UCL Energy Institute

Overview of Energy-Economic Modelling

Parliamentary Office of Science and Technology (POST) Training Seminar

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Overview of Session

- **Part I**
  - The science vs. art of energy modelling
- **Part II**
  - UK TIMES: An well-known energy systems optimisation model
- **Part III**
  - Sample results on the UK's long-term decarbonisation pathway

What this seminar is NOT…

- "Energy: Predicting the Future - Macro-economic & decarbonisation modelling"
  - I have never made a long term energy forecast in my life!
- Only sometimes is replicating historical trends a good idea
  - The past is not a good guide to the future
  - Models can replicate the past by tuning various combinations of their component variables
  - There can be a modelling trade-off between statistical validation and theoretical underpinnings
- Today I am going to talk about exploratory modelling of possible futures
  - Insights from comparing different futures is much more important than any one scenario

What this seminar is…

- Energy policy across the globe is grappling with a set of unprecedented challenges:
  - Including decarbonisation, security, competitiveness, equity
- Energy models provide essential quantitative insights into these 21st Century challenges
  - Energy models have very different methodologies, and are targeted at different research questions
  - Energy models are built, run, critiqued and applied by people
- **Let's open the black box of energy modelling**
  - **Energy modelling insights and policy making iteration**

What are energy models?

- What models are *not*
  - A generator of research papers or consultancy funding
  - A name based on a zippy acronym
    - e.g., GREEN, BLUE; PRISM, CUBE; ALPHA, GAMMA, DELTA; ALBATROSS
- UCL-Energy's approach to modelling
  - There will never be a universal model which will answer all questions
  - A range of models (& model linkages) are required for any given problem
  - Developing an expert/educated community of developers and users is critical
  - Models are only as good as the data you have to populate / challenge them

What is a mathematical energy model?

- A simplified imitation of the real thing
- A series of equations that together (try to) represent characteristics of a real-world system
- Based on observed and/or inferred data and insights
  - But may also rely heavily on scenario specific assumptions (especially for very long time horizons and complex systems

Uses of a model:

- A framework for analysing the modelled system

A model is not:

- A crystal ball that predicts the future

…And an energy system model?

- Models used for system level analysis
  - Usually all main sectors included (in some form)
  - Spatial, temporal and economic interactions also considered
- Focus varies between models
  - Technology, (macro)economics, integrated assessment
  - Local, global and everything in between
  - Temporally usually from some decades to hundreds of years
- Decision environments differ
  - Social planner vs heterogeneous agents

- Common characteristic: Describe interactions and interdependencies of the components of a highly complex system

Model characterization based on…

- Economic coverage
  - Partial vs. General equilibrium
  - Top down vs. bottom up
- Environmental coverage
  - Emission coverage
  - Integrated assessment vs energy system
- Geographical coverage
  - World, country, region, city...
- Time horizon
  - Static, short, medium, long term to very long term (100-200 years)
- Purpose of the model
  - Forecasting, scenario analysis, stylized dynamics
- Foresight and uncertainty
  - Deterministic, myopic, stochastic
  - What is uncertain, how is uncertainty resolved, how does it affect results?
- Solution algorithm/approach
- All of these have implications for interpreting the results

Computable General Equlibrium models

- General equilibrium (static or dynamic)
- e.g. EPPA, MERGE
- Focus on the economy, little detail on technology
- Consists of:
  - Tables of transaction values
  - Production function (labour, capital, materials, energy, other)
  - Elasticities for capturing behavioural responses (e.g., price, demand, trade, income elasticities etc)
- Solve model with a set of exogenous parameters (representing technology, wages, prices, and exchange rates) to bring all markets into equilibrium

Simulation models

- Partial Equilibrium (usually)
- e.g. POLES, TIMER, GCAM
- Simulate a 'system' by representing the relationships between key parts of it
- Is not prescriptive, but descriptive
  - Tries to capture observed dynamics (optimisation vs. simulation)
- Based on, e.g. use of multinomial logit functions or econometric relationships
- Can include relatively much detail on technology

Optimisation models

- Optimise an objective subject to constraints
- e.g., MARKAL, TIAM-UCL, MESSAGE
- Usually minimisation (over given time period) of costs for the energy system
- Partial equilibrium
- Prescriptive, usually "a social planner with perfect foresight" (additional constraints often used for descriptive purposes)
- Starting point the representation of a system. Then add:
  - an objective function – e.g. sum of simulated costs, to be minimised
  - specified constraints – e.g. power supply must equal or exceed demand
  - Some mathematical technique to seek the optimum (e.g. linear programming)

