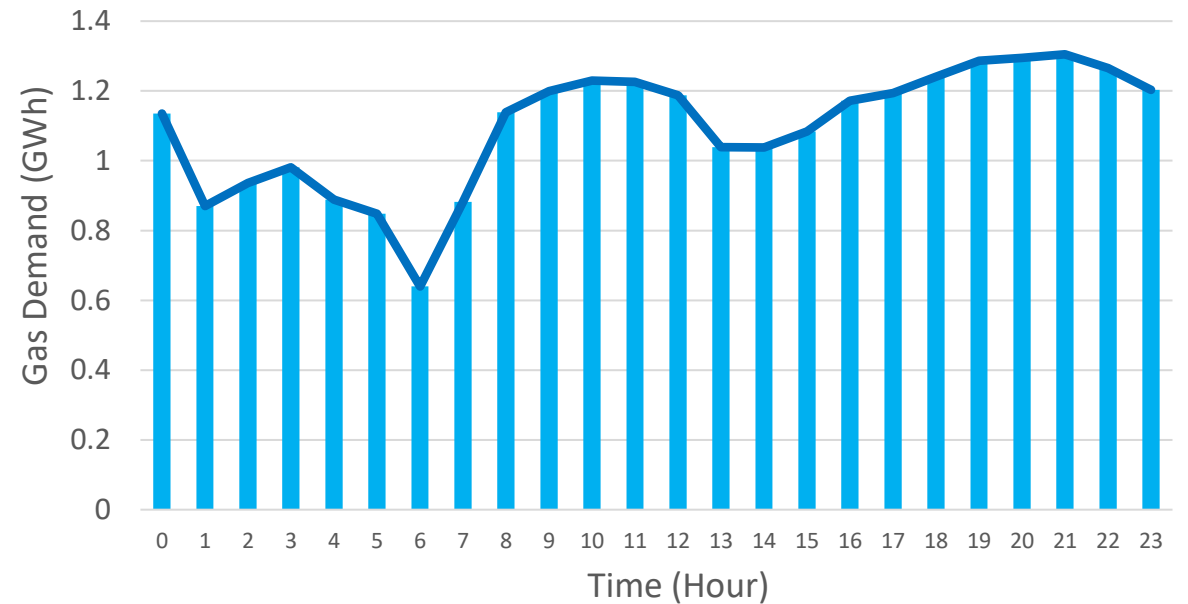
Heat Decarbonisation: North of Tyne (NoT)

Demand Overview

The heating scenarios use the coldest day in November 2019 as a baseline to model peak energy demand. Total energy demand reached 31 GWh, with gas consumption (24 GWh) significantly outpacing electricity (7 GWh). Daily domestic demand averaged 16.6 GWh (12.45 GWh for gas, 4.15 GWh for electricity).



Daily Profile of Total Electricity Demand for NoT in 2019



Daily Profile of Total Gas Demand for NoT in 2019

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Social Intervention Scenarios

The heat decarbonisation scenarios evaluate how social-based interventions impact electricity and gas networks and the broader energy system within the North of Tyne (NoT) region.

Developed to address decarbonisation needs, these scenarios model various heating interventions affecting 10% of households.

Scenario Formulation of Socio-Technical Interventions of Residential Heating in NoT

| Scenario | Intervention | Effect on Gas Demand | Effect on Electricity Demand |
|----------|---|----------------------|------------------------------|
| 1 | Decreasing the heating set point by 2°C | 20% decrease | No effect |
| 2 | Improving the whole building insulation level similar to Passivhaus standards | 77% decrease | No effect |
| 3 | Delay start of heating from October to November | 5.5% decrease | No effect |
| 4 | Use of radiator valves to turn off heating in unoccupied rooms | 4% decrease | No effect |
| 5 | Use of heat pumps | 21.3 % decrease | 7.1% increase |
| 6 | Use of hydrogen boilers | 10% decrease | No effect |

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Modelling Social-Technical Interventions Scenarios by Monte Carlo Simulation

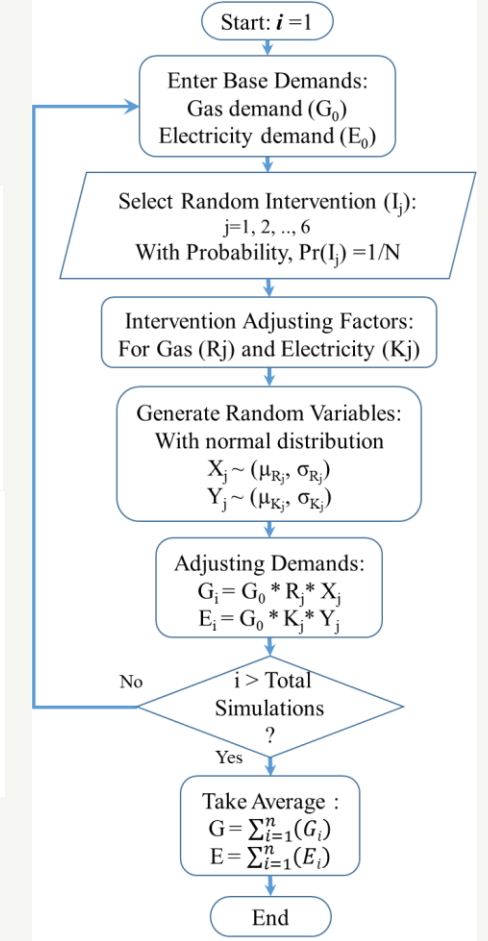
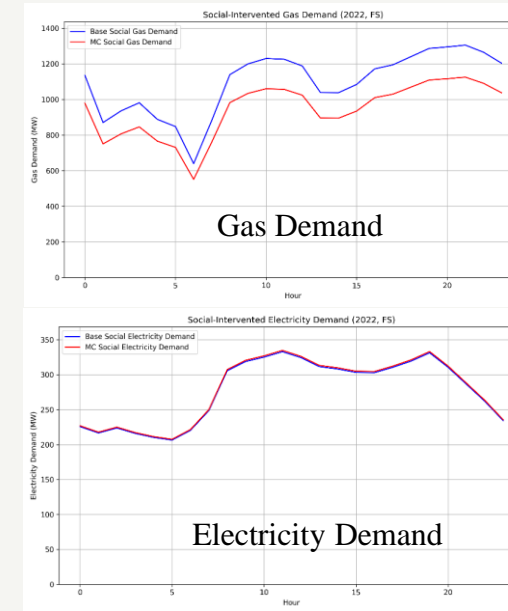
Let G_0 and E_0 represent the baseline gas and electricity demands, respectively. The adjusted demands G and E after applying a random intervention I_j .

$$G = \frac{1}{n} \sum_{i=1}^n \left(G_0 \times \sum_{j=1}^N \Pr(I_j) \cdot R_j \cdot X_j \right)$$

$$E = \frac{1}{n} \sum_{i=1}^n \left(E_0 \times \sum_{j=1}^N \Pr(I_j) \cdot K_j \cdot Y_j \right)$$

Where:
 R_j is the adjusting factor for intervention j (e.g., heating setpoint reduction, insulation improvement, etc.).
 K_j is the adjusting factor for intervention j (e.g., heat pumps, hydrogen boilers, etc.).
 X_j and Y_j are random variables drawn from normal distributions representing uncertainty, $X_j \sim (\mu_{R_j}, \sigma_{R_j})$ for gas change and $Y_j \sim (\mu_{K_j}, \sigma_{K_j})$ for electricity change).
 $\Pr(I_j)$ is the probability of selecting intervention j , (in 6 interventions, $\Pr = 1/N = 1/6$).
 N is the total number of interventions.
 i is the iteration of simulation out of n simulations.

The Monte Carlo simulation of heating interventions indicates a noticeable reduction in gas demand, with only a marginal increase in electricity demand.



