A systematic approach for analysing the robustness of a UK low carbon energy future using uncertainty analysis

Presentation to IQ SCENE, March 26th 2014

Steve Pye, Nagore Sabio and Neil Strachan
UCL Energy Institute

Presentation overview

- Research overview
- Research context
- Approach
- Results
- Key insights

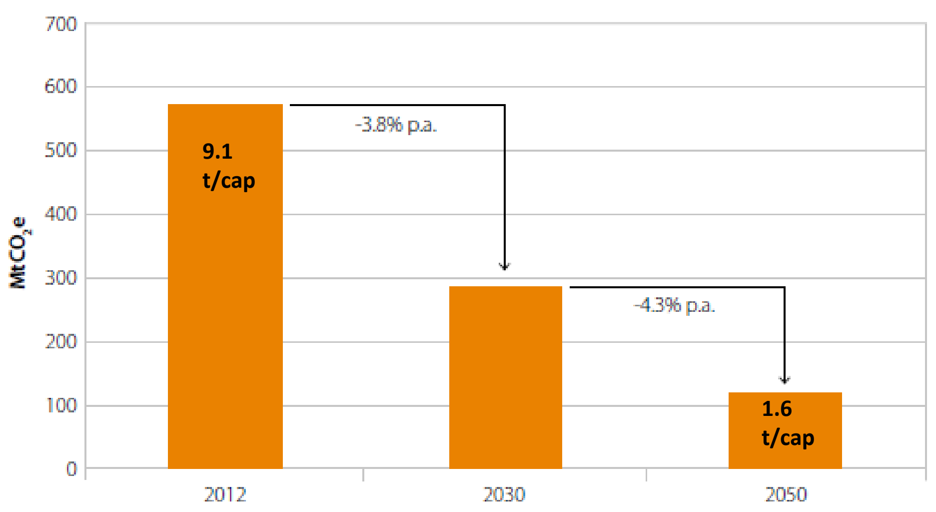
Research overview

- Working paper to explore impact of uncertainty on low carbon transition in the UK, and meeting targets
- Probabilistic approach to uncertainty analysis using ESME model, combined with sensitivity analysis
- Uncertainty focus ---> cost and uptake of key technologies in mid- to longer term. We analyse –
  - The likelihood of meeting emission reduction targets under a given set of carbon prices, and sensitivity of carbon price changes
  - Characteristics of technology-fuel combinations most prevalent across simulations meeting targets, through exploration of model outputs and sensitivity analysis.
  - Sensitivity analysis of model results to input uncertainties

Policy context

- Long term, stringent decarbonisation goal, meaning a transition to a radically different energy system
- Carbon budgets in near to mid term (-60% in 2030) and longer term target in 2050 (-80% rel. to 1990)

Figure 1.10: Rate of reduction of GHG emissions, excluding international aviation and shipping (2012-2050)



Source: NAEI (2013), CCC modelling.

Source: CCC (2013)

