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Impact of technology uncertainty on future low-carbon pathways in the UK

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Motivation

Low-carbon energy transition requires major technological changes

BUT: Availability, cost and performance of these technologies is **highly uncertain**

From the UK Government's Carbon Plan:

*"But there are **some major uncertainties**. How far can we reduce **demand**? Will sustainable **biomass** be scarce or abundant? To what extent will **electrification** occur across transport and heating? Will **wind, CCS or nuclear** be the cheapest method of generating large-scale low carbon electricity? How far can **aviation, shipping, industry** and **agriculture** be decarbonised?"*

Use **energy systems modelling** to explore the **impact of technology uncertainty** on the long-term development of the UK energy system

Research questions

- Which technologies are most crucial to realize the UK's long-term emission reduction commitment?
- Are there interdependencies between the use of different technologies?
- How are carbon prices and energy system costs influenced by the non-availability of important low-carbon options?

Methodological approach

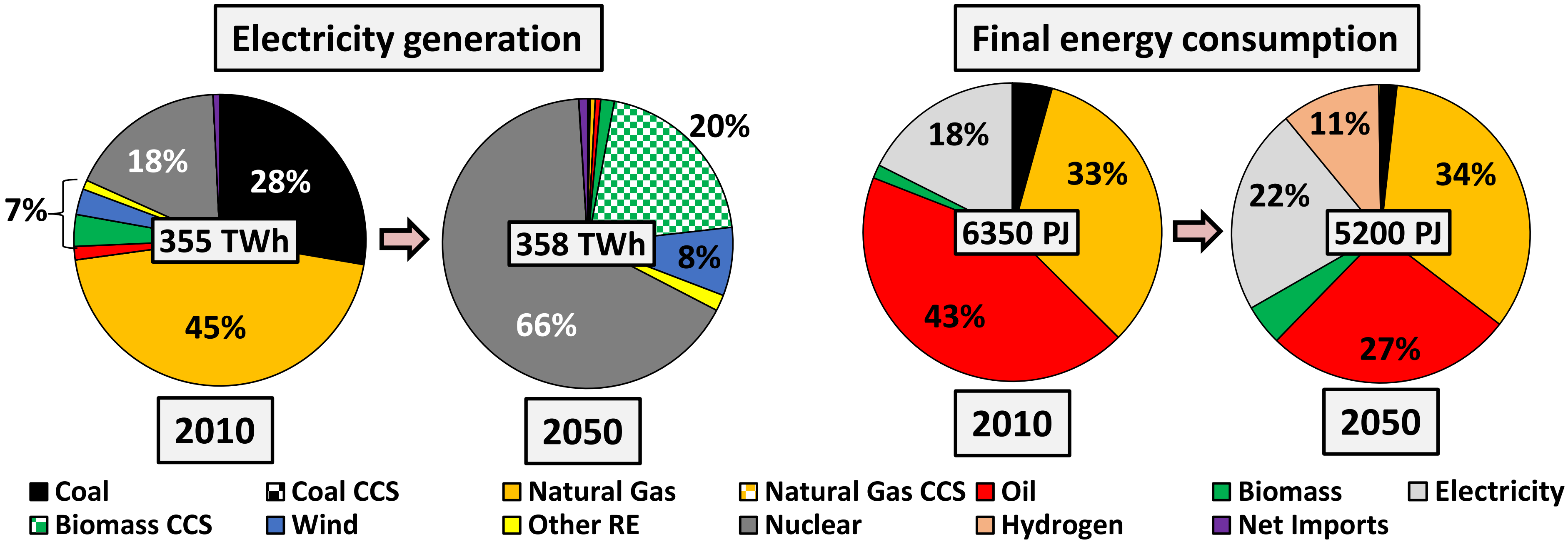
- **Model: UKTM-UCL**
  - Successor of UK MARKAL with updated data and new features
  - Strong policy engagement (DECC)
  - Open-source release planned for next year
- **Uncertainty analysis**
  - Focuses on the availability, cost and diffusion of key low-carbon options (both technologies and resources) for the UK energy system
  - 5 dimensions identified: nuclear, biomass, CCS, renewables, demand-side change – with either optimistic or pessimistic assumptions
  - Try out all possible combinations -> 2^5 = **32 scenarios**
  - All low-carbon scenarios: -80% reduction target implemented as cumulative budget
- **Results analysis**