Model Usefulness: Quote #1

- *"All models are wrong but some are useful"*
  - George Box
- My alternate version
  - "Some models are right, (or at least in practice, right enough), and even the wrong ones can still be useful"

Model Complexity: Quote #2

- *“entia non sunt multiplicanda praeter necessitatem*"
  - "entities must not be multiplied beyond necessity"
  - William of Ockham: 1288 – 1348
- In modelling terms:
  - Simplicity-elegance-parsimony
  - Complexity as necessary
    - **BUT** energy-economic system is inherently complex
  - Problem drives modelling and analysis

Model Quantification: Quote #3

- "*Model for insights, not numbers*"
  - Hill Huntington, 1982
- But decision makers don't really want insights!
  - They really want numbers
  - And they don't deal with uncertainty very well

Building and using a model, what matters?

Some critical modelling issues

- Technology
  - Development drivers and trends, learning, surprises
- Behaviour
  - Heterogeneous a
  - individuals) vs. a
  - emergence (ager
  - modelling?)
- Scale
  - Spatial: Local vs. national vs. global (policies, technologies, infrastructures)
  - Temporal: Months, years decade centuries. Surprises and responses to signals

Interpreting the model results

- What do the results mean?
  - Long term, global, perfect foresight, deterministic, social planner ≠ short term, local, stochastic, agent based
  - n highly model (and ecific, requires careful n!
- What can they be used for?
  - Can be very useful for, for example, policy advice, but need to be communicated properly (what is covered, what is assumed)
  - Generally: Not forecasts, but insights on the system (dynamics)!

Uncertainty!

