Technology pathways for a low-carbon energy transition – critical insights from the energy system model UKTM

Birgit Fais, Hannah Daly, Ilkka Keppo

b.fais@ucl.ac.uk

wholeSEM Annual Conference 2014

July 8th 2014

EPSRC Pioneering research and skills

Motivation and objective

Low-carbon energy transition requires major technological changes

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

From the 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

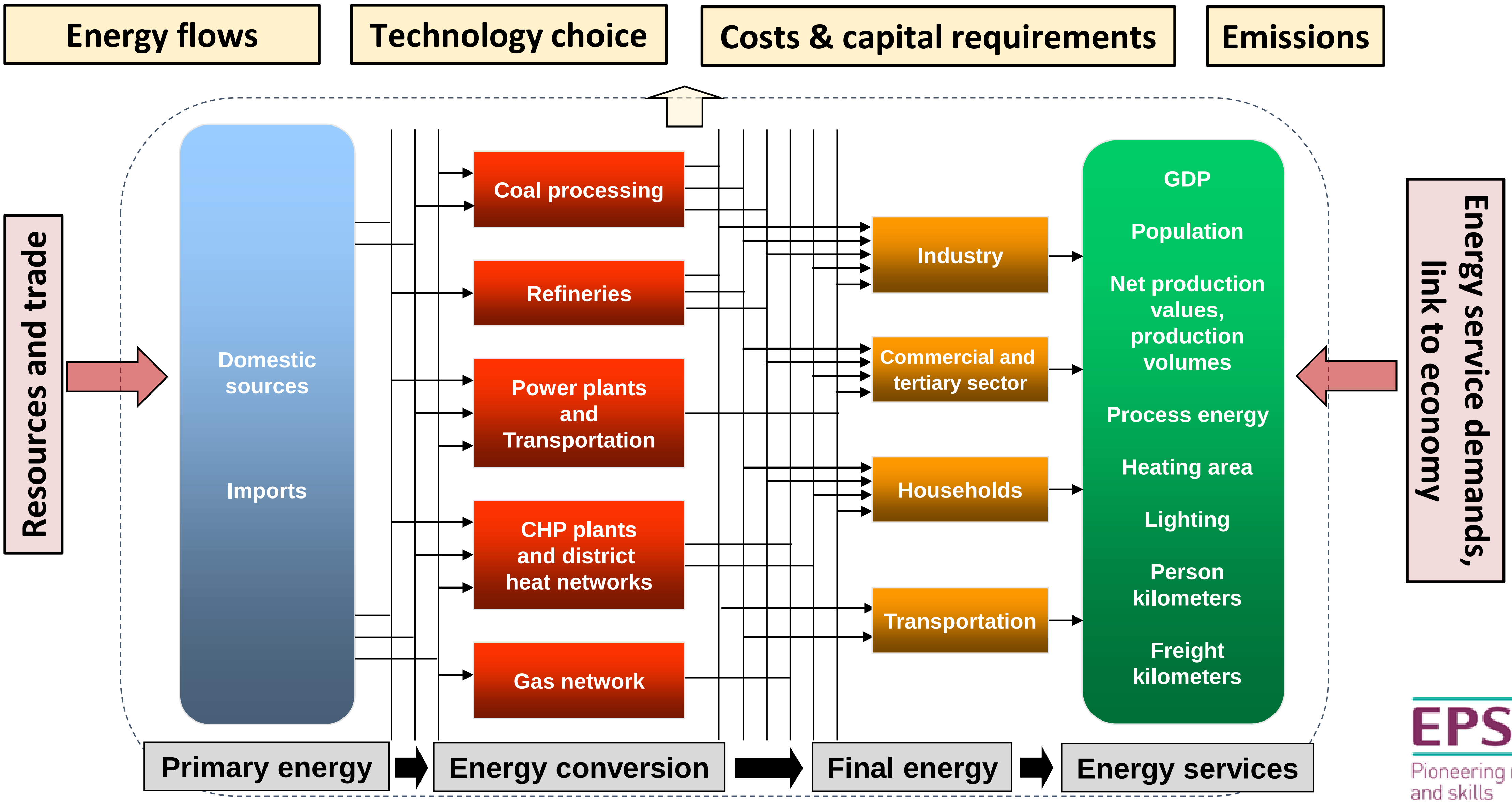
- Which technologies are most crucial to realize the UK's long-term emission reduction commitment?
- Are there interdependencies between the use of different technologies?
- How are carbon prices and energy system costs influenced by the non-availability of important low-carbon options?

EPSRC Pioneering research and skills

Agenda for today

- Overview on the new energy system model UKTM
- Reference case: The low-carbon transition in the UK
- The impact of technology uncertainty
- Outlook on wholeSEM research strands at UCL

1. UKTM – The UK TIMES energy system model



EPSRC
Pioneering research and skills

UKTM is the successor to UK MARKAL

Overview

Integrated energy systems model - Least cost optimization - Partial equilibrium model - Technology rich - sensitivity and uncertainty analysis

New features

- Non-CO_2 greenhouse gases
- Non-energy mitigation options
- Energy storage and other energy infrastructures
- New time slices (4 intra-day x 4 seasonal)
- New industry sector module

