Hydrogen Integration for Accelerated Energy Transitions

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

Integrating Social Interventions and Low-Carbon Technologies

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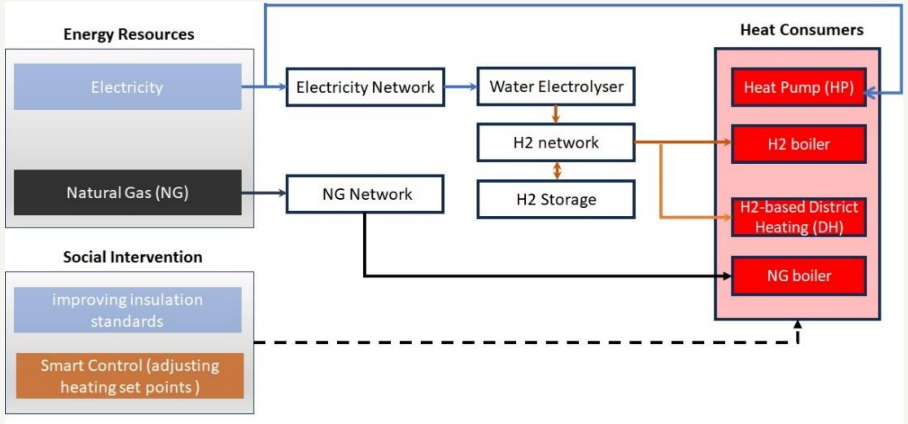
Heat Decarbonisation: North of Tyne (NoT)

Objective:

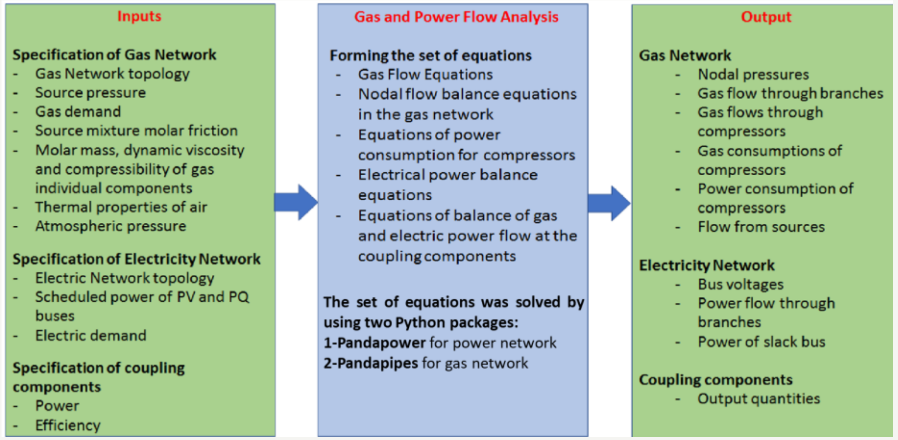
Assessment of the impacts of social and technical interventions for the decarbonisation of residential heating on the electricity and gas systems in the North of Tyne (NoT) region.



High-level diagram of resources-technology model

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?



Schematic Diagram of Modelling

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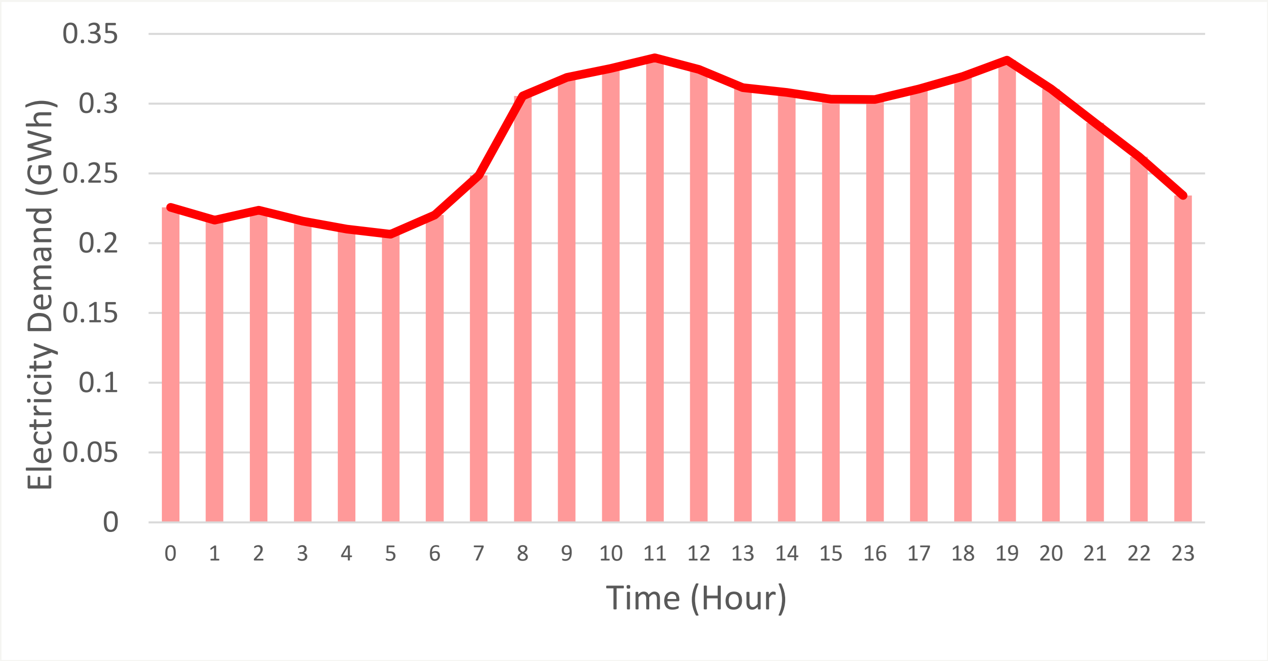
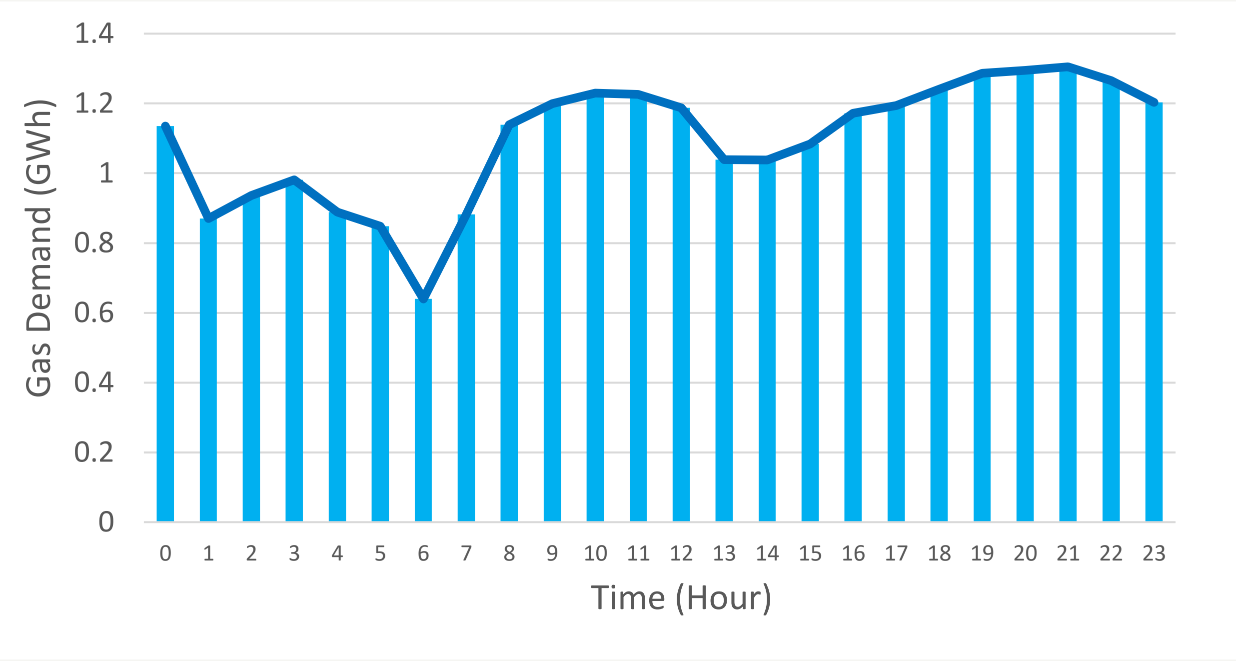
Demand Overview

The heating scenarios use the coldest day in November 2019 as a baseline to model peak energy demand.
Peak energy-demand day saw total consumption of 31 GWh, with gas (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.).

