Transition Pathways to a Low Carbon Electricity System

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Final Dissemination Conference
London, 18 April 2012

Transition Pathways: Consortium & Aims

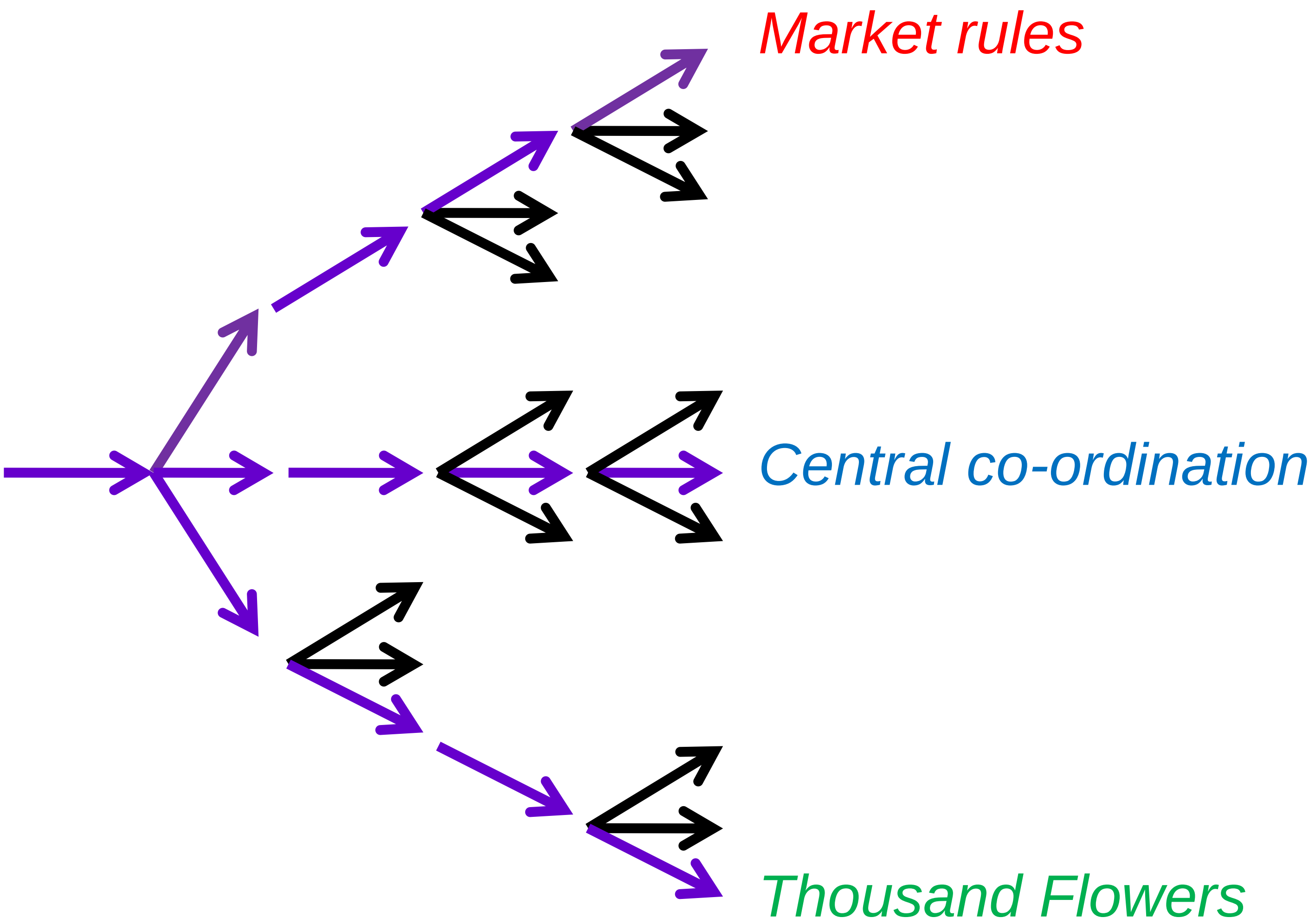
- Interdisciplinary University Consortium
  - Bath, Cardiff, East Anglia, Imperial College, Leeds, Loughborough, Strathclyde, Surrey, UCL
  - Funded by EPSRC & E.On UK (May ‘08 - April ‘12)
- Key aims:
  - Select, develop, analyse *transition pathways* to a ‘more electric’ low carbon future
  - *Integrated ‘whole system’ assessments* of pathways’ technical, economic, social & environmental implications
  - Inform thinking & decisions on low carbon transitions & how to ‘get there from here’
- UK Context
  - Climate Change Act 2008: 80% GHG cut by 2050
  - ‘Trilemma’: low carbon, secure, affordable energy