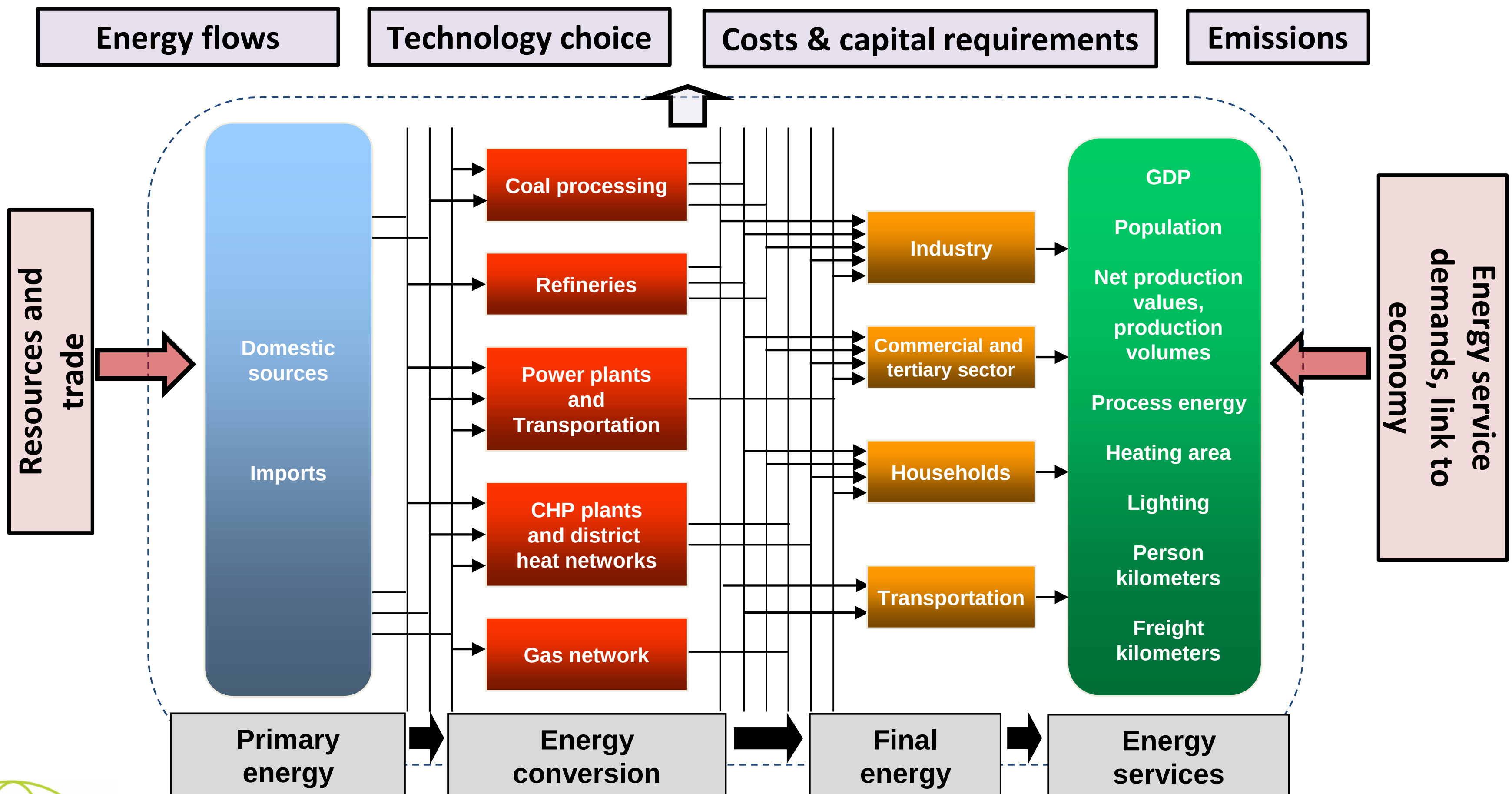
UKTM – The UK TIMES Model

- ***Overview***
    - Integrated energy systems model
    - Least cost optimization
    - Partial equilibrium
    - Technology rich

- **Successor to UK MARKAL**

- Used by UCL and DECC

UKTM – UK TIMES energy system model



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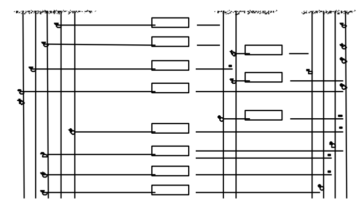
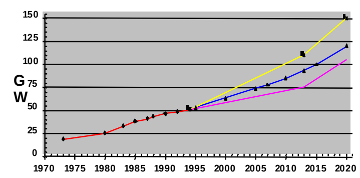
Components of an Energy System Model

* Energy system topology & organization



RES

* Numerical data



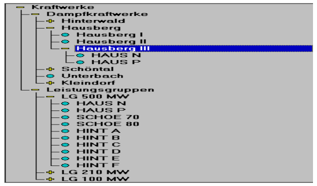
Time Series

* Mathematical structure
  – transformation equations
  – bounds, constraints
  – user defined relations

$$P_{BHKW\_S} = \eta_{BHKW} \cdot P_{Coal\_BHKW}$$
$$O_{BHKW\_CO_2} = \varepsilon \cdot P_{Coal\_BHKW}$$
$$Q_{BHKW\_H} = \eta_{2\_BHKW} \cdot P_{Coal\_BHKW}$$