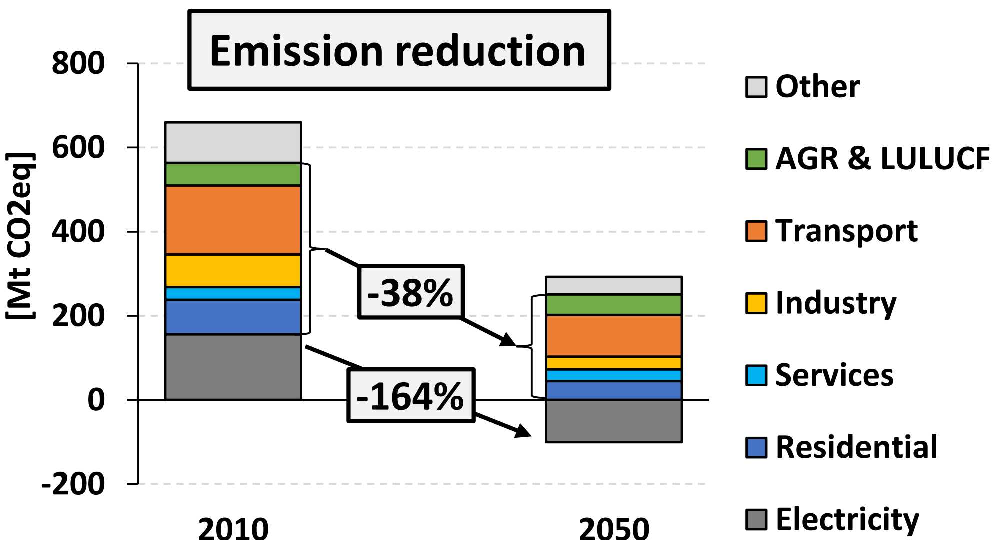
  Compare scenarios from different perspectives to identify **general trends**:
  - Sector-specific perspective
  - Fuel-specific perspective
  - Indicators (emissions, energy savings, renewable targets)
  - Costs

Dimensions on technology uncertainty

	Reference	Restricted
Nuclear (N)	New nuclear capacity limited to **33 GW** until 2050	**No additions** after 2010
CCS (C)	• Electricity: limited to **45 GW** in 2050 • Industry & hydrogen: growth constraints (**10% p.a.**) • Available in 2020 (2030 for BECCS)	CCS **does not become available** in the UK
Bioenergy (B)	Based on CCC Bioenergy Review: **1300 PJ** in 2050 (imports + domestic)	**380 PJ** in 2050
Renewables (R)	• High technical potential (**> 400 GW**) • learning effects for all technologies	• Restricted potential (**49 GW**), • higher cost assumptions for offshore wind & solar PV • marine & geothermal not available
Demand-side (D)	• **Medium** elasticities (-0.03 to -0.8) • growth constraints of **10 / 15%** p.a. on all innovative and energy-efficient technologies	• **Low** elasticities (-0.01 to -0.6) • growth constraints of **5% / 7.5%** on innovative and energy-efficient technologies

