UK's 80% GHG emissions reduction by 2050

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Rationale

- Legislated UK carbon budgets, within GHG targets of -34% by 2020 & -80% by 2050
- Analytical underpinning of carbon abatement pathways provided by a range of modelling frameworks
  - macro-economic, partial equilibrium energy systems optimisation, econometric, integrated assessment, sectoral (networks, buildings, and transport), etc.
- **However**, they are dependant of a range of uncertainties that are not resolvable at the current time (and not by UK actors)
  1. Will new energy technologies achieve desired technical and cost criteria?
  2. Achievable build rates of new (low carbon) infrastructures?
  3. Price path and availability of fossil resources and sustainable biomass imports?
  4. Evolution in future demands for (price elastic) energy services?
  5. What UK emissions targets will need to be in a global mitigation context?
- **Hence, policy making under deep uncertainty**

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Overview of UK MARKAL elastic demand (MED)

- A **least cost optimization** model based on life-cycle costs (2000-2050) of competing technology pathways (to meet **energy demand services)**
  - **maximises total societal welfare** (producer plus consumer surplus)
- Partial equilibrium model **assuming** rational decision making, perfect information, competitive markets, perfect foresight
- **Technology** rich bottom-up model
  - Conservation, end-use technologies, electricity & heat conversion, refineries and bio/H_2/nuclear chains, domestic and imported fuels, infrastructures
- An **integrated energy systems** model
  - Energy carriers, resources, processes, electricity/CHP, industry, services, residential, transport, agriculture, emissions, taxes, demands
- Physical, economic and policy **constraints** to represent UK energy system and environment
- Demand elasticities, hurdle rates and constraints to mimic behaviour
- Model and data **validation** and documentation (www.ukerc.ac.uk)
- Emphasis on **sensitivity and uncertainty analysis**

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Key parameters of the UK MARKAL MED model

Key parameter	Description									
Conversion factors	GDP deflators: 2000 = 100 ; 2005 = 116.9 ; 2009 = 125.8 Exchange rates: $/£ = 1.8, €/£ = 1.4 Physical: 1 MTOE = 11.6 TWhr = 48.9 PJ									
Discount and hurdle rates	Global discount rate of 3.5% (www.hm-treasury.gov.uk/data_greenbook_index.htm) Hurdle rates are implemented on conservation in buildings sectors (12.5%); and transport technologies (10% for public, 10% for hydrogen private, 7.5% for battery and methanol private)									
Carbon Target	2050 target of -80% (118.6MtCO_2) relative to 1990 emissions of 592.4MtCO_2. Equal annual reduction from 2020 target of 380.2MtCO_2 (35.8% reduction from 1990 levels)									
Fossil Fuel Price 2000-2050 (2000£/GJ)	Central case	Oil	4.12	9.35	6.41	6.87	7.33	7.79	8.25	8.25
		Gas	1.93	4.47	4.47	4.85	5.16	5.47	5.70	5.70
		Coal	0.91	2.97	2.23	1.62	1.62	1.62	1.62	1.62
Biomass Imports	Import constraint (increasing geometrically to 1,260PJ by 2050) Sensitivity on no bio imports									
Energy service demand	Derived on an individual ESD basis from UK national forecasts of key drivers 25% maximum reduction. Own price elasticity range from 0.25 to 0.61 dependent on specific ESD									
Policy variables & energy taxes	As of 2008 Energy Bill [www.decc.gov.uk/energy/whitepaper/] Note, no EU-ETS price in reference case									
Technologies	As in documentation (www.ukerc.ac.uk) with additions including biomass CCS, infrastructure costs by scale and distance, additional district heat/CHP options, increased CCS costs and efficiencies, restricted capacity (30%) of residential heat pumps and night storage									