Modelling UK low carbon pathways

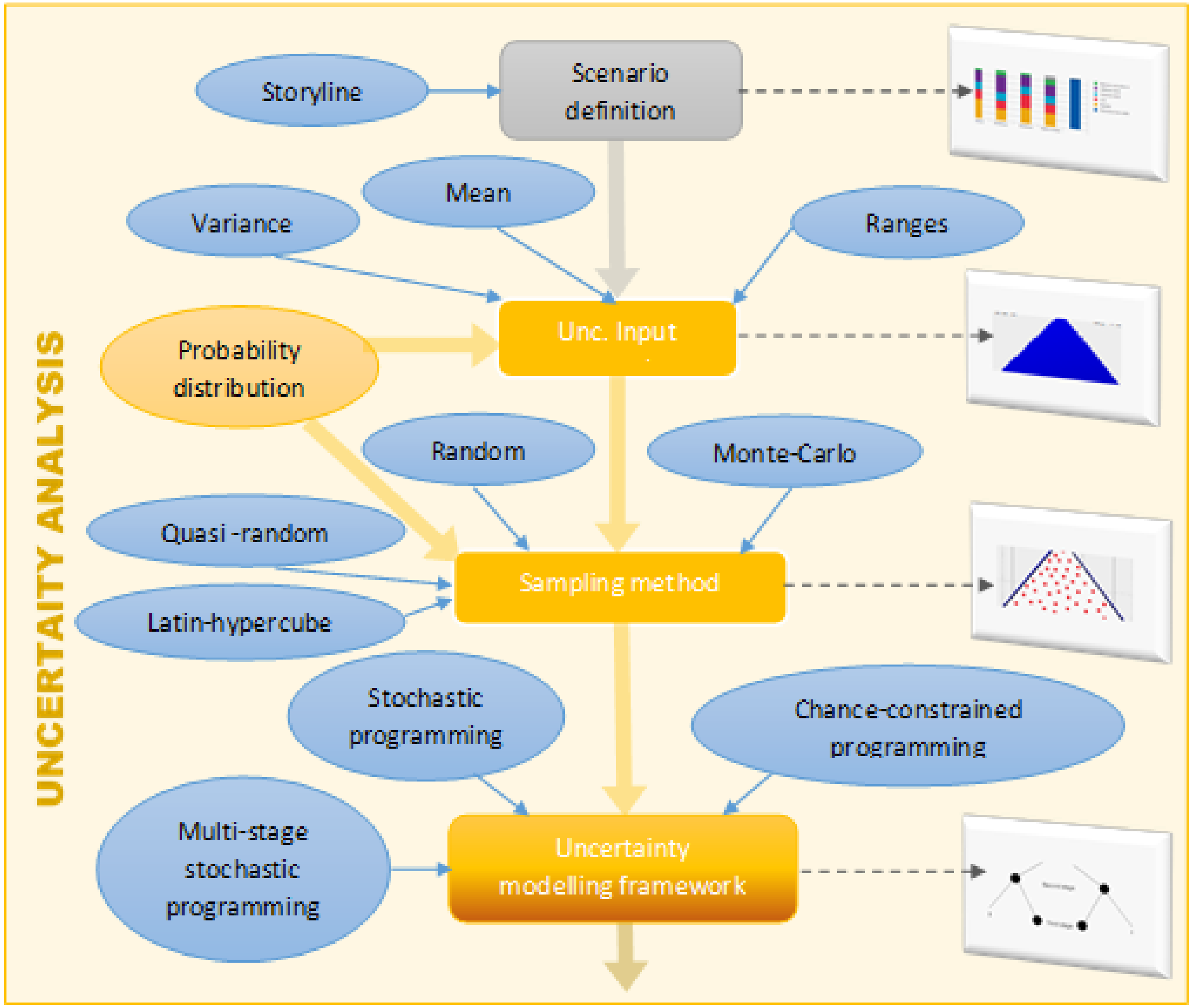
- Large number of studies since 2003 (Energy White Paper) resulting in many transition pathways
  - MARKAL model first used to assess long term decarbonisation goals, following RCEP 2000
- Optimisation models have played a critical role in informing strategy (e.g. Ekins et al. 2013)
- Limitations of deterministic analysis for complex and multi-faceted area of policy that is inherently uncertain (Usher and Strachan 2012)
  - Probability of an input value cannot be quantified
  - Disparate sensitivity scenarios make policy insights more difficult to determine
  - Cost of uncertainty is unknown

Approach to research

Overview of ESME model

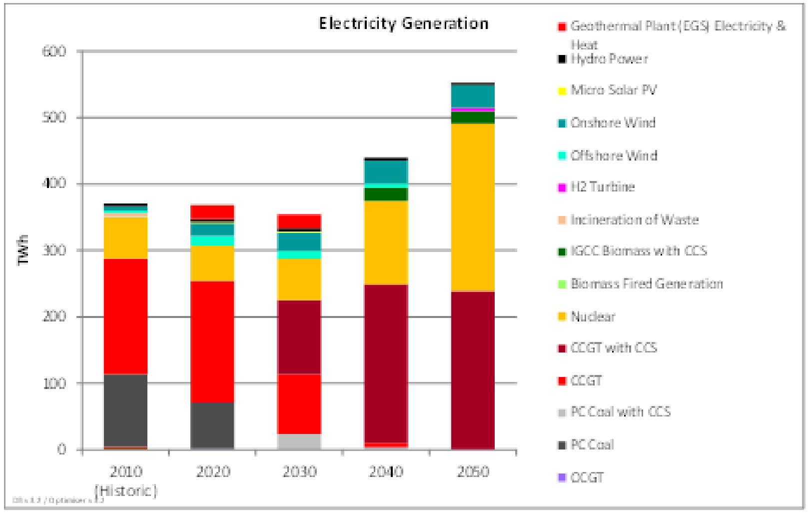
- Energy Systems Modelling Environment (ESME) – bottom-up, optimisation model using linear programming (in AIMMS environment)
- Funded and developed by the Energy Technologies Institute (ETI)
- Models system pathways out to 2050, in 5-10 year time steps
- Key feature is propagation of probability distributions across selected input parameters
- Another distinctive feature is the spatial disaggregation into different geographic nodes (onshore and offshore)
- Analysis uses v3.2 of the model, with elastic demand extension