TRANSITION PATHWAYS

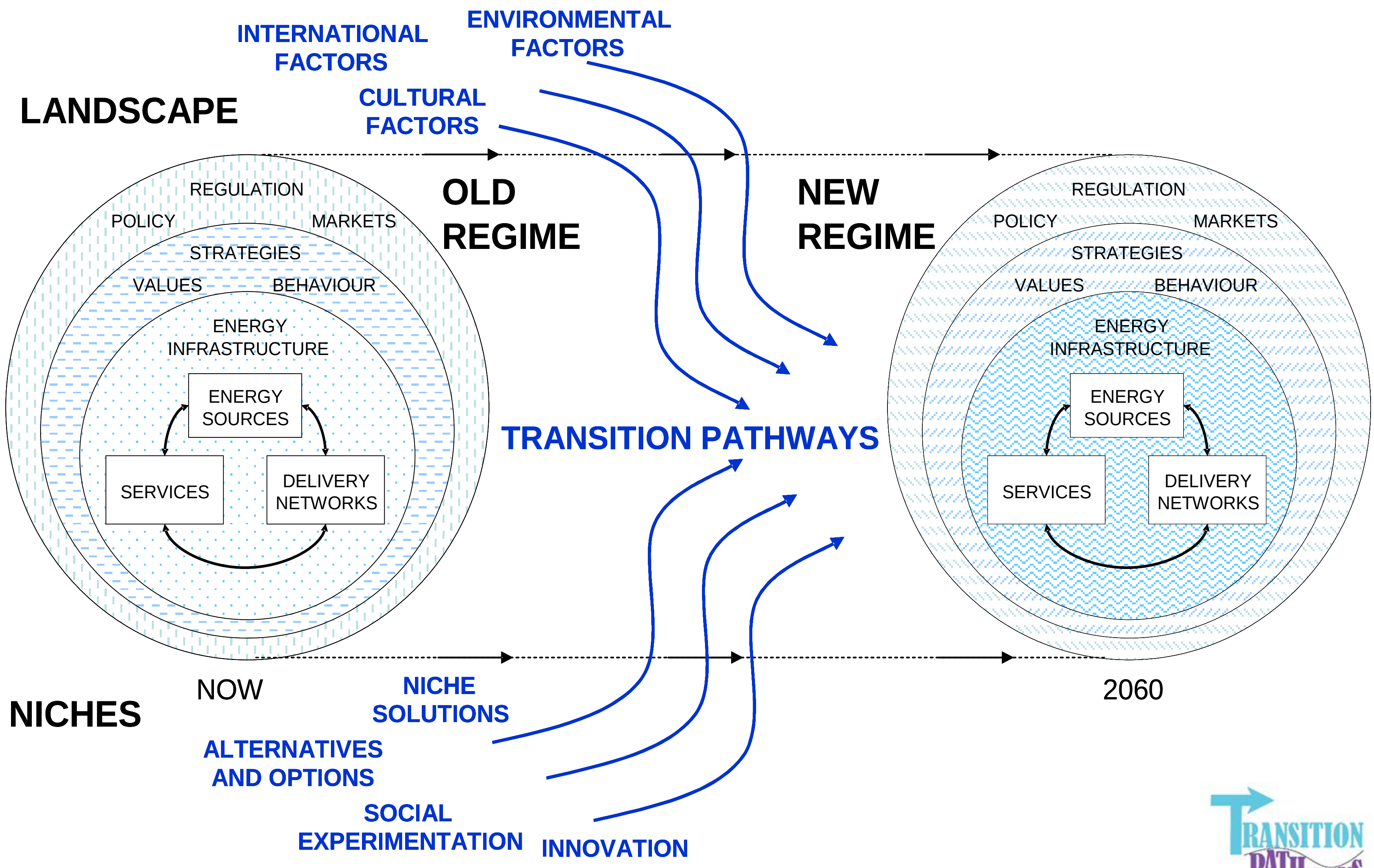
Transition Pathways approach

- Develop & analyse three transition pathways to a UK low carbon electricity system
  - Crucial influence of *market*, *government* & *civil society* actors' governance framings/'logics'
  - Pathways reflect 'co-evolution' of technologies, institutions, strategies/policies & user practices
  - Quantitative & qualitative pathway assessments
  - Exploration of pathway 'branching points'
  - Interaction with key stakeholders/advisers throughout
- Potential pathways - not predictions or roadmaps
  - Imaginative 'whole system' exploration of possibilities
  - To inform proactive & protective decisions & consensus-building towards common goals

