

Uncertainties in UK scenarios of long-term CO₂ reductions

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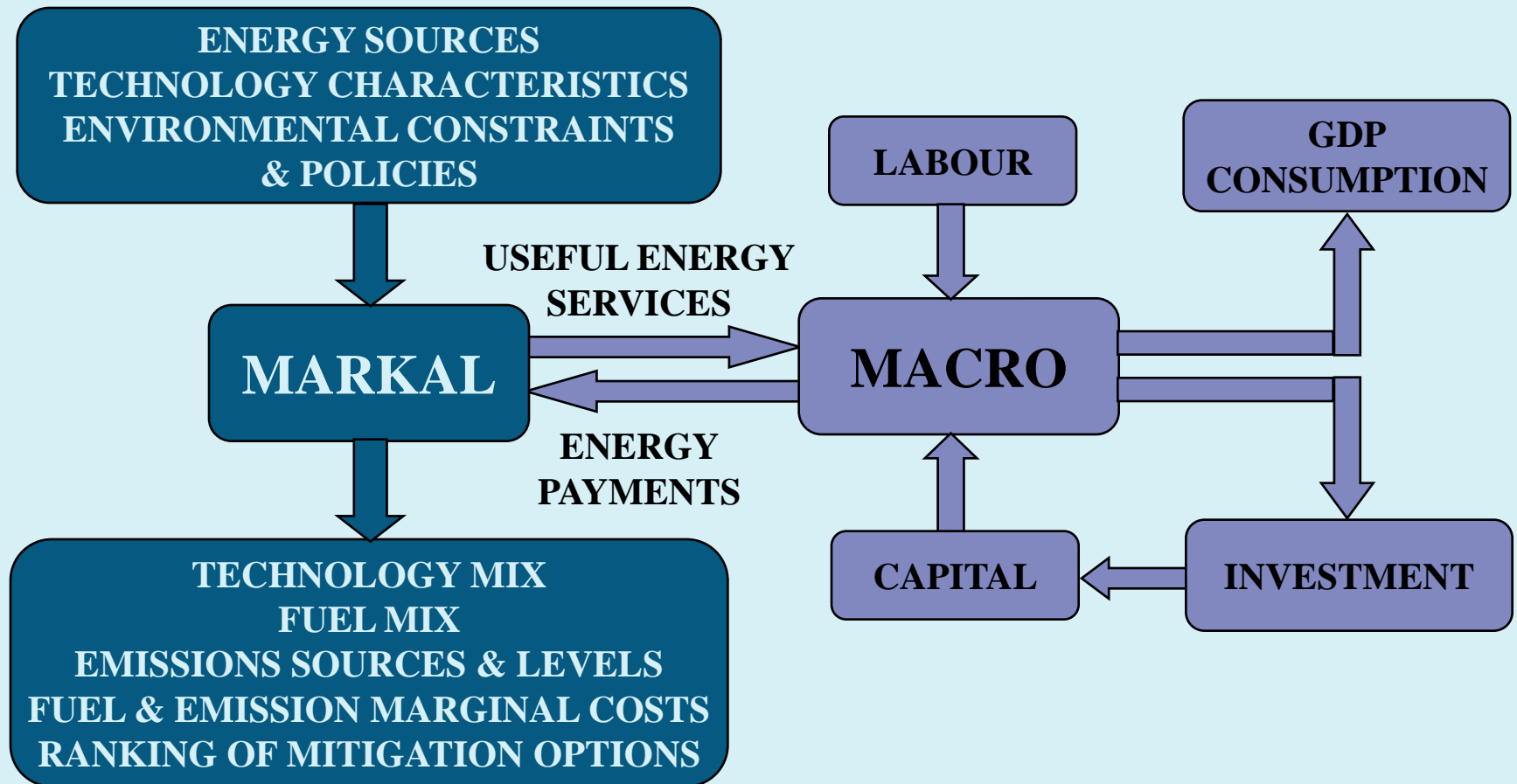
Outline

1. UK MARKAL-Macro (M-M) summary
2. Modelling of long-term UK CO₂ reduction scenarios
3. Applicability and policy relevance of sensitivity and uncertainty ranges on key variables

UK MARKAL modelling

- A **least cost optimization** model of competing technology pathways to meet **energy demand services**
- **Technology** rich bottom-up model
- An **integrated energy systems** model
 - Energy carriers, resources, processes, electricity/CHP, industry, services, residential, transport, agriculture
- Physical, economic and policy **constraints** to represent UK energy system and environment
- Model and data **validation**
- Emphasis on **sensitivity and uncertainty analysis**
- 2007 model substantially **rebuilt** – (ongoing 2008 improvements)
- **Extension** to MARKAL-Macro (M-M), Elastic Demand (MED), other variants
- **Peer review** (for example)
 - Strachan N. and R. Kannan (2008) *Hybrid Modelling of Long-Term Carbon Reduction Scenarios for the UK*, Energy Economics, doi:10.1016/j.eneco.2008.04.009