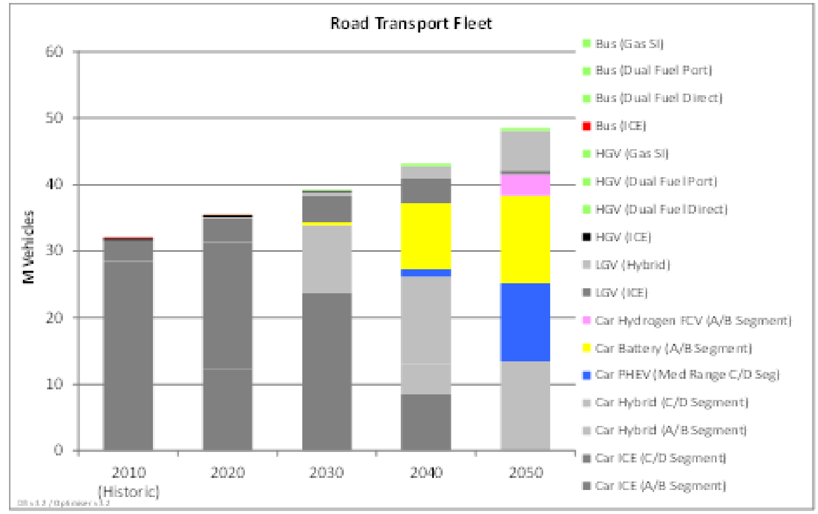
Approach to uncertainty analysis

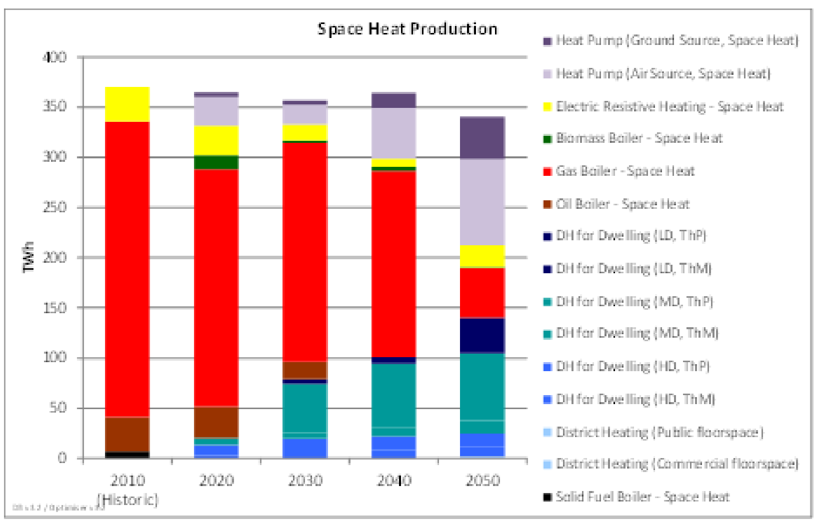


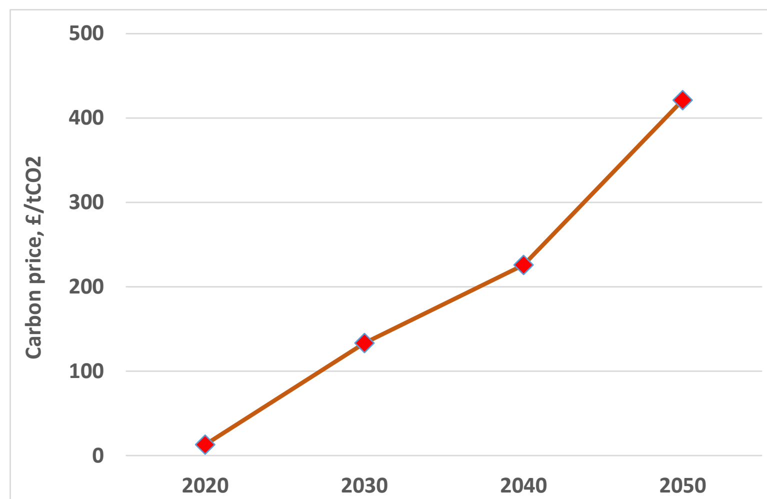
- Scenario definition
- Characterising uncertainty
- Sampling and propagation through model
- Sensitivity analysis of model outputs to uncertain inputs

Reference carbon price under pre-determined storyline









Characterising uncertainty

- Project focus on transition pathway determined uncertainties
  - 65 input parameters characterised as uncertain
  - Triangular distributions used
  - Range of uncertainty based on 'grey' policy-focused analyses

- Sampling approach using Monte Carlo technique

- No. of sample based on approach in Morgan et al. (1992)
  - 500 simulations used
  - Model run time ~24 hours

Input parameter	Description	Share
Investment costs – power generation		38%
Build rates – power generation	For key technologies including CCS, nuclear and wind	12%
Investment costs – hydrogen production		
Investment costs – cars	For both small (A/B) and large (C/D) cars	27%
Investment costs – heat pumps and district heating		9%
Resource availability – biomass	Max annual availability of biomass (incl. imports)	2%
Resource prices	Including fossil fuels and biomass	12%

Key uncertainty inputs

Sensitivity analysis method

ESME model: LP optimisation model

$$y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i$$

Objective function generic form

Outputs of interest:
- Total system costs (model obj. function)
- Emissions (model constraint)

Sensitivity analysis steps

1) Scatterplots
   - ❑ Partial correlations of each of the inputs in the output
   - ❑ Difficult to compare when differences are small

2) Multivariate linear regression
   - ❑ First order sensitivity index

$$S_{x_i}^{\sigma} = \frac{\sigma_{x_i} \delta y}{\sigma_y \delta x_i}$$

Standardised coefficients of the linear model – ranking of importance on output variability