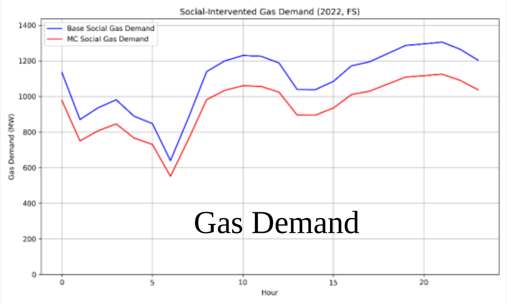
K_j is the adjusting factor for intervention j (e.g., heat pumps, hydrogen boilers, etc.).

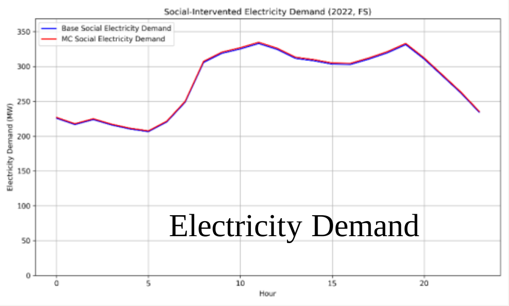
X_j and Y_j are random variables drawn from normal distributions representing uncertainty, $X_j \sim (\mu_{R_j}, \sigma_{R_j})$ for gas change and $Y_j \sim (\mu_{k_j}, \sigma_{k_j})$ for electricity change).

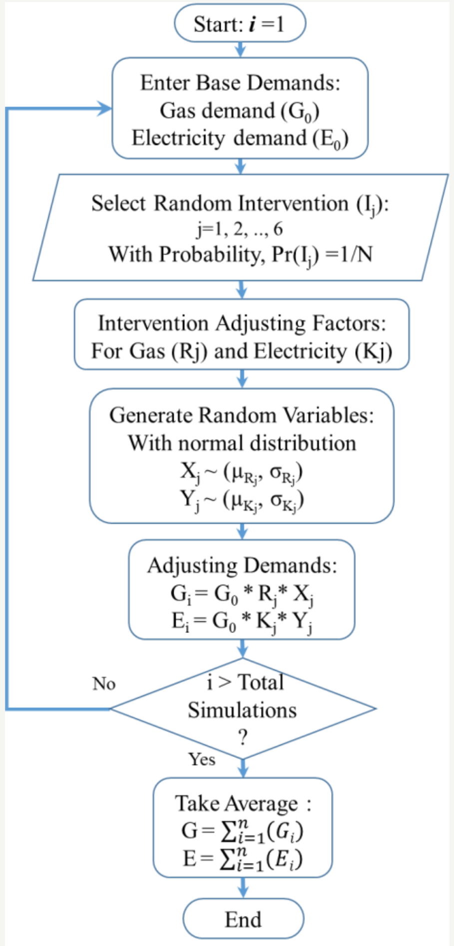
$Pr(I_j)$ is the probability of selecting intervention j, (in 6 interventions, Pr = 1/N = 1/6).

N is the total number of interventions.

i is the iteration of simulation out of n simulations.







Monte Carlo Simulation for Social and Technical Interventions of Heating Demand

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

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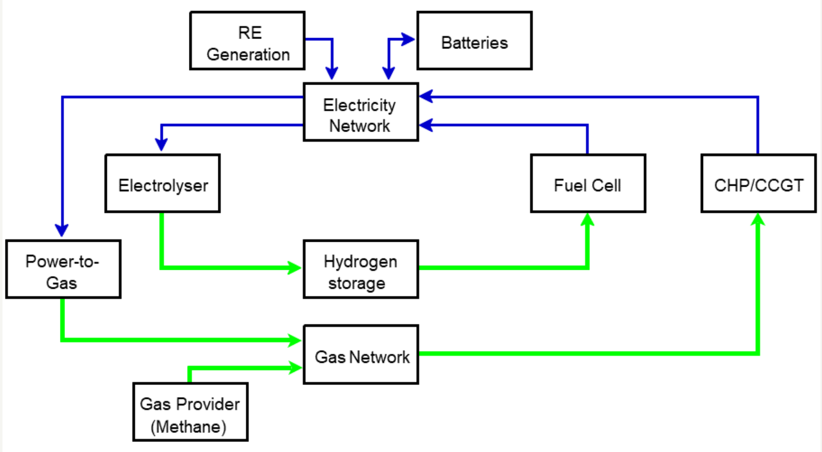
System Data

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

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Case Study

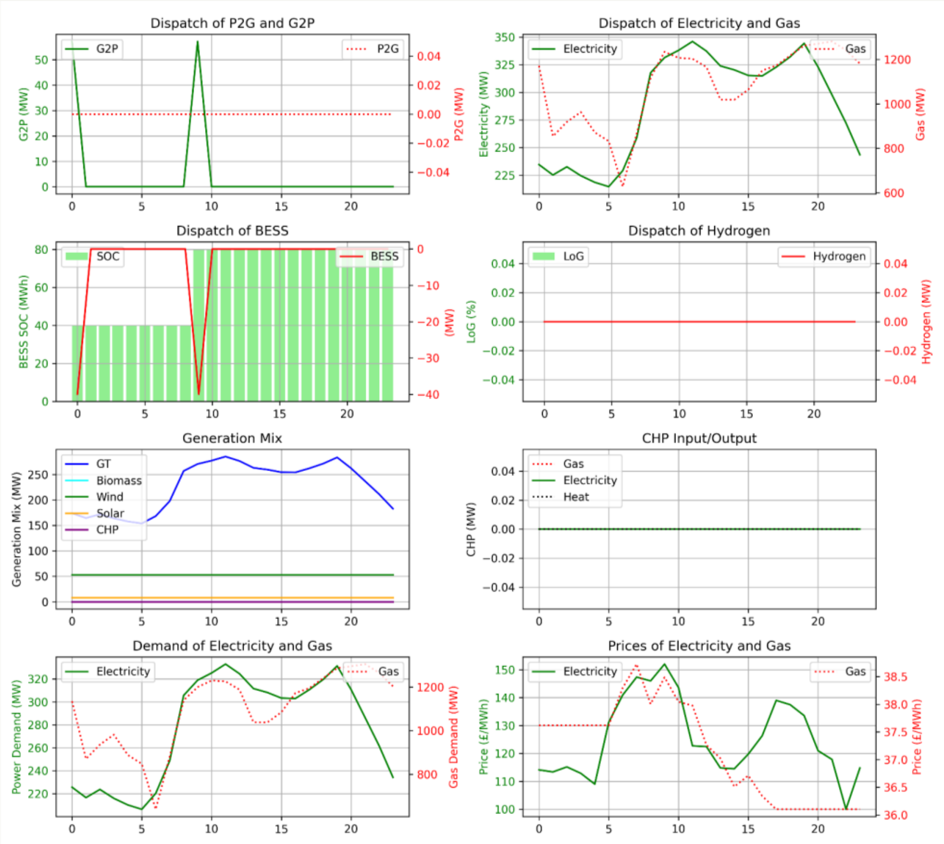
1) Analysis the economic dispatch for the base case (without interventions) and Monte Carlo simulation of the social and technical interventions.

BESS:
- (Positive) Discharging,
- (Negative) Charging.