UK MARKAL MACRO (M-M) model



UK MARKAL Modelling for UK policy

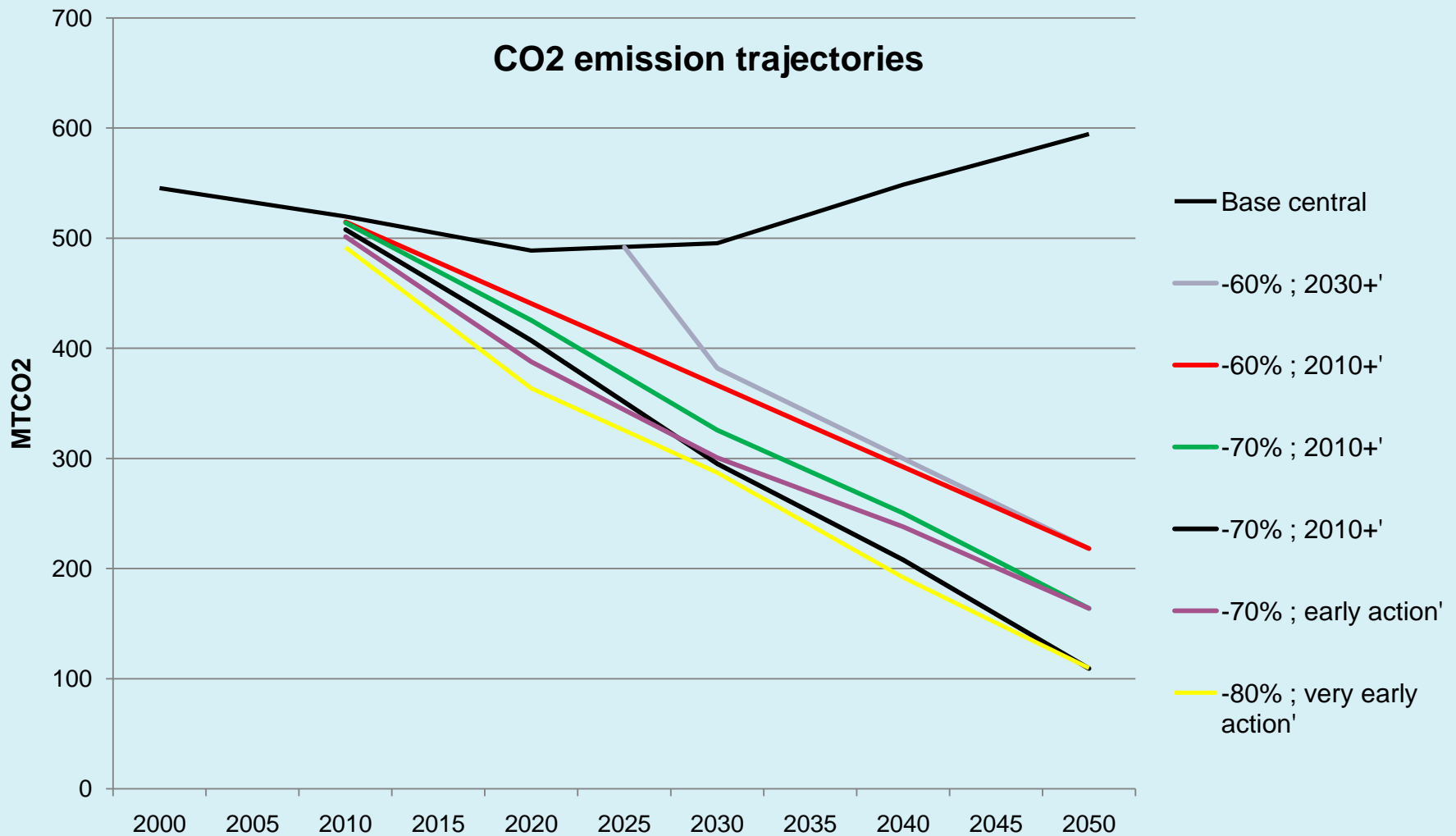
- 2003
 - 1st DTI Energy White Paper
 - Analysis using standard, simplified MARKAL model
- 2007
 - 2nd DTI-BERR Energy White Paper, DEFRA Climate Change Bill, WWF-IPPR scenarios, UK-Japan low carbon societies
 - Enhanced MARKAL, move to MARKAL-Macro (M-M)
- 2008/2009
 - Climate Change Committee, UKERC Energy 2050
 - MARKAL Elastic Demand (MED)
 - Global model, extended variants

40 UK M-M scenarios

- 2050 CO₂ constraint (relative to 2000 levels)
 - [Base]; -60%; -70%; -80%
- Constraint trajectory
 - +2030; +2010; early action (-29%, -35% in 2020)
- Resources Prices
 - Low, Central, High
- International aviation
 - None; Low growth; High growth
- Restricted innovation
 - To 2020 levels; to 2010 levels
- Government data
 - Uranium imports, electricity generation costs, restricted transport hybrids, restricted buildings conservation
- Key technology constraints
 - No nuclear; no CCS; no nuclear/CCS; restricted wind & biomass
- Additional international drivers
 - Elec. renewable learning, Biomass import limits; Intermittency constraints; Increased building efficiency; Emissions trading - Annex 1 buyers - Global buyers