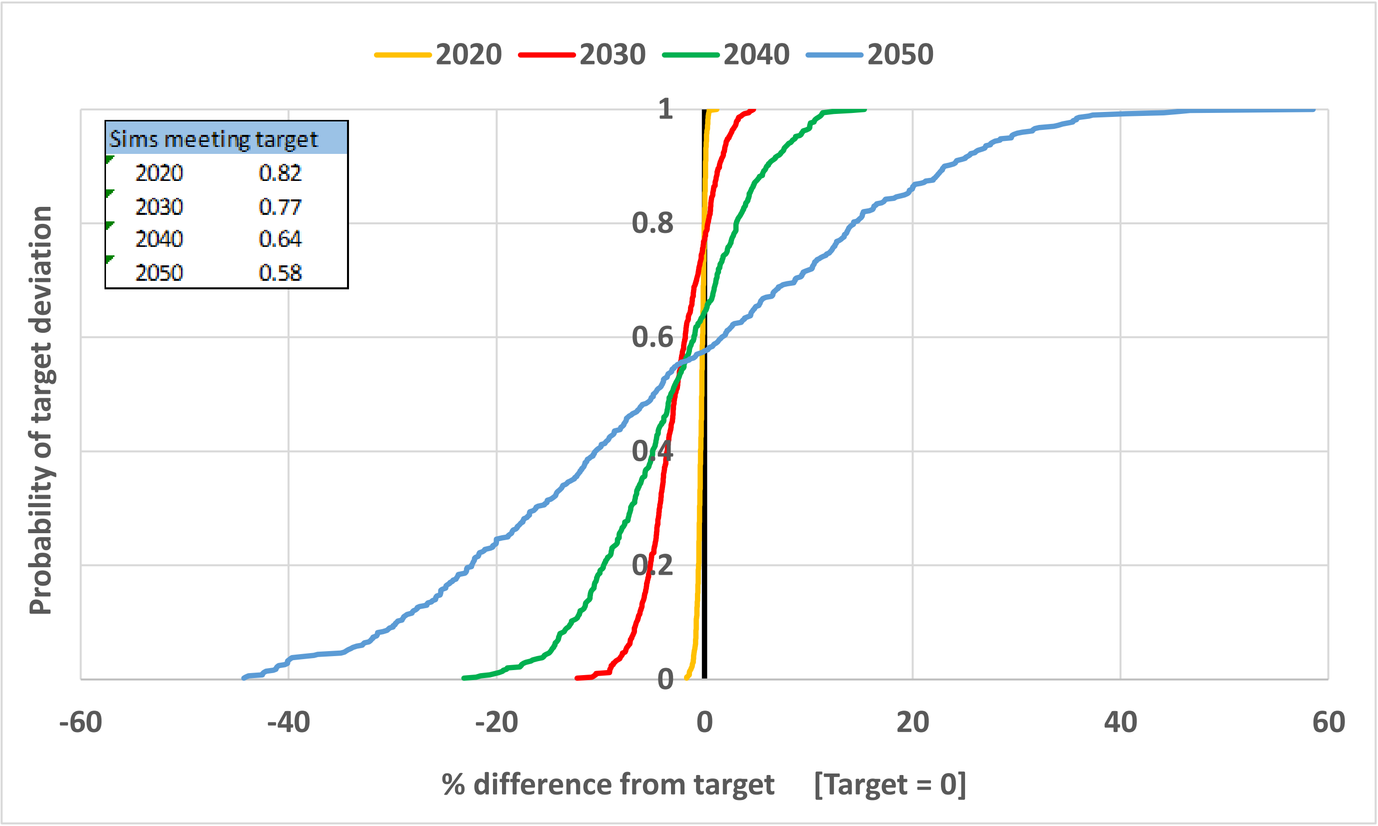
3) Stepwise multivariate linear regression
   - ❑ Ranking of model predictors on outputs