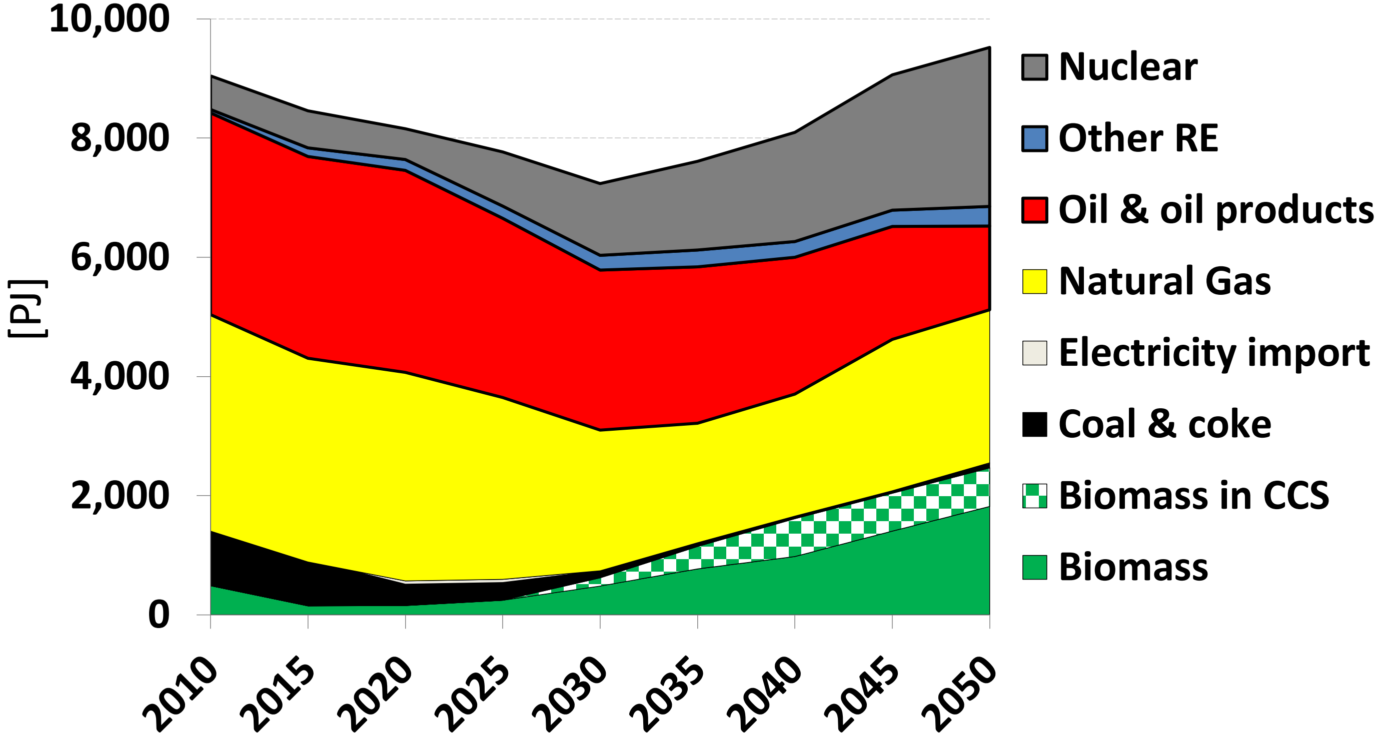
Development process

- **Transparency** at the forefront of development (data, assumptions, structure is clear and traceable, full replicability of results, comprehensive QA processes)
- Full sectoral data update & 2010 base-year recalibration
- User constraints categorized & explicit
- **UKTM will be fully open-source from September 2014**

2. The low-carbon transition in the UK

The reference case: 80% GHG emission reduction until 2050

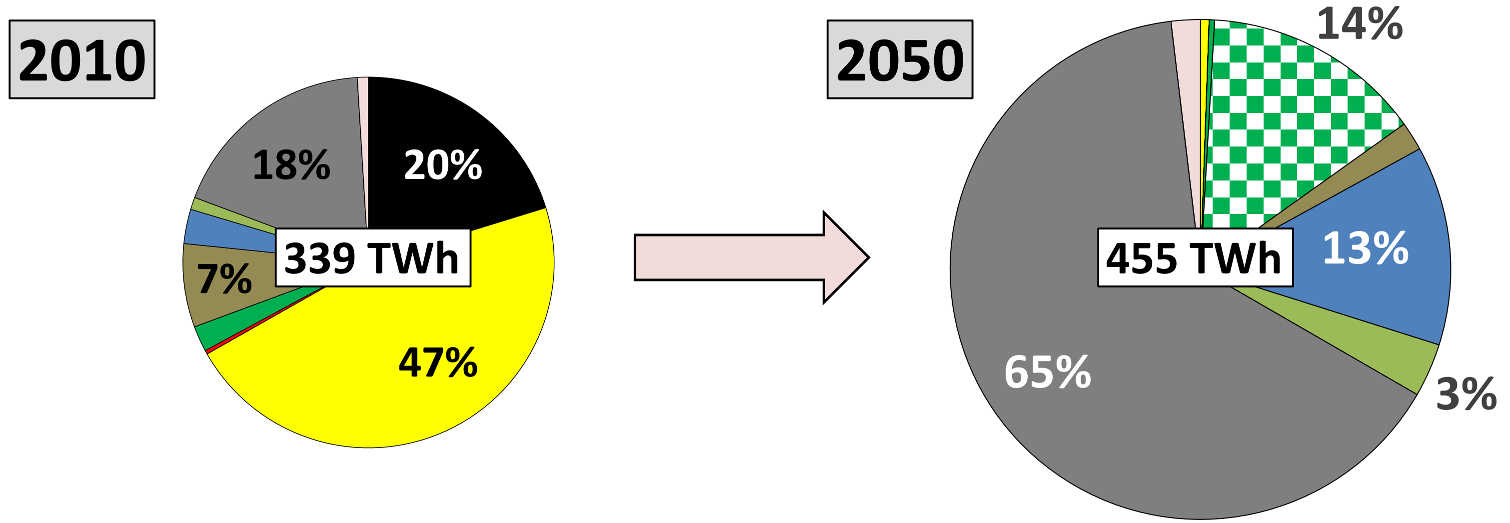
Primary energy consumption



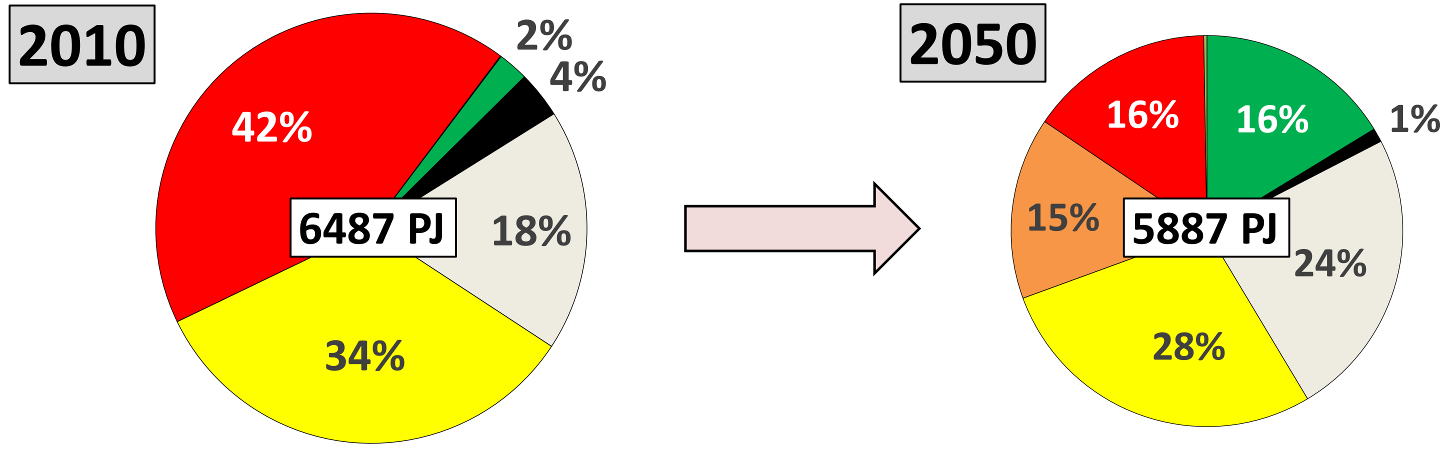
- Reduction until 2030 mainly due to energy efficiency improvements in electricity generation & industry
- Rising consumption after 2030 can be attributed to rising electricity consumption & increasing use of biomass (partially with CCS)
- Use of biomass and nuclear energy rises by about 5 times until 2050
- Consumption of petroleum products is more than halved
- Other renewables remain insignificant