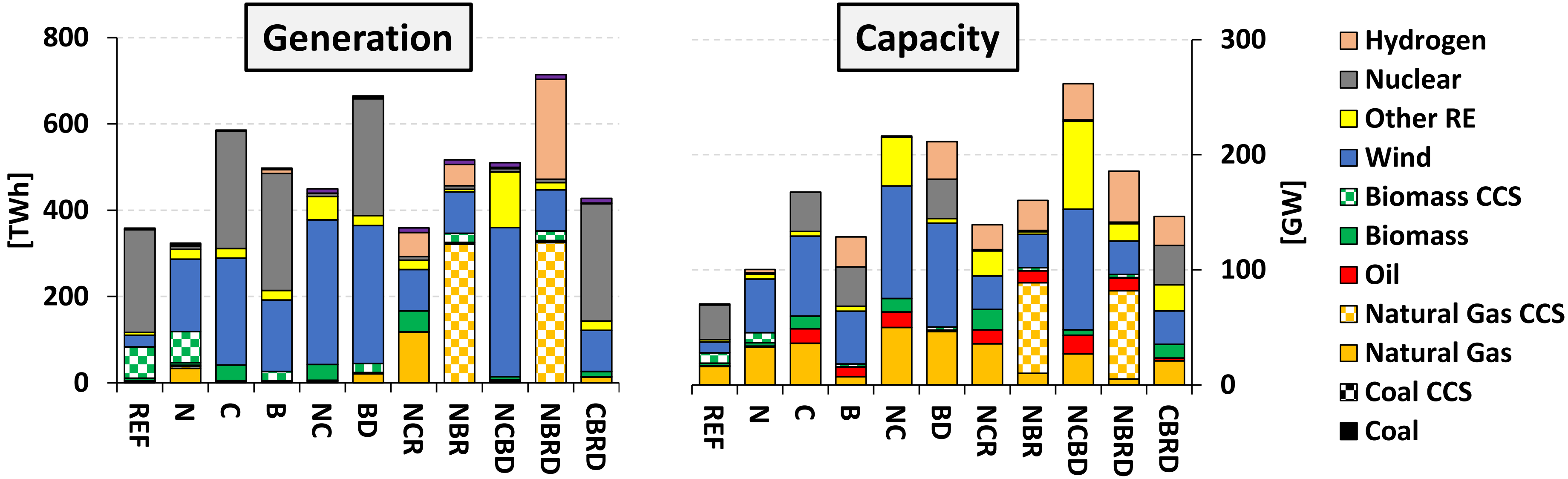
The unrestricted case





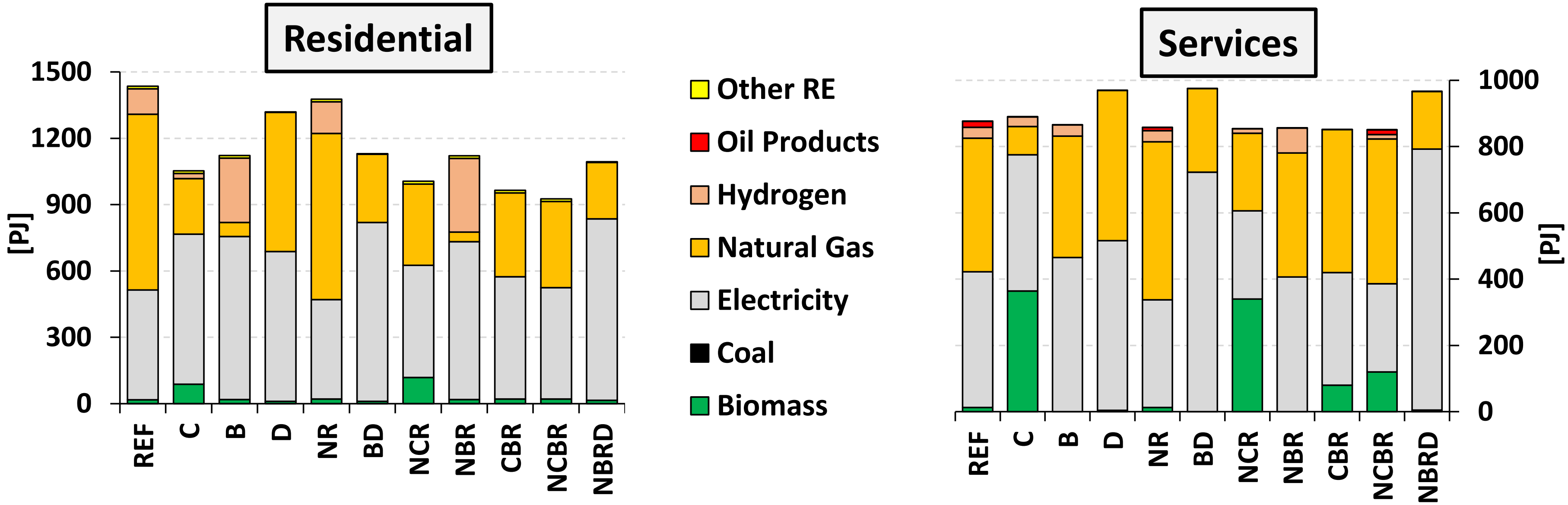
- Electricity generation dominated by nuclear and BECCS
- Limited change on the demand side
- Strong reliance on decarbonisation of electricity sector (BECCS!) to reach -80% reduction target