Report	CO2 constraint	2050 constraint	Constraint trajectory	Resources Prices	International aviation	Restricted innovation	Government data	Key technology constraints	International driver
EWP	Base	-	-	Central	-	-	-	-	-
EWP	Base	-	-	Central	-	to 2020	-	-	-
EWP	Base	-	-	Central	-	to 2010	-	-	-
EWP	Base	-	-	Central	-	-	Central	-	-
CCB	Base	-	-	Central	High growth	-	-	-	-
WWF-IPPR	Base	-	-	Central	Low growth	-	-	-	-
EWP	Base	-	-	High	-	-	-	-	-
EWP	Base	-	-	Low	-	-	-	-	-
EWP	CO2	-60%	2010+	Central	-	-	-	-	-
CCB	CO2	-60%	2010+	Central	High growth	-	-	-	-
EWP	CO2	-60%	2030+	Central	-	-	-	-	-
EWP	CO2	-60%	2030+	Central	-	to 2020	-	-	-
EWP	CO2	-60%	2030+	Central	-	to 2010	-	-	-
EWP	CO2	-60%	2030+	Central	-	-	-	No nuclear	-
EWP	CO2	-60%	2030+	Central	-	-	-	No nuclear/CCS	-
EWP	CO2	-60%	2030+	Central	-	-	Central	-	-
EWP	CO2	-60%	2030+	Central	-	-	High	-	Electric renewable learning
EWP	CO2	-60%	2030+	High	-	-	-	-	-
EWP	CO2	-60%	2030+	Low	-	-	-	-	-
CCB	CO2	-70%	2010+	Central	-	-	-	-	-
CCB	CO2	-70%	2010+	Central	-	-	-	Wind & transport biofuel	-
CCB	CO2	-70%	2010+	Central	-	-	-	No nuclear	-
CCB	CO2	-70%	2010+	Central	-	-	-	No nuclear/CCS	-
CCB	CO2	-70%	early action	Central	-	-	-	-	-
CCB	CO2	-80%	2010+	Central	-	-	-	-	-
CCB	CO2	-80%	2010+	Central	-	to 2010	-	-	-
CCB	CO2	-80%	2010+	Central	-	-	-	Wind & transport biofuel	-
CCB	CO2	-80%	2010+	Central	-	-	-	No nuclear	-
