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Net zero heating: identifying evolvable least-cost system architectures for the UK

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CREDS Heat Challenge

- Applies an Energy System Architecture perspective to the challenge of decarbonising heat
- ESA is defined as "the spatial, topological and functional organisation of energy generation, conversion, transmission, distribution, storage, end-use and regulatory systems within the whole energy system." [1]
- And ESA perspective can "help us to understand and organise the emergent complexity of the energy system, both operationally and in terms of its evolution, in response to the trajectories of costs and performance of individual energy technologies over time." [1]
- Requirements for the energy system include sustainability, resilience, flexibility, evolvability, cost, and equity. [1]
- This presentation focuses on the concept of evolvability
- More information: www.creds.ac.uk/decarbonisation-of-heat/

[1] Lowe *et al* (2021). Lost generation: Reflections on resilience and flexibility from an energy system architecture perspective. *Applied Energy*, **298**: 117179

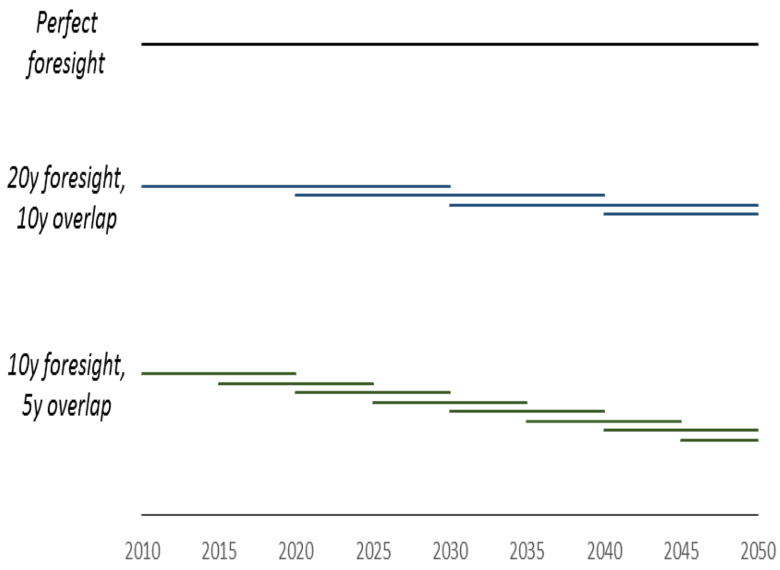
Why explore evolvable heat decarbonisation architectures?

- Current lack of consensus on the best way to decarbonise heat (heat pumps, hydrogen, heat networks etc.)
- Future uncertainties, changes and requirements could affect the outcome
- Evolvable heat sector architectures can reduce the impact of these uncertainties
- Evolvability concerns *"the ability of the system to move from one architectural state to another over the medium to long term"* [1]
- This includes quantifying the implications of changing course
- Implications include costs, deployment rates, decision points and system impacts

[1] Scamman *et al* (2020). Heat Decarbonisation Modelling Approaches in the UK: An Energy System Architecture Perspective. *Energies*, *13*(8), 1869.

Using myopic UK TIMES Model to explore evolvability

- Least cost model of the UK energy system
- Identifies transition pathways for a set of assumptions
- Perfect foresight: single solution; all future changes visible.
- Myopic: consecutive runs; limited foresight of future changes
- Myopic modelling assesses the evolvability of decarbonisation pathways to future uncertainties by limiting foresight of those uncertainties
- Better approximation for real-world policymaking