Cross-check of previous findings

Analysis results

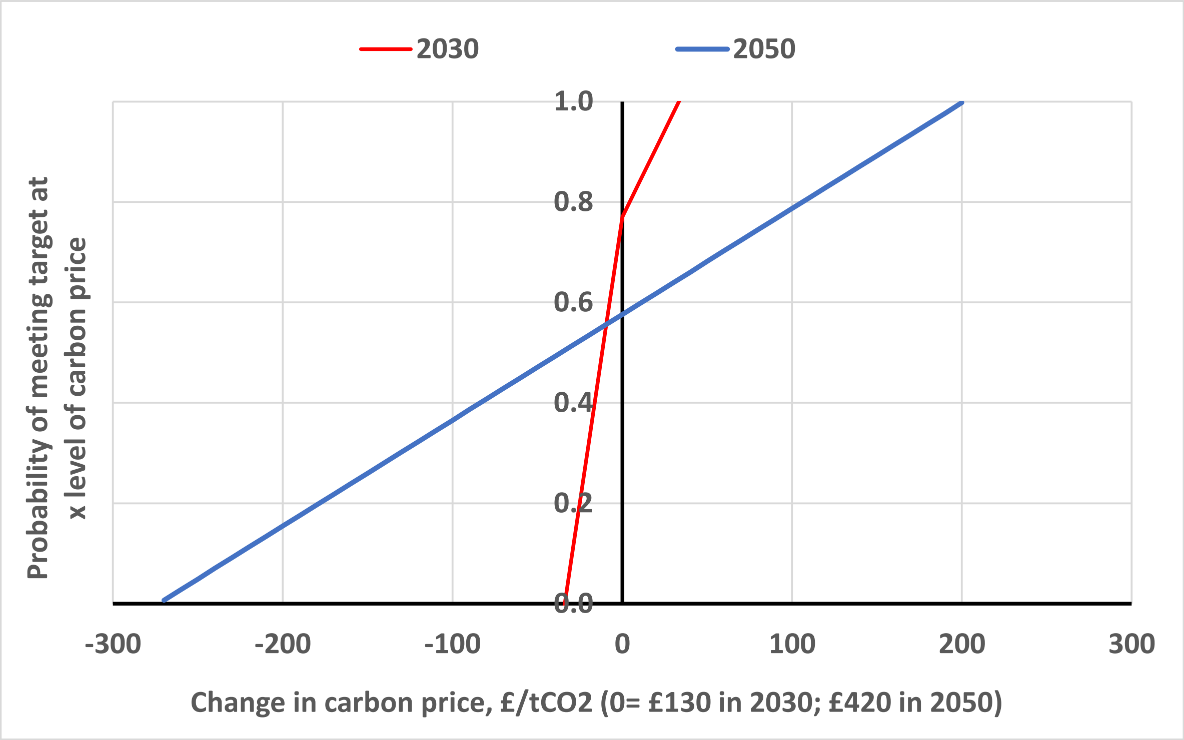
Meeting future targets under uncertainty

- Probability of meeting target in 2030 (77%) higher than in later periods, with limited deviation for simulations exceeding target
- In 2050, probability at 58%, with much stronger deviation from target level (range of -/+ 40%)
- How far should policy makers mitigate via carbon price?



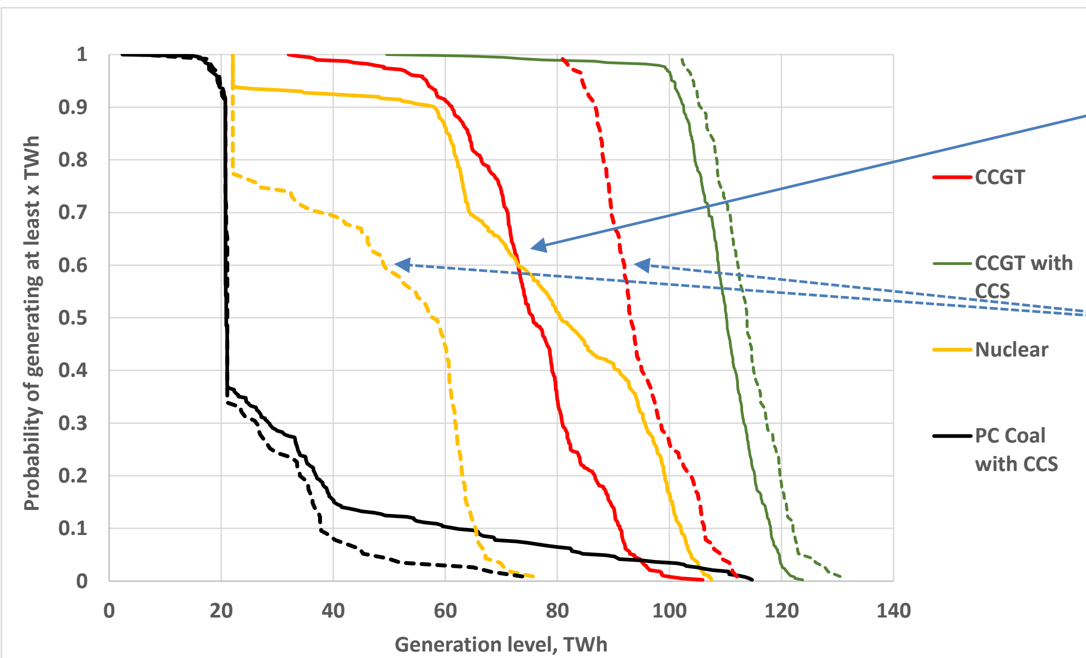
Setting carbon price level

- High and low carbon price (+/- 25%) simulations allow for exploration of carbon price level to mitigate uncertainty
- In 2030, probability of meeting target sensitive to carbon price level; +/- £30/tCO2 strongly mitigates uncertainty or not at all
- Key policy insight that setting level in mid term is critical to achieve objectives; in longer term, uncertainty much greater



Achieving the target: power sector decarbonisation

- The critical role of power sector decarbonisation is seen across all simulations
- However, even lower carbon intensity of generation in simulations meeting target
- In mid-term (2030), key trade off between nuclear and gas plant; in 2050, it is nuclear and CCGT w/ CCS, plus the level of biomass in CCS plant.
- Sensitivity analysis highlights importance of nuclear CAPEX and gas prices for CCGT plant