Three Core Pathways & Governance Modes

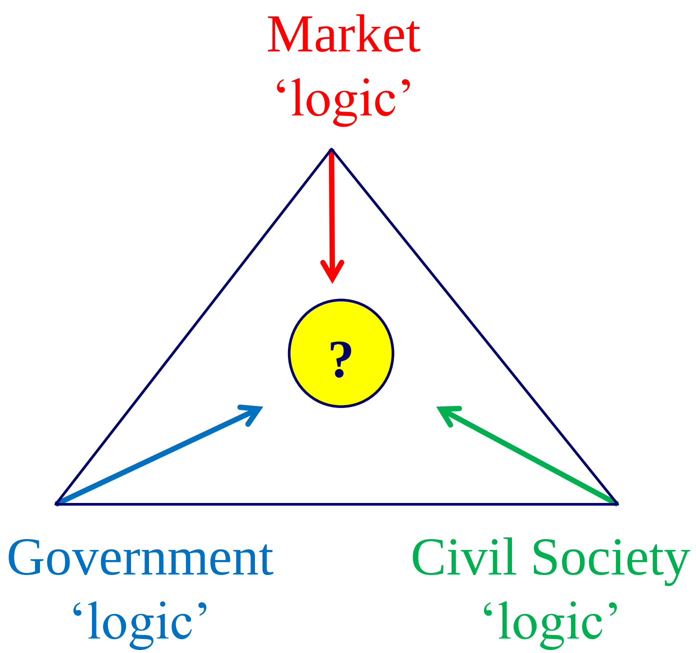


Multi-level Perspective on Transition Pathways



Source: Transition Pathways Team

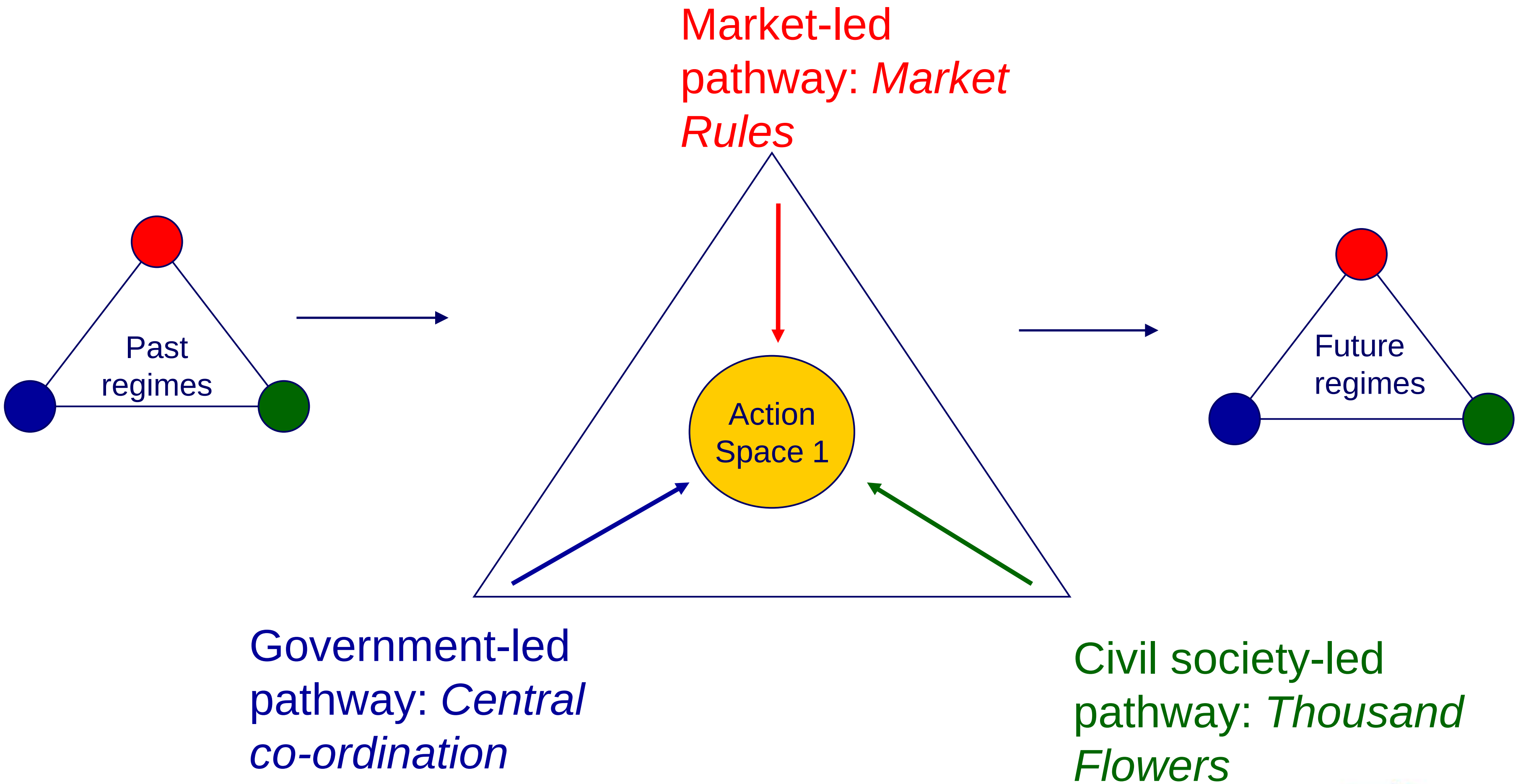
Action-Space Approach to Governance – 3 Key Actor Groups: Market, Government & Civil Society



Source: Jacquie Burgess & Tom Hargreaves – Transition Pathways Project

- Differing, simplified actor representations of other actors ('gatekeeper' interviews)
- Choices depend on actors' competing 'logics' : messy, dynamic, interactive
- Action-space maps shifting relationships
- Via their *interactions,* each actor tries to '*enrol*' the others
- The dominant actor – i.e. best 'enroler' - defines that period's action-space
- Influencing the pathway & its branching points

The Action Space for Transition Pathways



Three Transition Pathways

1) *Market Rules*
- Limited interference in market arrangements; high carbon price
- Large companies dominate; big technologies in ‘highly electric’ future – inc. CCS-ready coal/gas, nuclear power, offshore wind
- 80% generation linked to high-voltage in 2050: grid reinforcement

2) *Central Co-ordination*
- Central government & Strategic Energy Agency commission tranches of low-carbon generation from big companies
- Via large-scale centralised technologies
- Cooperation & tensions between key actors

3) *Thousand Flowers*:
- More local, bottom-up diverse solutions led by ESCOs (big & small), local communities & NGOs: closer engagement of end-users
- Local leadership in decentralized options (50% share)
- Key technologies: onshore & offshore wind, renewable CHP & solar PV; ‘smart grid’ technologies to handle power flows