Modelling approach

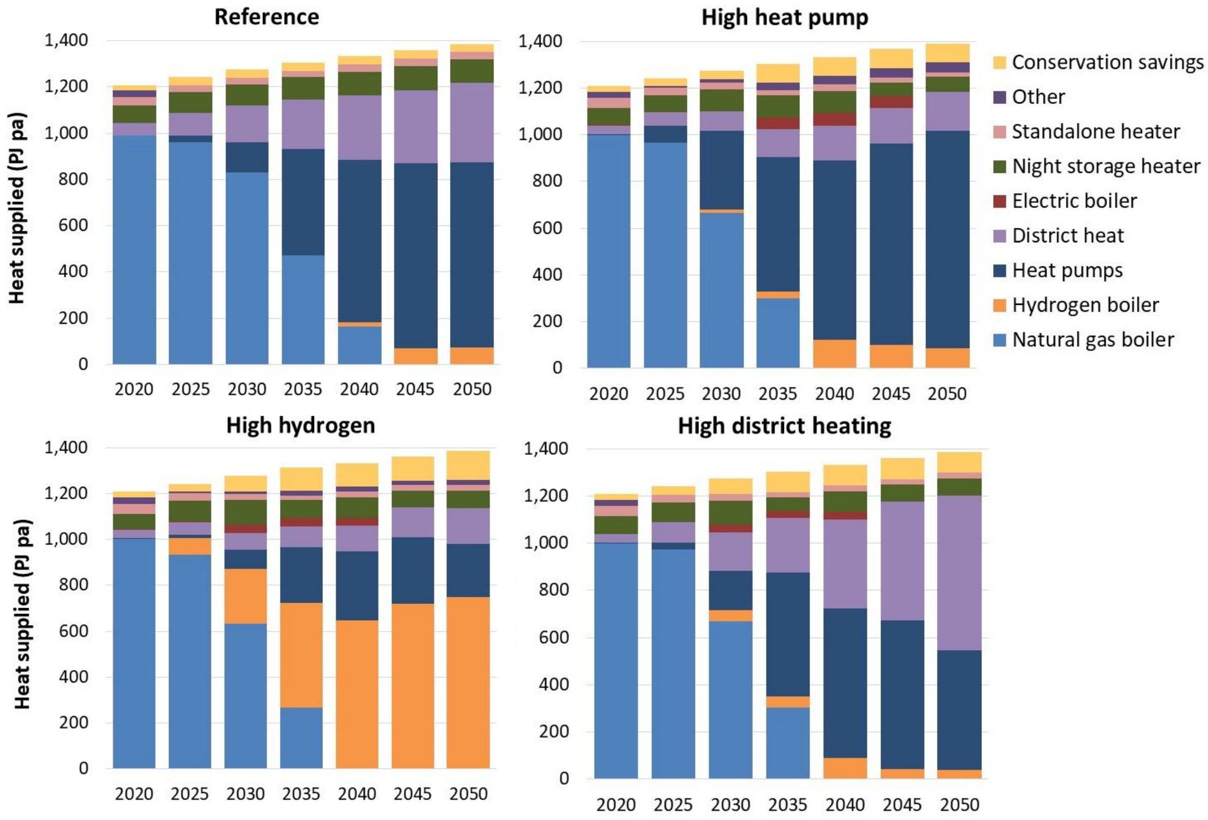
- UKTM scenarios run for net-zero in 2050 (net of 50 $MtCO_2$), with interim carbon budgets
- Reference and high share core pathways - heat pumps (~70%) in 2050, hydrogen (~70%) and heat networks (~50%)
- Additional "Mixed" scenario with minimum 15% HPs, 15% H_2 and 10% HN in 2030
- Investigate evolvability by imposing a switch in 2030 from these midpoints to high share endpoints in 2050
- Assess implications for evolvability

		2050 Endpoints		
		High HP	High HYG	High HN
2030 Midpoints	High HP	HP-HP	HP-HYG	HP-HN
	High HYG	HYG-HP	HYG-HYG	-
	High HN	-	-	HN-HN
	Mix	Mix-HP	Mix-HYG	Mix-HN