<u>60% probability level (2030):</u>

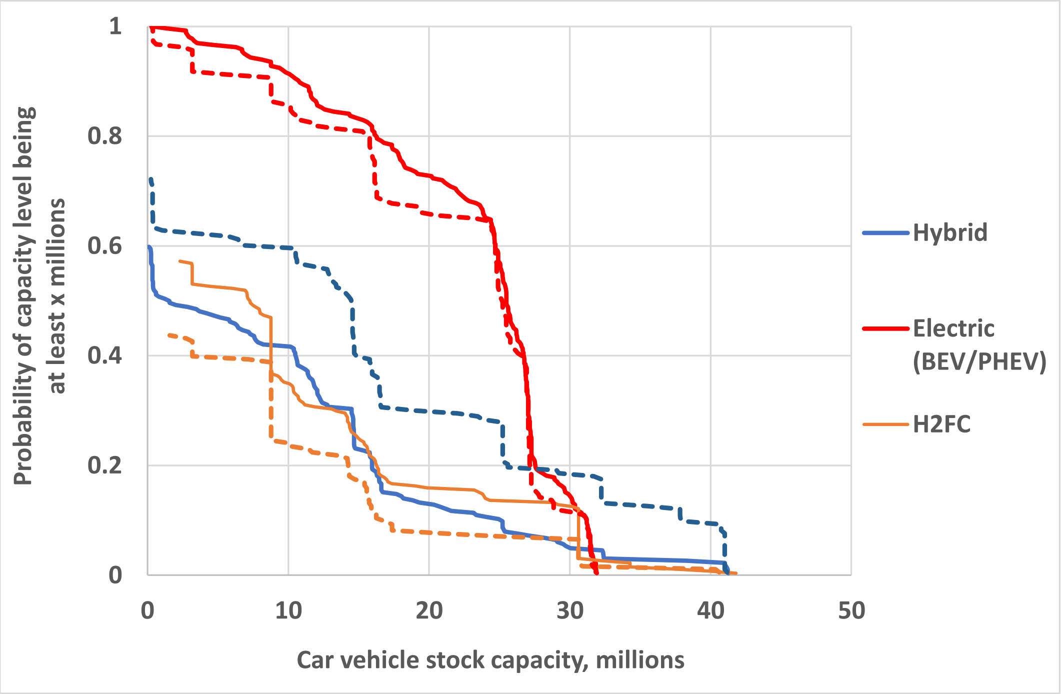
Meeting targets (contin.) - nuclear / CCGT at 72 TWh

Not meeting target (dashed) – nuclear 50 TWh, CCGT 92 TWh

Achieving the target: transport choices

- Stronger role for hybrids / EVs compared to ICE vehicles in 2030
- Trade-off in 2050 between hydrogen vehicles and hybrids; limited change in electric vehicles, highlighting role of power sector decarbonisation
- A key uncertainty relates to role of biofuels in the system, allowing for higher % of ICEs (not shown) / hybrids in 2050.

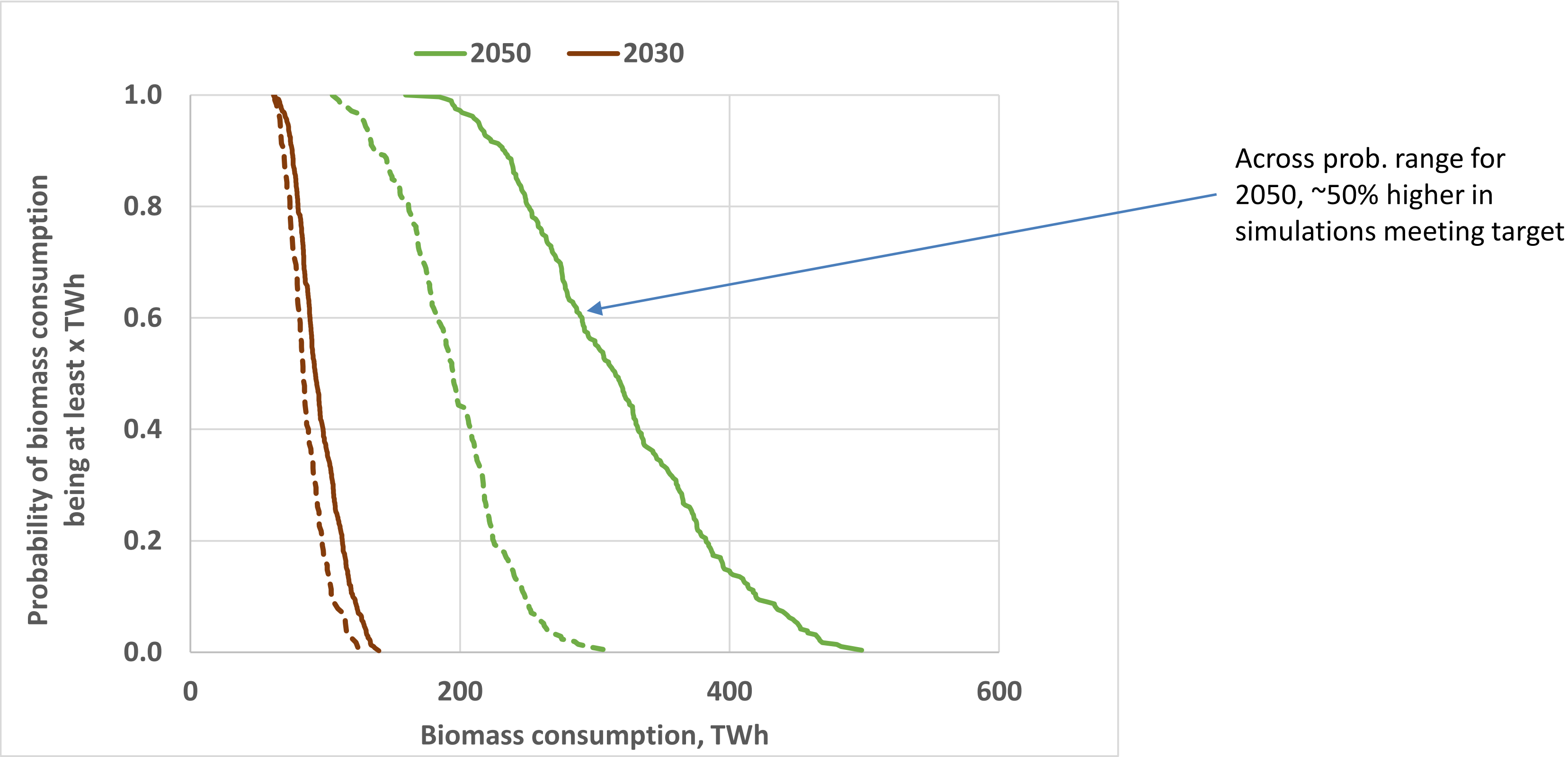
- Sensitivity analysis highlights importance of transport fuel costs and costs of low carbon vehicles