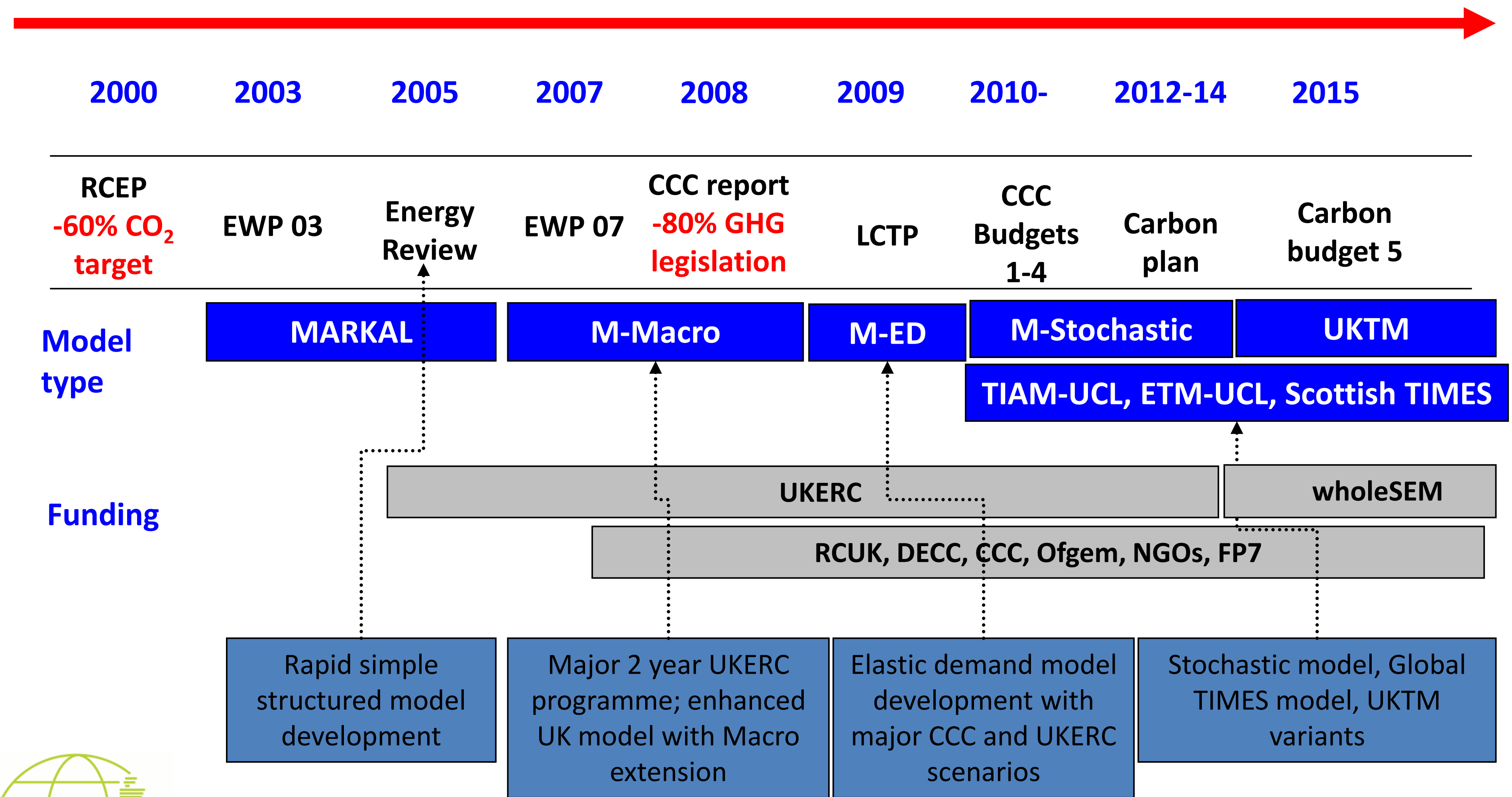
GAMS Model

* Scenarios and strategies



Cases

Energy systems modelling for UK policy



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UK Energy Policy Timeline (1)

Year	Energy Policy Landmark	Modelling study
1992	**Dept. of Energy disbanded** OFGEM as independent regulator; Energy Efficiency Office created	Updated Emissions Projections (UEP)
1993		
1994		
1995	UNFCCC negotiations; Nuclear review	UEP
1996		
1997	Kyoto Protocol	
1998		
1999		
2000	UNFCCC 3rd National Communication Renewable electricity obligation (RO), Climate change levy (CCL)	UEP
2001	**Royal Commission on Environmental Pollution (-60% CO_2 target)**	
2002		
2003	Energy White Paper	MARKAL
2004	UK emissions trading scheme; EUETS National allocation plan Phase I; Climate change agreements (CCA); Carbon Trust	UEP

UK Energy Policy Timeline (2)