Sector-specific (1) - Electricity



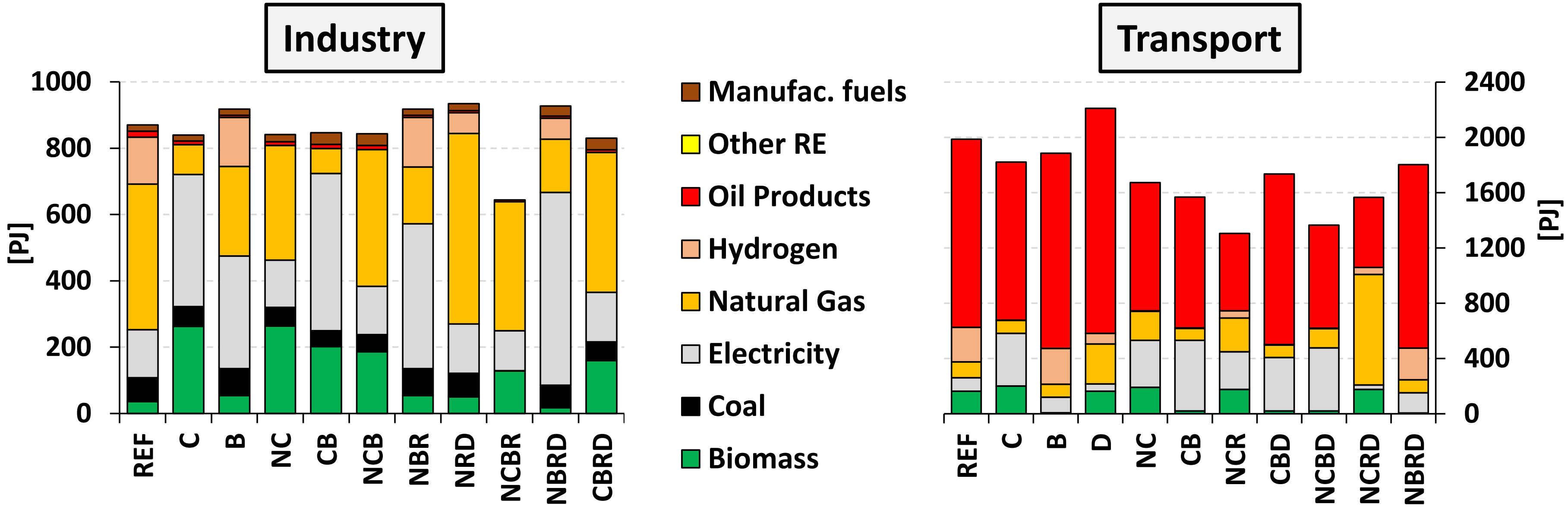
- Stronger electrification in scenarios where biomass and/or CCS not available and demand-side technology diffusion restricted
- Central role of wind in restricted scenarios -> expansion of renewables can lead to almost quadrupling of today's installed capacity
- Significant role of gas only if nuclear energy not available & RE and/or biomass additionally restricted -> substantial role of gas CCS
- Hydrogen partially replaces gas as back-up capacity in some scenarios, significant contribution to generation only in NBRD