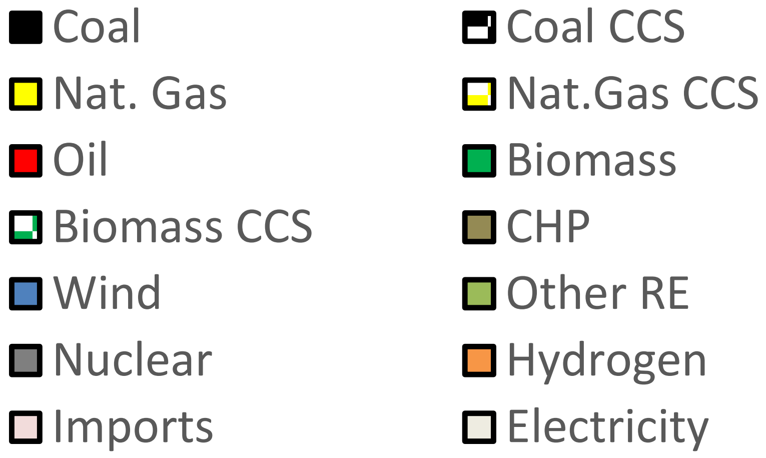
EPSRC
Pioneering research and skills

The reference case: Electricity generation…

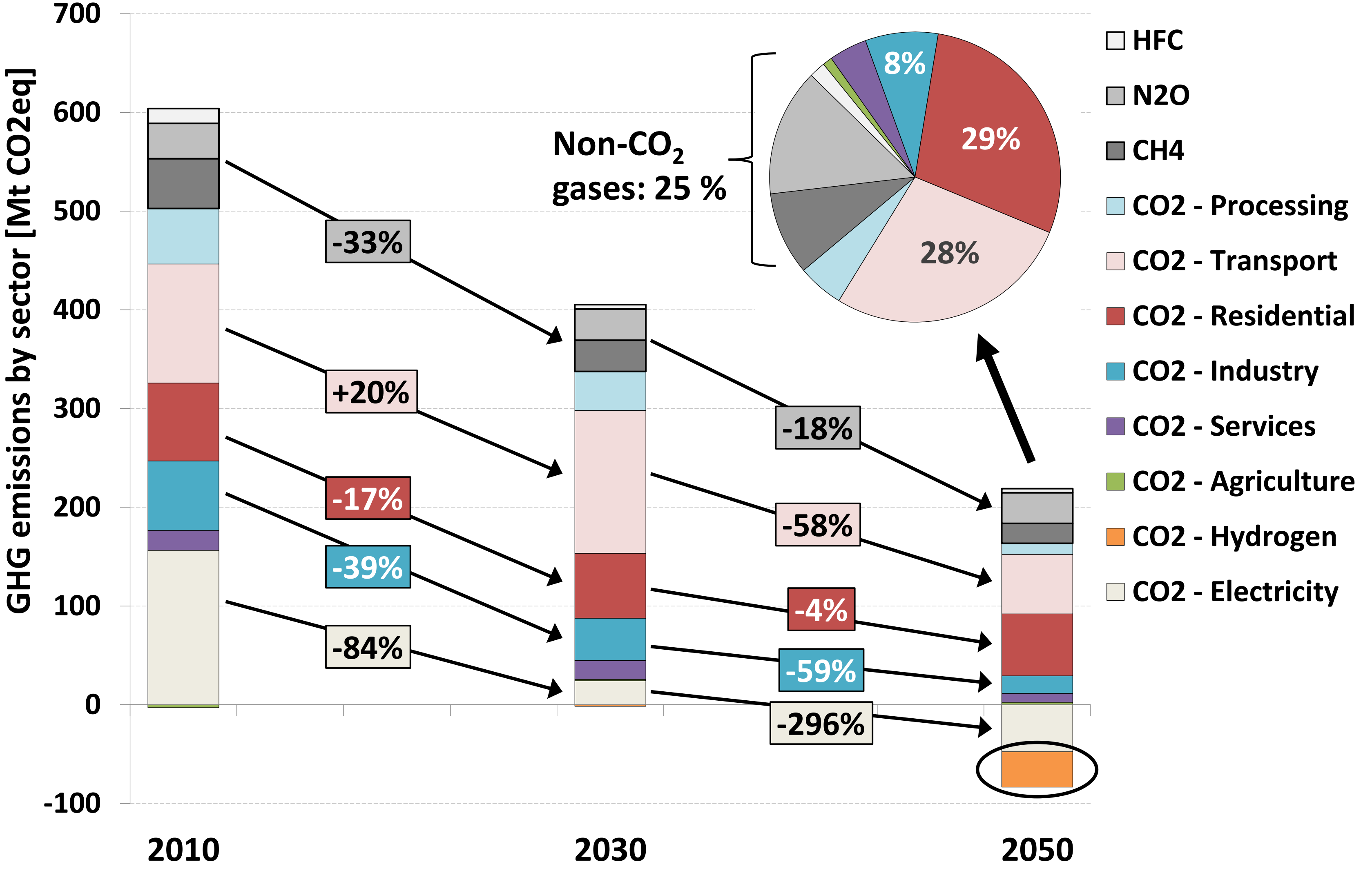


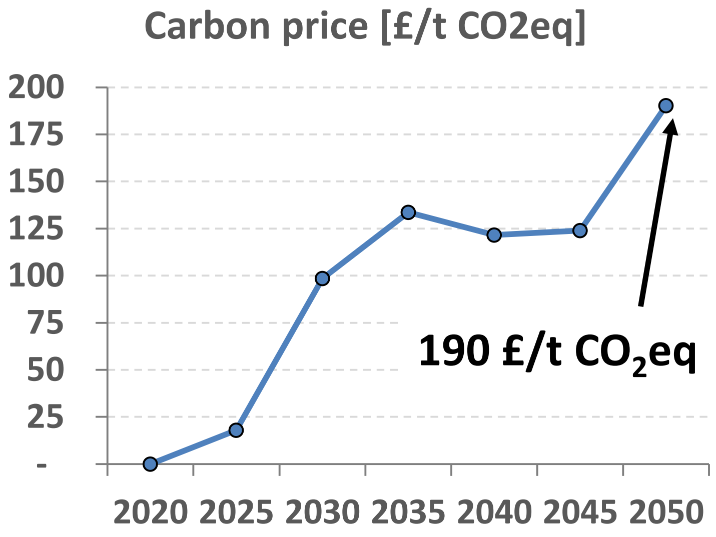
…and final energy consumption





The reference case: Emission reduction and carbon prices





3. The impact of technology uncertainty

The reference case shows a consistent, least-cost pathway to achieve the UK's low-carbon energy transition, but …

Feasibility of large-scale energy investment projects?

Biomass availability?