CCB	CO2	-80%	2010+	Central	-	-	-	No nuclear; & wind and biofuel	-
CCB	CO2	-80%	2010+	Central	-	-	-	No nuclear/CCS	-
CCB	CO2	-80%	2010+	Central	-	-	-	No nuclear/CCS; & wind and biofuel	-
LCS	CO2	-80%	2010+	Central	Low growth	-	-	-	-
LCS	CO2	-80%	2010+	Central	-	-	-	-	Electric renewable learning
LCS	CO2	-80%	2010+	Central	-	-	-	-	Limits on biomass imports
WWF-IPPR	CO2	-80%	2010+	Central	Low growth	-	No nuclear	-	Intermittency constraint
WWF-IPPR	CO2	-80%	2010+	Central	Low growth	-	No nuclear	-	Increased building efficiency
LCS	CO2	-80%	2010+	Central	-	-	-	-	Emissions trading - Annex 1 buyers
LCS	CO2	-80%	2010+	Central	-	-	-	-	Emissions trading - Global buyers
CCB	CO2	-80%	2010+	High	-	-	-	-	-
CCB	CO2	-80%	very early action	Central	-	-	-	-	-

CO₂ constraints



Resource prices

Source: BERR, 2006 UK Energy Review

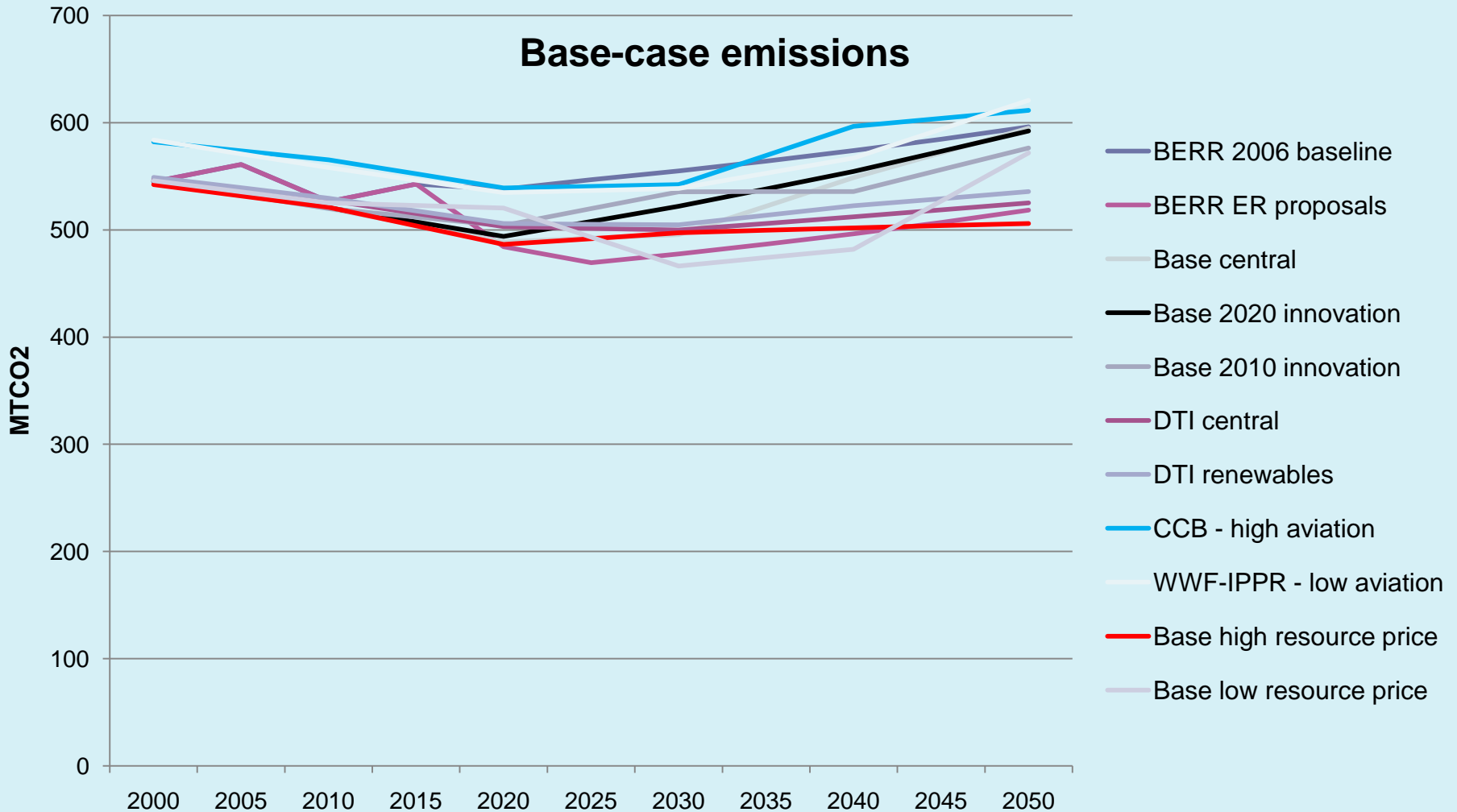
	Central			High Prices			Low Prices		
	Oil \$/bbl	Gas £/MWhr	Coal £/GJ	Oil \$/bbl	Gas £/MWhr	Coal £/GJ	Oil \$/bbl	Gas £/MWhr	Coal £/GJ
2005	55	14.0	1.33	55	14.0	1.33	55	14.0	1.33
2010	40	11.4	1.06	67	17	1.33	20	6.1	0.78
2015	42.5	11.9	1.06	69.5	17.5	1.44	20	6.7	0.67
2020	45	12.5	1	72	18.1	1.44	20	7.2	0.56
2025	47.5	13	1.06	77	19.1	1.44	22.5	7.7	0.61
2030	50	13.5	1.11	82	20.1	1.56	25	8.2	0.67
2035	52.5	14	1.17	82	20.1	1.67	27.5	8.7	0.72
2040	55	14.5	1.22	82	20.1	1.67	30	9.2	0.72
2045	55	14.5	1.22	82	20.1	1.67	32.5	9.7	0.78
2050	55	14.5	1.22	82	20.1	1.67	35	10.2	0.83