Sector-specific (2) – Buildings sector



- Electrification & demand reduction in the residential sector key strategy in most restricted scenarios
- In the services sector, most energy savings potentials are already exploited in the unrestricted case & less clear trend in terms of electrification
- While biomass does not play a substantial role in the residential sector, its use is increased significantly in the services sector (if CCS is not available & biomass not restricted, mostly in district heating plants)

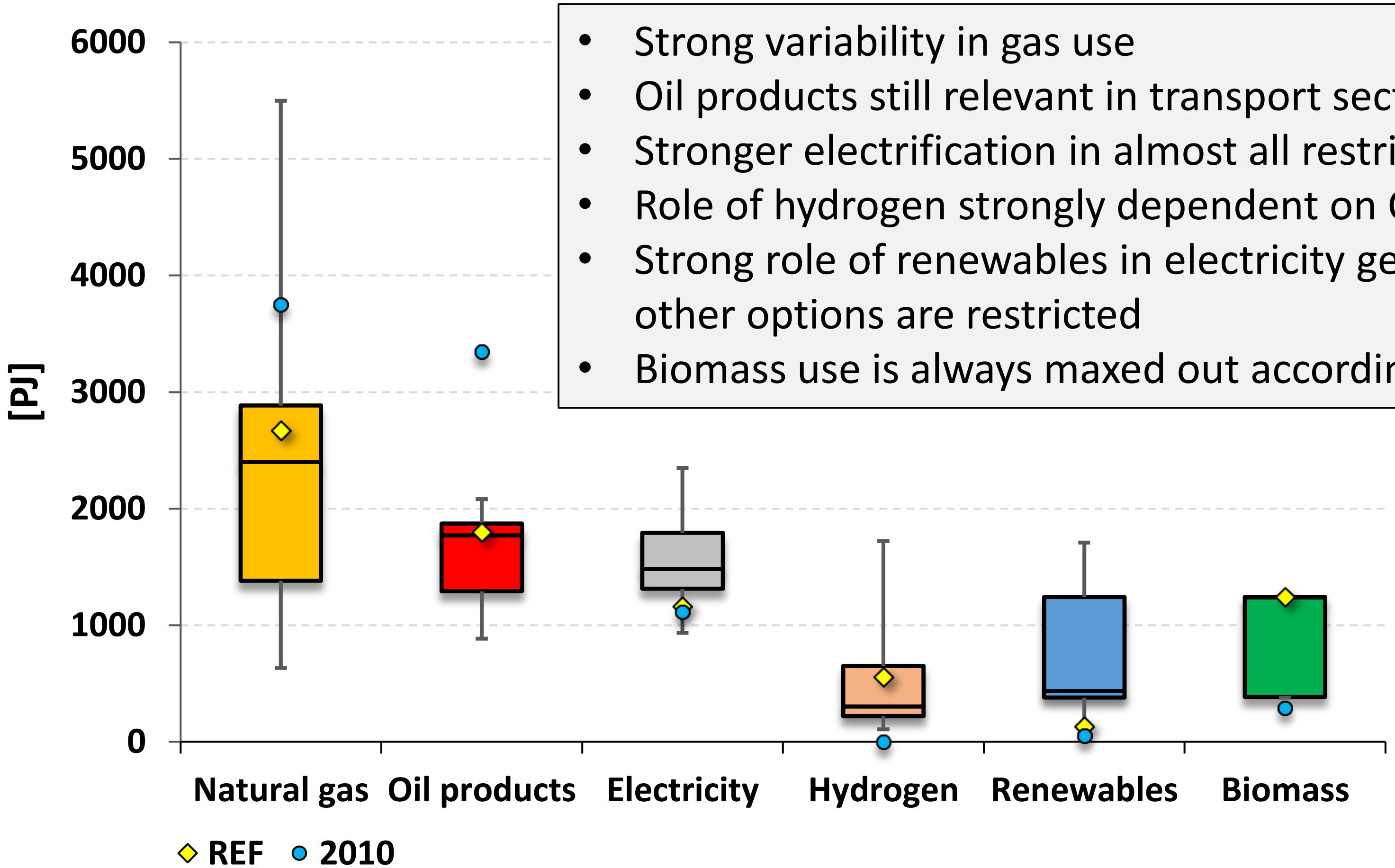
Sector-specific (3) – Industry & Transport