Barriers to investments in the end-use sectors?

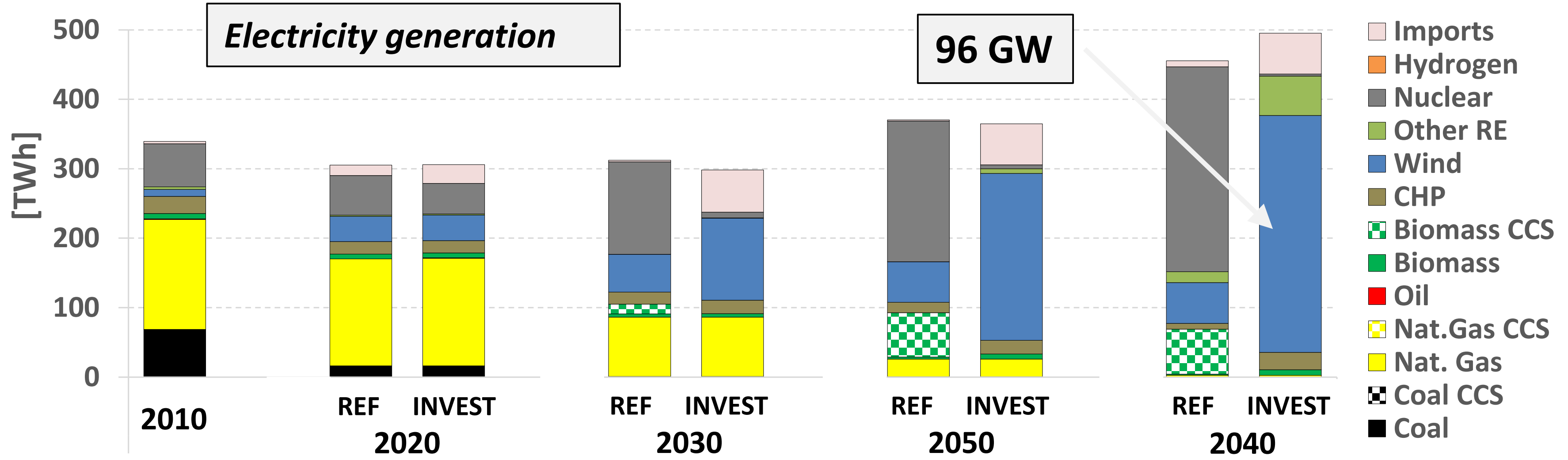
Comparative scenario analysis on the reference case

Name	Alternative assumptions on technology availability
INVESTMENT	No new investments in nuclear and CCS technologies
BIOMASS	Low biomass availability; based on CCC Bioenergy Review - Constrained Land Use Scenario
BARRIERS	Higher hurdle rate (20%) on highly efficient and innovative technologies
PESSIMISTIC	Pessimistic scenario, combination of the three cases above

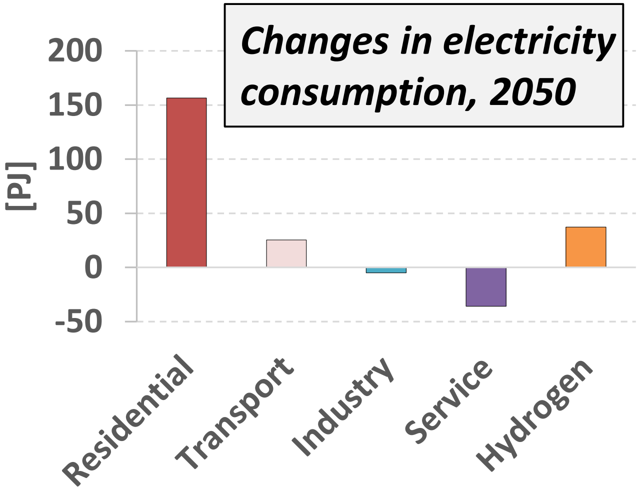
EPSRC
Pioneering research and skills

INVESTMENT scenario *– How is electricity generation and consumption affected?*

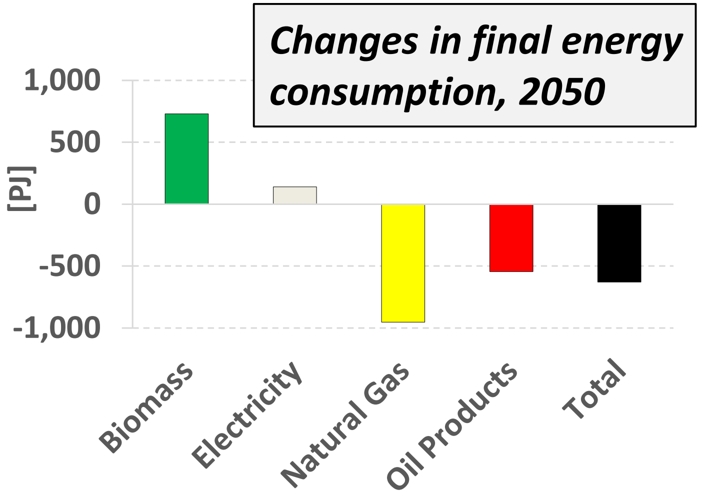
In 2050, **37 GW of nuclear** and **8 GW of biomass CCS capacity** need to be replaced



Marginal costs of electricity generation more than double in 2050 compared to REF, but decarbonized electricity essential to reach emission targets!



How is emission reduction through CCS compensated?

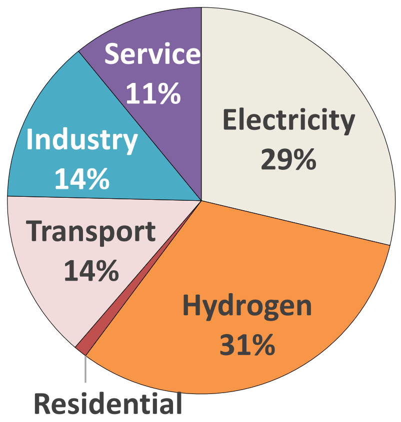


Scenario BIOMASS *– How is the use of biomass compensated in the various sectors?*