2050 Car vehicle stock by type

Achieving the target: the role of biomass

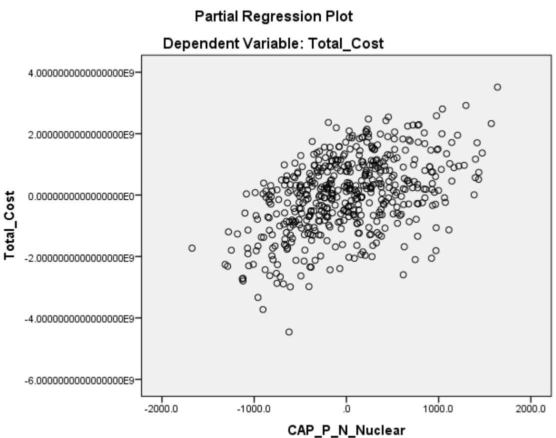
- Biomass availability has a critical role in 2050
- Driven by its use in CCS plant (power generation, biofuel production)
- Critical uncertainties not captured e.g. policy view on negative emission credits

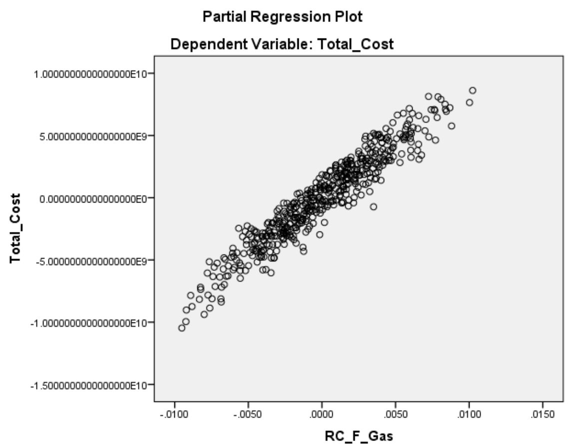


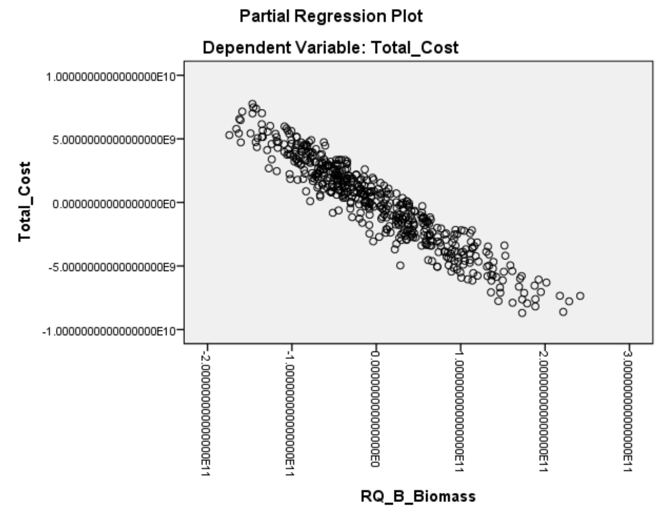
2030 / 2050 Biomass consumption levels

Insights from sensitivity analysis

- Simple scatterplots provide initial insights into the independent effects of uncertain inputs on model outputs
- Correlation between total system costs and nuclear, gas res. costs and biomass availability shown
- However, scatterplots for most input uncertainties do not provide further understanding

