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Policy Experiences and Future Requirements of Hybrid Energy-Economic Modelling

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ETSAP-UCC Workshop on Methodologies Linking Energy Systems Models and Economic Models

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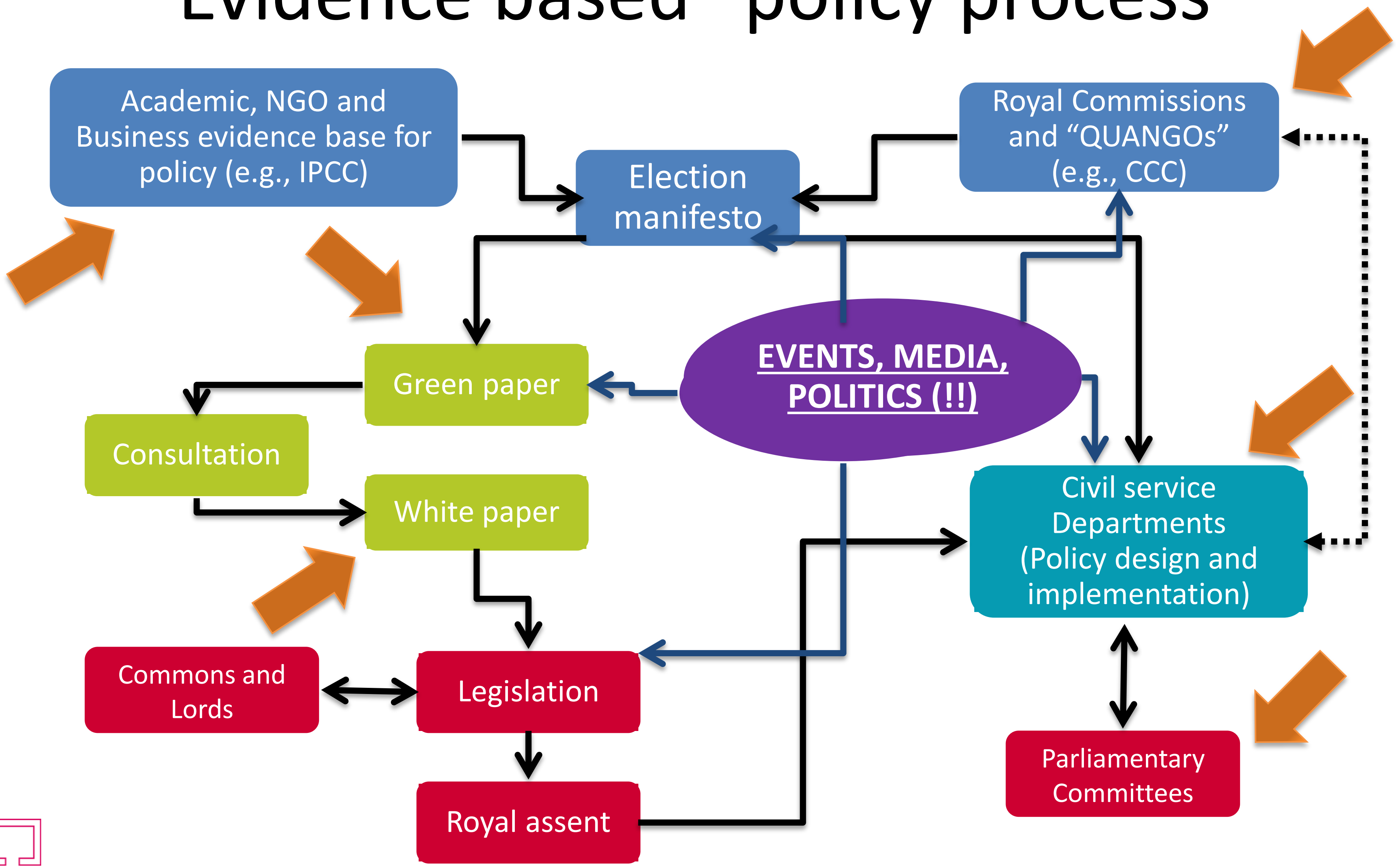
Overview

- Experience of using hybrid energy-economic models in the UK energy policy process
  - Timeline of UK energy policy and analysis
- Key interdisciplinary methodological directions for hybrid energy economic modelling
  - Synergies between policy requirements vs. modeller's interests