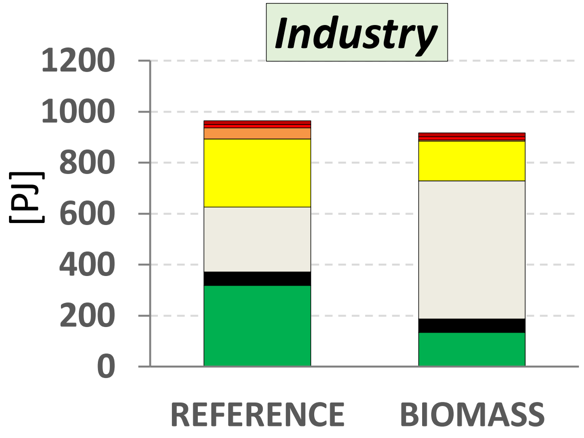
In the reference case

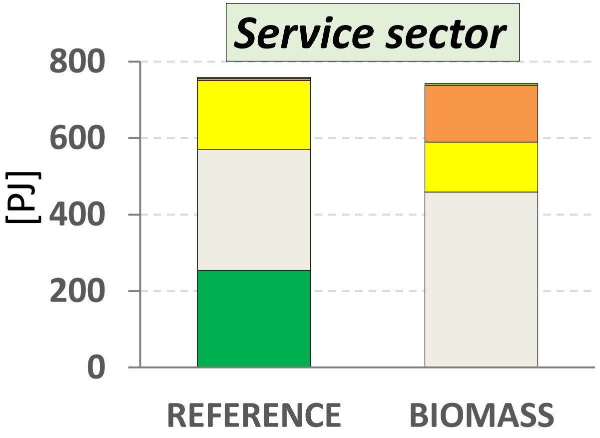
Total consumption of biomass in 2050:

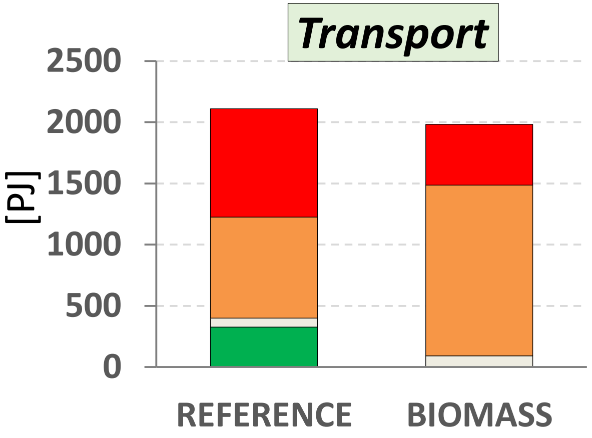
2325 PJ



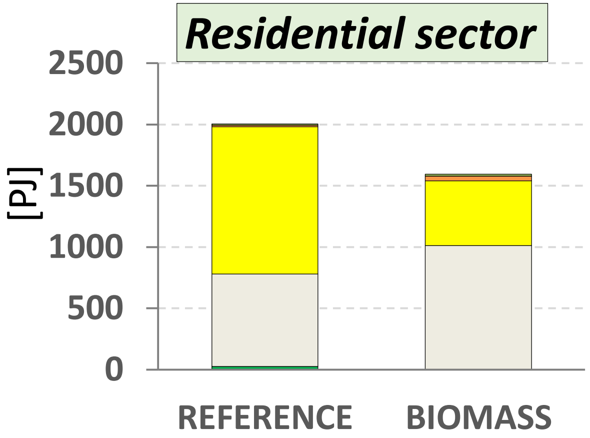
Effects in 2050

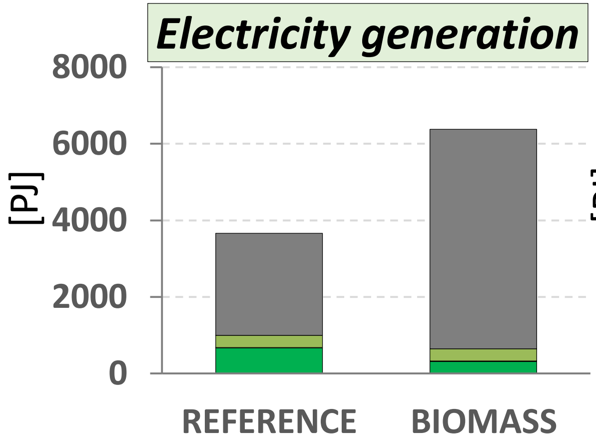


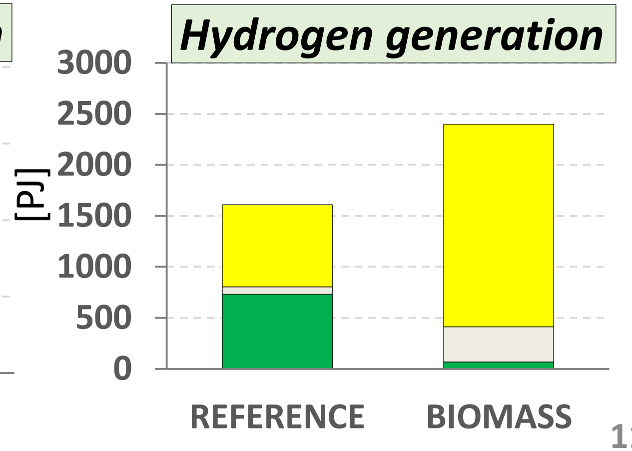




Biomass | Coal | Electricity | Natural Gas | Hydrogen | Oil Products | Other RE | Man. fuels | Uranium







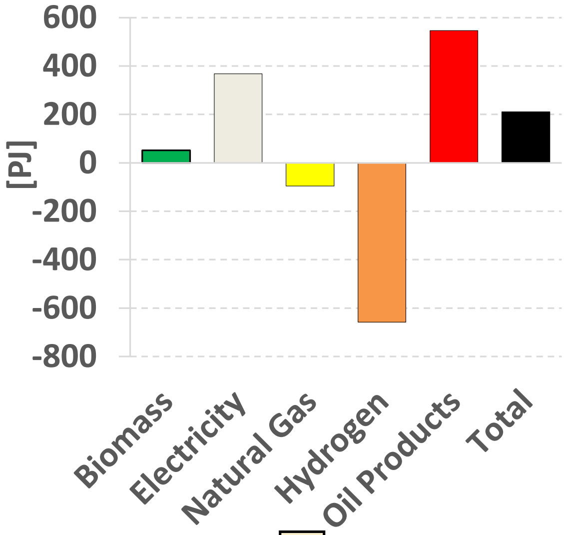
Reduced to max.

510 PJ

in scenario BIOMASS

BARRIERS Scenario – *Do higher hurdle rates affect investment decisions?*

Change in final energy consumption, 2050



Transport sector
- Reduced use of hydrogen
- Stronger reliance on petroleum
- Increased use of biofuels in road transport and aviation

Industry sector
- Limited uptake of efficiency measures, esp. in the paper and iron & steel industry
- Switch from gas to electricity
- Increased use of biomass for heating

Residential sector
- No change in uptake of conservation measures
- Switch from electric heat pumps to gas boilers

Service sector
- No change in uptake of conservation measures
- Increased use of biomass in boilers and district heating
- Stronger use of electric boilers