Monte Carlo Simulation for Social and Technical Interventions of Heating Demand

Heat Decarbonisation: North of Tyne (NoT)

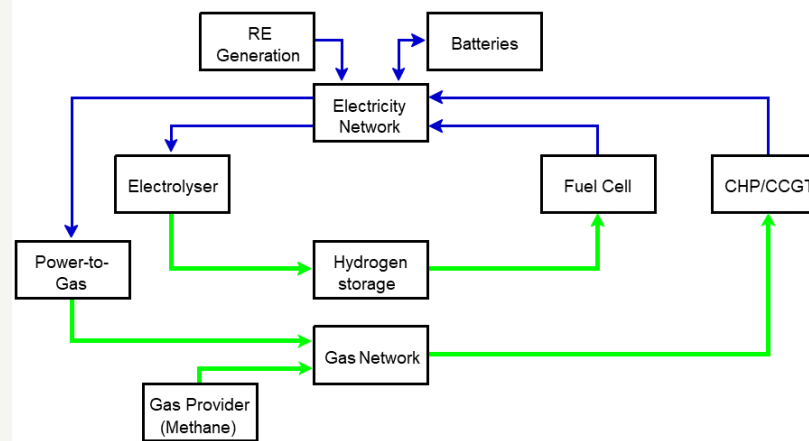
System Data

Energy Generation, Coupling and Storage

| Generation Type | Total Capacity (MW) | Cost (£/MWh) | Economic Life (years) | Emissions (tCO ₂ /MWh) |
|---|--|--------------|-----------------------|-----------------------------------|
| GT (Gas Turbine) | 2247.75 | 85 | 13 | 0.488 |
| Biomass | 18.25 | 75 | 18 | 0.786 |
| Wind | 52.60 | 46 | 18 | 0.000 |
| Solar | 10.12 | 44 | 18 | 0.000 |
| CHP (Combined Heat and Power) | Basically 10%, will be excluded with 100% intervention from heat pumps and hydrogen boilers. | 76 | 23 | 0.488 |
| P2G (Power-to-Gas) and G2P (Gas-to-Power) | Unlimited to simulate the import and export of energy into and out of the system. | - | - | - |
| EZ (Electrolyser) | Basically 10%, varies with interventions from hydrogen boilers. | 42 | 13 | 0.000 |
| FC (Fuel Cell) | Basically 10%, varies with interventions from hydrogen boilers. | 42 | 13 | 0.000 |
| BESS (Battery Energy Storage System) | Capacity: 80 MWh, Efficiency: 90%, Charge/Discharge Rate: 40 MW Primarily compensates for solar energy. | - | - | - |

General and Economic Parameters of the Energy System

| Parameter | Value |
|--------------------------------|---|
| Electricity OPEX Cost | £33.69 per MWh |
| Gas OPEX Cost | £9.73 per MWh |
| Hydrogen OPEX Cost | £9 per MWh |
| Electricity Price | Hourly variable, average: £125 per MWh |
| Gas Price | Hourly variable, average: £37.5 per MWh |
| Discount Rate | 5% |
| CO ₂ Price | £43.29 per tonne (example, varies by year) |
| Carbon Capture Cost Adjustment | 30% increase in gas price for CCS (in 2040, 2045, 2050) |
| CCS Capacity | Absorbed from deployed technology (e.g., GT, Biomass) by 15% share; CO ₂ capture rate: net zero (0%) |



Interaction within
the energy system

Heat Decarbonisation: North of Tyne (NoT)

Case Study

1) Analysis the economic dispatch for the base case (without interventions) and Monte Carlo simulation of the social and technical interventions.

BESS:

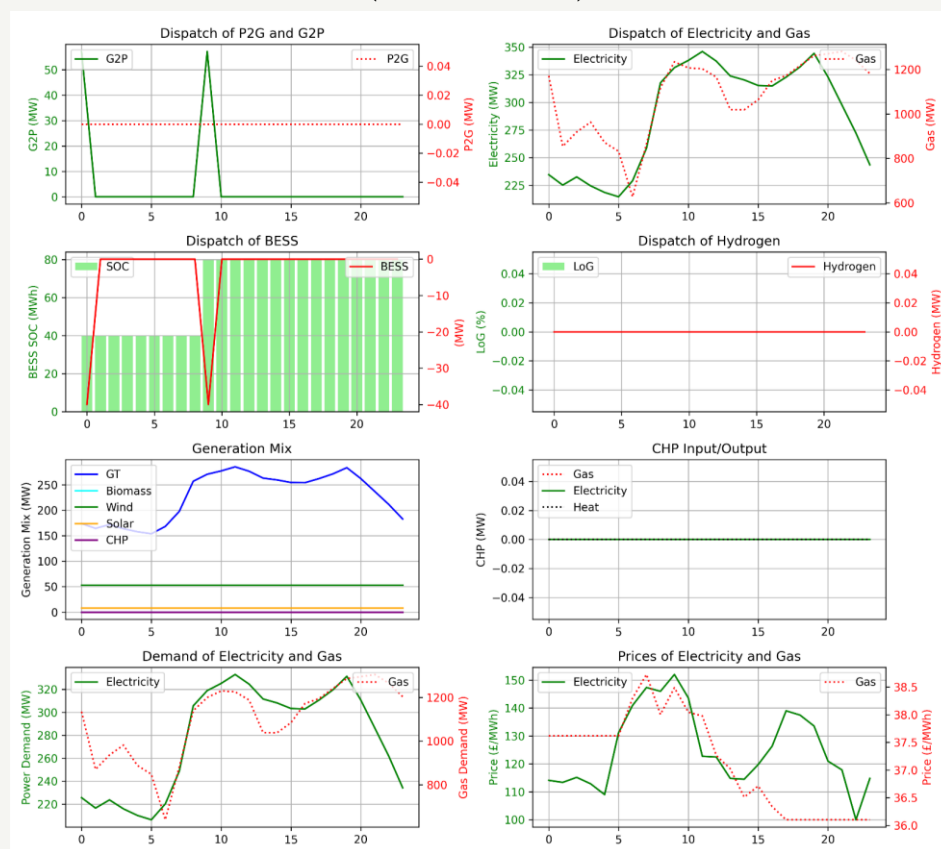
(Positive) Discharging,
(Negative) Charging.

Hydrogen:

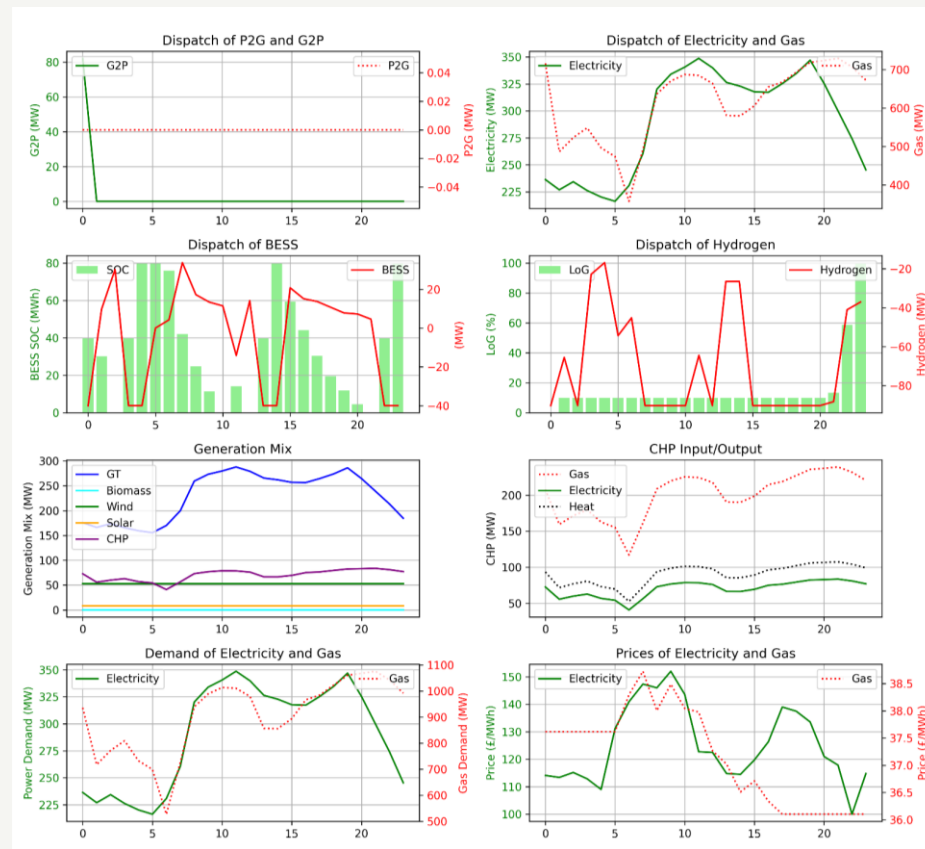
(Positive) Fuel Cell,
(Negative) Electrolyser.