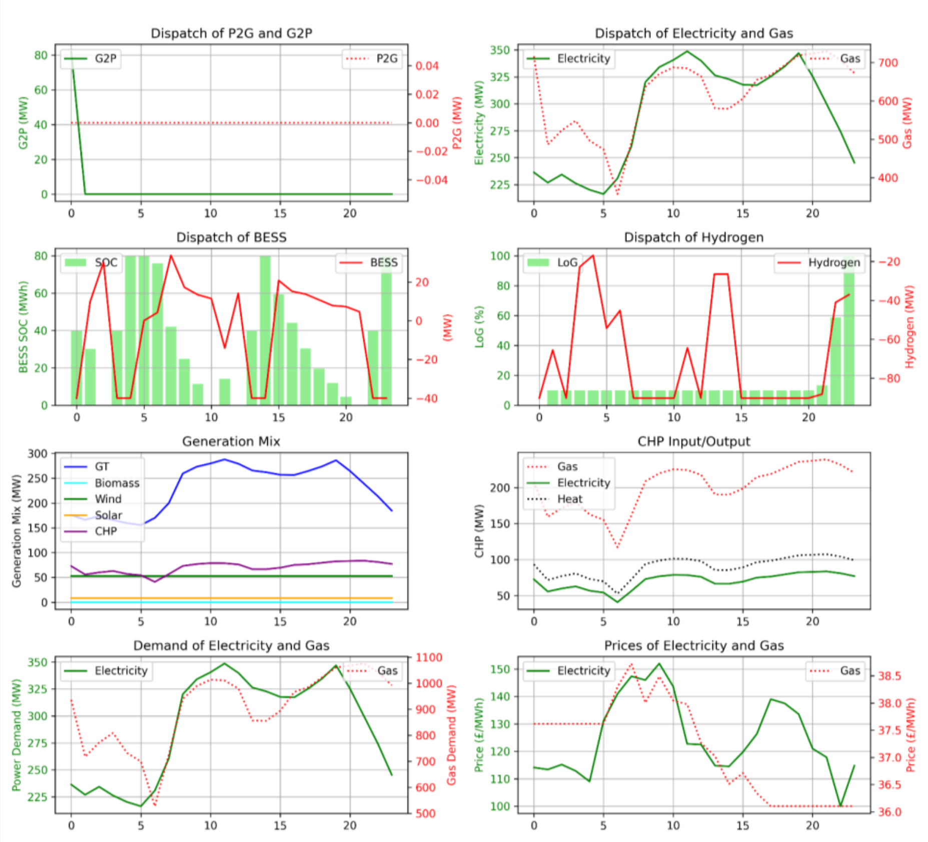
Hydrogen:
- (Positive) Fuel Cell,
- (Negative) Electrolyser.

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

(Base Case)



(Monte Carlo Simulation of Interventions)



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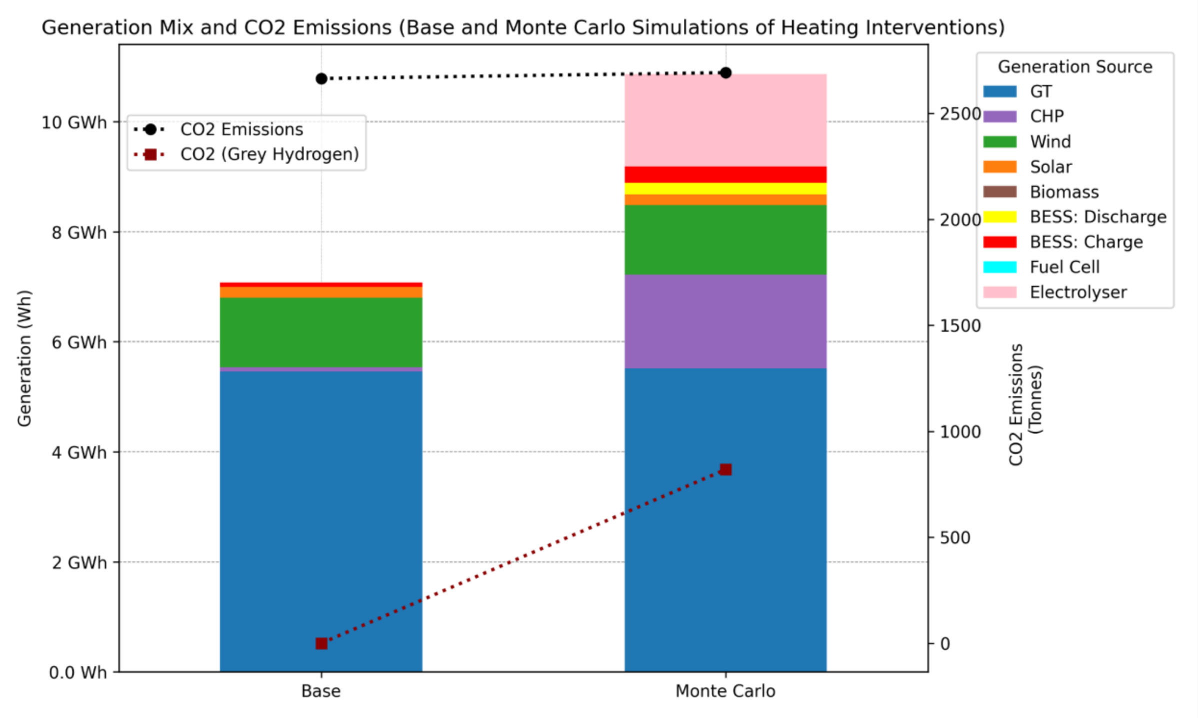
Case Study

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.

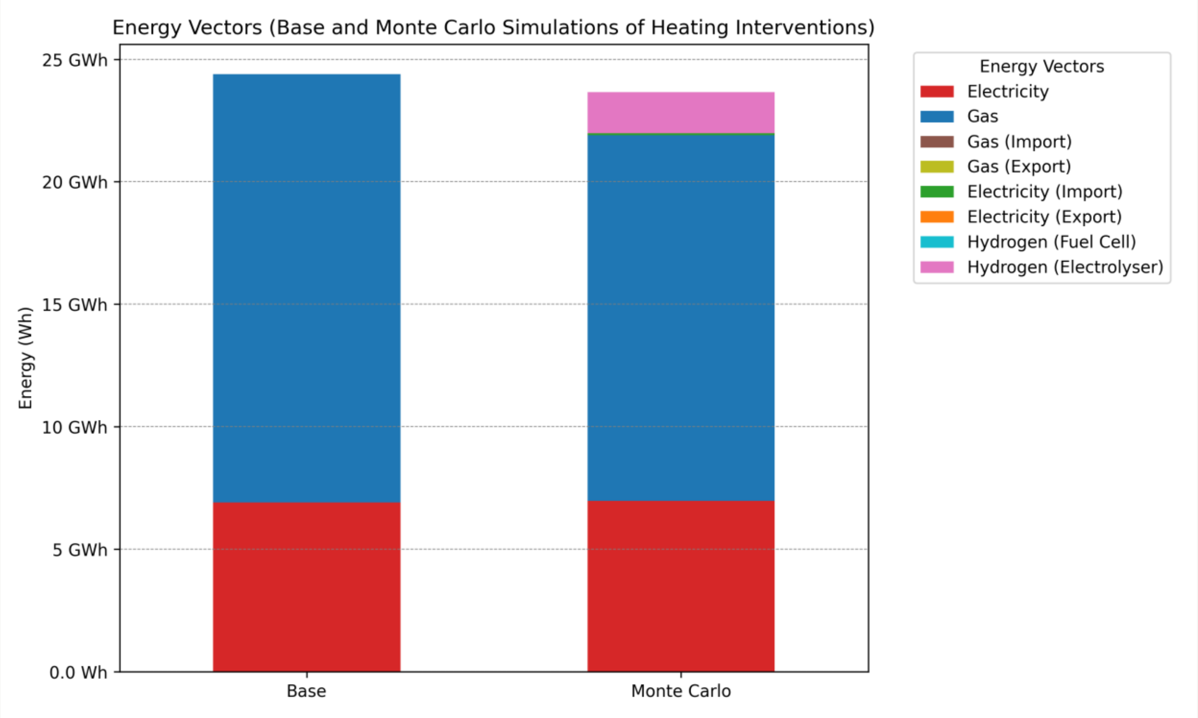
Note: The energy and emissions of hydrogen production are included in the model.