Electricity generation

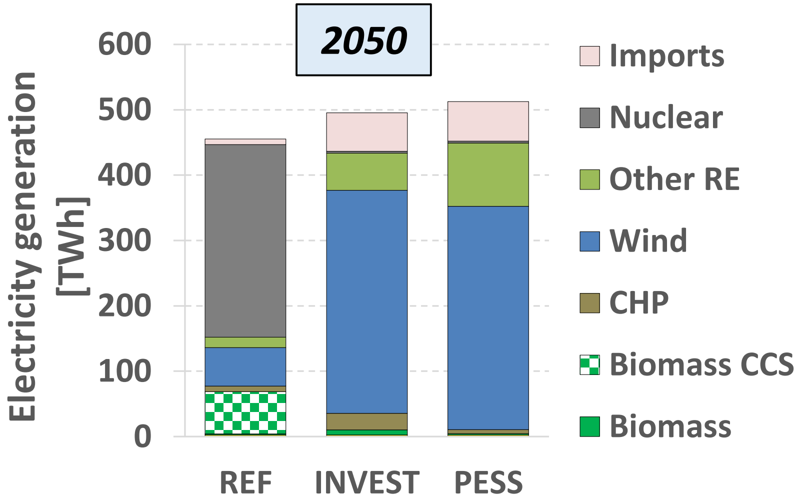
To compensate for higher use of fossil fuels in end-use sectors, stronger uptake of biomass CCS (+6 GW wholeSEM

UCL

PESSIMISTIC Scenario – *How is the low-carbon transition still achieved?*

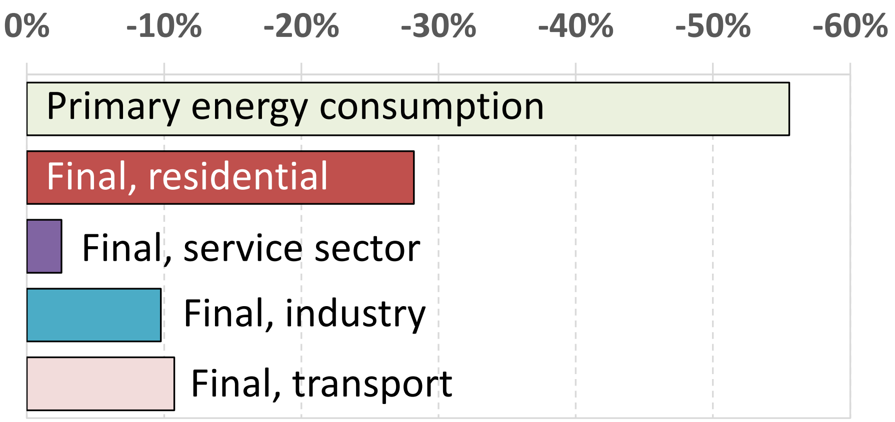
1.

Decarbonisation of the electricity sector



2.

Energy savings



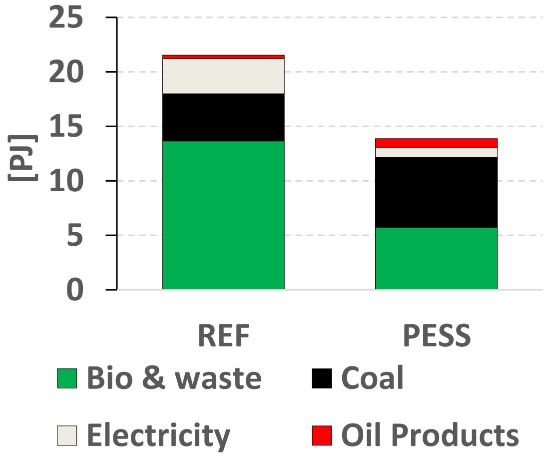
3.

Uptake of innovative technologies in the end-use sectors

Transport sector is heavily dominated by hydrogen

About half of heat demand in the residential sector is provided by electric heat pumps

Alternative production processes are applied in industry (e.g. 'low-CO2' cements, Fischer-Tropsch technology in steam cracking)