Conversion factors:

- All price in £2000; gross calorific values
- £1 = \$1.8 ; 1GJ = 0.278 MWhr ; 1Toe = 41.87GJ ; 1tonne coal = 26.8GJ

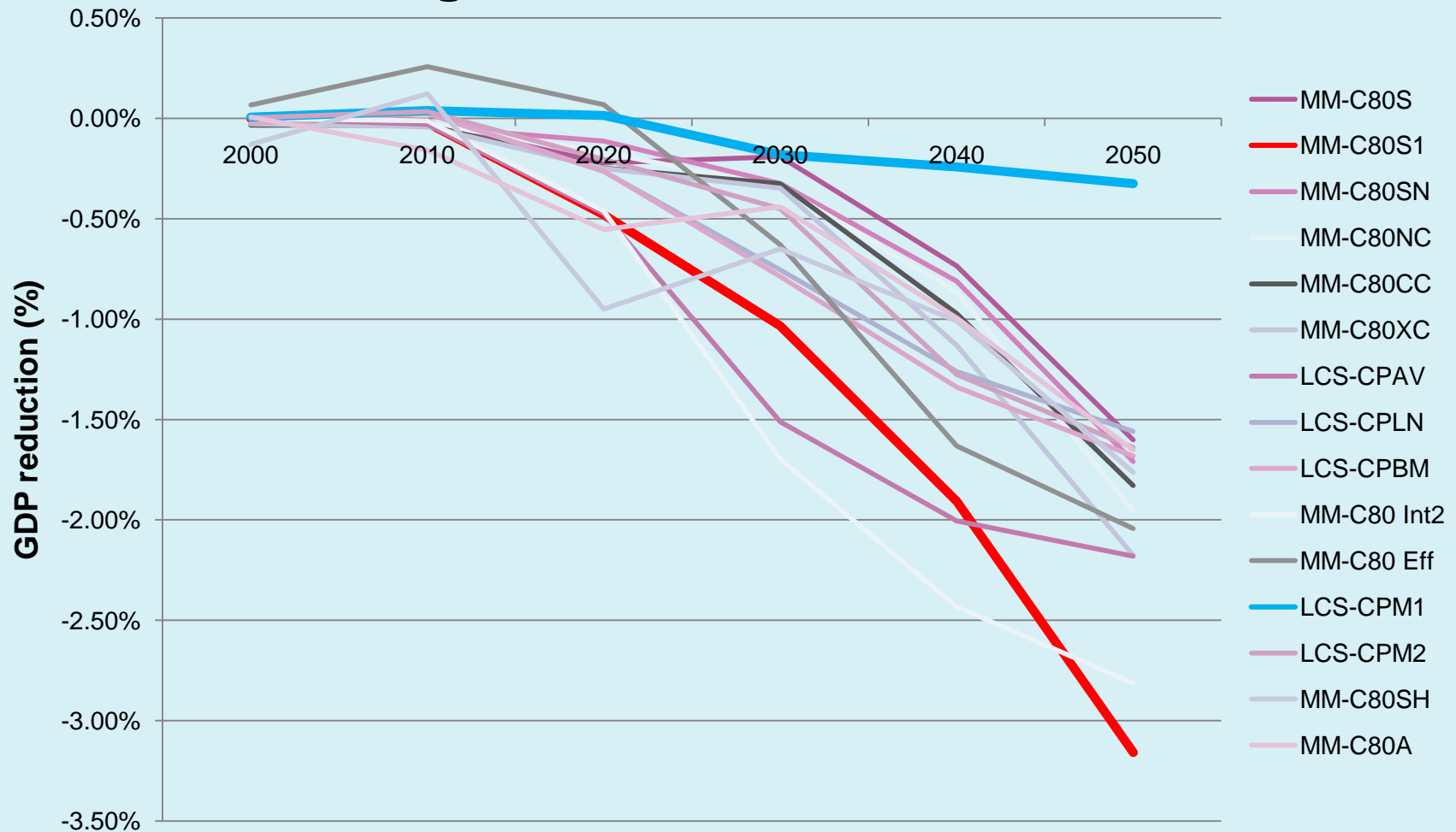
Base-case emissions

(120 MTCO₂ spread)