Electricity (G2P), Gas (P2G):
(Positive) Utilize or Importing,
(Negative) Export.

(Base Case)



(Monte Carlo Simulation of Interventions)



Heat Decarbonisation: North of Tyne (NoT)

Case Study

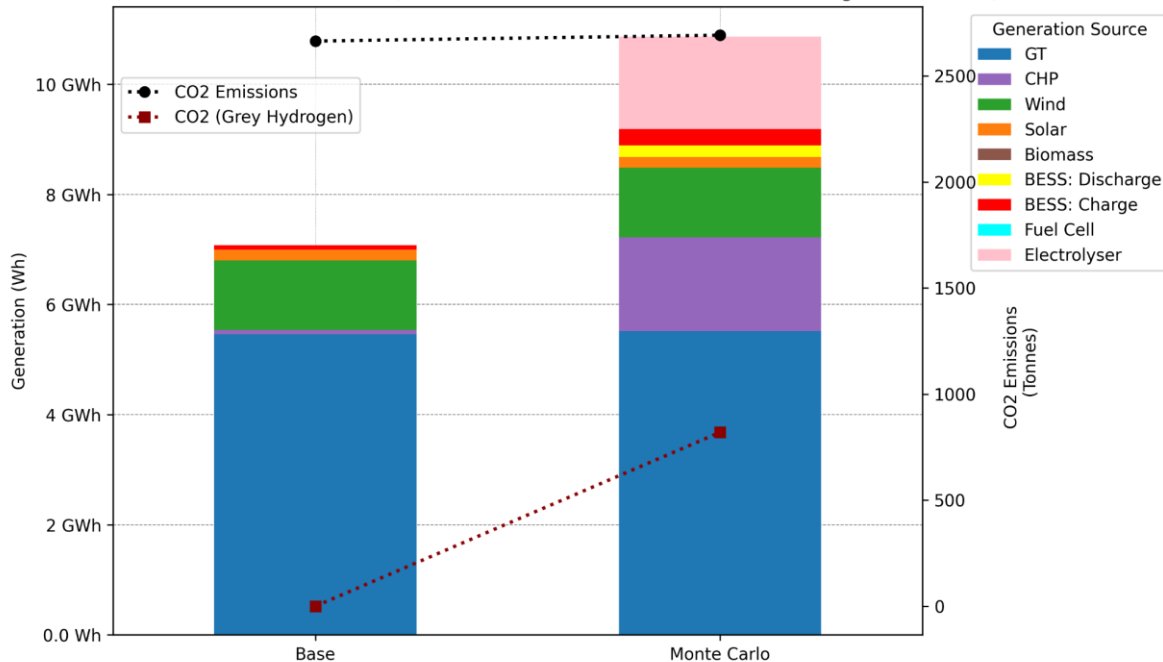
2) Investigating the impacts social and technical interventions on the supply side for both cases:
(A) Base (without interventions) and (B) Monte Carlo simulation for heating interventions.

Note: The energy and emissions of hydrogen production are included in the model.

CO₂ Emissions → CO₂ emissions is system-wide emissions, and the hydrogen is green.
CO₂ (Grey Hydrogen) → CO₂ emissions from producing grey hydrogen only.

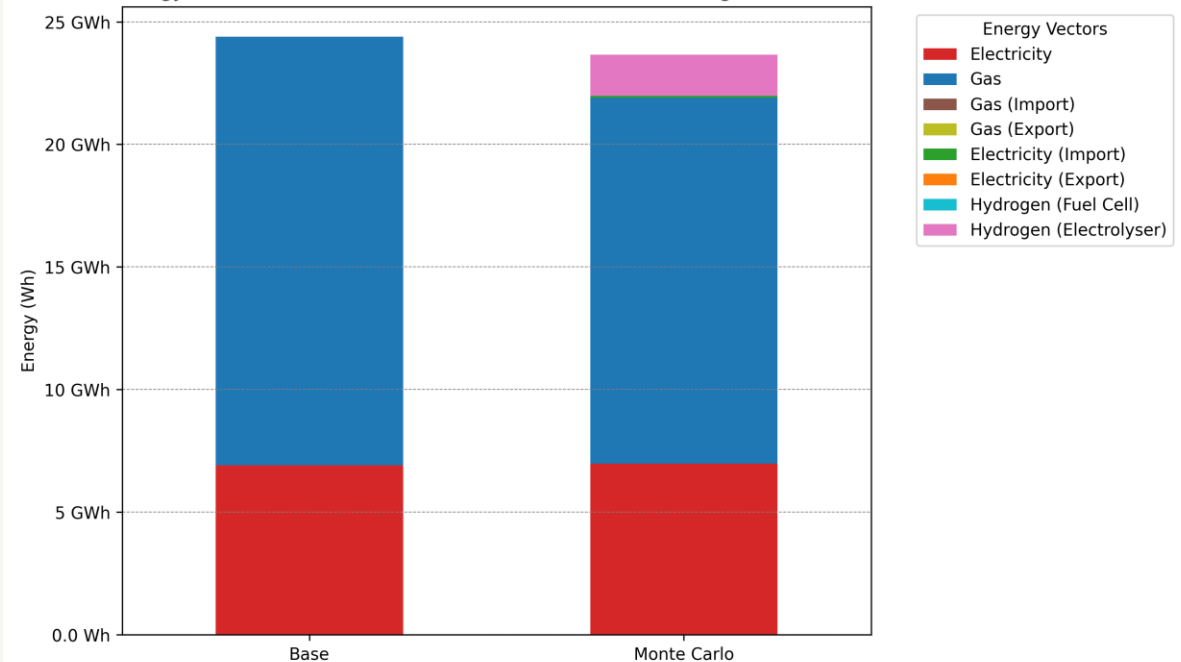
(Generation Mix: (A) Base and (B) Interventions cases)

Generation Mix and CO₂ Emissions (Base and Monte Carlo Simulations of Heating Interventions)



(Energy Vectors: (A) Base and (B) Interventions cases)

Energy Vectors (Base and Monte Carlo Simulations of Heating Interventions)



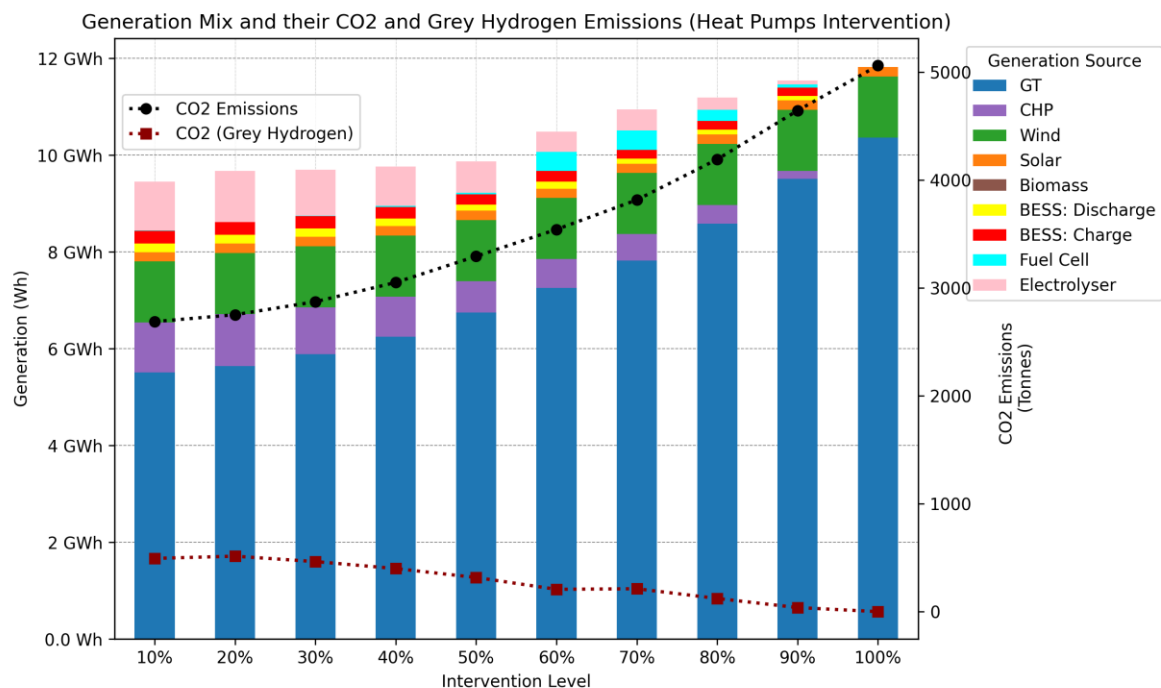
Heat Decarbonisation: North of Tyne (NoT)