CO2 Emissions ➔ CO_2 emissions is system-wide emissions, and the hydrogen is green.
CO2 (Grey Hydrogen) ➔ CO_2 emissions from producing grey hydrogen only.

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



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



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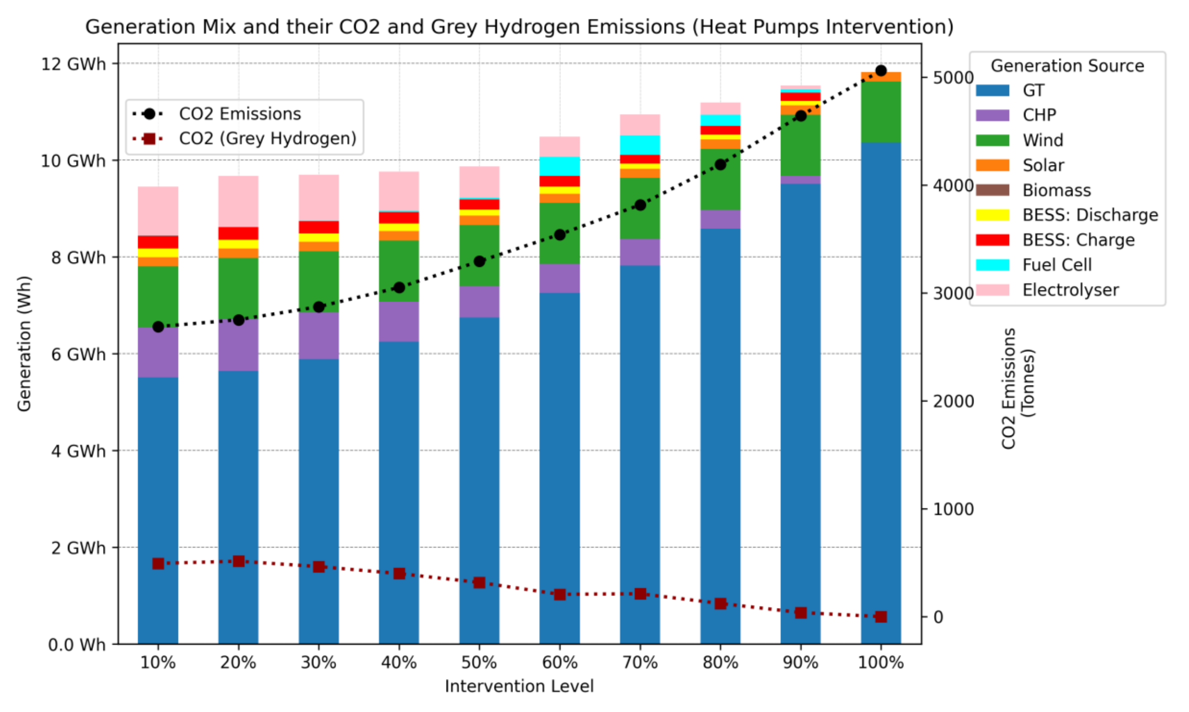
Heat Decarbonisation: North of Tyne (NoT)

Case Study

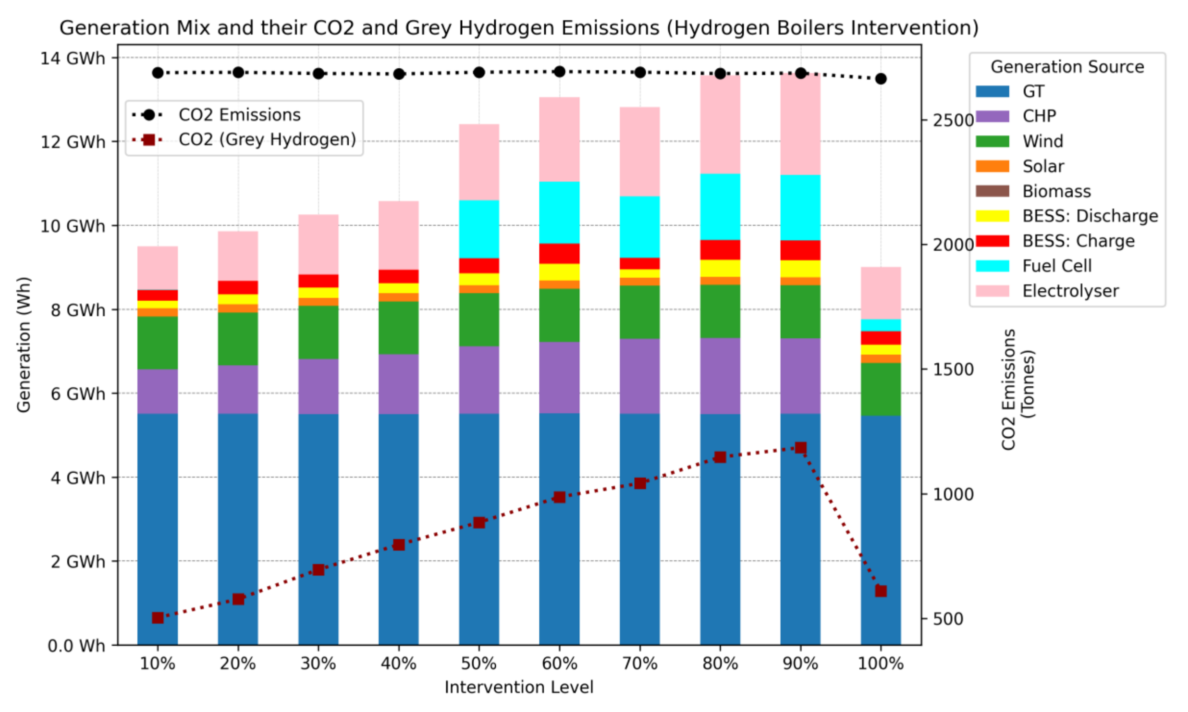
3) Investigating the impacts heat pumps and hydrogen boilers with different interventions levels (10% - 50%) separately. Other social-technical interventions complete the remaining heating demand.

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)