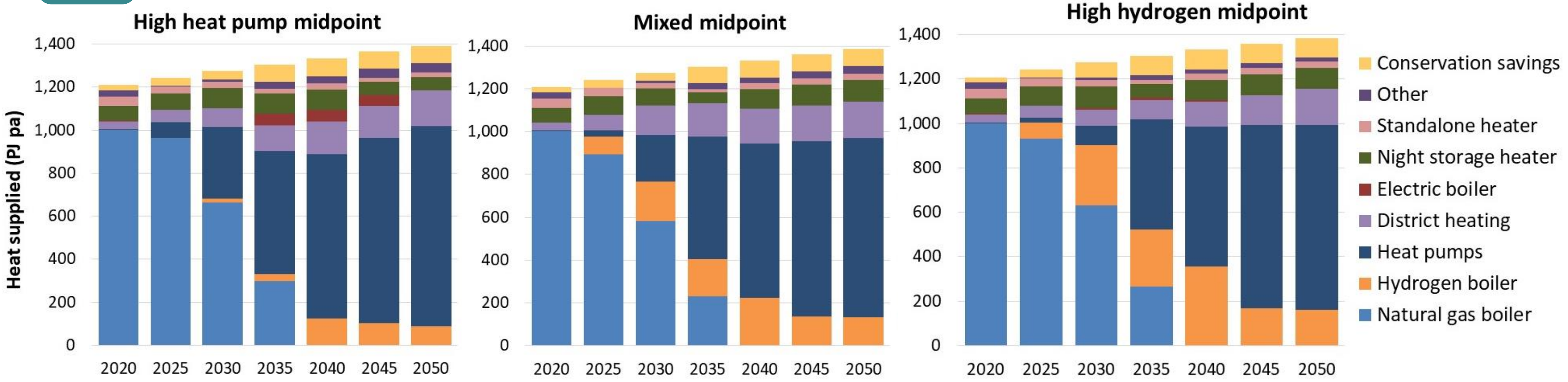
Core pathways
Switched pathways

Core high share pathways

- Heat sector largely decarbonised by 2050
- Balanced reference case versus high share cases
- Myopic approach generates more disjointed pathways
- Quite different endpoints and implications for system architecture

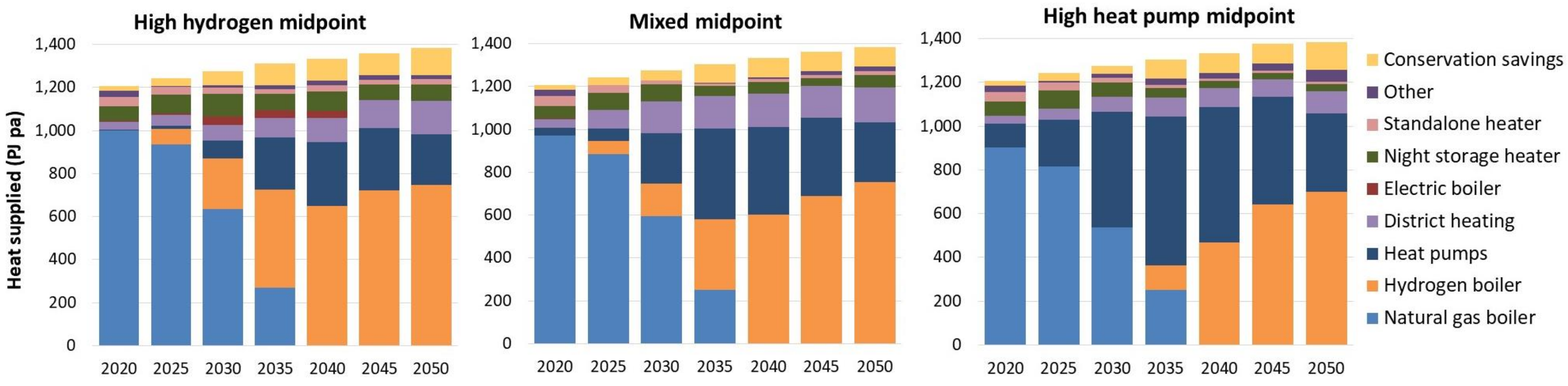


Switched runs: High heat pump endpoint



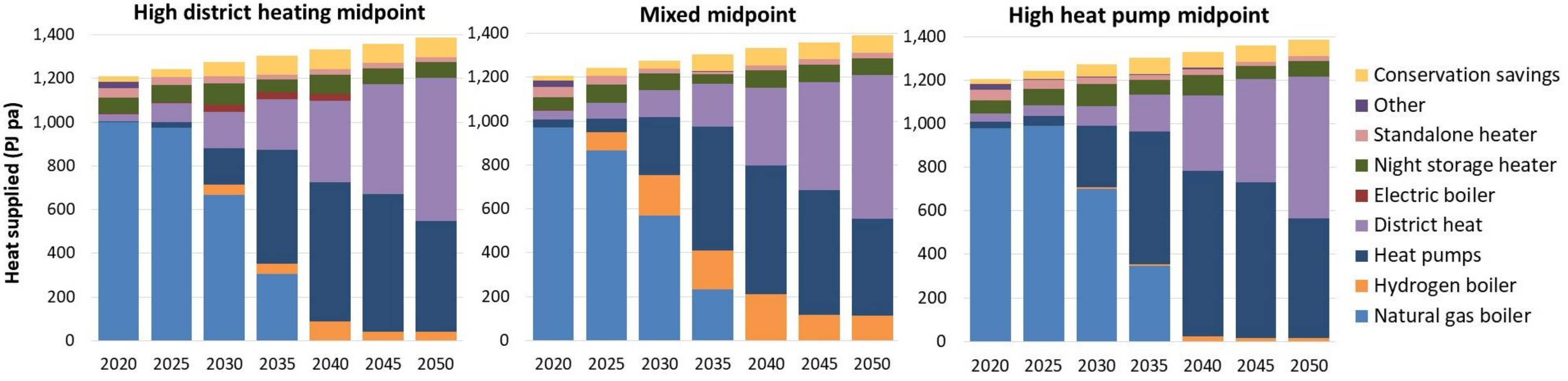
- Core HP pathway has high fractions of heat from heat pumps in both 2030 and 2050
- Switched pathways peak in hydrogen usage around 2030 before moving to other sectors later
- Large switch to heat pumps after 2030
- Slightly lower overall level of HP deployment reached in 2050