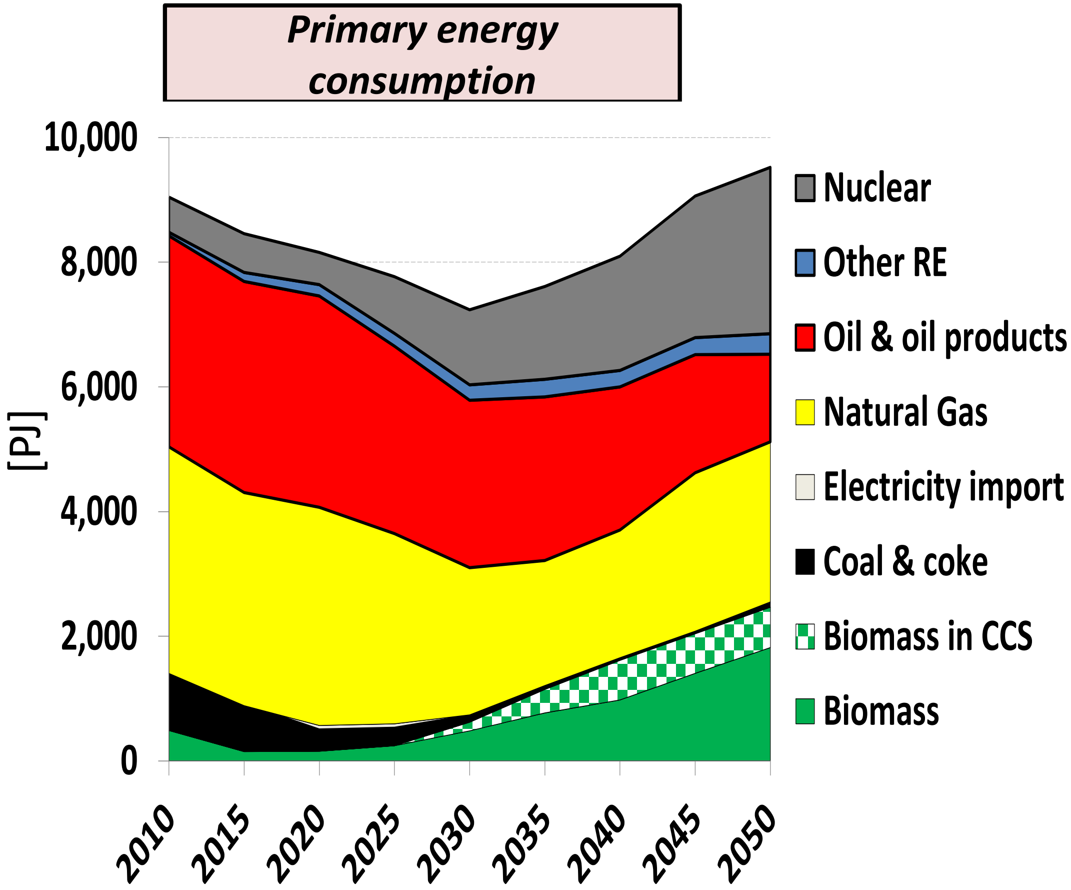
Year	**Energy Policy Landmark**	**Modelling study**
2005	*UKERC commissioned*	
2006	Energy Review, EUETS National allocation plan - phase II, Warm front; Renewable transport fuel obligation (RTFO). Plus Stern Review	UEP; PAGE
2007	Energy White Paper	UEP; MARKAL-Macro
2008	**Climate Change Act (-80% GHG target)** **DECC founded. (CCC) formed and inaugural report**	UEP; MARKAL-Macro, MDM-E3
2009	Scottish Climate Change Act Low Carbon Transition Plan for 1st, 2nd, 3rd carbon budget periods (2008-12, 2013-17 and 2018-22)	UEP; MARKAL spatial, AMOS
2010	4th carbon budget (2022-27)	UEP; MARKAL Stochastic, DECC Calculator, Zephr
2011	**Carbon Plan** Green Deal; Green Investment Bank	UEP, Global TIAM-UCL MARKAL elastic demand
2012	Electricity Market Reform (CO_2 floor price, emissions standard, feed in tariff) Review of carbon budgets and competitiveness	UEP, DSIM, AMOS, MRIO
2013-	4th carbon budget review (2022-27) Review of carbon budgets and energy prices	UEP, TIAM-UCL, ESME
2015	5th carbon budget	UKTM, range of models

UK GHG budgets

5 year Carbon budget	Years	Budget (MtCO2e)	% reduction vs 1990 levels	Status
1st	2008-2012	3,018	23%	Achieved
2nd	2013-2017	2,782	29%	On target
3rd	2018-2022	2,544	35%	Legislated
4th	2023-2027	1,950	50%	Legislated
5th	2028-2032	1,765	57%	Proposed by CCC in Dec 2015 (DECC response due)