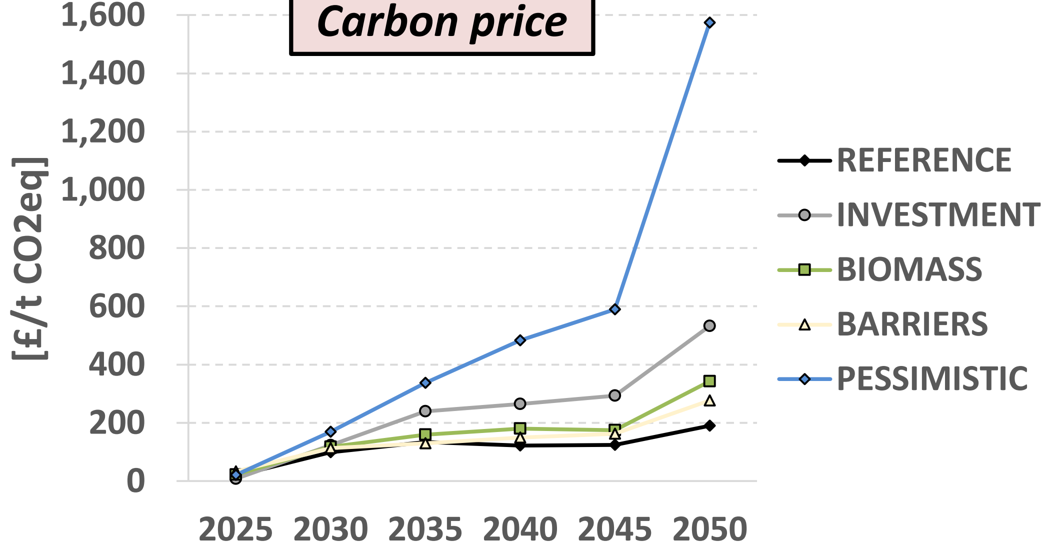


Cement industry fuel demand, 2050

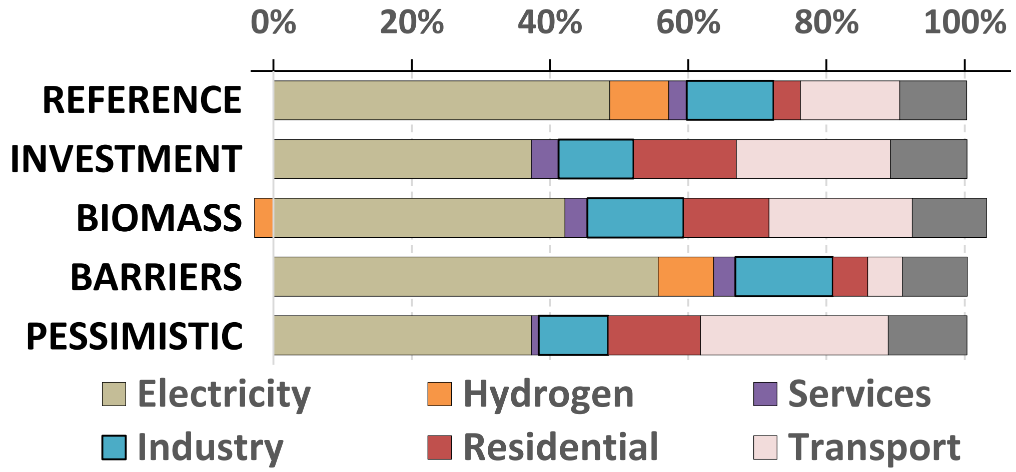
EPSRC
Pioneering research and skills

Scenario comparison

Carbon price



Contribution to emission reduction, 2050 compared to 2010

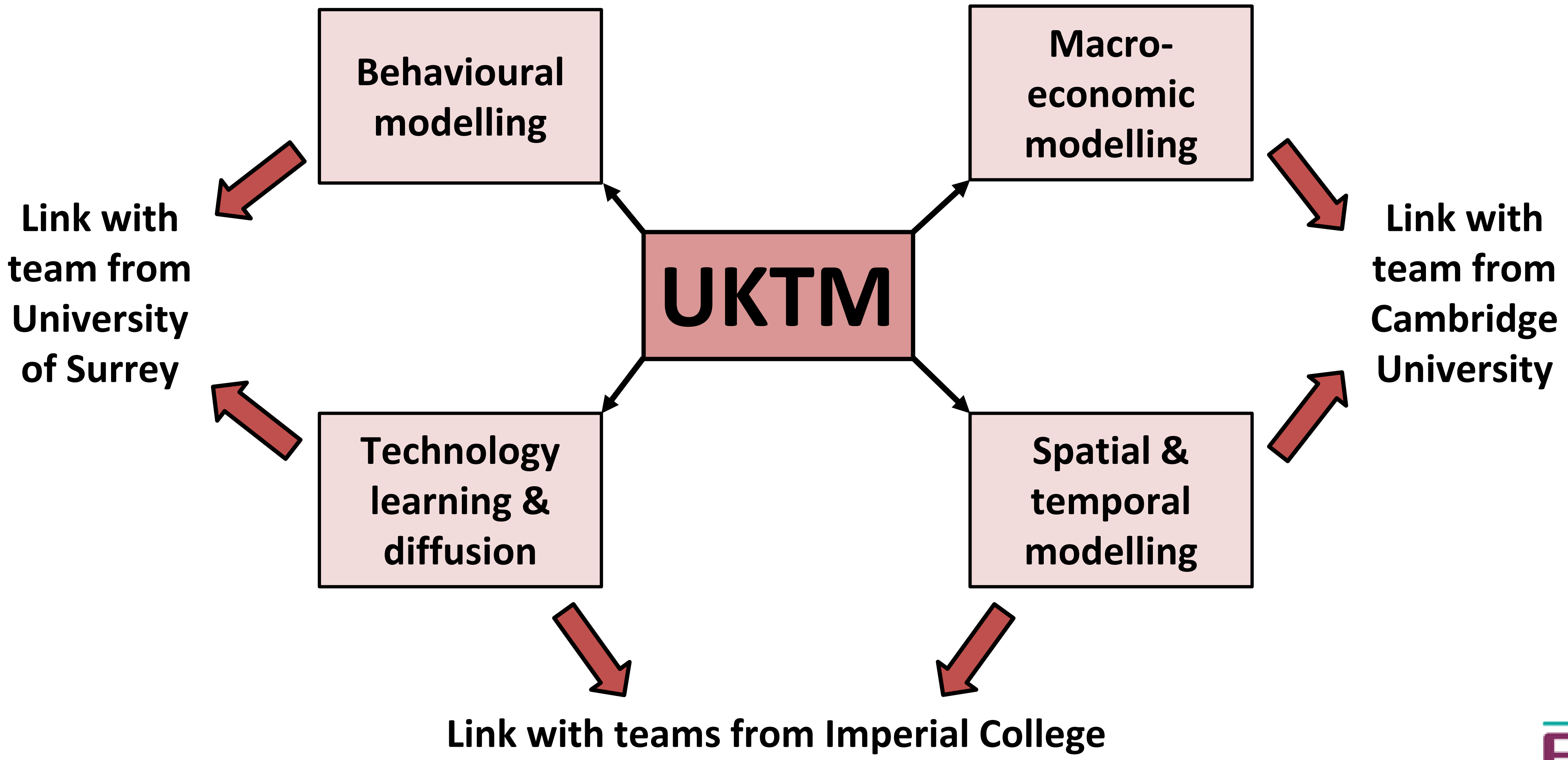


Energy efficiency

	Change in 2050 compared to 2010	
	Energy intensity (PEC/GDP)	**Reduction in final energy demand**
REFERENCE	-59%	-9%
INVESTMENT	-72%	-19%
BIOMASS	-55%	-19%
BARRIERS	-57%	-6%
PESSIMISTIC	-82%	-23%

EPSRC Pioneering research and skills

4. UCL research strands & interactions in wholeSEM



Conclusion

Achieving the low-carbon energy transition in the UK requires the availability of a variety of low-carbon energy technologies