Switched runs: High hydrogen endpoint



- Core hydrogen pathway has some hydrogen in 2030; High HP midpoint has none
- Switched pathways have large transitions to hydrogen after 2030
- Slightly lower overall level of hydrogen reached in 2050
- Large HP deployment initially in switched pathways, reduces after 2030 at end-of-life

Switched runs: High district heating endpoint

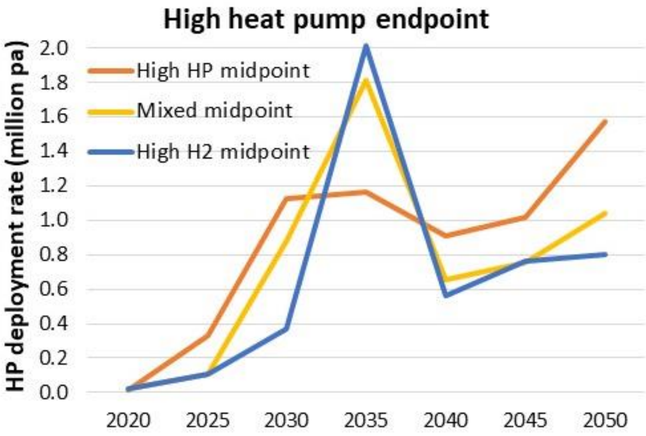


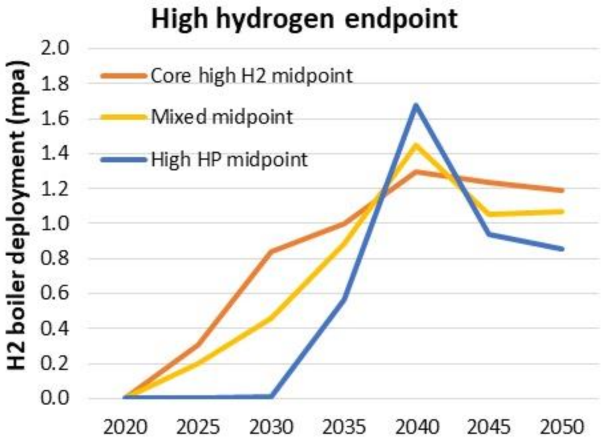
- District heating supplies about 50% of heat in 2050 in all three scenarios
- Switched pathways have slightly faster transitions to district heating after 2030
- Mixed midpoint peaks in hydrogen usage around 2030 before moving to other sectors later
- High HP midpoint has no hydrogen in 2030, but does have a higher fraction of heat pumps.