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Stochastic UK MARKAL

- Built on technologically detailed, partial equilibrium energy systems optimisation MARKAL model
  - www.ukerc.ac.uk/support/tiki-index.php?page=ES_MARKALModelFamily&structure=Energy+Systems
- Development of a new stochastic variant of UK MARKAL
  - Key uncertainties categorized by alternate outcomes of a random variable
    - Two stage stochastic programming solution
    - Defined by states of the world [SOW] – discrete (e.g., 50/50 likelihood), or via a probability density function
  - The partial equilibrium objective function is maximised based on the expected weighted costs for each state of the world (SOW) based on the assumed probabilities and the costs for that SOW
    - $Expected\ Cost_{Scen} = \sum(Cost_{SOW} * Prob_{SOW})$
    - EC = maximisation of producer plus consumer surplus (i.e. welfare): annualised capital, fuel, O&M, emissions charges, taxes/subsidies, salvage costs, demand reductions
- BUT…
  - Subjective choice of which uncertain variables and how to assign probabilities
  - Requires at least transparency and justification, at best full expert elicitation

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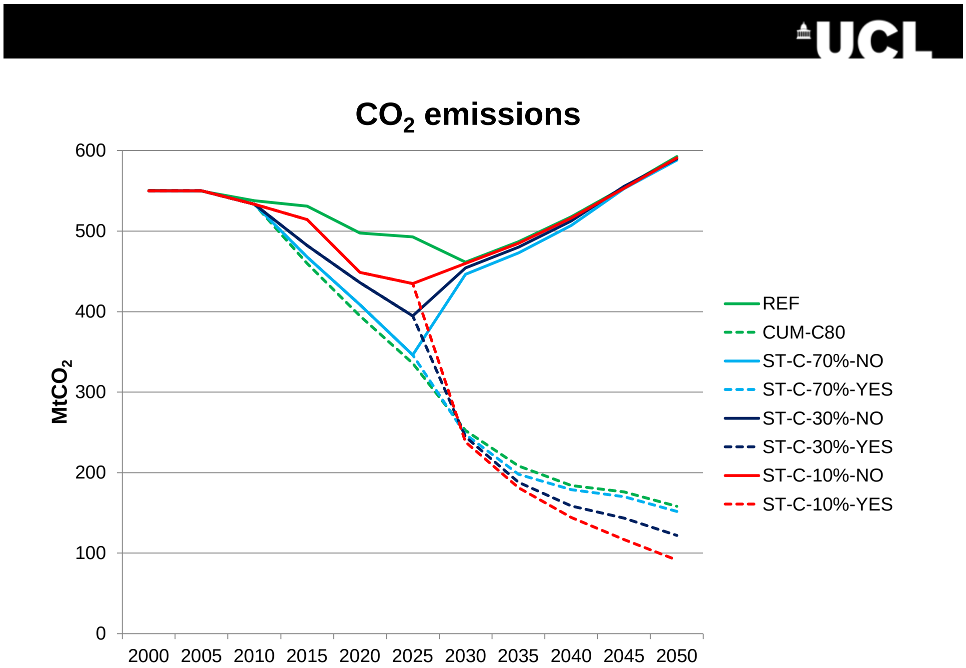
Stochastic MARKAL cumulative CO_2 emissions target scenario

- Cumulative (2000-2050) CO_2 emissions (19.01 $GtCO_2$)
  - Equivalent to annual target (-34% in 2020; -80% in 2050)
- Only in 2030 is CO_2 target imposition confirmed (or not)
  - Stage 1: Hedging strategy (through the 2020s)
  - Stage 2: Multiple (per SOW) recourse strategies (2030-2050)
- Optimal solutions
  - Prior probability of -80% CO_2 target being imposed
  - **10%** "unlikely"; **30%** "possible"; **70%** "probable"