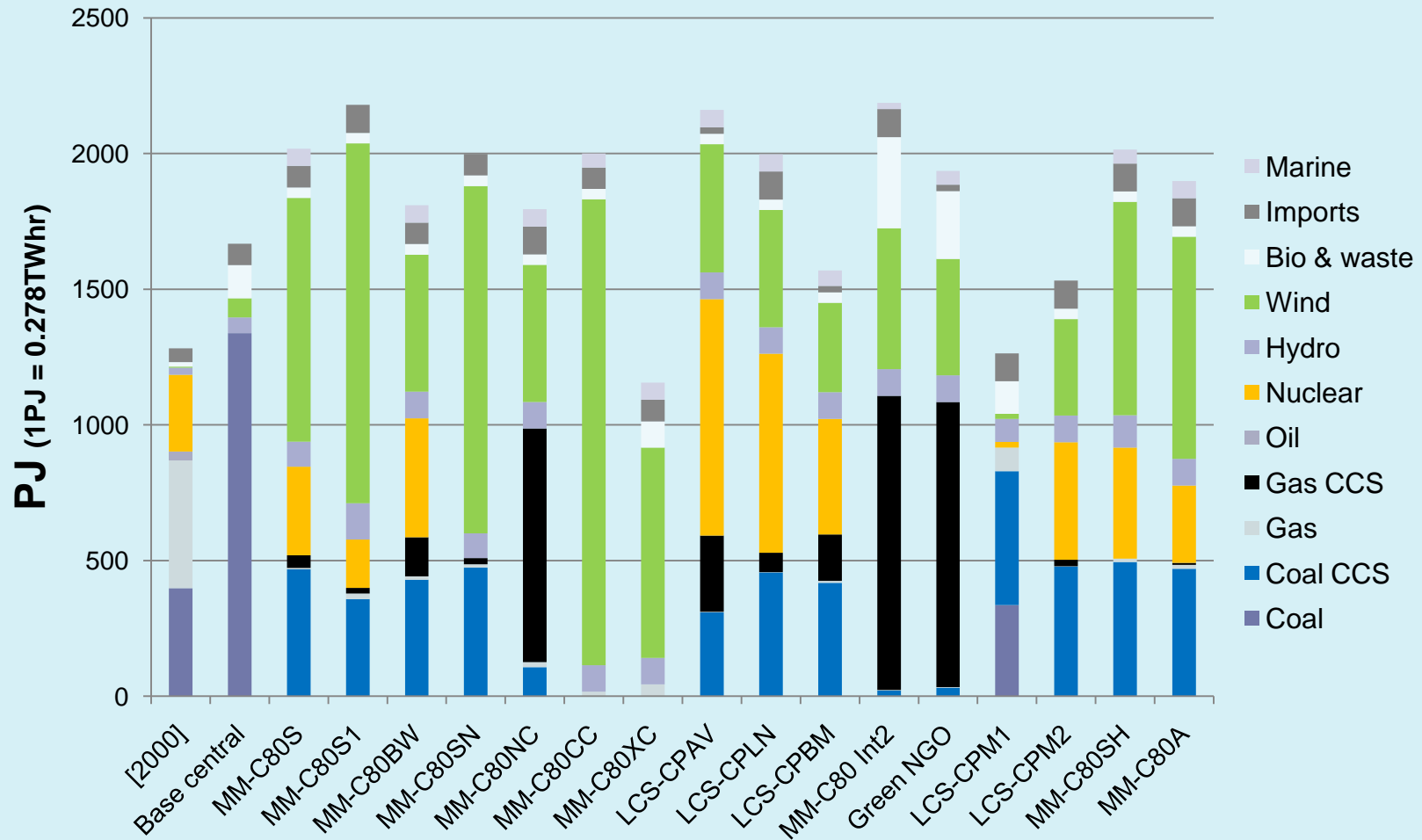
“What-If” Sensitivity Analysis

Change in GDP - 80% scenarios



Illustrate key uncertainties

-80% Scenarios - Electricity Generation



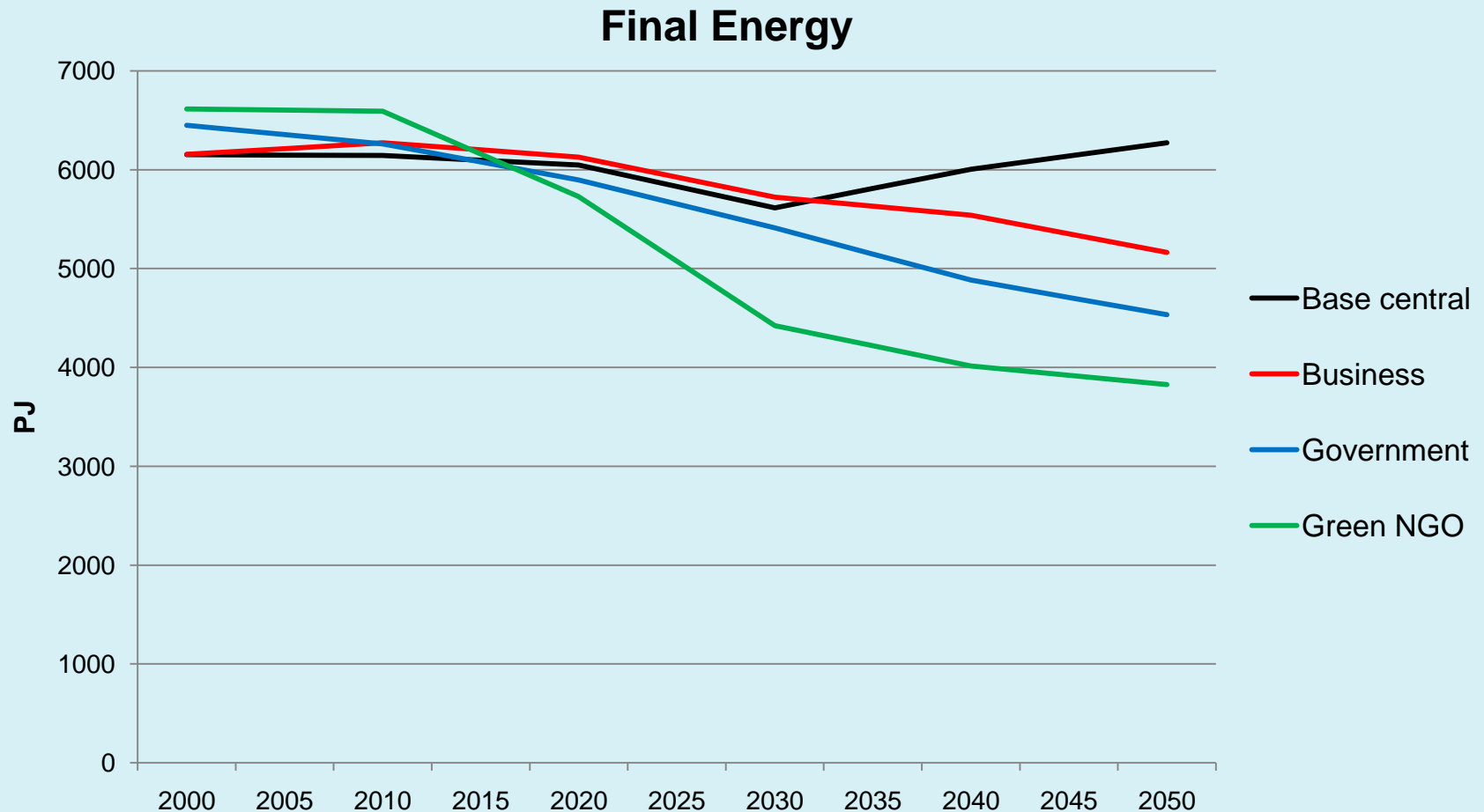
At best - subjective probabilities
 At worst – invalid exercise

Marginal CO ₂ prices (MTCO ₂)			
Percentile in 2050	All Scenarios	-60% scenarios	-80% scenarios
0	64.8	64.8	74.9
10	85.0	78.9	210.6
20	106.0	91.0	219.6
30	115.3	104.2	228.1
40	142.8	105.6	234.3
50	176.3	108.8	242.7
60	209.2	110.4	250.8
70	229.0	119.0	266.5
80	247.5	127.9	319.5
90	298.5	160.2	387.0
100	398.5	176.3	398.5