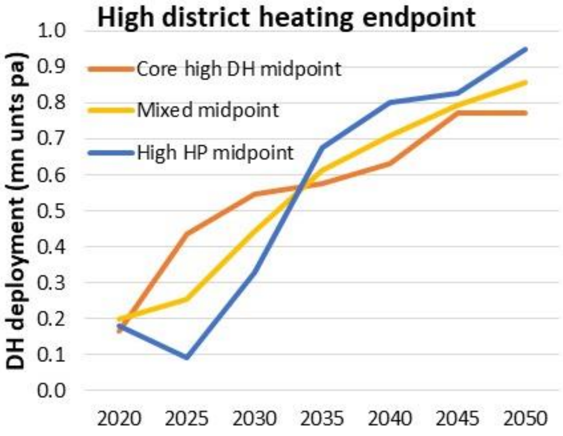
Evolvability metrics

1. Deployment rates
2. Costs
3. System implications

Extensive switching increases peak deployment rates

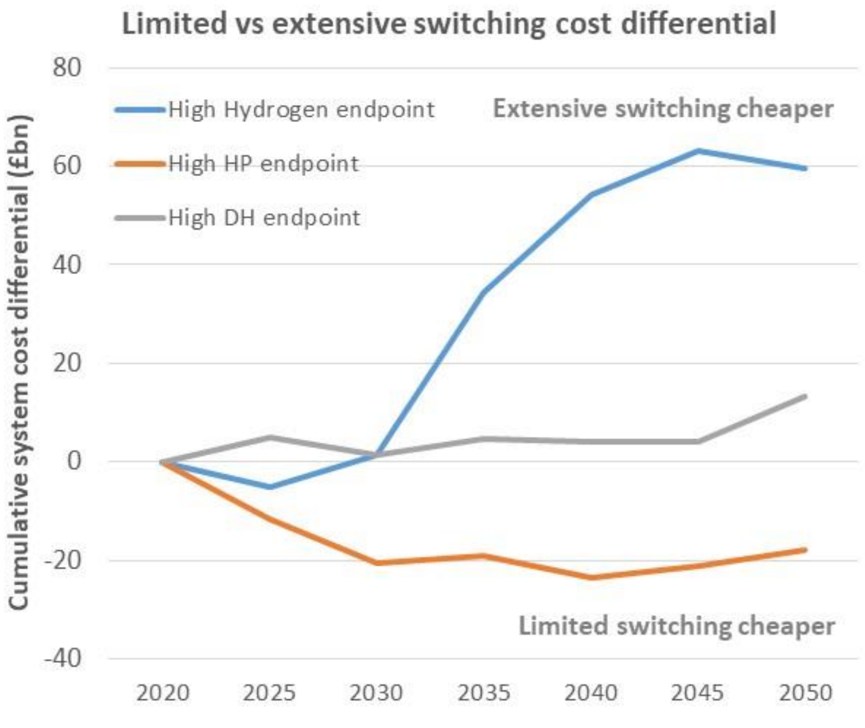






- Core scenarios highest deployment rates in 2020s, lower in 2030s and 2040s.
- High switching scenarios reached the highest deployment rates after 2030.
- Mixed scenarios modest deployment rates before and after 2030
- Reduced switching can reduce the deployment rates required after 2030
- Large spikes needed to catch up towards 2050 target, while meeting interim Carbon Budgets