"Evidence based" policy process



Model availability

"You go to war with the army you have" Donald Rumsfeld

- Selected UK energy models
  - Econometric & dispatch (e.g., DECC energy model as used for UEP)
  - Energy systems optimisation (e.g., MARKAL/TIMES, ESME)
  - Macro-economic or macro-econometric (e.g., AMOS, MDM-E3)
  - Input-output (e.g., MRIO)
  - (aggregated) IAM (e.g., PAGE 2009)
  - Accounting (e.g., DECC Calculator)
  - Electricity and gas network models (e.g., DSIM, Zephyr)
  - Transport (simulation) models (e.g. NTM, AMMUA)
  - Buildings (stock) models (e.g., BREDEM, NHM)

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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) Stern Review	UEP; PAGE
2007	Energy White Paper	UEP; MARKAL-Macro
2008	**Climate Change Act (-80% GHG target)** **Department of Energy and Climate Change founded** **Climate Change Committee (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 *wholeSEM commissioned*	UEP, UK TIMES, TIAM-UCL, ESME

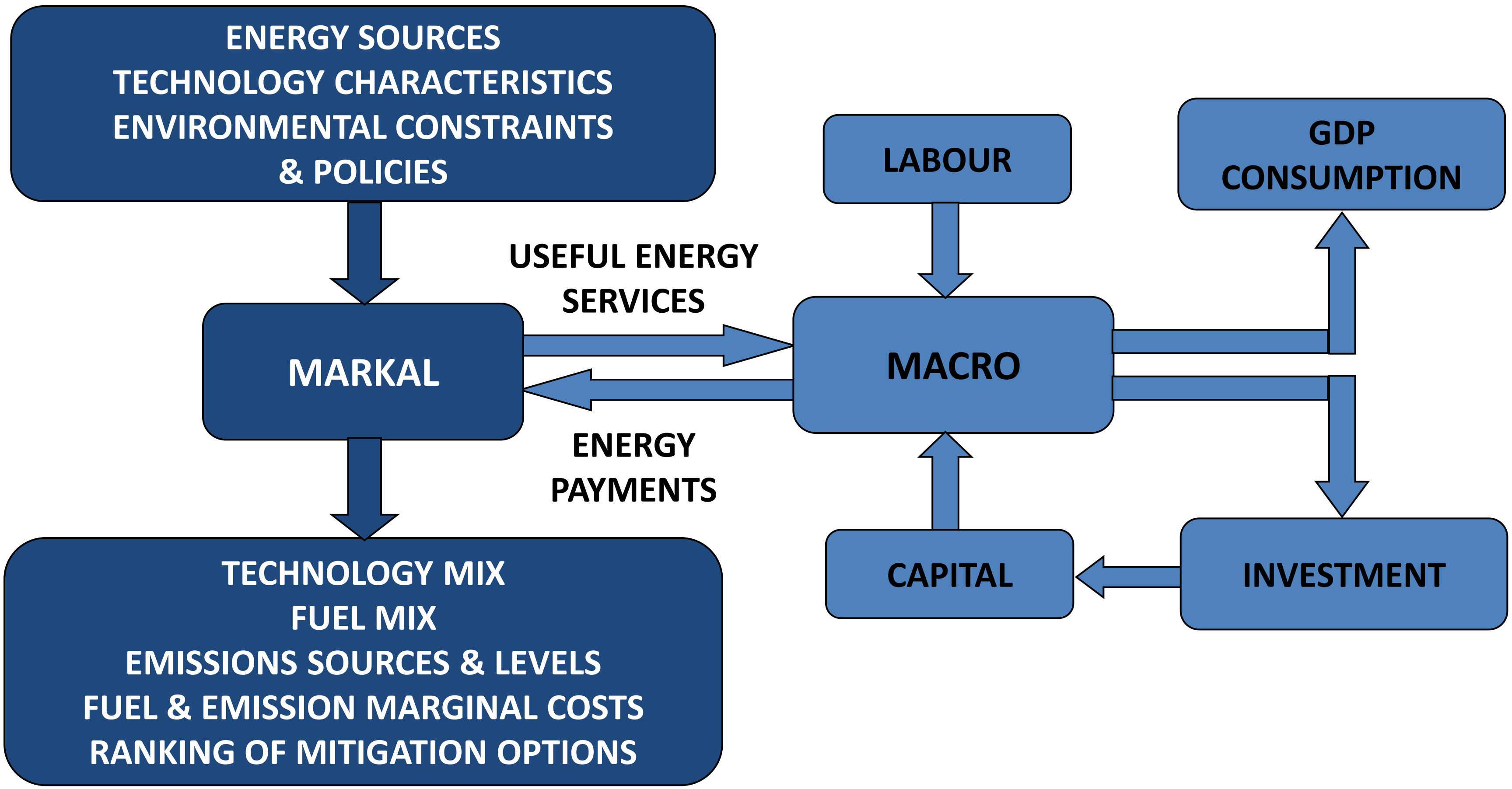
UK policy use of hybrid models

- Macro-economics was *not* the major driver of the decarbonisation policy process
  - Driven more by science and by subsequent political dynamics
- Sufficient analysis to show that the long-term costs were manageable, and the near-term costs were small
  - Policy makers generally find partial equilibrium energy system optimisation models easier to understand than general equilibrium macro-economic models
- The UK debate over the last five years has been on how to manage the transition to a low carbon secure energy system
  - This process is being put under severe pressure by (macro-economic) austerity and the (micro-economic) rise in energy costs