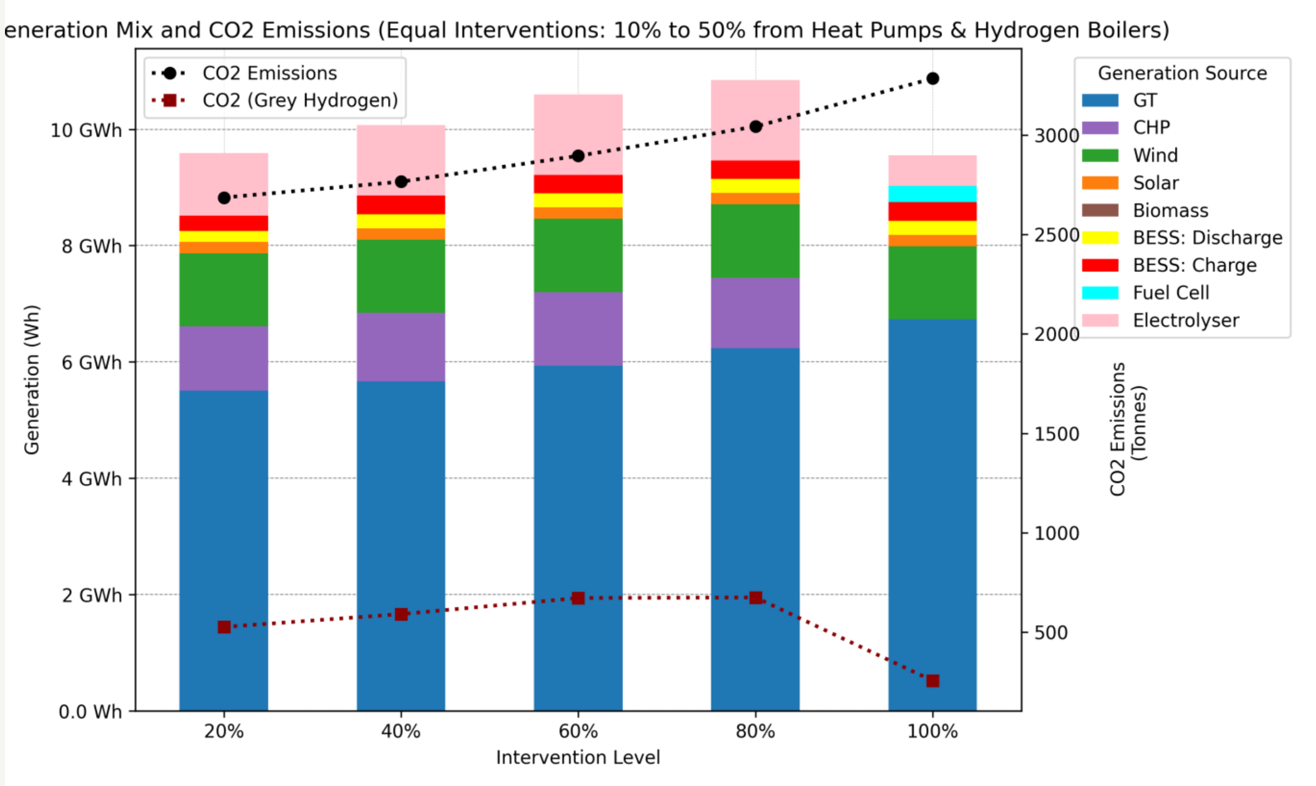
Heat Decarbonisation: North of Tyne (NoT)

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



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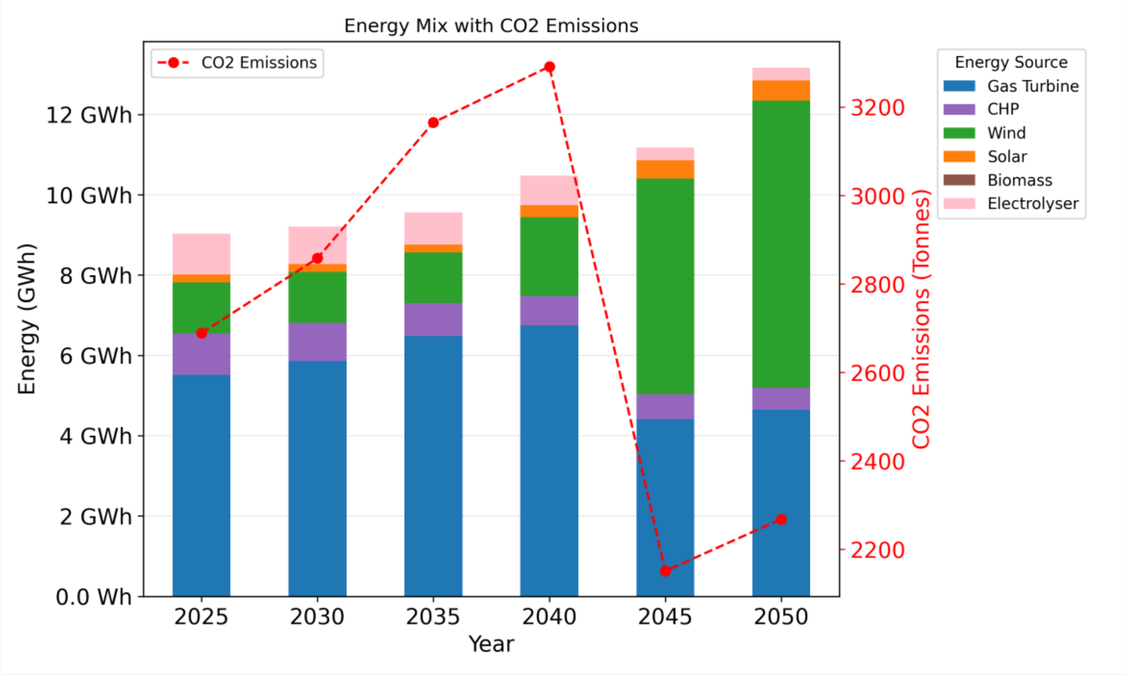
Heat Decarbonisation: North of Tyne (NoT)

Case Study

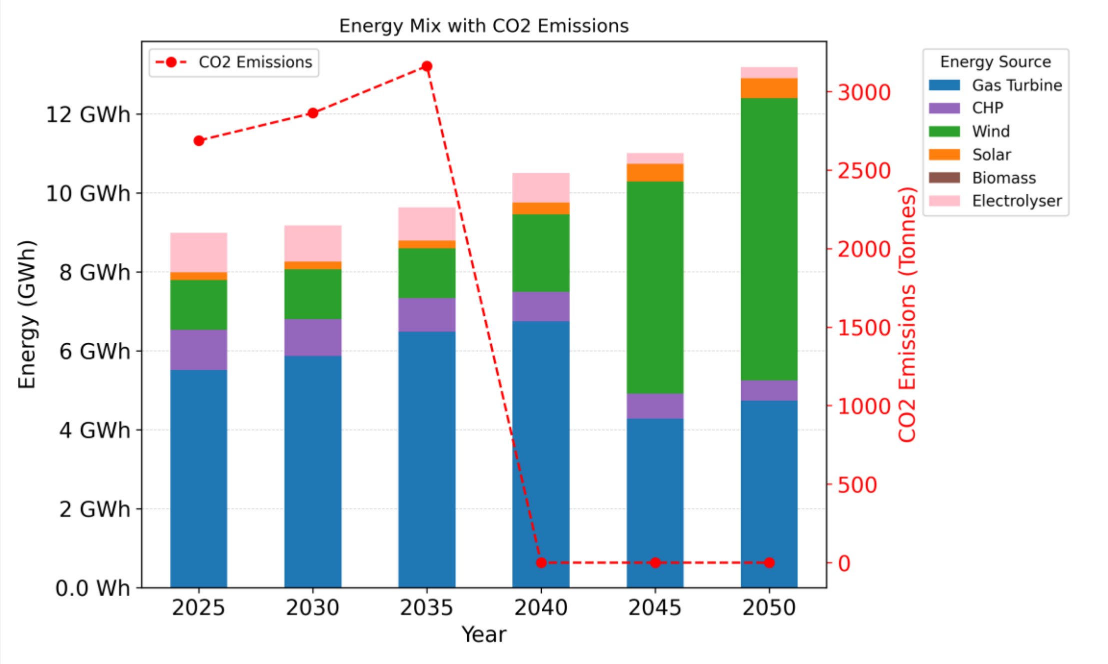
5) Economic planning for one day heating demand from Monte Carlo simulated social and technical interventions with level equal share for each intervention. Planning years are 2025 to 2050, so the economic dispatch of one day is planned in each year.