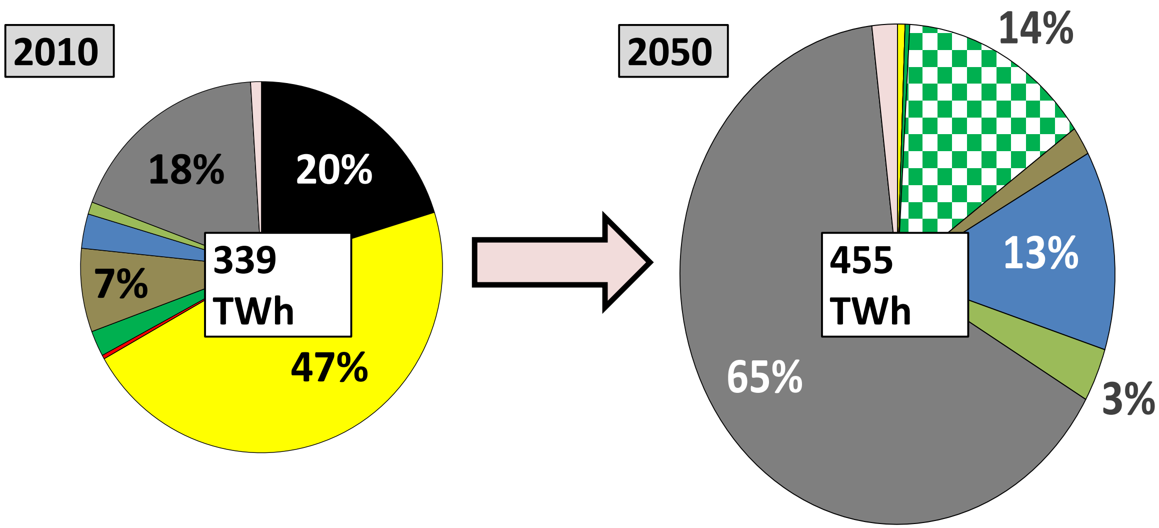
The low-carbon transition in the UK

80% GHG emission reduction until 2050

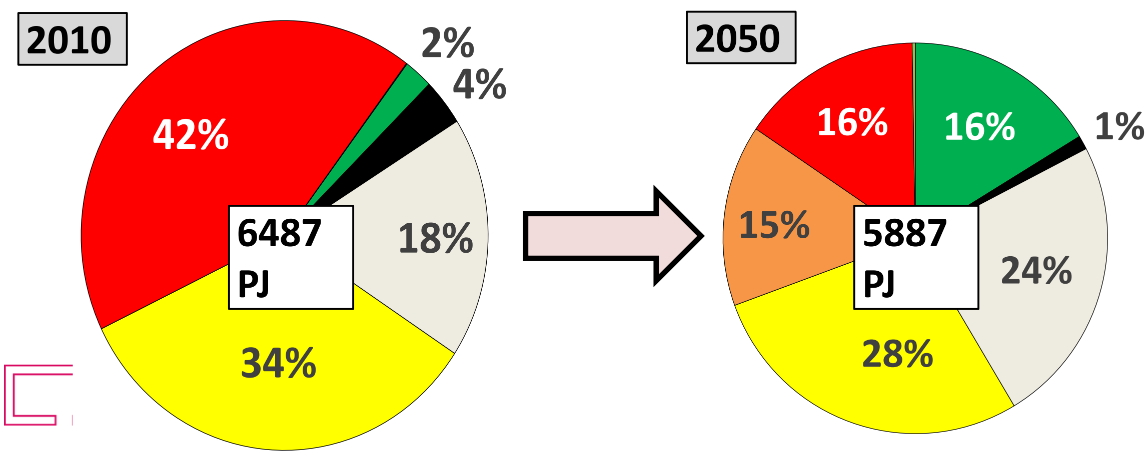


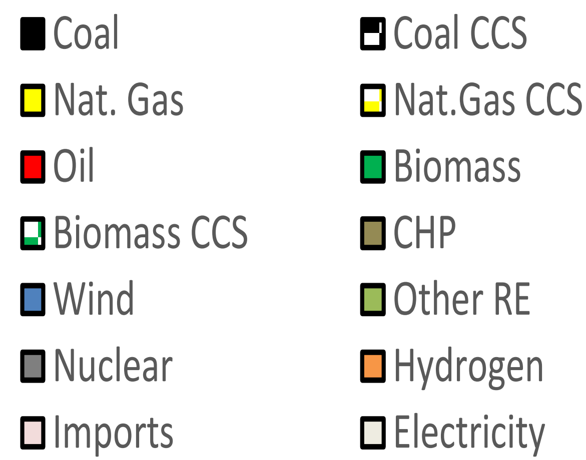
- Reduction until 2030 mainly due to energy efficiency improvements in electricity generation & industry
- Rising consumption after 2030 can be attributed to rising electricity consumption & increasing use of biomass (partially with CCS)
- Consumption of petroleum products is more than halved
- Use of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