UK uses "usual suspects" hybrid models

1. UK MARKAL-Macro (TIMES-Macro) model
   - A detailed technological and sectoral bottom-up optimisation approach hard linked to a single sector neoclassical growth model to provide aggregated energy demand endogeneity and GDP impacts
2. AMOS computable general equilibrium model
   - UK and Scottish versions of a CGE model with energy related sectoral detail combined with a disaggregated electricity sector technology depiction
   - *[Also use of MDM-E3 and E3MG macro-econometric models]*

Overview of UK MARKAL Macro (M-M) model



M-M equations

$$\text{Utility} = \sum_{t=1}^{T-1} (\text{udf}_t)(\log\ C_t) + (\text{udf}_T)(\log\ C_T)/[1-(1-\text{udr}_T)^{\text{ny}}]$$
$$\text{udf}_t = \prod_{t=0}^{t-1} (1-\text{udr}_t)^{\text{ny}}$$
$$\text{udr}_t = (\text{kpvs})/\text{kgdp} - \text{depr} - \text{grow}$$

$$Y_t = C_t + I_t + \text{EC}_t$$

$$Y_t = \left[\text{akl}(K_t)^{\rho\alpha}(L_t)^{\rho(1-\alpha)} + \sum b_{\text{dm}}(D_{\text{dm},t})^{\rho}\right]^{1/\rho}$$
$$L_0 = 1,\ L_t = (1+\text{grow}_{t-1})^{\text{ny}} L_{t-1}$$
$$\rho = 1 - 1/\text{ESUB}$$

$$[Y/D_{\text{dm}}]^{1-\rho} * b_{\text{dm}} = \text{price}(\text{ref})_{\text{dm}}$$

$$K_{t+1} = \text{tsrv}K_t + (\text{ny}/2)(\text{tsrv}I_t + I_{t+1})$$
$$\text{tsrv} = (1-\text{depr})^{\text{ny}}$$
$$I_0 = (\text{grow}_0 - \text{depr})K_0$$

$$K_t(\text{grow}_t + \text{depr}) \le I_t$$

Further detail

- Strachan N. and R. Kannan (2008) *Hybrid Modelling of Long-Term Carbon Reduction Scenarios for the UK*, Energy Economics, 30(6): 2947-2963
- Strachan N., S. Pye and N. Hughes (2008) *International Drivers of a UK Evolution to a Low Carbon Society*, Climate Policy, 8: S125-S139

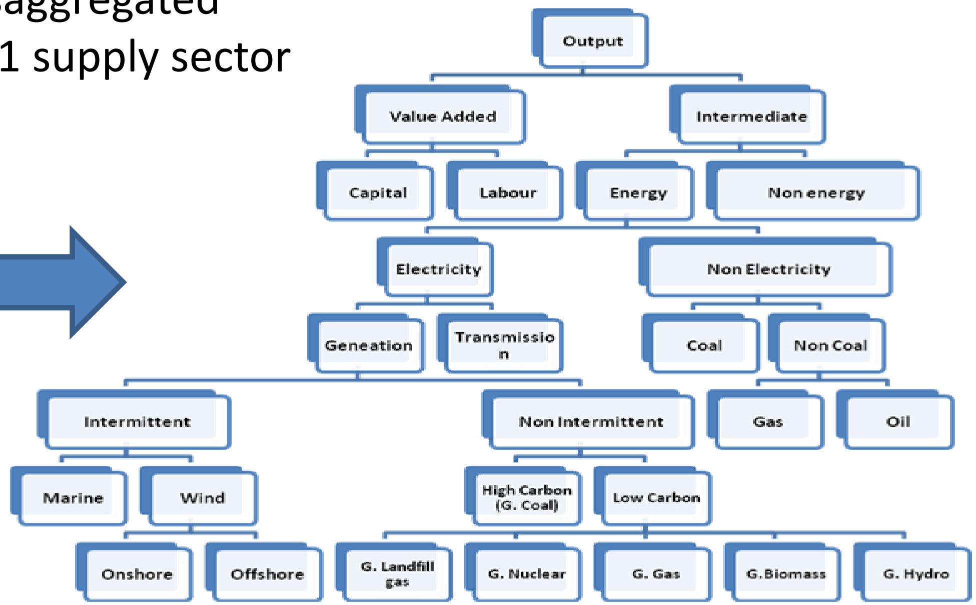
UK M-M scenarios (2008): Macro-economic costs