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



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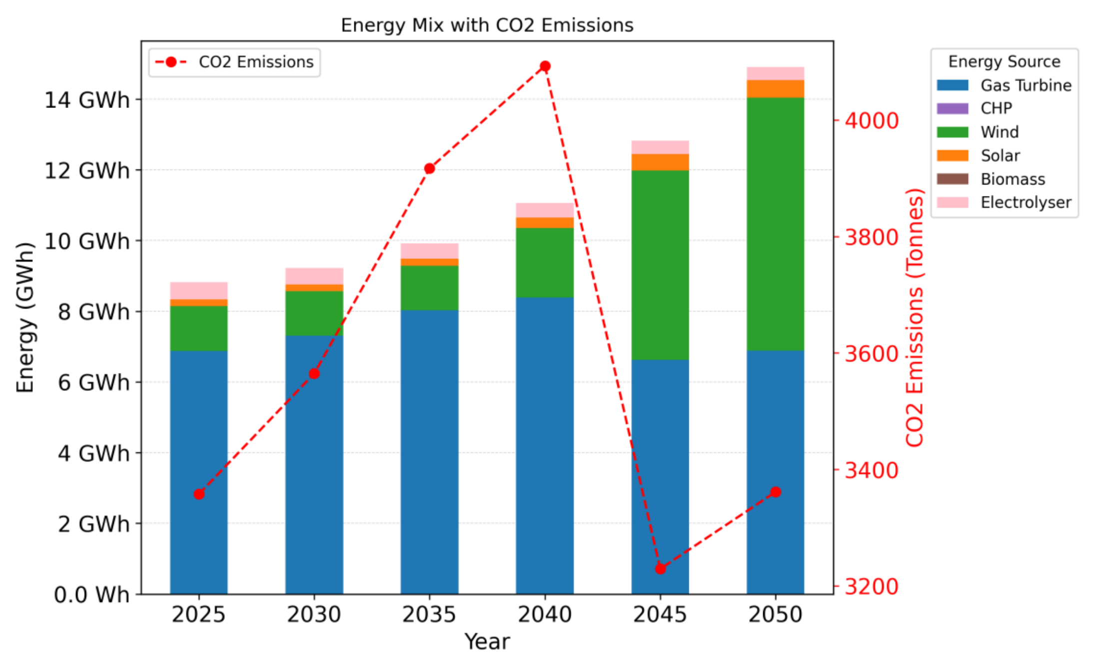
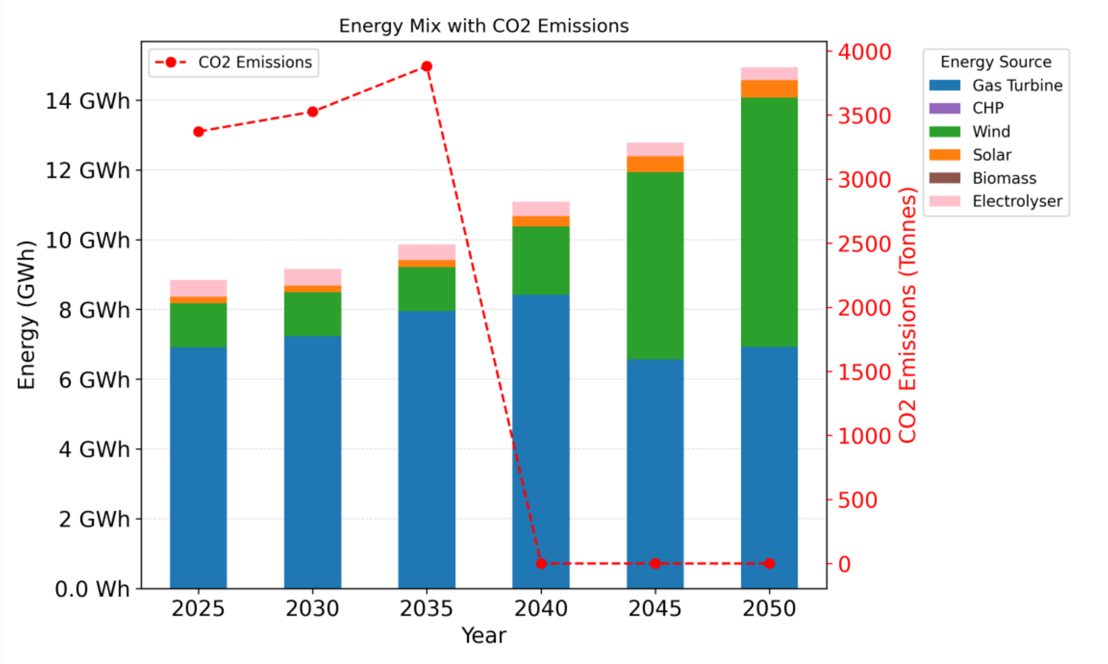
Case Study

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



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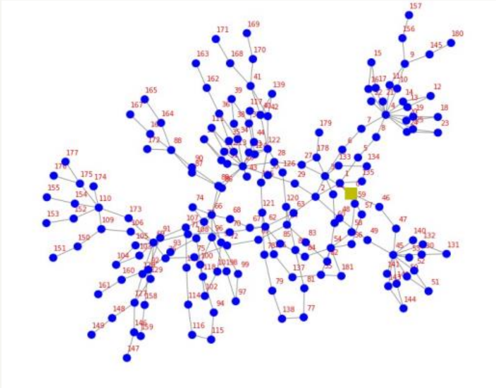
Case Study

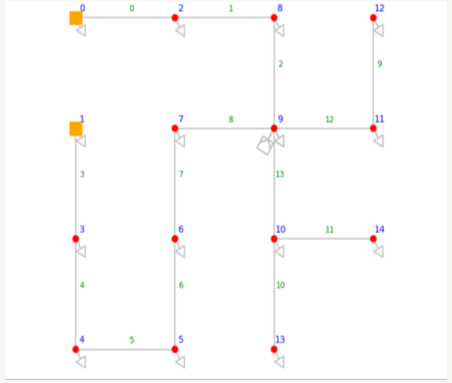
7) Economic planning for one day with hydrogen blending into the existing natural gas network

Combining Game-Theory model with OPGF model

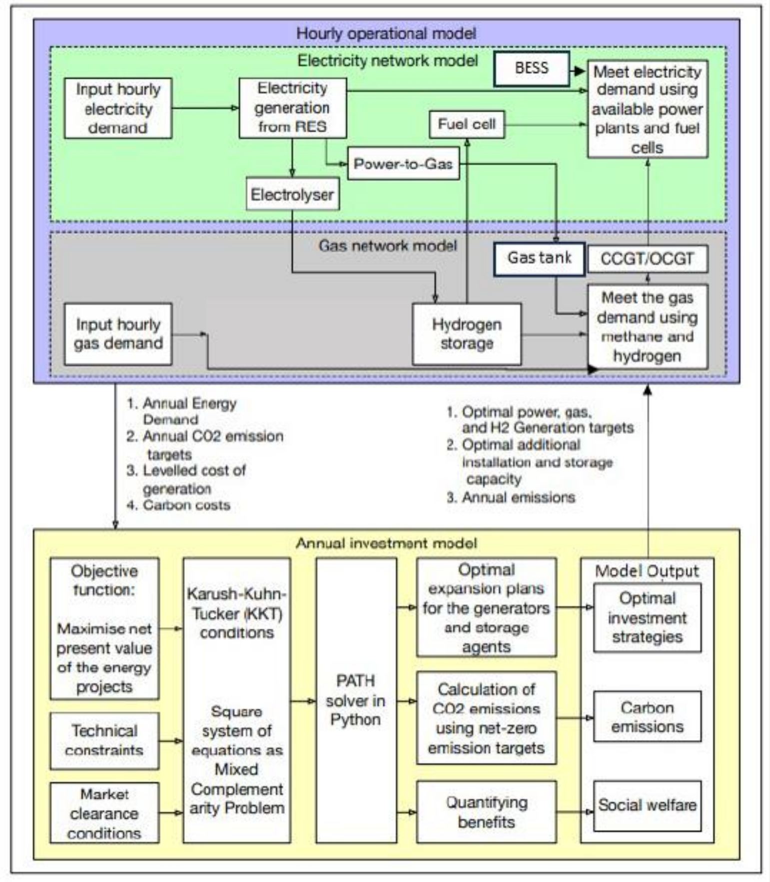
GT model output ➔ OPGF output ➔ GT model