Electricity generation…

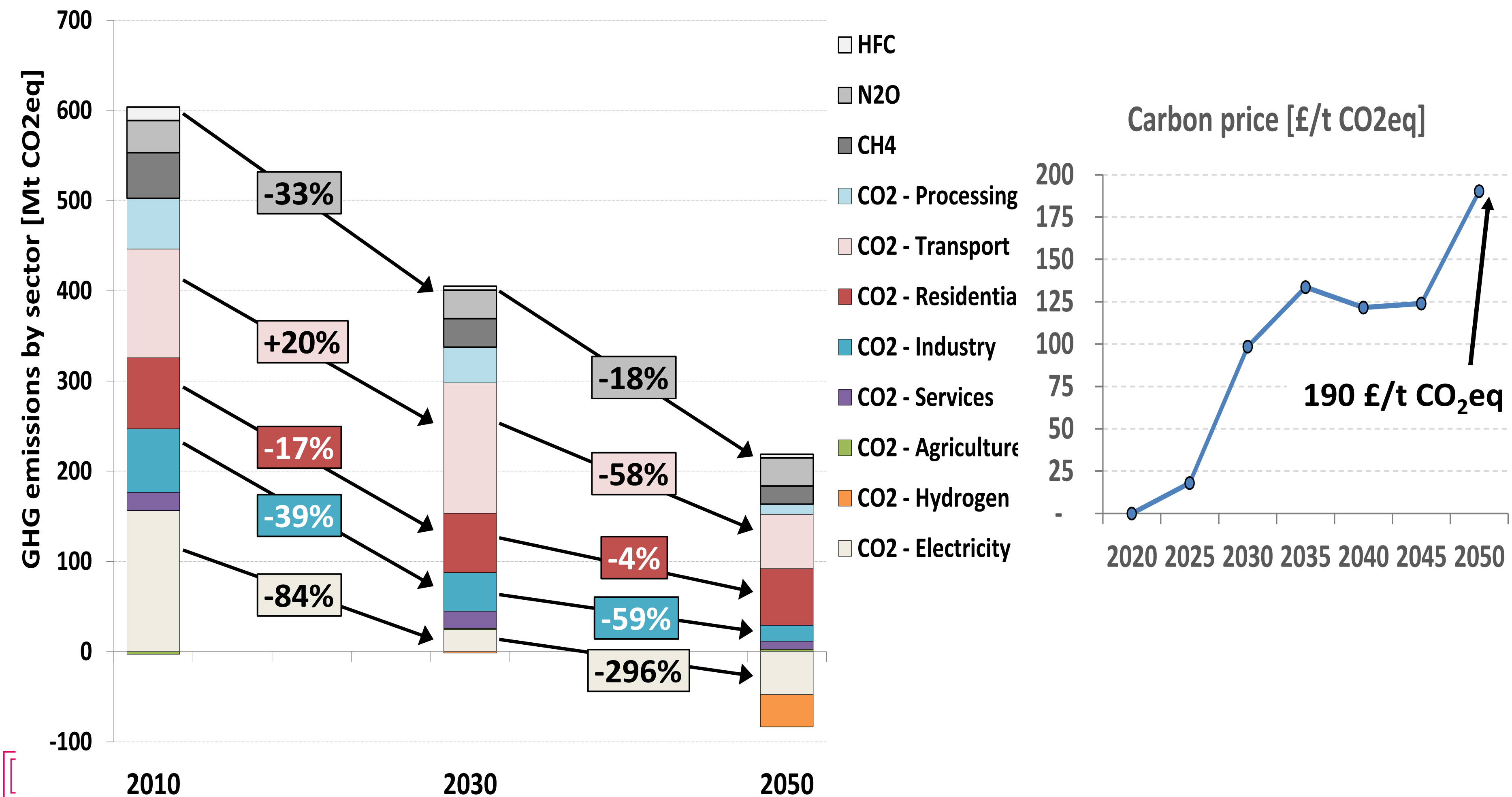


…and final energy consumption





Emission reduction and carbon prices



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?