System costs: limited vs extensive switching

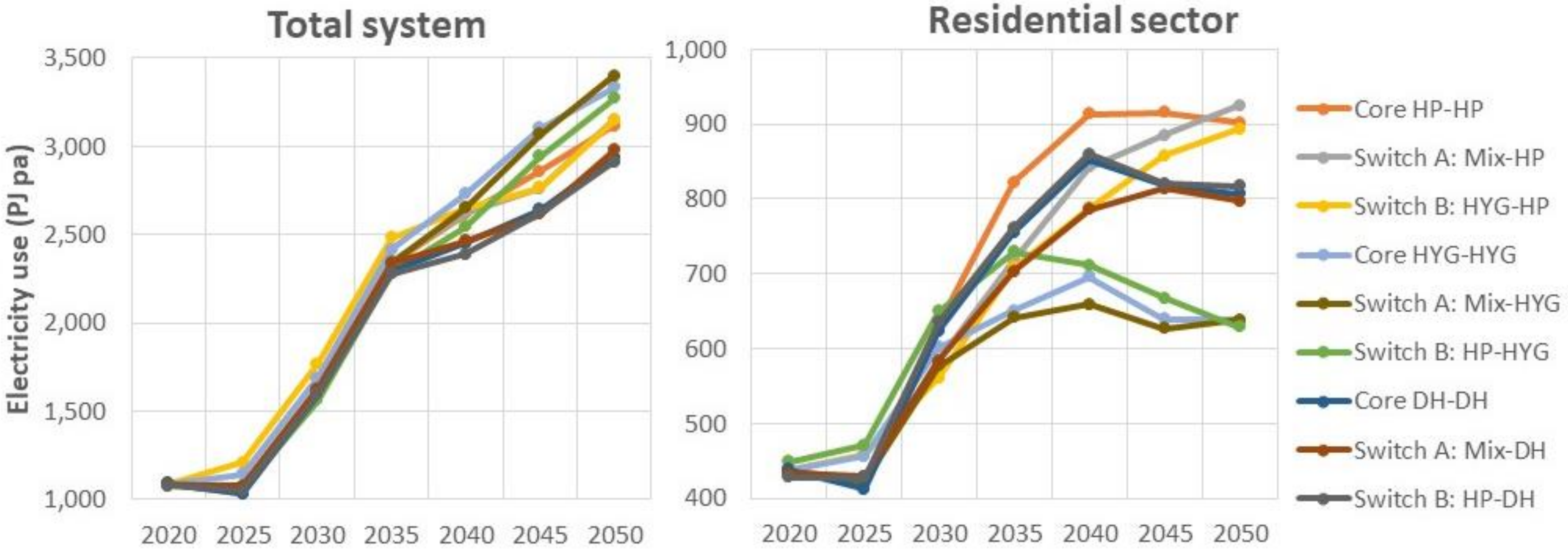


- Cumulative system cost differential between the Extensive (high HP/H_2/DH midpoints) and Limited (Mixed midpoint) switching runs
- High H_2 endpoint: Extensive switching from high HP midpoint cheaper (avoided initially more expensive hydrogen)
- High HP endpoint: Limited switching cheaper (less early deployment of hydrogen)
- High DH endpoint: Extensive switching from high HP midpoint slightly cheaper with less hydrogen.

System costs: emerging insights

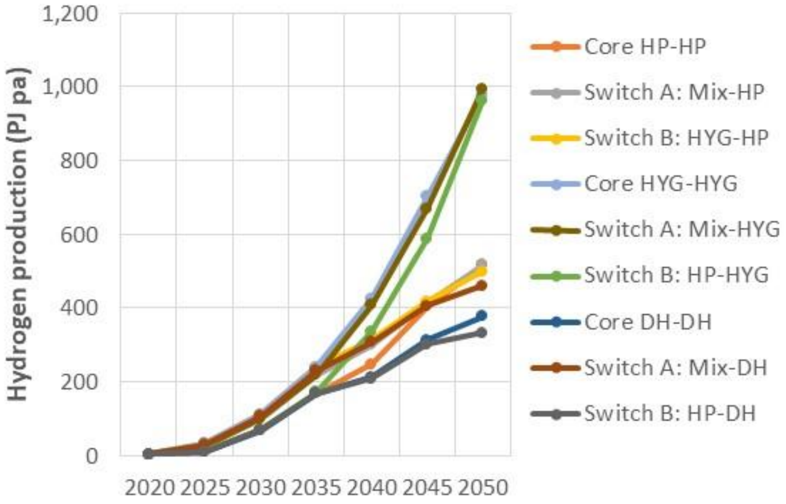
- Switching can be more expensive due to higher overall deployment of supporting infrastructure.
- However costs might be reduced if switching delayed until technology costs are lower. Timing of switching vs extent of switching.
- Early deployment of technologies to smooth ramp-up rates could result in early usage of technologies before costs reduce.

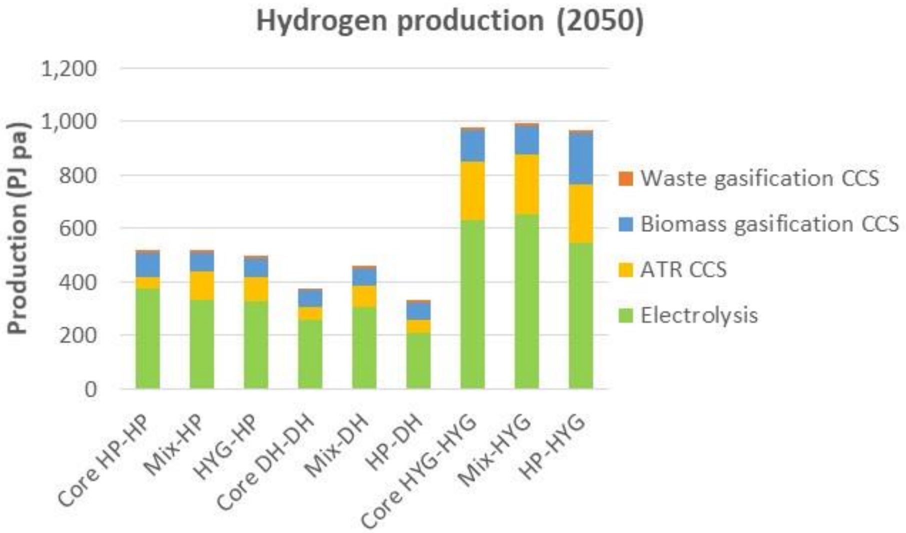
System impacts: Electricity consumption



- Large increase in usage across the whole system (left panel). Limited effect of switching
- High H_2 case has lower residential electricity use (right panel), but higher system use due to electrolysis. Extensive switching reduces electricity usage slightly faster.
- High DH cases have slightly lower residential electricity consumption than the high HP runs.