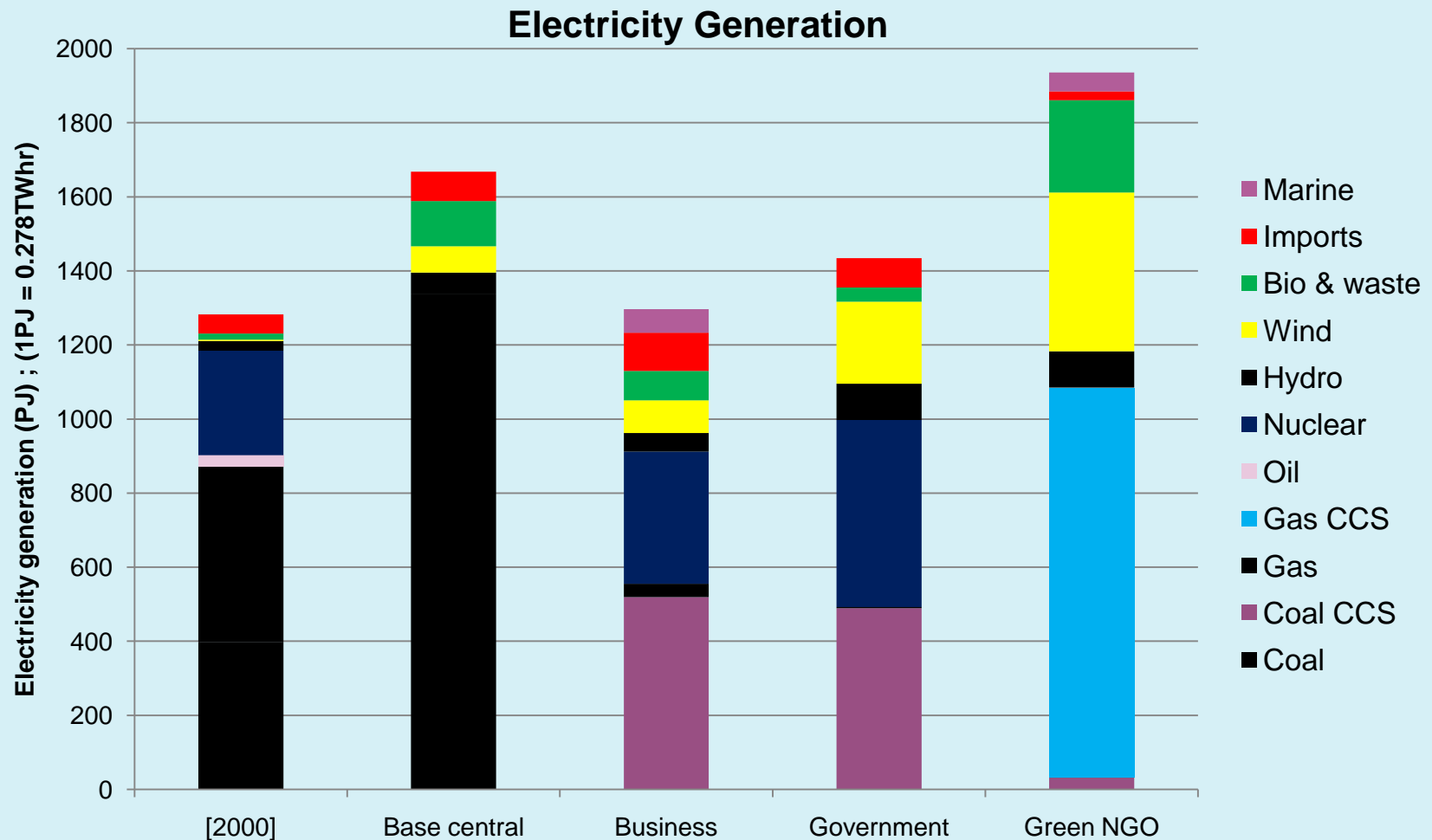
Scenario comparison

- Comparison of quite different and internally consistent scenarios
 - **Business**
 - -60% CO₂ target, from 2030, cheaper uranium imports, revised electricity generation costs, restricted transport hybrids, restricted buildings conservation
 - **Government**
 - -70% CO₂ target, from 2010, technology neutral
 - **Green NGO**
 - -80% CO₂ target, from 2010, with low growth international aviation, no nuclear, sustainable biomass imports, intermittent generation constraints, reduced hurdle rates for conservation

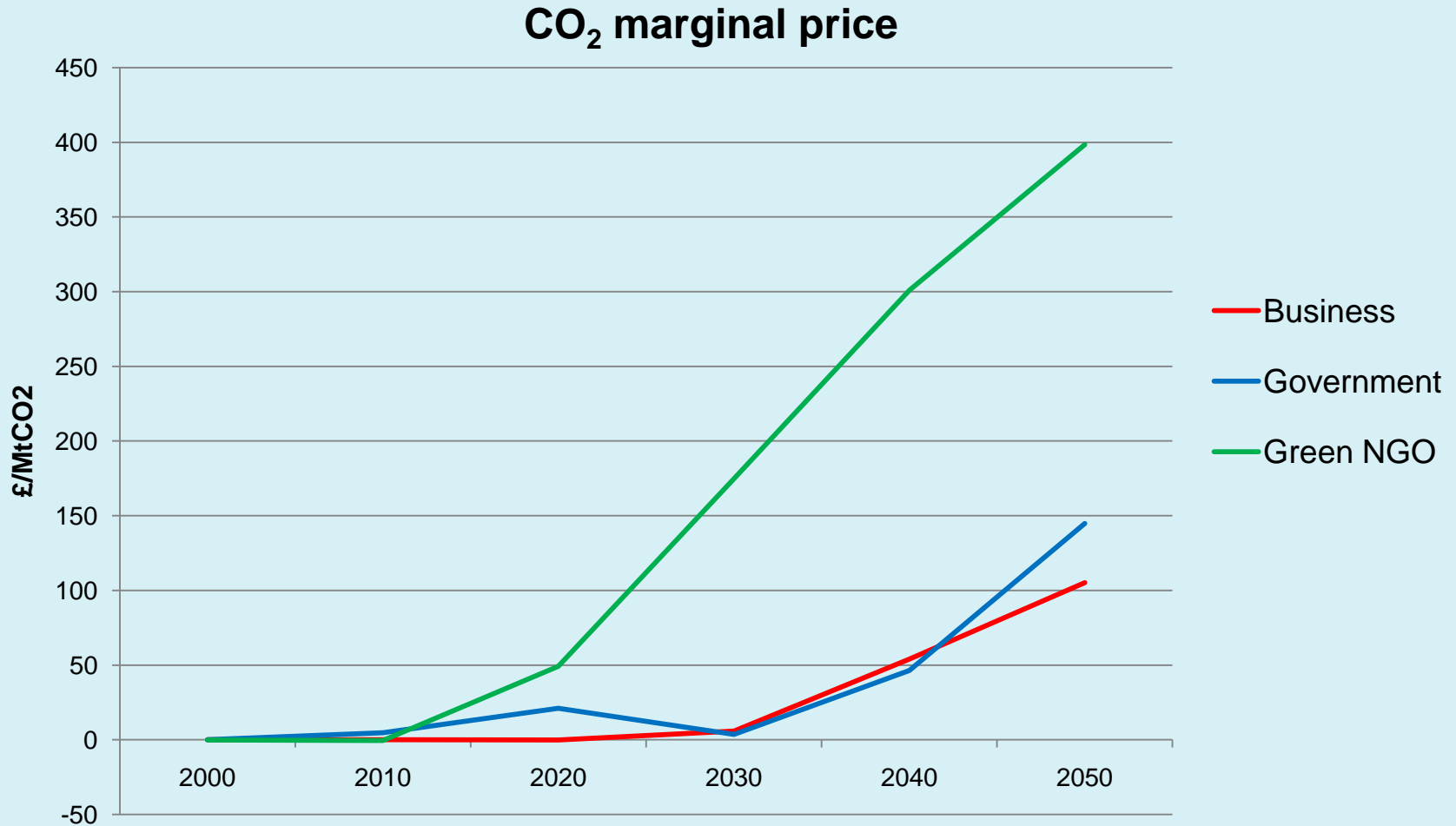
Business, Government, Green NGO Final energy