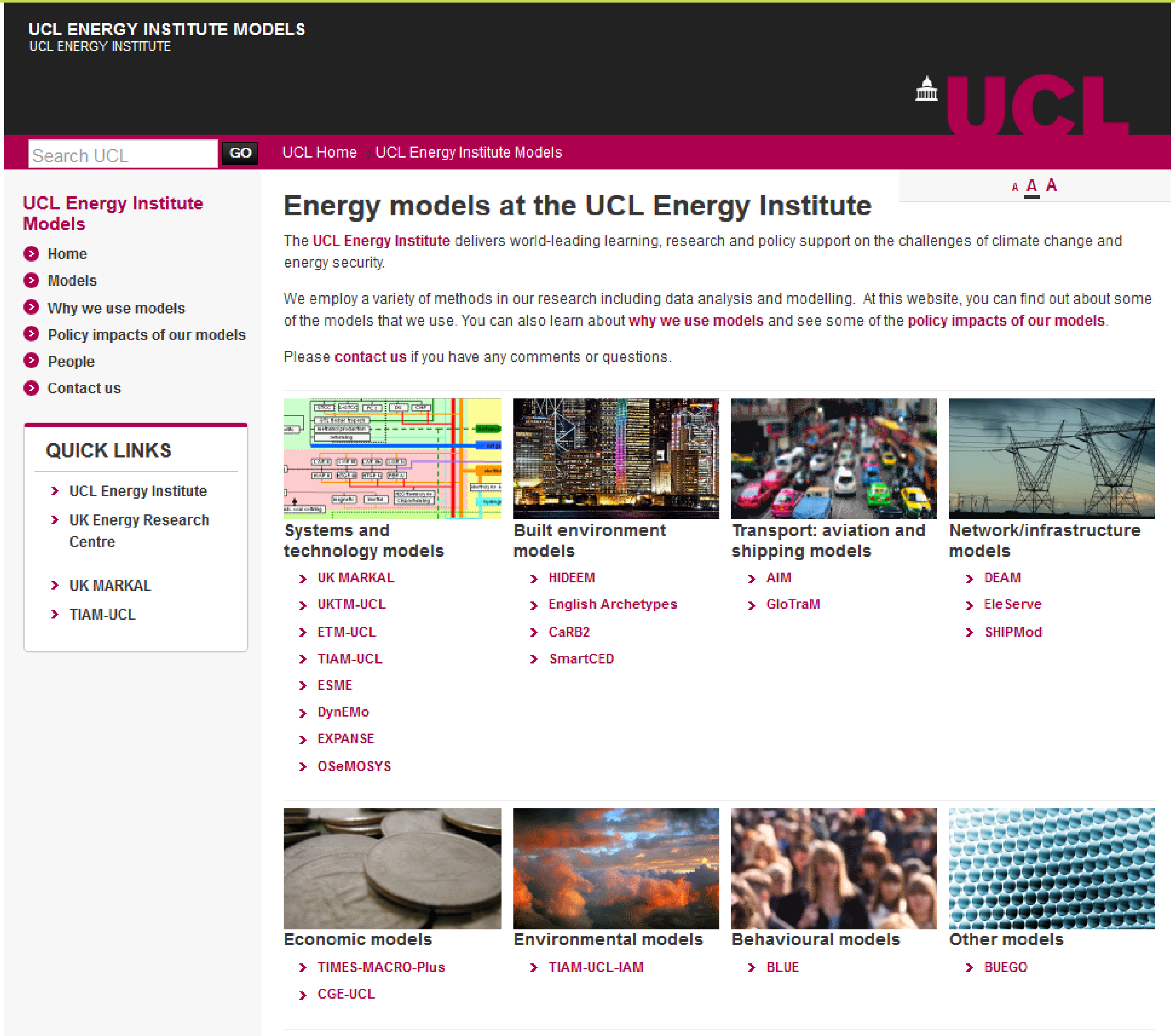
↓

Energy systems models can provide a comprehensive view on the long-term impact of technology uncertainty and can therefore benefit the policy making process

↓

Policy support usually tries to follow a technology-neutral approach, but might it be necessary at some point to start "picking winners"?

EPSRC Pioneering research and skills



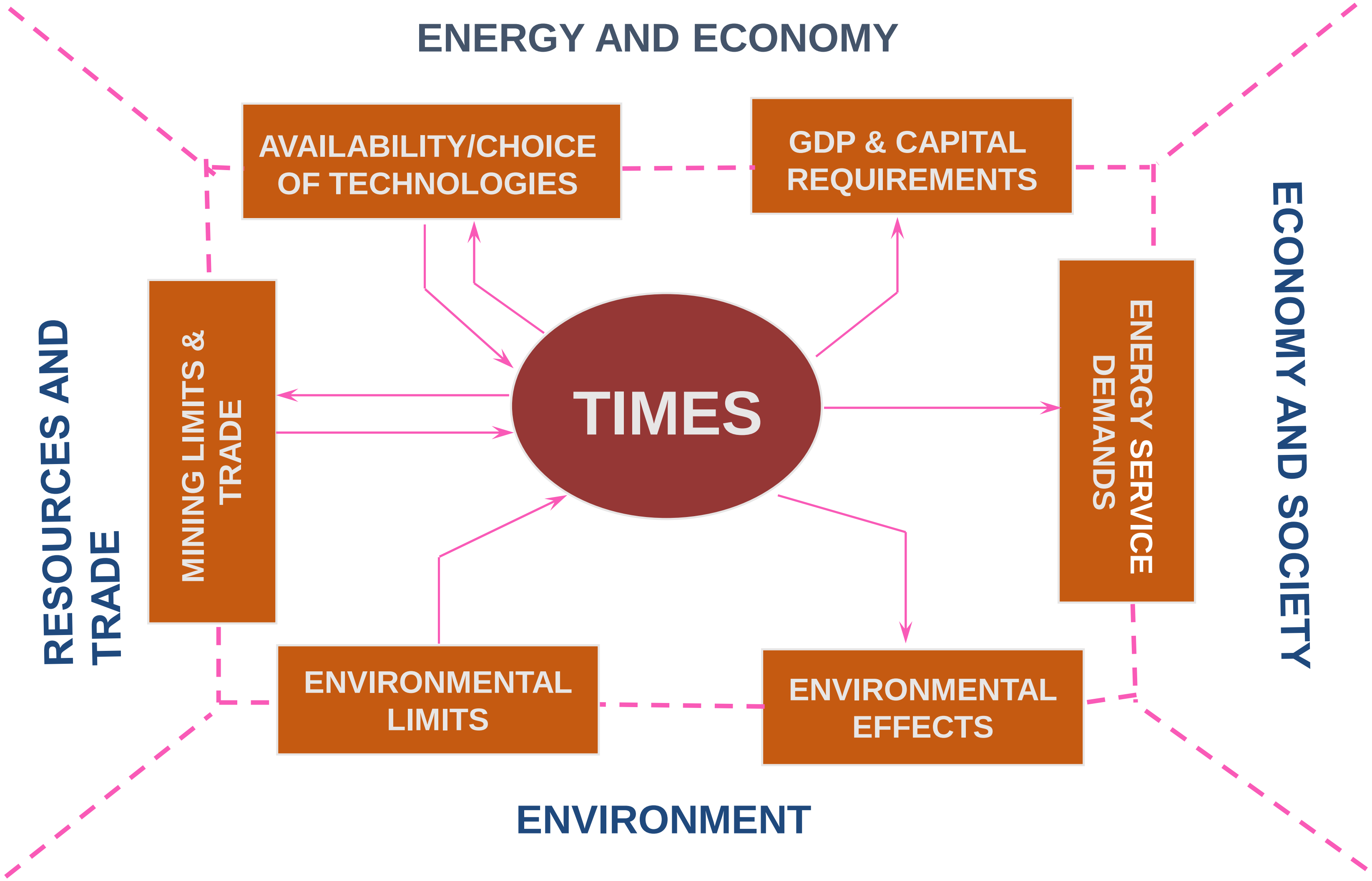
Thank you for your attention!

UCL-Energy Models:
www.ucl.ac.uk/energy-models

EPSRC
Pioneering research and skills

Back-up

Energy, Economy, Engineering & Environment (E4) Interactions



TIMES: Selected Advantages and Disadvantages

- **Advantages**
  - Well understood least-cost modelling paradigm (efficient markets)
  - International support network through the IEA's ETSAP network
  - Interactions within entire energy system
  - Coherent and transparent framework; open assumptions on data, constraints etc
- **Disadvantages [and remedies]**
  - TIMES is data intensive (characterization of technologies and RES)
    - Data sharing and collaboration improving the situation
  - Results sometimes sensitive to small changes in data assumptions
    - Stepped supply curves and market share algorithms
  - Limited ability to model behavior
    - Growth constraints, "hurdle" rates, demand elasticities (Macro)
  - Limited representation of economic impact of energy policy
    - TIMES Macro and other linkages
  - Spatial and temporal aggregation
    - Linkages to GIS frameworks (DfT Horizons)

EPSRC
Pioneering research and skills