Case Study

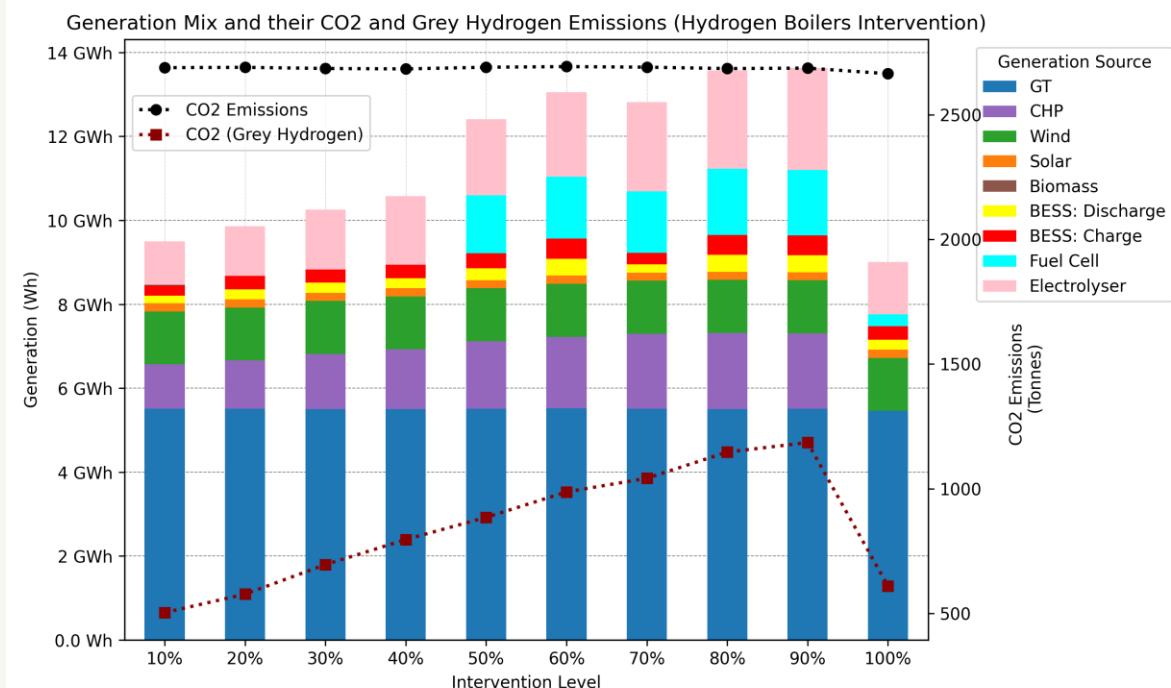
3) Investigating the impacts heat pumps and hydrogen boilers with different interventions levels (10% - 50%) separately. Other social-technical interventions complete the remaining heating demand.

Note: In consideration of customer comfort and affordability, we focus more on technical interventions, such as heat pumps and hydrogen boilers. The share of heat energy from CHP is excluded when the intervention consists entirely of heat pumps or hydrogen boilers (@ 100%).

(Heat Pumps Interventions)



(Hydrogen Boilers Interventions)



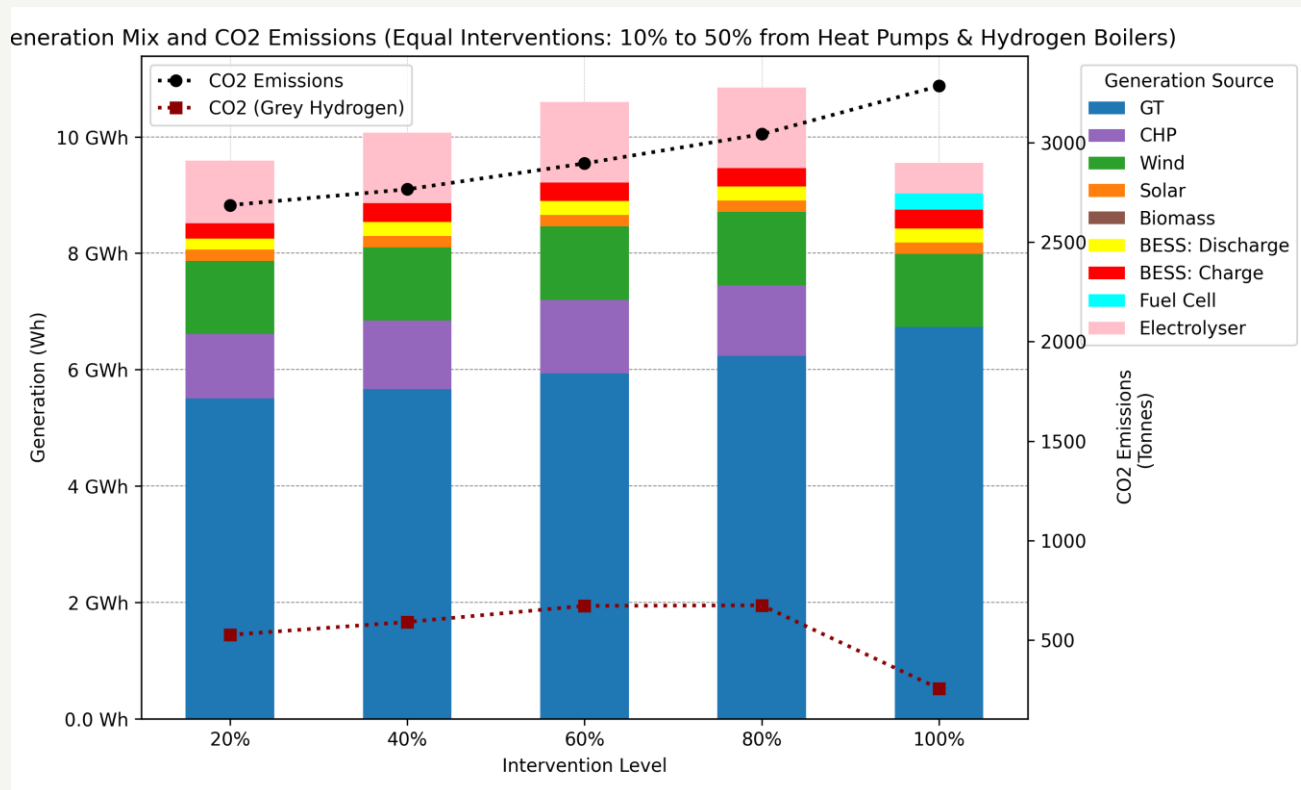
Heat Decarbonisation: North of Tyne (NoT)

Case Study

4) Investigating the impacts heat pumps and hydrogen boilers with different interventions levels (10% - 50%) for each. Other social-technical interventions complete the remaining heating demand, except when HPs=50% and HBs=50%.

Note: The share of heat energy from CHP is excluded when the intervention consists entirely of heat pumps or hydrogen boilers (@ 100%).