- Model choice of resources, technologies, infrastructures, demand changes etc
- CO_2 marginal price, welfare cost
  - Penalty vs. deterministic runs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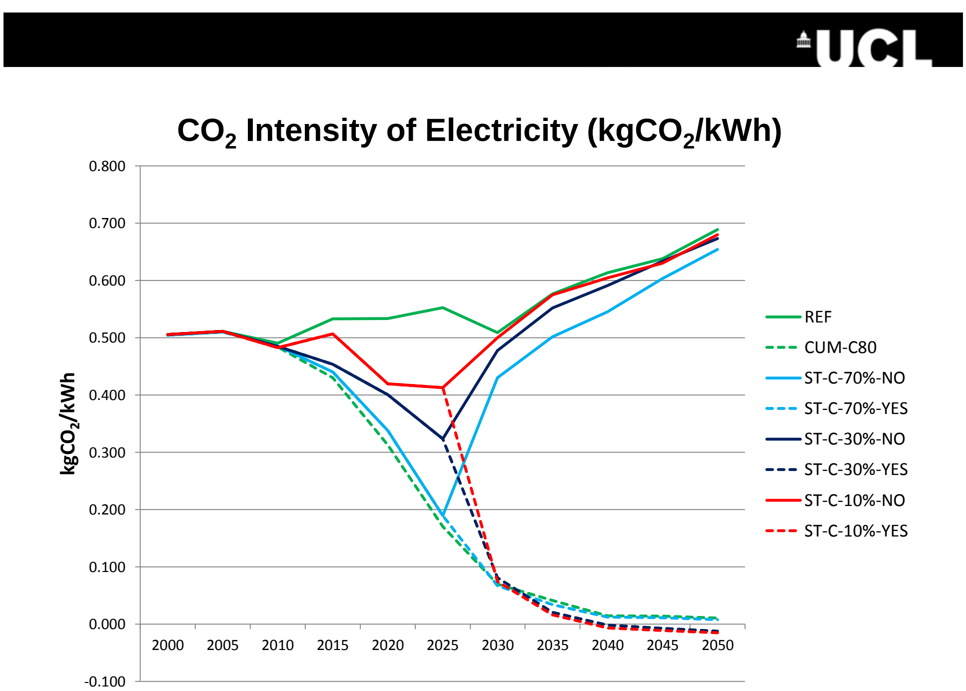
CO2 emissions
MtCO2
600
500
400
300
200
100
0
2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050
REF
CUM-C80
ST-C-70%-NO
ST-C-70%-YES
ST-C-30%-NO
ST-C-30%-YES
ST-C-10%-NO
ST-C-10%-YES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CO2 Intensity of Electricity (kgCO2/kWh)
kgCO2/kWh
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050
REF
CUM-C80
ST-C-70%-NO
ST-C-70%-YES
ST-C-30%-NO
ST-C-30%-YES
ST-C-10%-NO
ST-C-10%-YES

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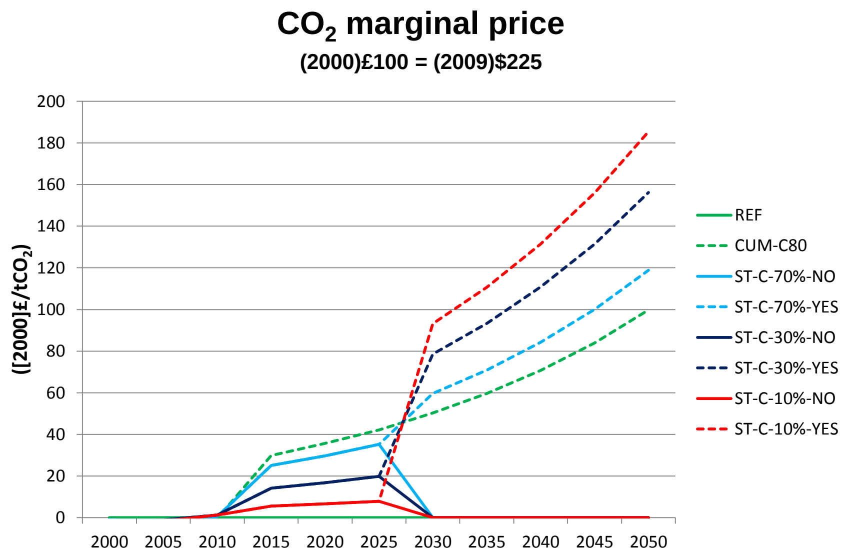
CO2 marginal price
(2000)£100 = (2009)$225
200
180
160
140
120
100
80
60
40
20
0
([2000]£/tCO2)
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
REF
CUM-C80
ST-C-70%-NO
ST-C-70%-YES
ST-C-30%-NO
ST-C-30%-YES
ST-C-10%-NO
ST-C-10%-YES