- Further demand reductions in the industry sector only induced in extreme scenarios with no CCS and strong restrictions on the electricity sector
- Increased biomass use in industry in scenarios without CCS (even if biomass restricted)
- Highest use of CCS in industry in scenarios with restricted biomass
- Significantly higher demand reduction in transport in scenarios with strongly restricted electricity sector
- Dimension D clearly limits transition to alternative vehicles
- Stronger electrification when CCS is restricted

Fuel-specific perspective

Use in 2050, across all 31 scenarios

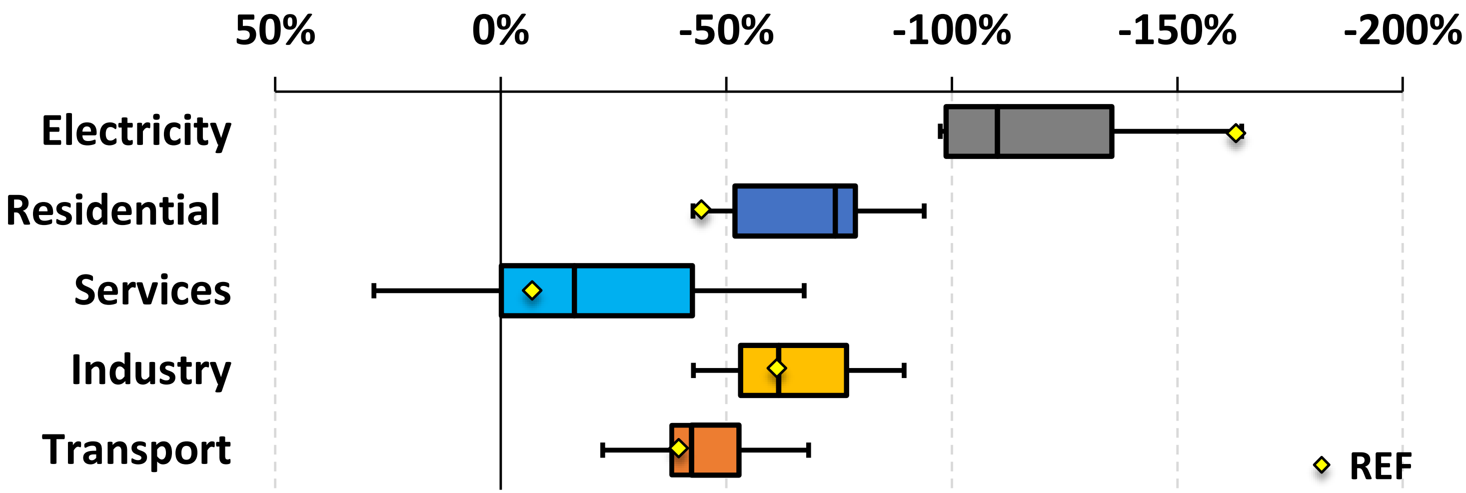


- Strong variability in gas use
- Oil products still relevant in transport sector
- Stronger electrification in almost all restricted scenarios
- Role of hydrogen strongly dependent on CCS availability
- Strong role of renewables in electricity generation when other options are restricted
- Biomass use is always maxed out according to constraint