Heat Pumps and Hydrogen Boilers interventions with equal shares (10% - 50%) for each



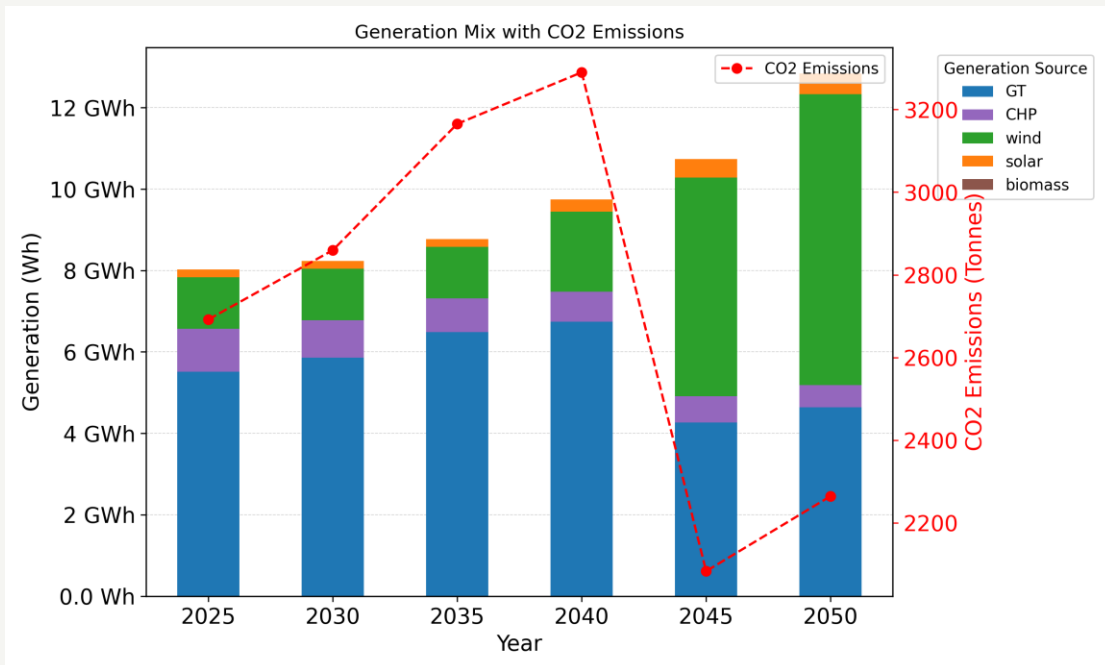
Heat Decarbonisation: North of Tyne (NoT)

Case Study

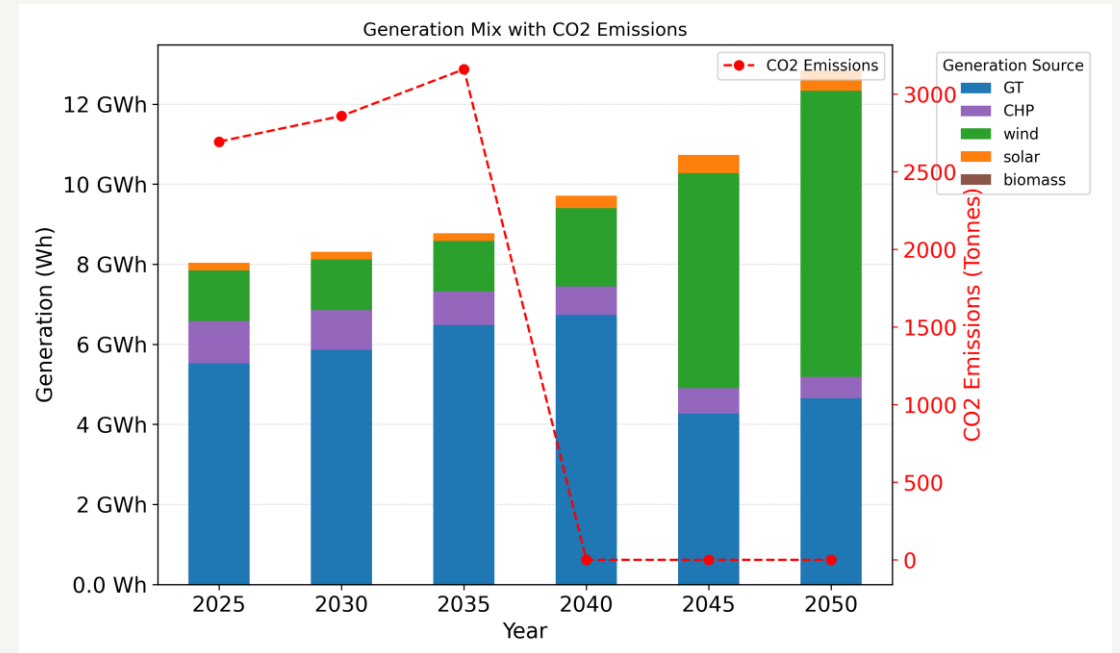
5) Economic planning for one day heating demand from Monte Carlo simulated social and technical interventions with level equal share for each intervention. Planning years are 2025 to 2050, so the economic dispatch of one day is planned in each year.

Note: To match with the future energy supply installations, the day demand is scaled by the trend of demand change according to the (FS) scenario in Energy Future Scenarios from National Grid.

(A) Without CCS deployment



(B) With CCS deployment, from 2040 to 2050

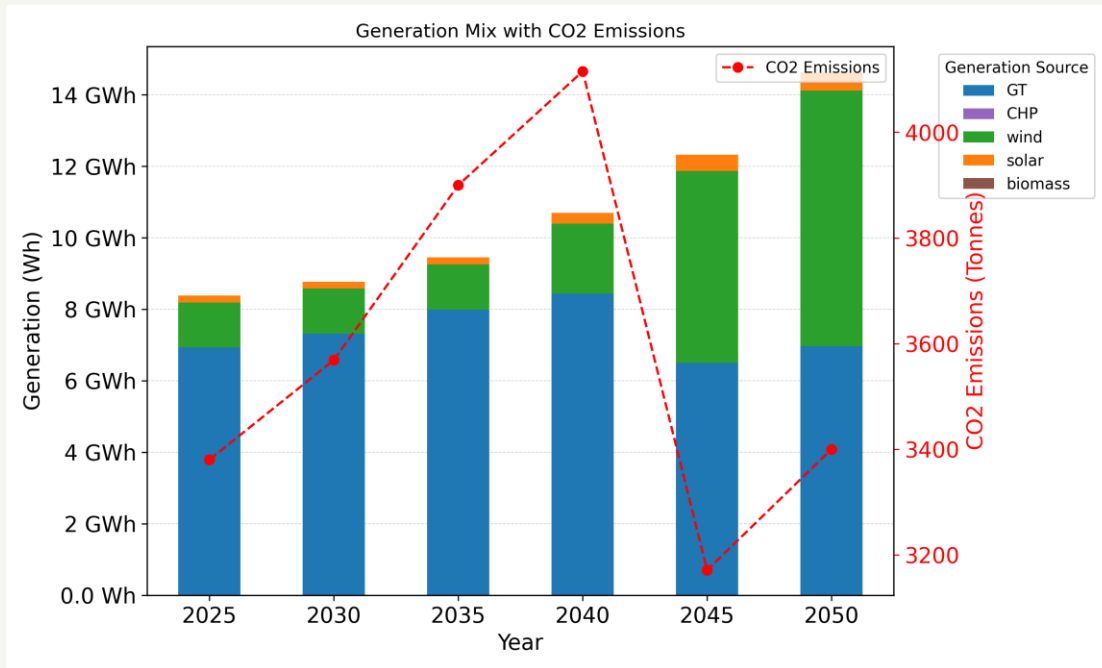


Heat Decarbonisation: North of Tyne (NoT)