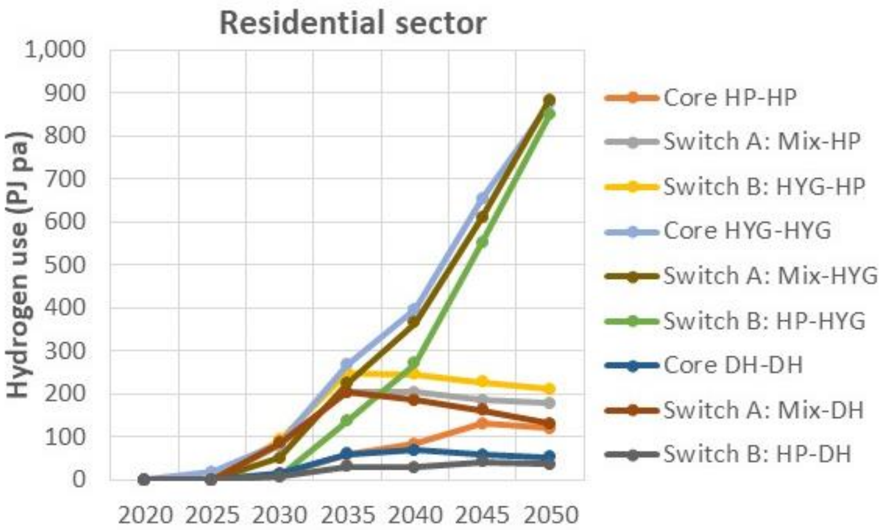
System impacts: Hydrogen production

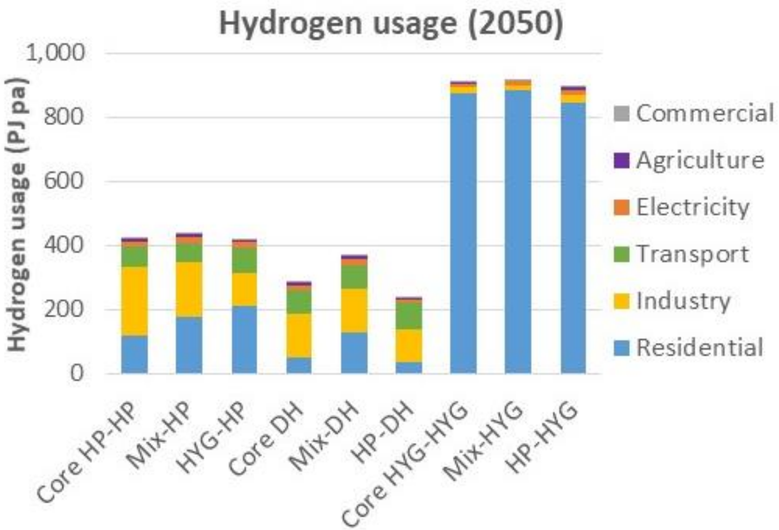




- High-hydrogen endpoint scenarios generate significantly more hydrogen than the others
- HP-HYG switched run (in green, left panel) has accelerated rollout of hydrogen production after 2040
- Most hydrogen produced by electrolysis in 2050 (right panel). All other technologies use CCS.