GHG emission reduction

Total emissions reduction: cumulative approach highlights **cost efficiency of early action**
→ none of the scenarios reaches -80% in 2050 (range from -67% to -76%)
→ the more restricted the technology availability the higher the tendency for early action

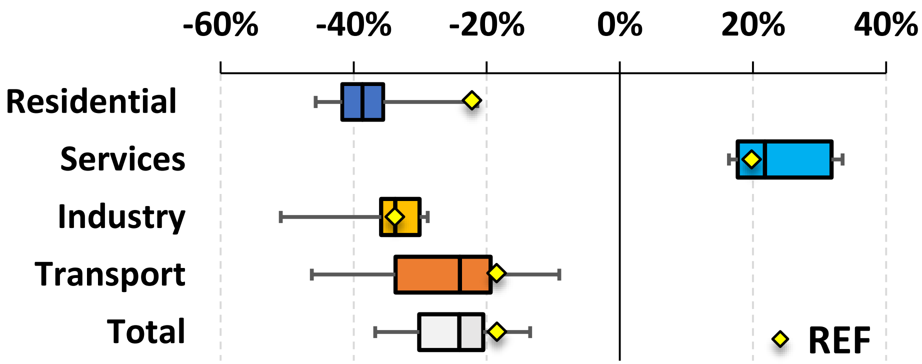
GHG emissions reduction (2050 to 2010)



- **Electricity:** contribution maxed out in unrestricted case, but always zero-carbon sector from 2035 onwards
- **Residential:** contribution increases significantly in most of the restricted cases
- **Services:** Strong variation, even with possibility of emission increase
- **Industry:** contribution depends strongly on availability of biomass & electricity
- **Transport:** higher contribution from transport needed when CCS and low-carbon electricity options not available

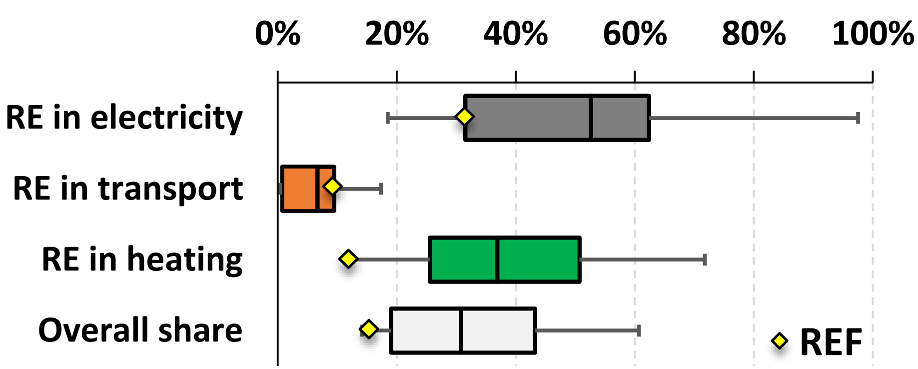
Energy savings & use of renewable energy

Reduction in final energy consumption (2050 to 2010)