‘Market Rules’ pathway overview

Pathway aspect	**Characteristics**
Key technologies	**Coal and gas with carbon capture and storage (CCS); nuclear power; offshore wind**; onshore wind; imports; tidal barrage; wave and tidal power
Key concepts	Successful demonstration of CCS leads to high levels of deployment from 2020 onwards; **high carbon price makes CCS, nuclear and large-scale renewables economical to build**, and enables roll-out of retrofit of CCS to remaining coal and gas power stations; increasing electricity demand from heating and transport somewhat offset by technical efficiency improvements
Key actors	**Regime actors (large energy companies) dominate**; few new entrants; consumers remain in ‘passive’ role
Key multi-level patterns	Landscape pressures (climate change and energy security) on regime actors leads to focus on carbon reduction and retrenchment around large-scale technologies; small-scale renewable technologies fail to emerge from niches
Key learning processes	Learning to achieve commercial deployment of CCS; **large energy companies see ‘high-electric’ future as a strategic business opportunity**, with increasing demand for electric heating and electric vehicles in a carbon-constrained world
Key infrastructure aspects	80% of generation still connected at high-voltage transmission level by 2050, with coal and gas CCS and new nuclear following siting of existing plants, and offshore wind concentrated around Scotland, implying need for high levels of transmission reinforcement

TRANSITION PATHWAYS

‘Central Co-ordination’ overview

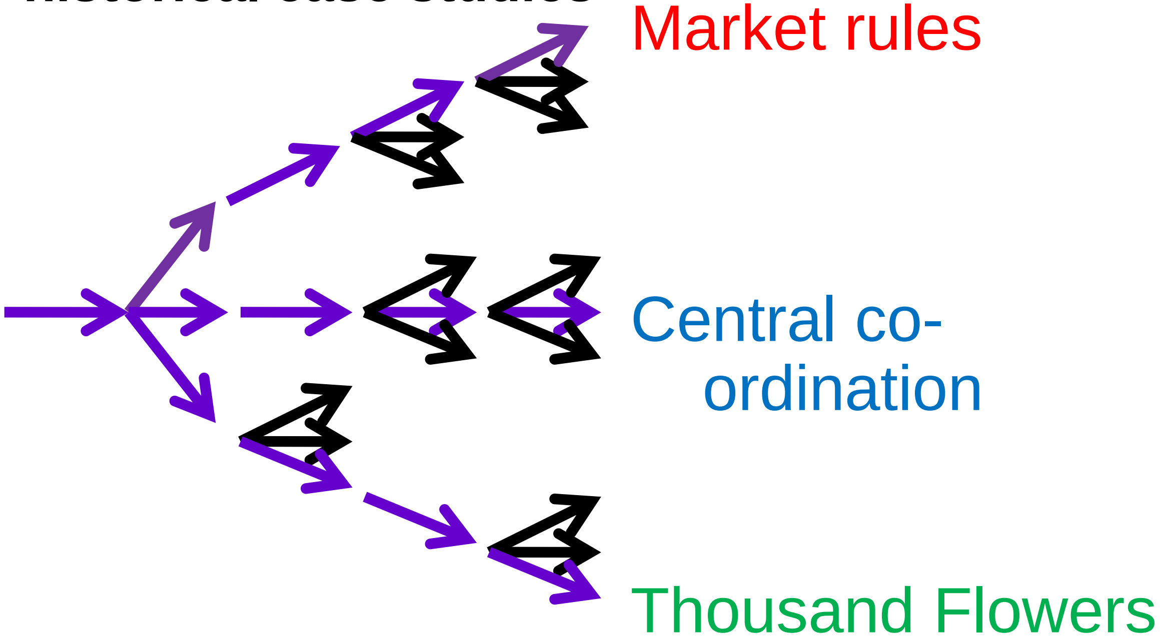
Pathway aspect	**Characteristics**
Key technologies	**Coal and gas CCS; nuclear power; offshore wind**; onshore wind; tidal barrage; wave and tidal power.
Key concepts	Role of **Strategic Energy Agency** and use of **central contracts** to reduce the risks of low-carbon investment.
Key actors	Central government, through creation and direction of Strategic Energy Agency; large energy companies in delivery of large-scale low-carbon investment
Key multi-level patterns	Landscape pressures, particularly energy security concerns as well as climate change, lead to **greater role for central government, working closely with large energy companies**; niche-level activity focused on large-scale technologies, particularly offshore wind and CCS, with less focus on small-scale technologies
Key learning processes	Learning to achieve commercial deployment of CCS; co-operation but also tensions between government and large energy companies; increasing demand for electric heating and electric vehicles in a carbon-constrained world
Key infrastructure aspects	80% of generation still connected at high-voltage transmission level by 2050, with coal and gas CCS and new nuclear following siting of existing plants, and offshore wind concentrated around Scotland and in the North Sea, implying need for high levels of transmission reinforcement