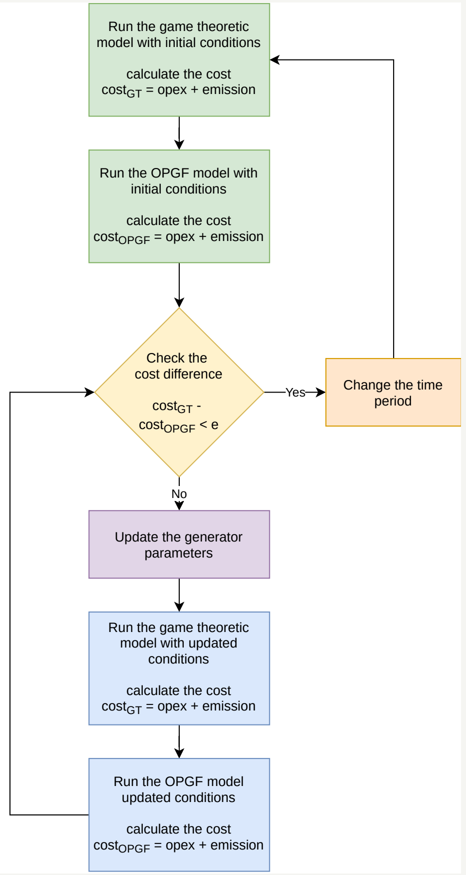
Electricity Network



Gas Network



Schematic Diagram of Game-Theoretic Model



Short-term operation & long term planning

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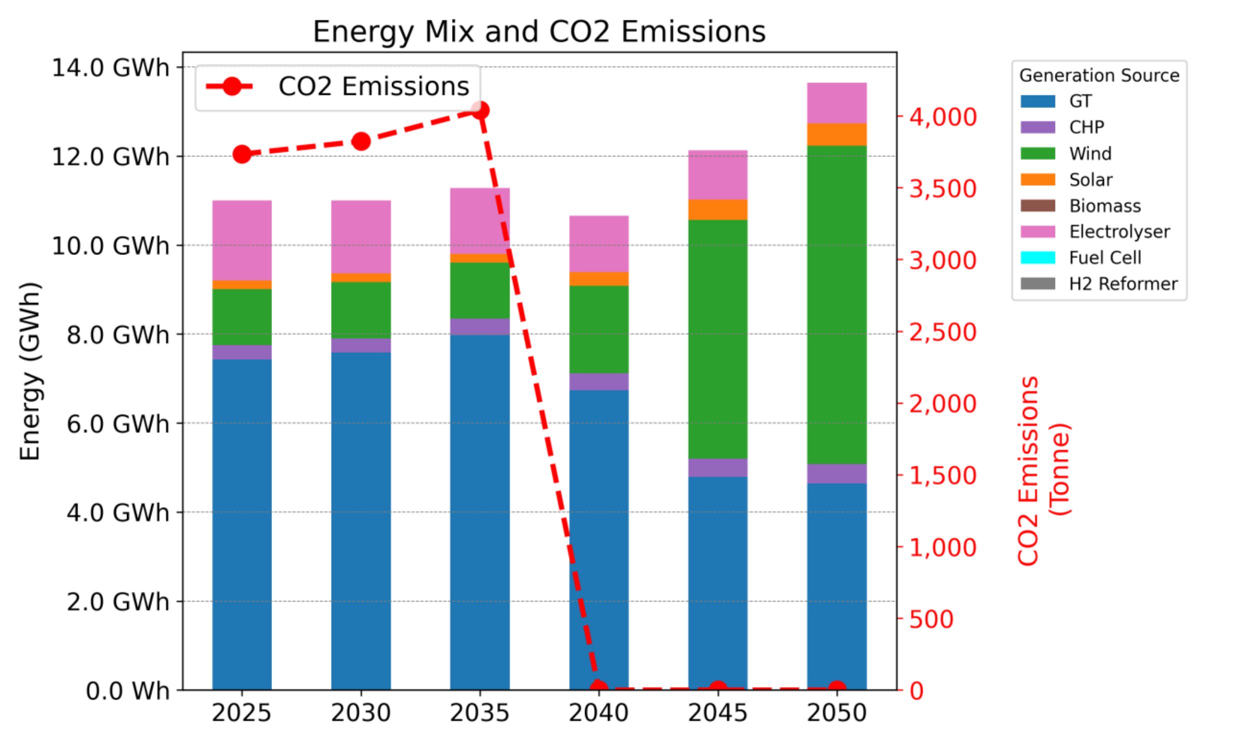
Heat Decarbonisation: North of Tyne (NoT)

Case Study

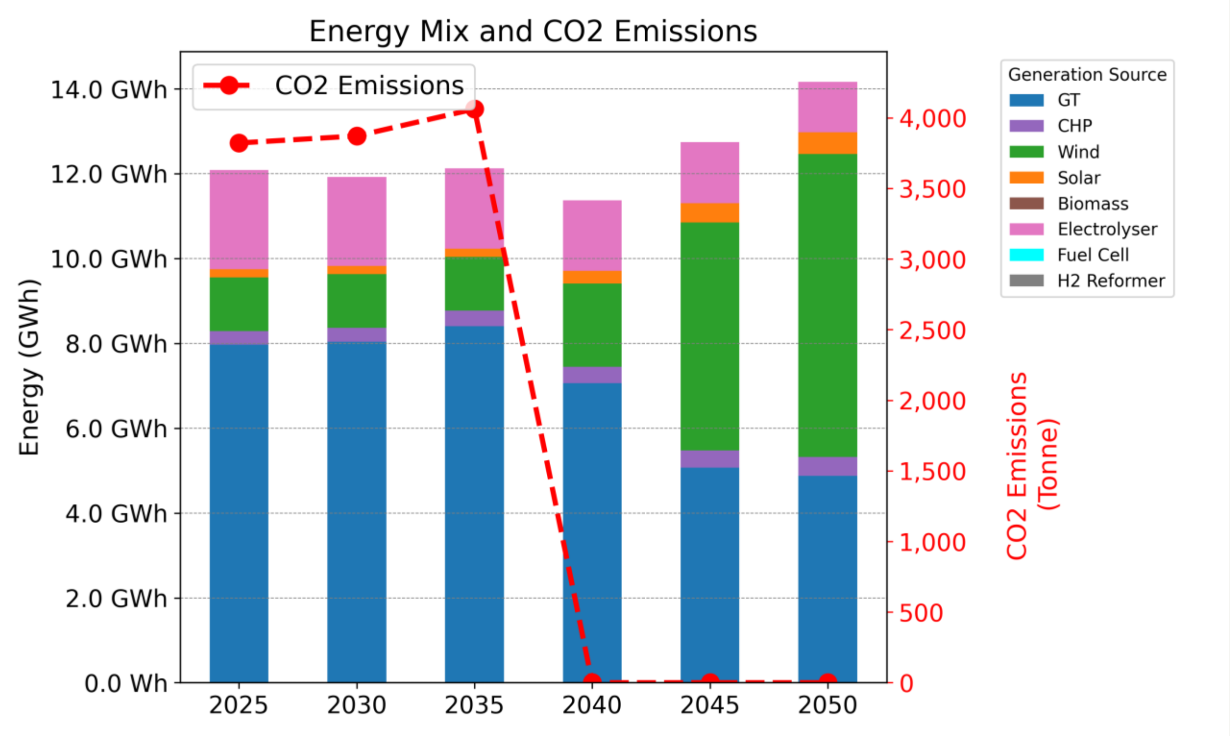
7.1) Economic planning with hydrogen blending for one day with heating demand from Monte Carlo simulated social and technical interventions with level equal share for each intervention.