System impacts: Hydrogen usage



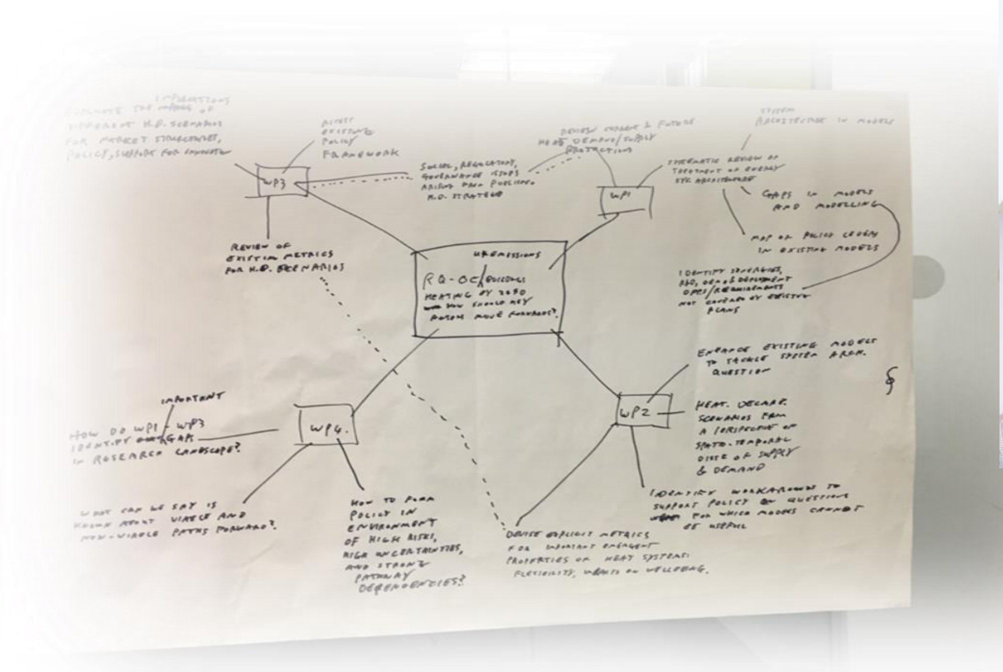


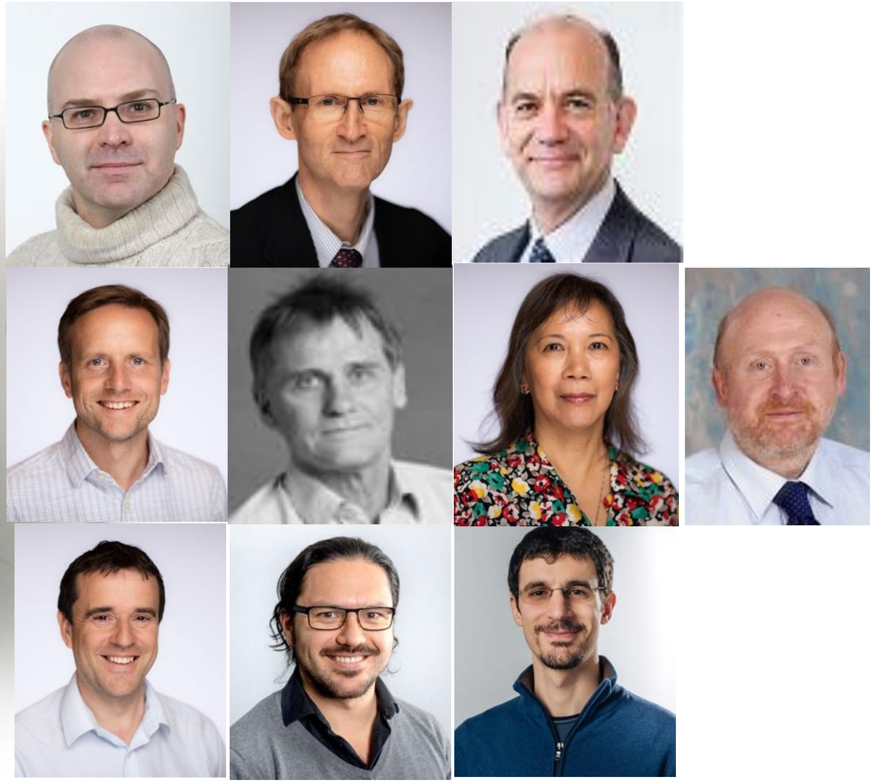
- Some scenarios use hydrogen in residential sector initially, before usage switches to other sectors
- High-hydrogen scenarios use substantially more hydrogen in the residential sector. Very little hydrogen used in transport and industry, with implications for these sectors
- Other scenarios use substantial quantities of hydrogen in transport and industry

Conclusions

1. Heat decarbonisation requires urgent action, but significant uncertainties remain
2. Evolvable heat sector architectures could reduce impact of these uncertainties.
3. Costs, deployment rates and system implications of disruptions can provide insights into the evolvability of different pathways.
4. Core pathways highlight large range of plausible pathways
5. Switching pathways can lead to large disruptions in costs, deployment rate requirements and system impacts.
6. Mixed initial pathway could improve evolvability by reducing disruption, though this depended on a range of assumptions
7. Next steps: extend the analysis of how these metrics can help identify evolvable heat decarbonisation pathways that can reduce the impact of future uncertainties.

Heat Challenge Team





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Thank you!

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