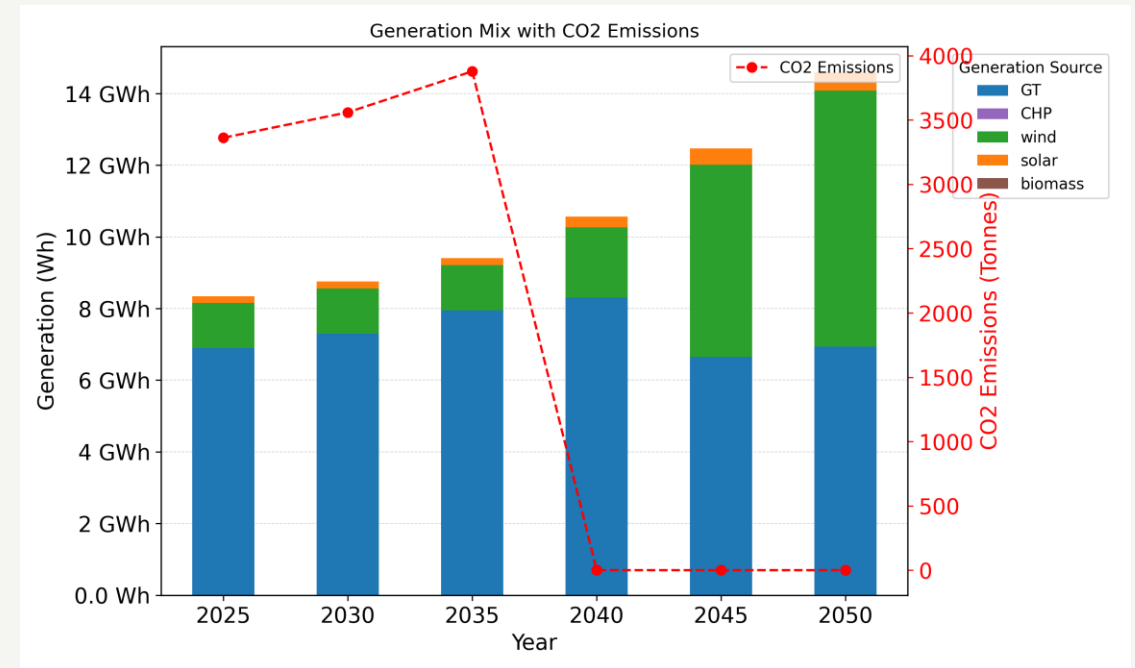
Case Study

6) Economic planning for one day with heating interventions 50% of heat pumps and 50% hydrogen boilers (2025 - 2050).

(A) Without CCS deployment



(B) With CCS deployment, from 2040 to 2050



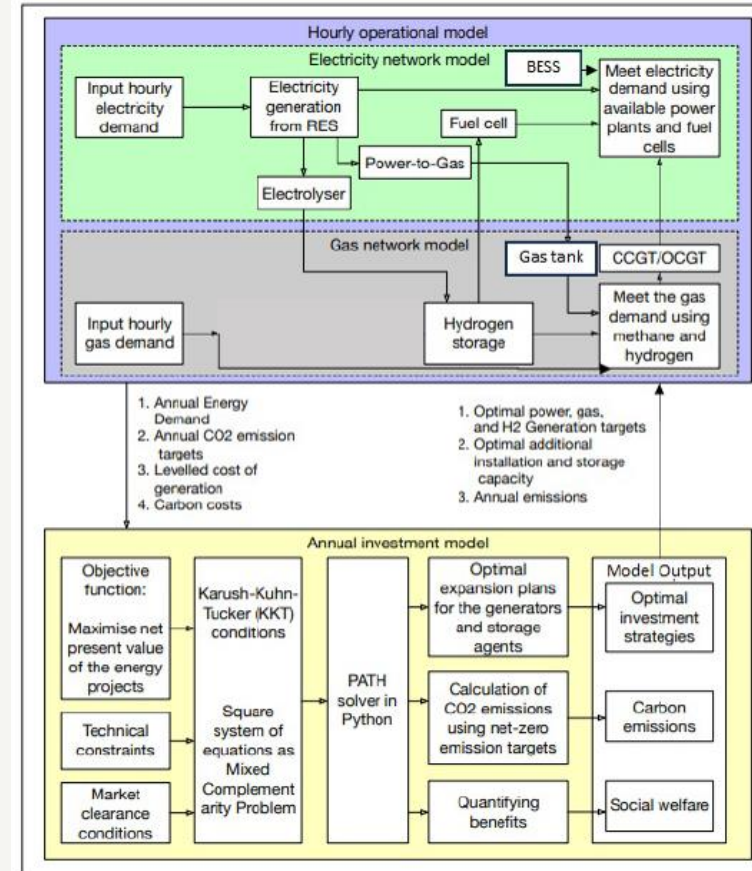
Heat Decarbonisation: North of Tyne (NoT)

Case Study

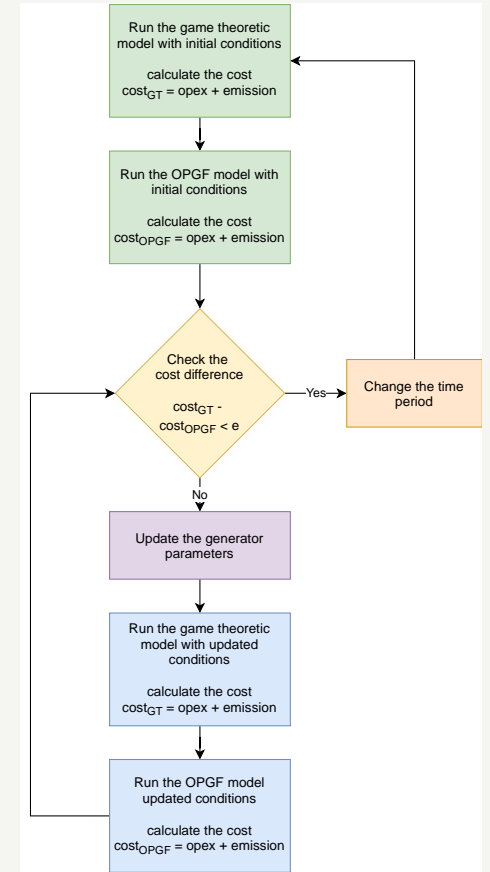
7) Economic planning for one day with hydrogen blending into the existing natural gas network

Combining Game-Theory model with OPGF model

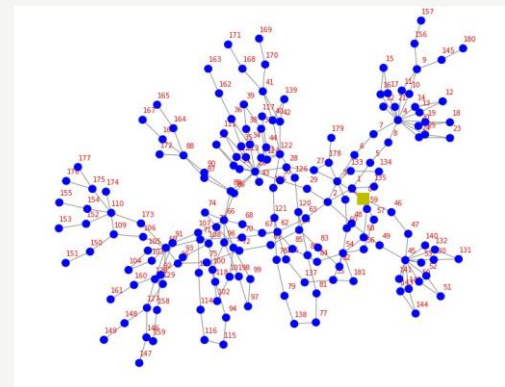
GT model output → OPGF output → GT model



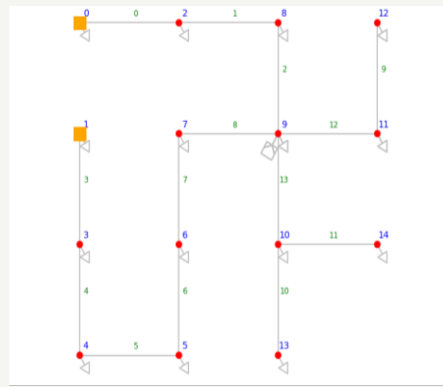
Schematic Diagram of Game-Theoretic Model