Scenario	% of GDP			
	2020	2030	2040	2050
Central scenario	0.46	1.70	2.43	2.81
With accelerated technological change	0.45	1.60	2.35	2.58
With higher fossil fuel prices	0.45	1.54	2.27	2.64
With accelerated energy efficiency	-0.07	0.63	1.63	2.04

AMOS energy production overview

Original electricity sector disaggregated into 9 generation types and 1 supply sector

Electricity supply sector – nested production function



Further detail

- Allan, G., McGregor, P.G., Swales, J.K. and K. Turner (2007a), Impact of alternative electricity generation technologies on the Scottish economy: an illustrative Input-Output analysis, *Proceedings of the Institution of Mechanical Engineers: Part A, Journal of Power and Energy*, Vol. 221 (2), pp. 243-254
- Allan, G., Lecca, P., McGregor, P.G., Swales, J.K., Tamba, M. And Winning, M. (2012), The impact of the introduction of a carbon tax for Scotland, *Fraser of Allander Economic Commentary: Special issue on economic and energy system modelling*, University of Strathclyde, April 2012, pp. 13-19

AMOS – UK carbon tax £22/tCO_2

Carbon tax: 22£ per tonnes of CO2 - UK	No recycling		Income tax		Gov_Expend	
Regional Bargaining Fixed labour supply	SR	LR	SR	LR	SR	LR
Emissions	-28.40	-35.18	-28.18	-34.87	-28.58	-35.43
Income Tax	Eps	Eps	-2.39	-2.07	Eps	Eps
GDP	-0.07	-1.22	0.25	-0.68	-0.09	-1.13
Consumer Price Index	-0.47	-0.25	-0.46	-0.38	-0.18	-0.07
Unemployment Rate	1.52	10.91	-6.45	2.20	1.92	10.11
Total Employment	-0.10	-0.70	0.41	-0.14	-0.12	-0.65
Nominal Gross Wage	-0.57	-1.40	-1.21	-1.65	-0.30	-1.14
Real Gross Wage	-0.10	-1.15	-0.75	-1.27	-0.13	-1.07
Real Wage after Tax	-0.10	-1.15	0.45	-0.23	-0.13	-1.07
Replacement cost of capital	-1.57	-0.16	-1.07	-0.29	-0.76	0.03
Labour supply	Eps	Eps	Eps	Eps	Eps	Eps
Households Consumption	-0.43	-0.61	-0.04	-0.11	-1.29	-1.38
Gov Consumption	-	-	-	-	1.94	2.23
Net investment	-2.26	-2.30	-1.87	-1.74	-2.66	-2.11
Capital Stock	Eps	-2.11	Eps	-1.60	Eps	-1.95
Export	1.06	0.32	1.19	0.55	0.81	-0.02

Synergies: policy analysis vs. hybrid modelling improvements

UK Energy policy analytical priorities	Energy-economic modelling key issues
Impacts on macro- and micro-economy	**Core analytical focus of hybrid energy models**
	Highly data intensive with long computational times Reliance on aggregated parameters (e.g., substitution elasticities)
Spatial and temporal detail (especially in infrastructures)	Lack of spatial and temporal disaggregation
The role of behavioural change and the impact of different societal groups	Limited ability to model behaviour
Interactions between the energy sector and the broader environment	Assumptions on substitutability between different forms of capital
Sectoral implementation (transport, buildings etc) of detailed policy measures	Range of stylised assumptions: e.g, competitive energy markets, flow of information, frictionless implementation and transition costs
Focus on uncertainty analysis, notably non-marginal changes	Only deterministic treatment of uncertainties

5 critical directions for hybrid energy modelling

1. Multi-sectoral TIMES-Macro models
   - To facilitate a more nuanced investigation of energy quantity/price and technology/infrastructure selection on alternate parts of the economy
2. Detailed disaggregation of CGE models based on household income and characteristics
   - To allow analysis of the impact of energy and environment policies on households differentiated by income
3. A greater level of sectoral detail for energy intensive economic sectors
4. An extended treatment of natural capital stocks within CGE models
   - Via nested production functions which focus on the substitutability between these natural and conventional inputs to the economy
5. A renewed emphasis on model transparency and replication
   - This is a particular challenge given the complexity and computation sophistication of energy-economic hybrid models