‘Thousand Flowers’ overview

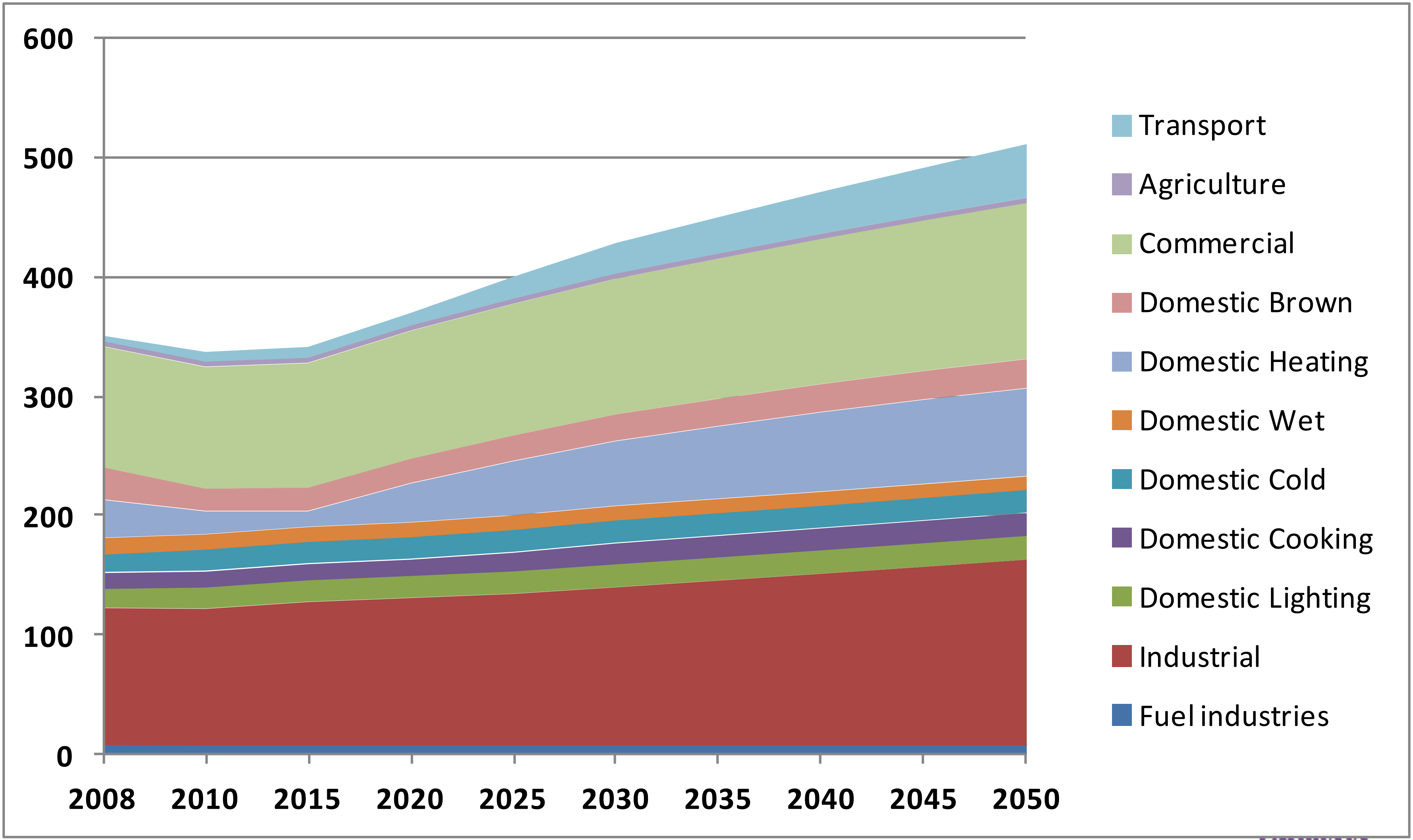
Pathway aspect	**Characteristics**
Key technologies	**Onshore wind; offshore wind; renewable CHP; solar PV**; imports; tidal barrage; wave and tidal power
Key concepts	**Move to ESCO business model**; **technological and behavioural changes lead to significant end-user demand reductions**; positive feedbacks lead to ‘virtuous cycles’ in deployment of small-scale distributed generation technologies; greater community ownership of generation, including onshore wind and biomass CHP.
Key actors	ESCOs (both new entrants and diversified existing energy companies); local communities; NGOs
Key multi-level patterns	Landscape pressures (climate change and energy security) on regime actors and government support for small-scale and community-level initiatives leads to focus on demand reduction and small-scale technologies; small-scale renewable technologies emerge from niches
Key learning processes	**Learning to achieve commercial deployment of range of distributed generation technologies**, with the emergence of a small number of ‘dominant designs’; large energy companies diversify into ESCO business model; focus on community-led renewable district heating schemes reduces the expected demand for electric heating, but rise in demand from electric vehicles
Key infrastructure aspects	50% distributed generation requires development of ‘smart grid’ technologies to handle two-way power flows; 50% still connected at high-voltage transmission level by 2050, dominated by high efficiency gas generation and offshore wind concentrated around Scotland and in the North Sea, implying need for significant levels of transmission reinforcement