Short-term operation & long term planning



Electricity Network



Gas Network

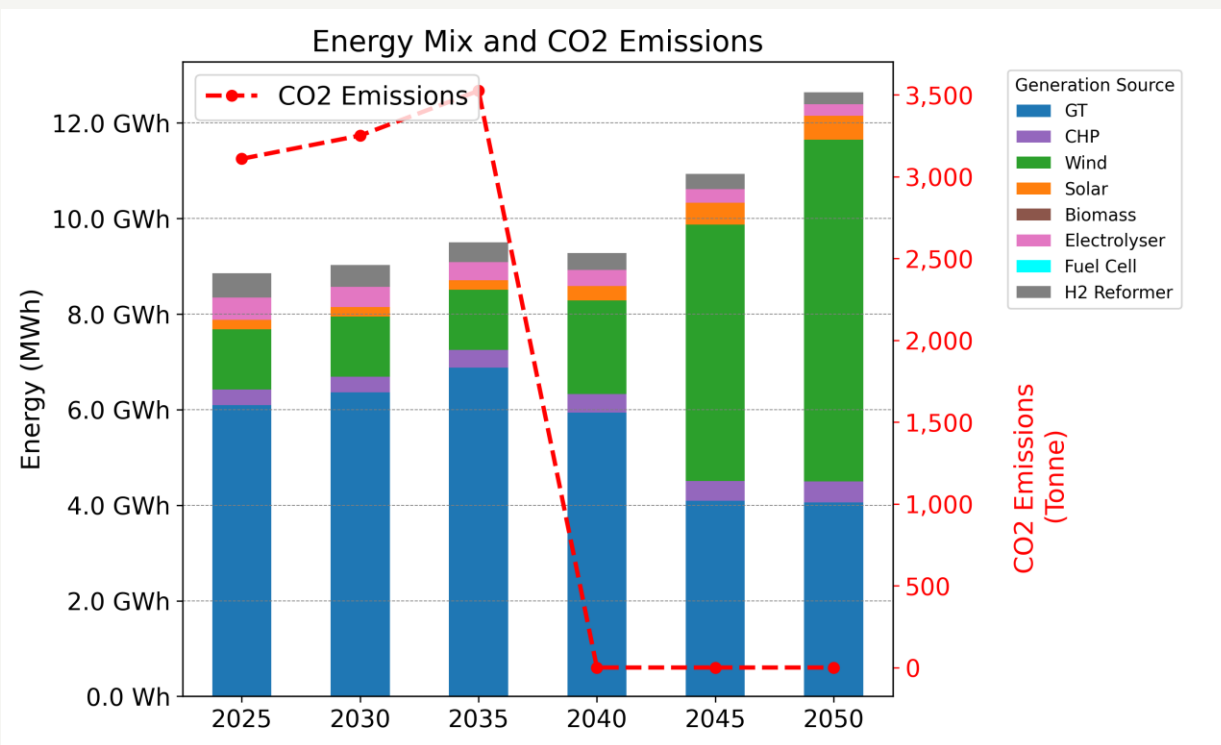
Heat Decarbonisation: North of Tyne (NoT)

Case Study

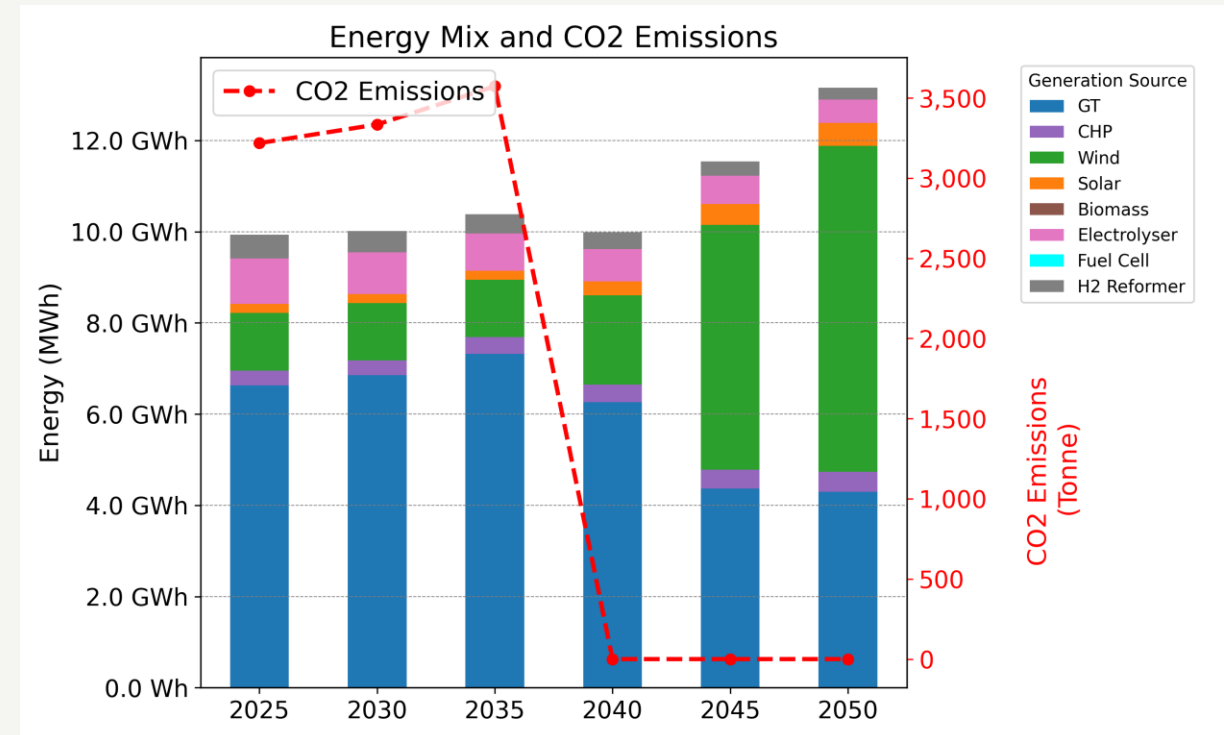
7.1) Economic planning with hydrogen blending for one day with heating demand from Monte Carlo simulated social and technical interventions with level equal share for each intervention.

Hydrogen blending is by volume (up to 20%)
 $E(\text{electrolyser}) + E(\text{H}_2 \text{ reformer}) = E(\text{H}_2 \text{ boilers}) + E(\text{H}_2 \text{ blending})$
 Any surplus H_2 goes to Fuel Cell
 With CCS deployment (2040 to 2050) and high renewables.

(A) Hydrogen Blending = 10 %



(B) Hydrogen Blending = 20 %



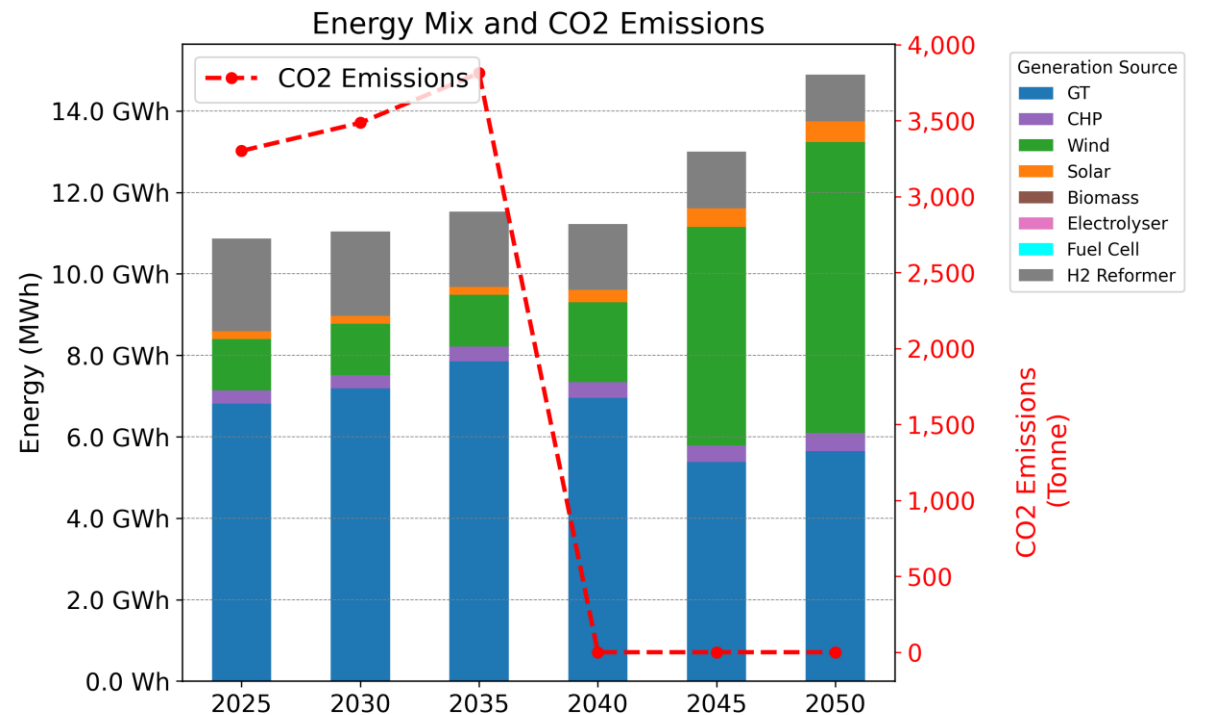
Heat Decarbonisation: North of Tyne (NoT)