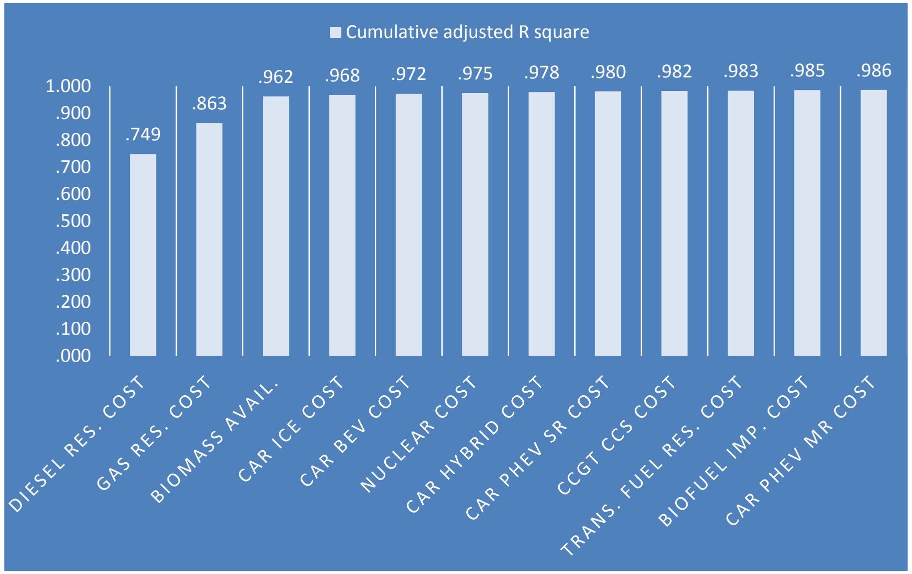




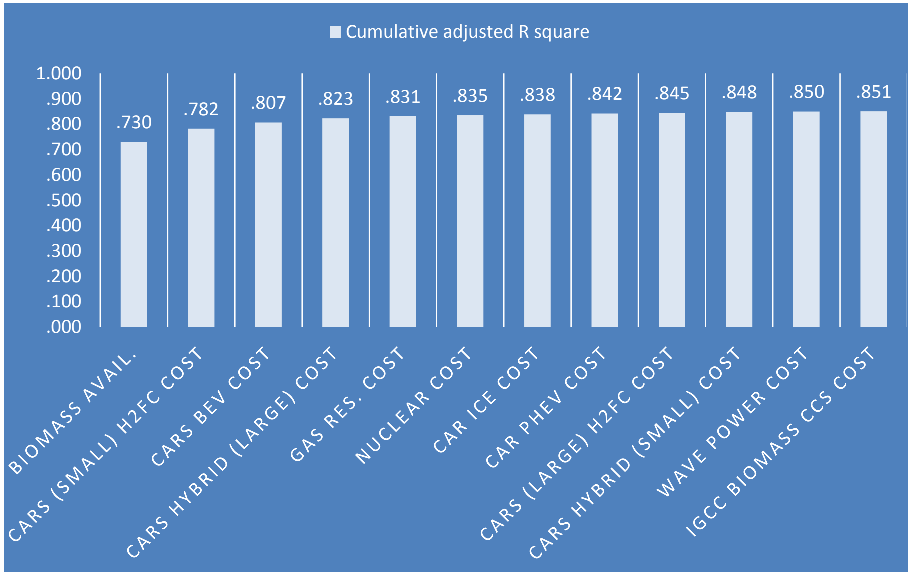


Insights from sensitivity analysis

- Stepwise multivariate regression allows ranking of uncertain inputs based on prediction of output metrics
- System costs highly sensitive to biomass availability, transport fuels and gas resource costs, nuclear and CCS costs, and vehicle costs
- Emissions level sensitivity similar to above although limited impact of transport fuels, with greater sensitivity to low carbon vehicle costs



Total system cost



Total emissions (2050)

Insights from research

Key insights from analysis

- Key system uncertainties impact on delivery of mid-term and longer term targets
- Setting the carbon price at an appropriate level can mitigate these impacts
- Key role for different technologies and fuels in delivering reduction levels
- Sensitivity analysis highlights the key uncertainties
  - The important role of nuclear CAPEX and gas price in driving generation choice
  - Transport system choices, depending on transport fuel costs and cost of low carbon vehicles
  - Biomass availability and its key role in meeting stringent LT decarbonisation targets
- A number of uncertainties do not appear so important e.g. build rates, other power generation technologies, heating in buildings (heat pumps, district heating)

Moving research forward

- Key issues emerge concerning approach to analysis
  - Robustness of insights for policy versus model set-up (location of uncertainty)
  - Narrow uncertainty range due to approach, growing uncertainty over time, and assumptions (level of uncertainty)
  - Broader uncertainties missing, narrowing the range (public acceptability, technology failure, societal and economic structure etc.)

- Policy relevance of analysis requires further engagement with stakeholders, and further iteration of analysis
  - Scrutiny of input assumptions and results, based on improved understanding of model behaviour
  - Iterative analysis to fix non-important input assumptions, with focus on key uncertainties

Thank you for your attention

Steve Pye, UCL Energy Institute
s.pye@ucl.ac.uk