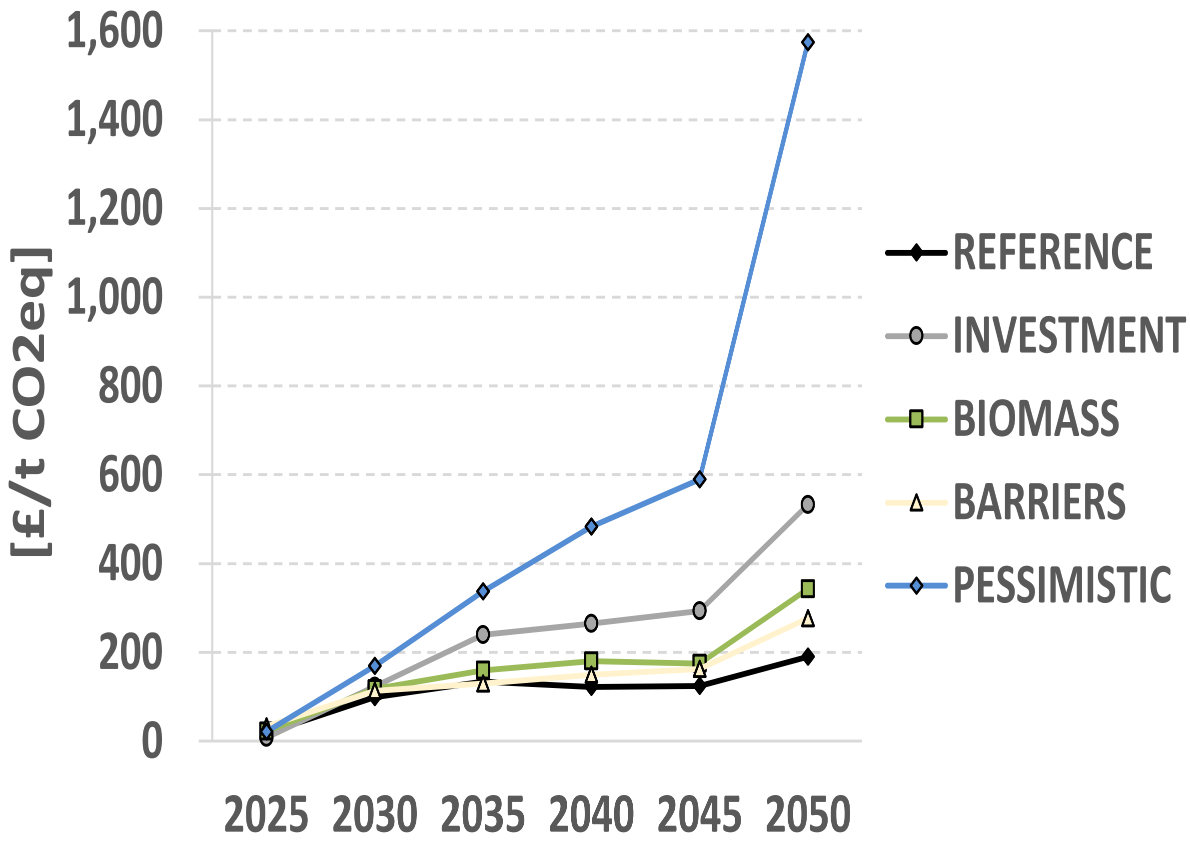
Barriers to investments in the end-use sectors?

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

Scenario comparison

Carbon price



Costs in perspective [All in 2010 £]

Expenditure	2010 cost (B£/yr)	2050 cost (B£/yr)	per 2010 UK capita (£/yr)	per 2050 UK capita (£/yr)
UK GDP	1,400	3,100*	23,400	47,700
-80% GHG costs		63 – 187[#]		970 - 2900
Final energy consumption	75	166*	1,250	2,550
UK Bank bailout	500		8,300	
Health budget	124	270*	2,060	4,200
Education budget (to 18 years)	58	130*	970	2,000
BP, Shell, Exxon profits	6 - 25			
Nuclear decommissioning	46		760	
New nuclear weapons	16		260	
Public renewable energy R&D	0.15		2.5	

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Thank you for your attention!

- **Whole Systems Energy Modelling Consortium:** www.wholeSEM.ac.uk
- **UCL-Energy Models:** www.ucl.ac.uk/energy-models

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