Explore, interrogate & revise pathways

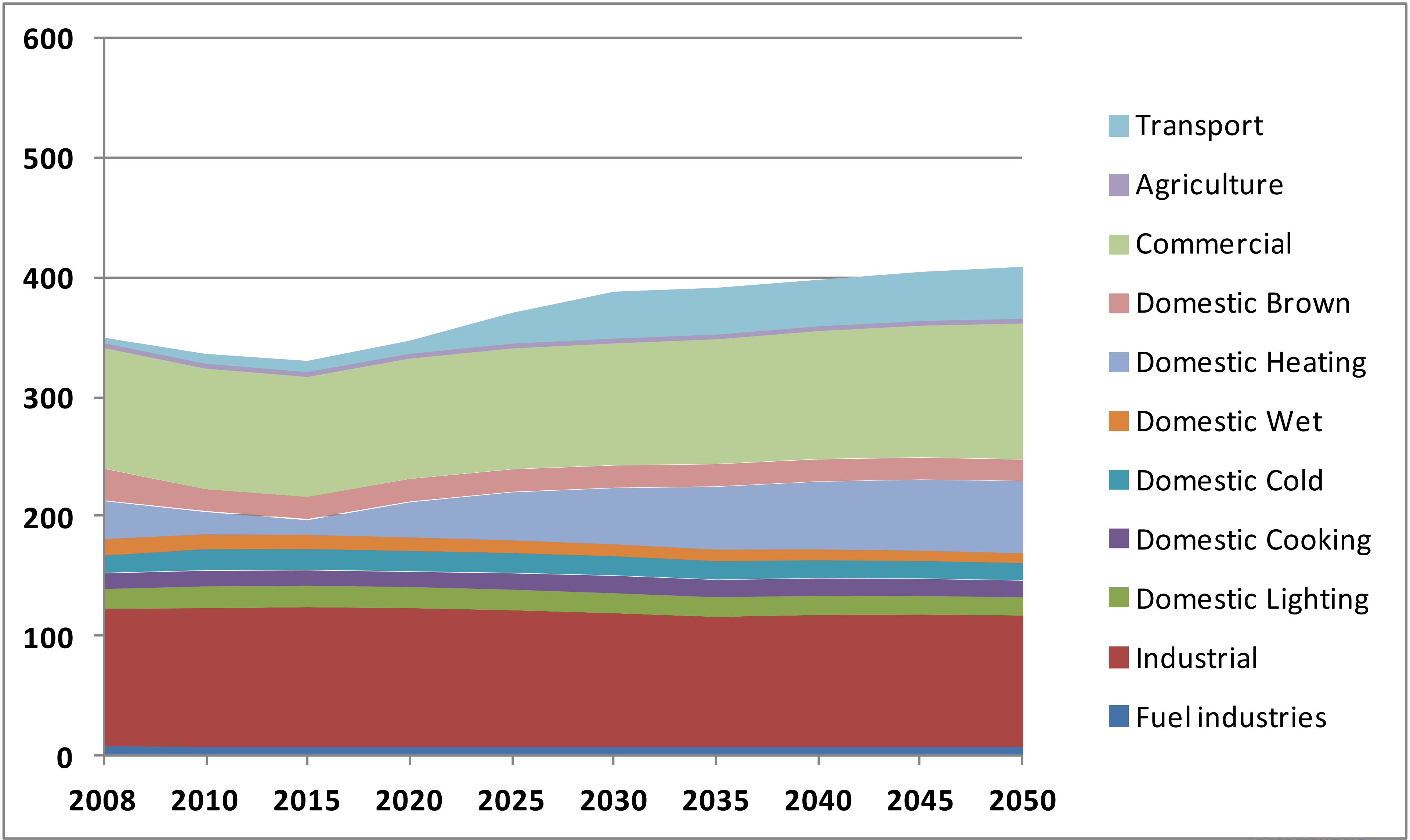
- Explore and interrogate pathways (2 iterations)
  - Technical feasibility, e.g. electricity grid enhancements
  - Social acceptability, e.g. visual energy display trials
  - **Whole systems appraisal, e.g. life cycle carbon emissions**
- Branching point analysis
  - **Test pathway sensitivity & robustness**
  - **Informed by historical case studies**