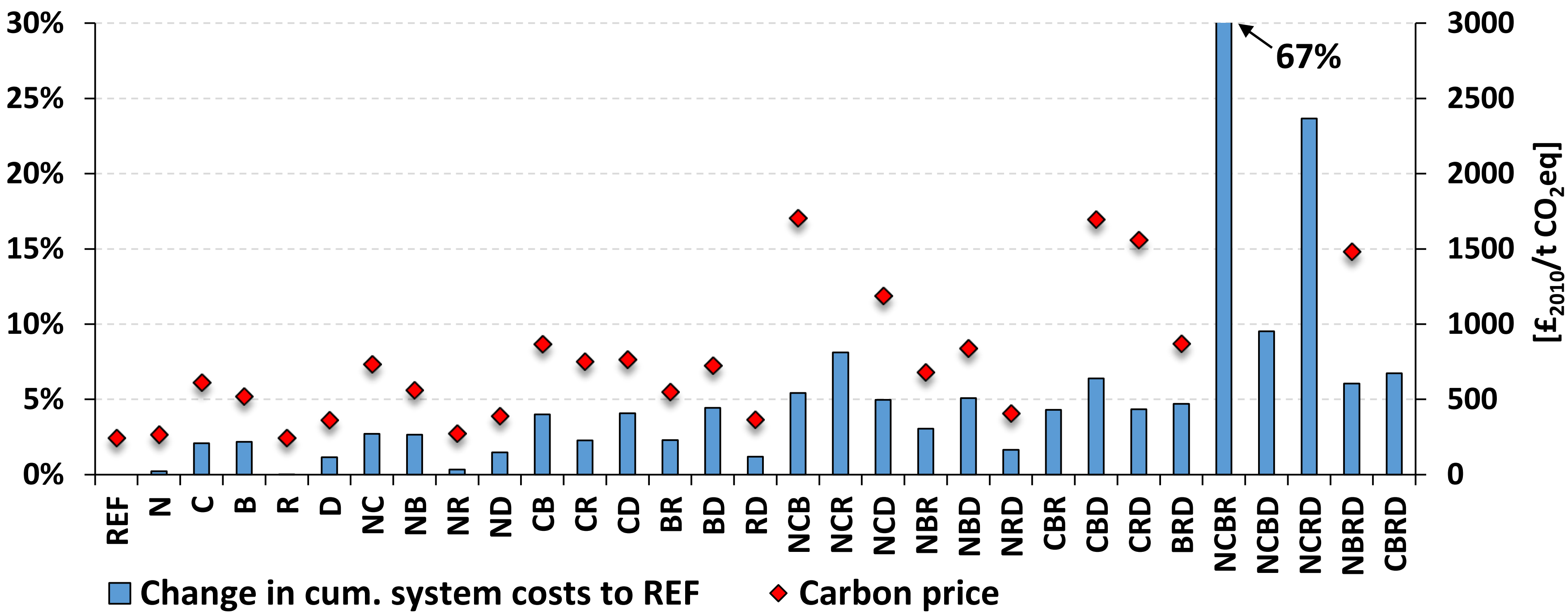
- Crucial role of the residential sector in restricted scenarios
- Strong variation in transport fuel demand
- Strong overall reductions in scenarios without CCS & high levels of electrification or when supply side is very restricted

Renewable share in gross final energy consumption (2050)



- Strong variation, especially in electricity
- Restriction of low-carbon options tends to increase the use of renewables
- Biofuels no relevant option for the transport sector
- Renewable use for heating dominated by heat pumps

Cost parameters



- Non-availability of CCS and restricted biomass have the strongest impact in case of scenarios with one restriction
- Combined effect of several restrictions is usually greater than individual effects, exemption: CB
- Dimension R has strong impact in cases where other low-carbon electricity options are restricted
- In cases where all other dimensions fail, availability of nuclear and CCS (followed by renewables) most important to limit transition costs
- Carbon price at 244 – 7000 £ t/CO_2eq in 2050 (with some extreme outliers); ranking usually quite similar to system cost, exemptions: CR/CBR & BD/NBD -> depends on shape of abatement cost curve

Conclusions

Comparative scenario analysis allows to identify critical insights on:

- Complementarity of technologies (e.g. strong dependence of hydrogen development on CCS availability)
- Substitutability of technologies (e.g. replacement of nuclear by renewables with limited cost increases)
- Critical technologies / low-carbon options (electrification!!) vs. "failed" technologies (marine?)
- Issues of timing and path dependencies (e.g. importance of early action)

In terms of government strategy: is it better to support a wide range of technologies or is it time to "pick winners" at some point?

Thank you for your attention!

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