Hydrogen blending is by volume (up to 20%)
E(electrolyser) + E(H_2 reformer) = E(H_2 boilers) + E(H_2 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 = 2**0 %**



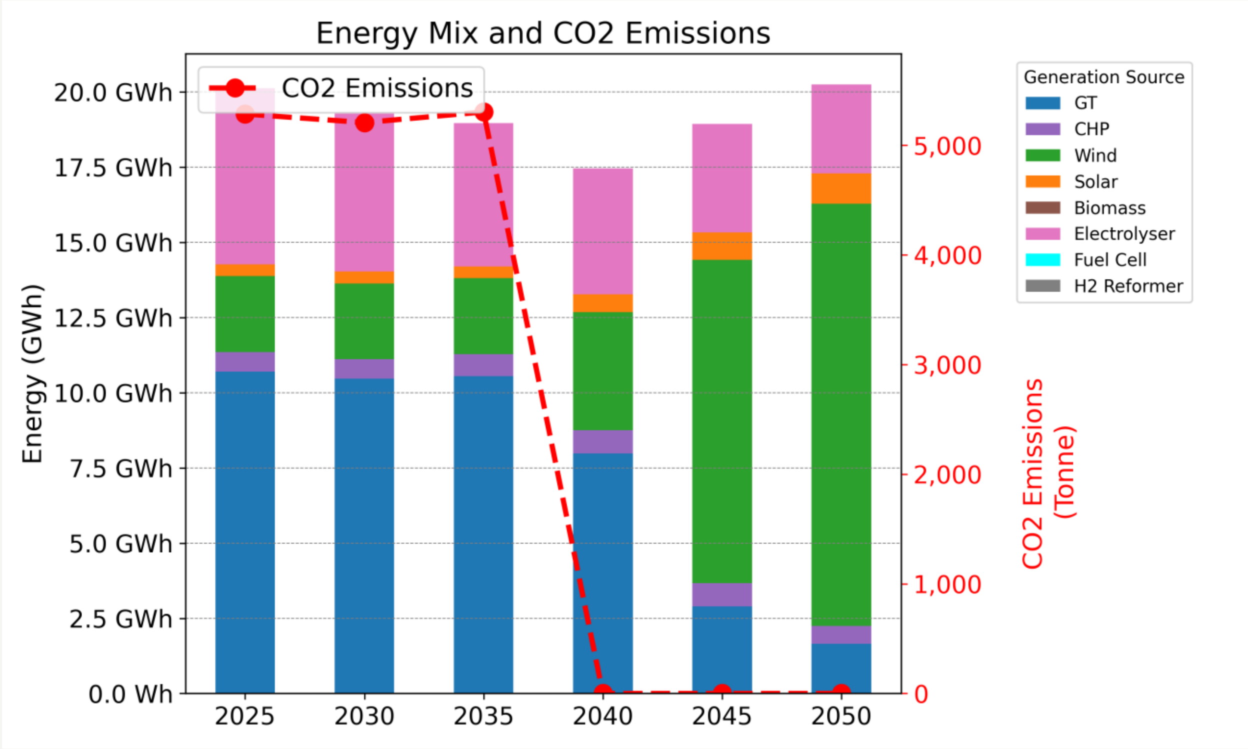
Heat Decarbonisation: North of Tyne (NoT)

Case Study

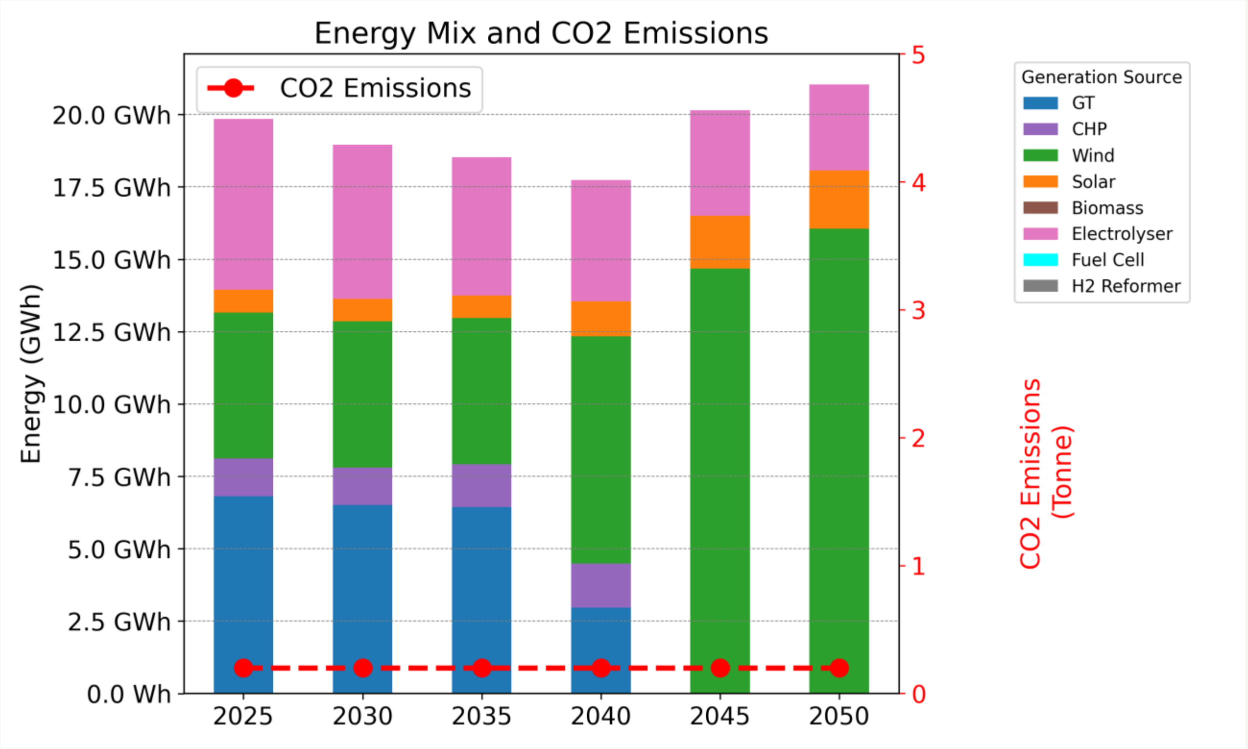
7.2) Economic planning for one day with heating interventions 50% of heat pumps and 50% hydrogen boilers (2025 - 2050).

Hydrogen blending is by volume (up to 20%)
E(electrolyser) + E(H_2 reformer) = E(H_2 boilers) + E(H_2 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 Interventions

H_2 Ratio (%)	Emissions (tonnes)	Cost (m£)
0	3994	2.16
10	4040	2.28
20	4062	2.39
100	0	4.79

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

H_2 Ratio (%)	Emissions (tonnes)	Cost (m£)
0	5738	3.28
10	5542	3.32
20	5302	3.35
100	0	4.13

Marginal Abatement Cost (MAC) (£/t)

$$MAC = \frac{(Cost_{Low\ Emission} - Cost_{High\ Emission})}{(Emission_{High} - Emission_{Low})}$$

Scenario	High Emission	Low Emission	Cost High (m£)	Cost Low (m£)	MAC (£/tonne)
STI	4062	0	2.39	4.79	590.842
50/50 HP & HB	5738	0	3.28	4.13	148.135
100% HP	4850	0	1.59	2.59	206.186
100% HB	10829	0	7.84	9.48	151.445

(3) 100 % of Heat Pumps

H_2 Ratio (%)	Emissions (tonnes)	Cost (m£)
0	4749	1.45
10	4803	1.51
20	4850	1.59
100	0	2.59

(4) 100 % of Hydrogen Boilers

H_2 Ratio (%)	Emissions (tonnes)	Cost (m£)
0	10829	7.84
10	10446	7.90
20	10008	7.98
100	0	9.48

Heat Decarbonisation: North of Tyne (NoT)

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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	1.87
10	0	1.94
20	0	2.03
100	0	3.40

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

H_2 Ratio (%)	Emissions (tonnes)	Cost (m£)
0	0	2.23
10	0	2.25
20	0	2.30
100	0	2.94

(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

(4) 100 % of Hydrogen Boilers

H_2 Ratio (%)	Emissions (tonnes)	Cost (m£)
0	0	4.56
10	0	4.62
20	0	4.69
100	0	6.11

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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 CO_2 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.

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Thank you for your attention