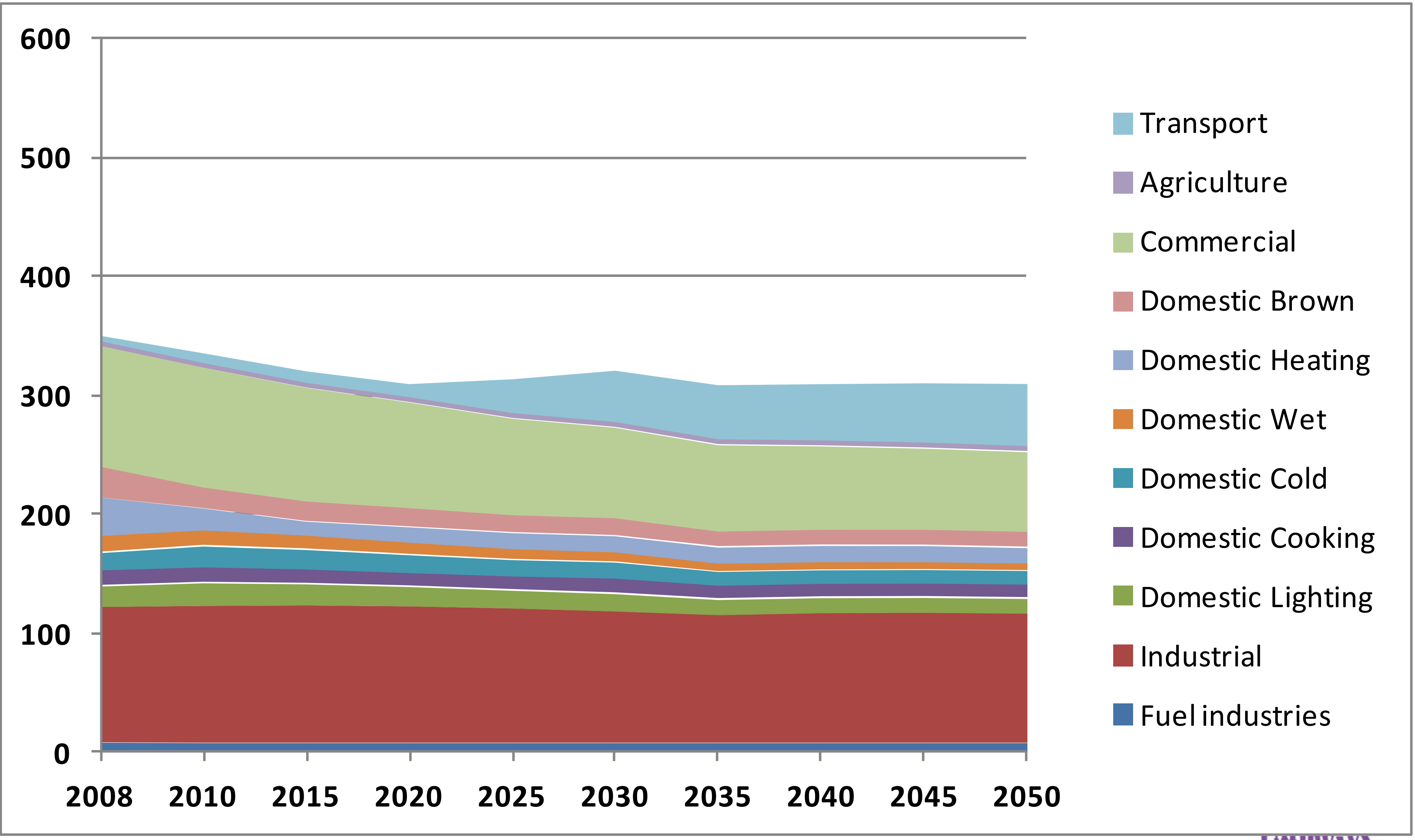
Market Rules electricity demand (TWh)



Central Coordination electricity demand (TWh)