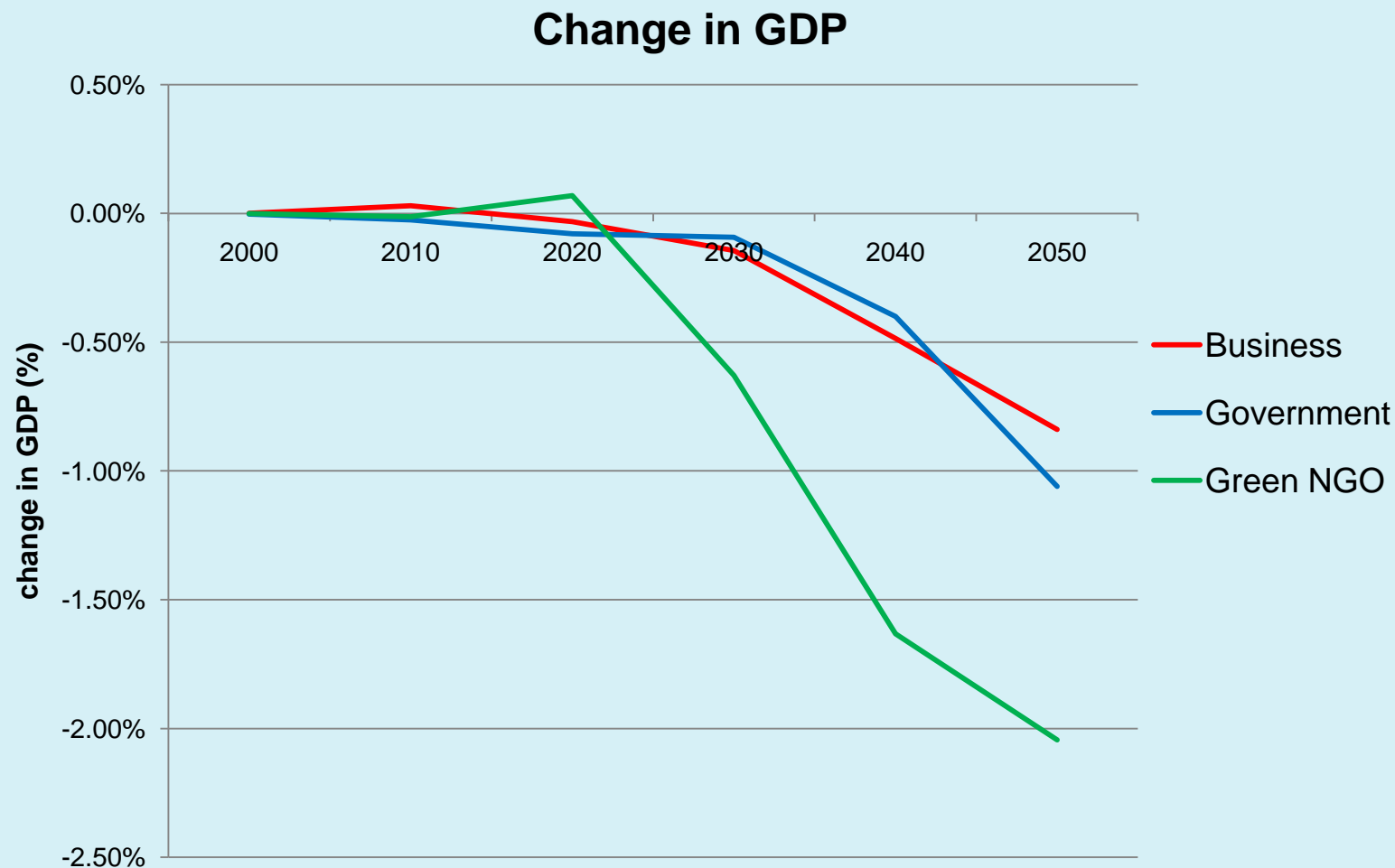
Business, Government, Green NGO Electricity generation



Business, Government, Green NGO Marginal CO₂ prices



Business, Government, Green NGO GDP reductions



Discussion

- **“What-if” scenario insights**
 - Scope and appropriateness of model runs
 - Investigate key tradeoffs
 - e.g., no dominant technology in the electricity sector
 - Inability to assign probability
- **Ongoing UK MARKAL modelling focus**
 - Consistent, integrated, storylines
 - e.g., international drivers on UK, behavioural change
 - Check for transitional feasibility
 - Staged optimization
 - Stochastic (probabilistic) optimization