Case Study

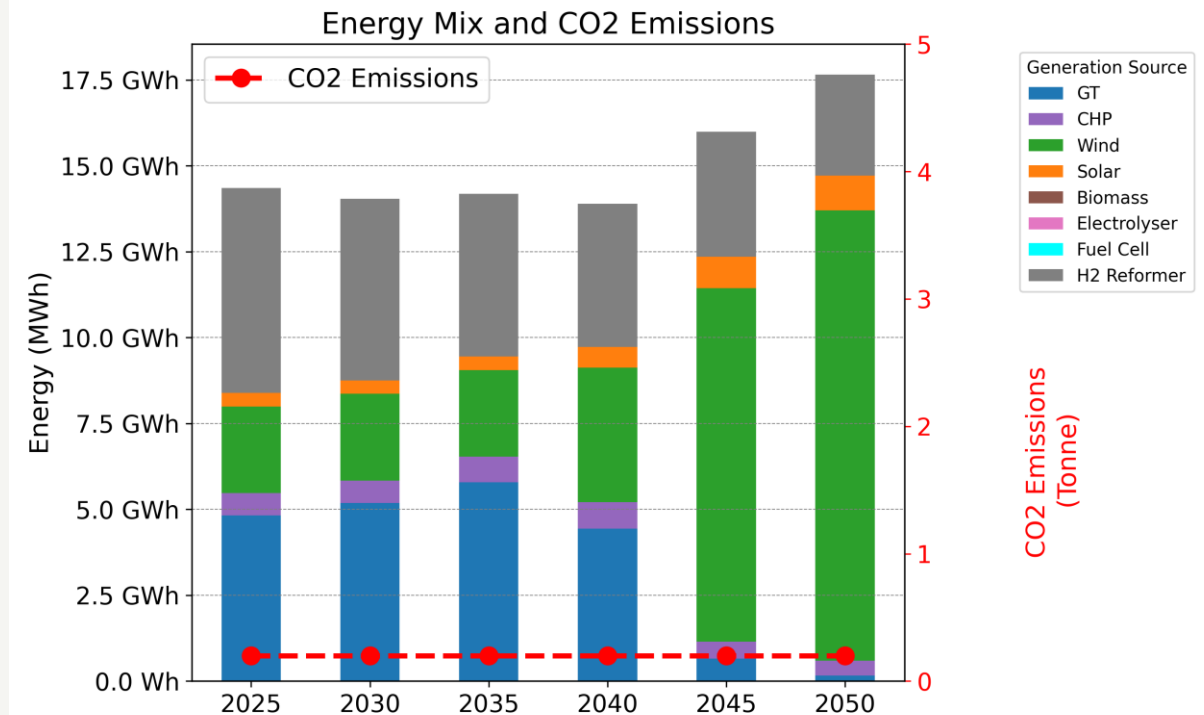
7.2) Economic planning for one day with heating interventions 50% of heat pumps and 50% hydrogen boilers (2025 - 2050).

Hydrogen blending is by volume (up to 20%)
 $E(\text{electrolyser}) + E(\text{H}_2 \text{ reformer}) = E(\text{H}_2 \text{ boilers}) + E(\text{H}_2 \text{ blending})$
 Any surplus H_2 goes to Fuel Cell
 With CCS deployment (2040 to 2050) and high renewables.

(A) Hydrogen Blending = 20 %



(B) Hydrogen Blending = 100 %



Heat Decarbonisation: North of Tyne (NoT)

Comparison in terms of operational cost for a peak demand day in **2035**.

Assuming no CCS deployment

(1) STI: Social-Technical

| H ₂ Ratio (%) | Emissions (tonnes) | Cost (m£) |
|--------------------------|--------------------|-----------|
| 0 | 3467 | 1.96 |
| 10 | 3521 | 2.06 |
| 20 | 3574 | 2.17 |
| 100 | 0 | 4.28 |

(3) 100 % of Heat Pumps

| H ₂ Ratio (%) | Emissions (tonnes) | Cost (m£) |
|--------------------------|--------------------|-----------|
| 0 | 6171 | 1.45 |
| 10 | 6178 | 1.51 |
| 20 | 6164 | 1.59 |
| 100 | 0 | 2.59 |

Cost per CO₂ tonne abated (£/t)

| Scenario | Zero-Emissions Cost (m£) | Baseline Emissions (t) | Cost per t abated (£/t) |
|----------------|--------------------------|------------------------|-------------------------|
| Base_MC_Interv | 4.28 | 3467 | 1234 |
| HP_HB_Interv | 4.05 | 4123 | 982 |
| HP_Interv | 2.59 | 4747 | 546 |
| HB_Interv | 9.86 | 3440 | 2866 |

(2) 50/50 Mix of Heat Pumps and Hydrogen Boilers

| H ₂ Ratio (%) | Emissions (tonnes) | Cost (m£) |
|--------------------------|--------------------|-----------|
| 0 | 4122 | 2.54 |
| 10 | 3970 | 2.58 |
| 20 | 3808 | 2.61 |
| 100 | 0 | 4.05 |

(4) 100 % of Hydrogen

| H ₂ Ratio (%) | Emissions (tonnes) | Cost (m£) |
|--------------------------|--------------------|-----------|
| 0 | 3440 | 4.84 |
| 10 | 3319 | 4.95 |
| 20 | 3180 | 5.07 |
| 100 | 0 | 9.86 |

Heat Decarbonisation: North of Tyne (NoT)

Comparison in terms of operational cost for a peak demand day in **2050**.
Assuming full CCS deployment and high renewable integration.

(1) STI: Social-Technical Interventions

| H ₂ Ratio (%) | Emissions (tonnes) | Cost (m£) |
|--------------------------|--------------------|-----------|
| 0 | 0 | 1.76 |
| 10 | 0 | 1.82 |
| 20 | 0 | 1.90 |
| 100 | 0 | 3.13 |

(3) 100 % of Heat Pumps

| H ₂ Ratio (%) | Emissions (tonnes) | Cost (m£) |
|--------------------------|--------------------|-----------|
| 0 | 0 | 1.10 |
| 10 | 0 | 1.19 |
| 20 | 0 | 1.30 |
| 100 | 0 | 2.98 |

(2) 50/50 Mix of Heat Pumps and Hydrogen

| H ₂ Ratio (%) | Emissions (tonnes) | Cost (m£) |
|--------------------------|--------------------|-----------|
| 0 | 0 | 2.25 |
| 10 | 0 | 2.29 |
| 20 | 0 | 2.32 |
| 100 | 0 | 3.07 |

(4) 100 % of Hydrogen Boilers

| H ₂ Ratio (%) | Emissions (tonnes) | Cost (m£) |
|--------------------------|--------------------|-----------|
| 0 | 0 | 3.76 |
| 10 | 0 | 3.84 |
| 20 | 0 | 3.92 |
| 100 | 0 | 6.98 |

Heat Decarbonisation: North of Tyne (NoT)

Conclusion

- The system-wide modeling approach for residential heating in the NoT region shows that, although the applied social and technical interventions effectively reduce gas demand, their overall impact on CO₂ emissions remains limited under the current system infrastructure.
- The scale of required generation capacity (GWh/day) points to substantial requirement for infrastructure expansion.
- In the NoT region, lower levels of hydrogen blending, coupled with the deployment of CCS from 2040, play a crucial role in driving the decarbonisation of the residential heating sector.
- Integrating 50/50 mix of hydrogen boilers and heat pumps with CCS offers a viable route to net-zero emissions in North of Tyne (NoT) by 2050.
- In terms of operational costs, at the full hydrogen integration, the deployment of 100% heat pumps yields the lowest costs, then comes 50/50 mix of hydrogen boilers and heat pumps.
- While the scenario of 100% hydrogen boilers has the highest operational costs.
- Hydrogen blending into the gas network can support emissions reduction while meeting heating demand. However, its impact is limited! Since 20% of hydrogen blending leads to about 7% reduction in emissions.

Thank you for your attention