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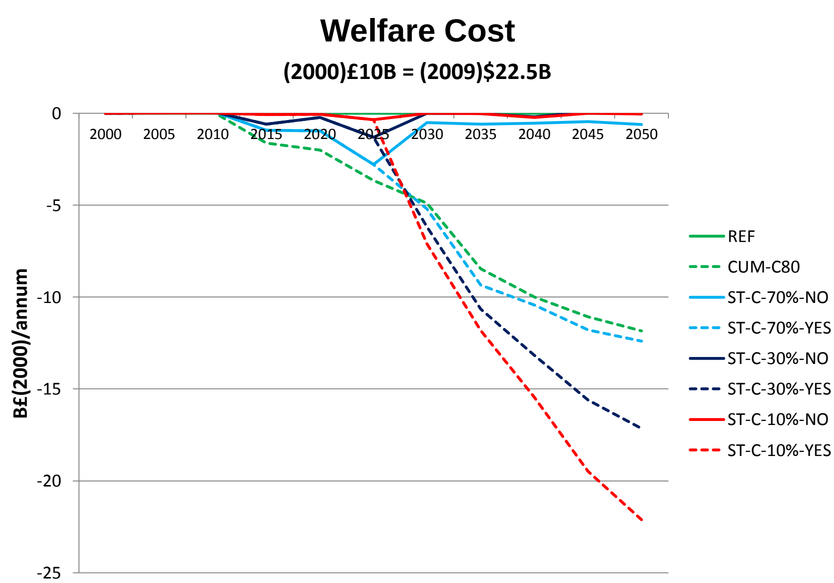
Welfare Cost
(2000)£10B = (2009)$22.5B
0
-5
-10
-15
-20
-25
B£(2000)/annum
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
REF
CUM-C80
ST-C-70%-NO
ST-C-70%-YES
ST-C-30%-NO
ST-C-30%-YES
ST-C-10%-NO
ST-C-10%-YES

Costs in perspective

[Source: D MacKay, 2009, Sustainability without the Hot Air]
All in 2009 US $

Expenditure	Cost per year (B$/yr)	One time cost (B$)	Cost per UK resident ($/yr or $)
-80% CO_2 welfare costs by 2050	**27 - 52**	**-**	**450 - 870**
UK GDP (2000) *UK GDP (2050, 2.3% growth)*	1,300 *4,000*	- -	21,700 *57,000*
UK Bank bailout	-	500	8,300
Health budget	159	-	2,650
Education budget (to 18yrs)	85	-	1420
BP*; Shell; Exxon profits	10-45	-	-
Nuclear decommissioning	-	73	1,220
New nuclear weapons	-	25	420
Final energy consumption	112	-	1,870
Renewable energy R&D	0.012	-	0.2

Summary

- Long-term UK energy policy decision making under deep (non resolvable?) uncertainties
- Stochastic MARKAL as one model to investigate
  - But require transparency on why/how choose and assign uncertainties
  - Single hedging and multiple recourse strategies
- Under a -80% cumulative CO_2 target setting
  - Asymmetric and significant costs of ignoring uncertainty
  - Costs as a lower bound (assuming a 1st best policy environment)
  - Inertia of energy system under decarbonisation pathways
  - Feasibility of recourse strategies?