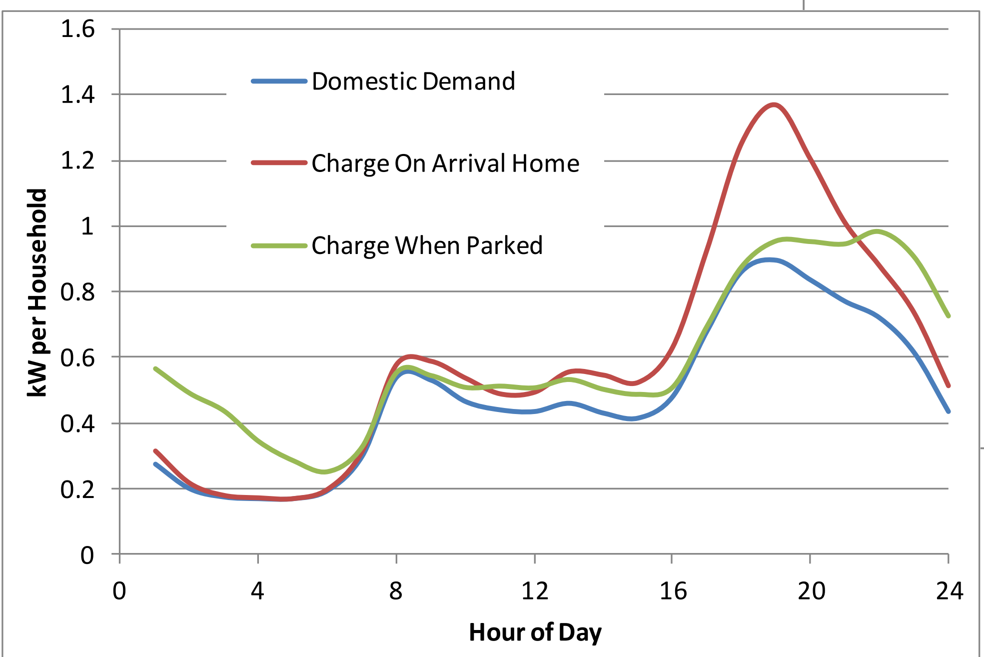


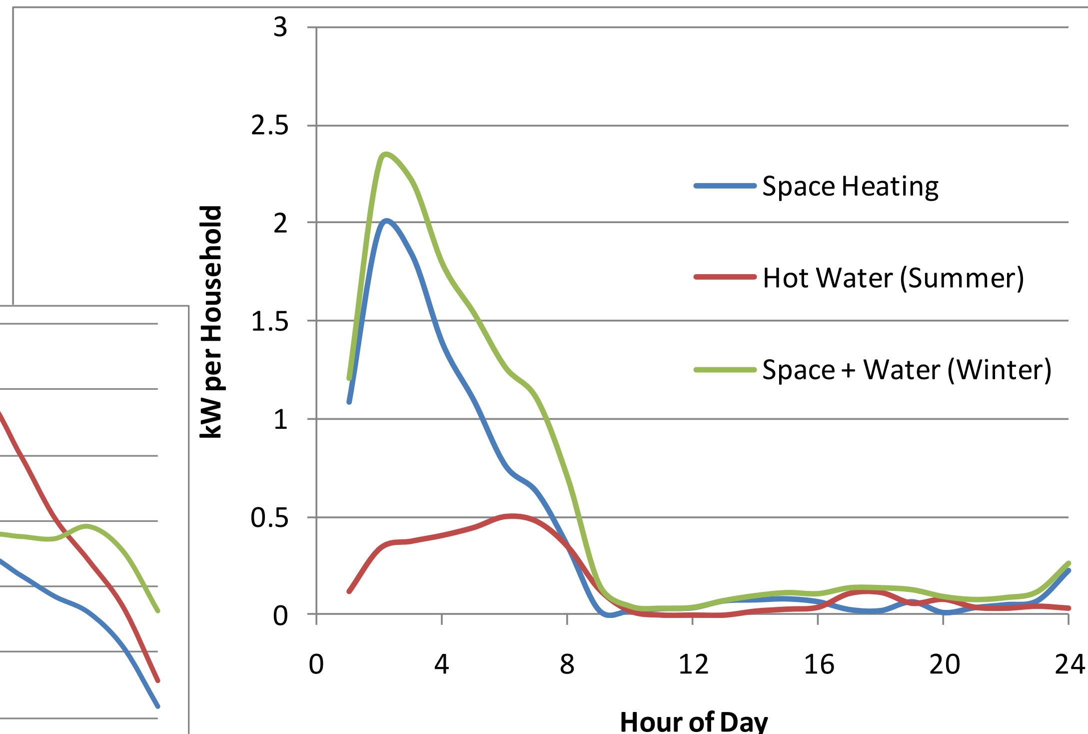
Thousand Flowers electricity demand (TWh)



From annual to hourly demands

- The FESA model was used to generate hourly demand profiles to reflect the overall energy service demands and end-use technology shares, by pathway





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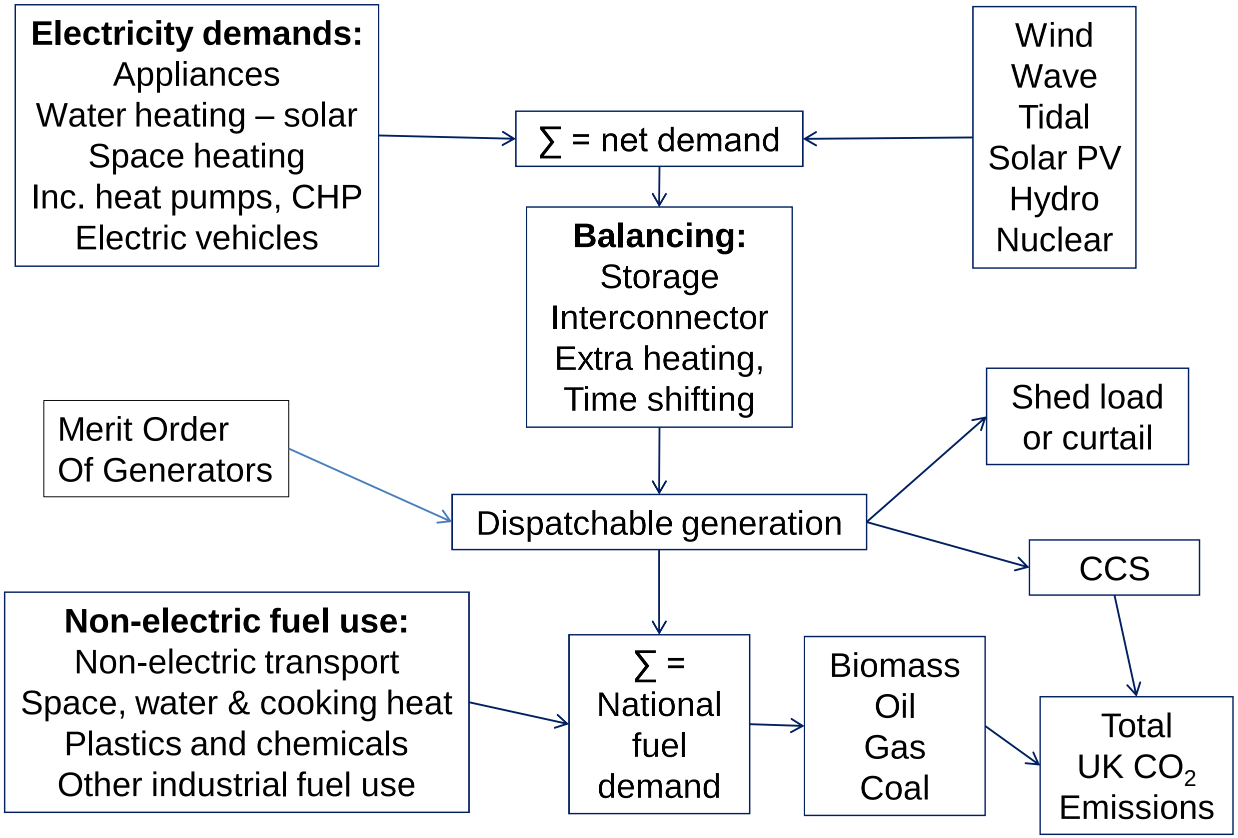
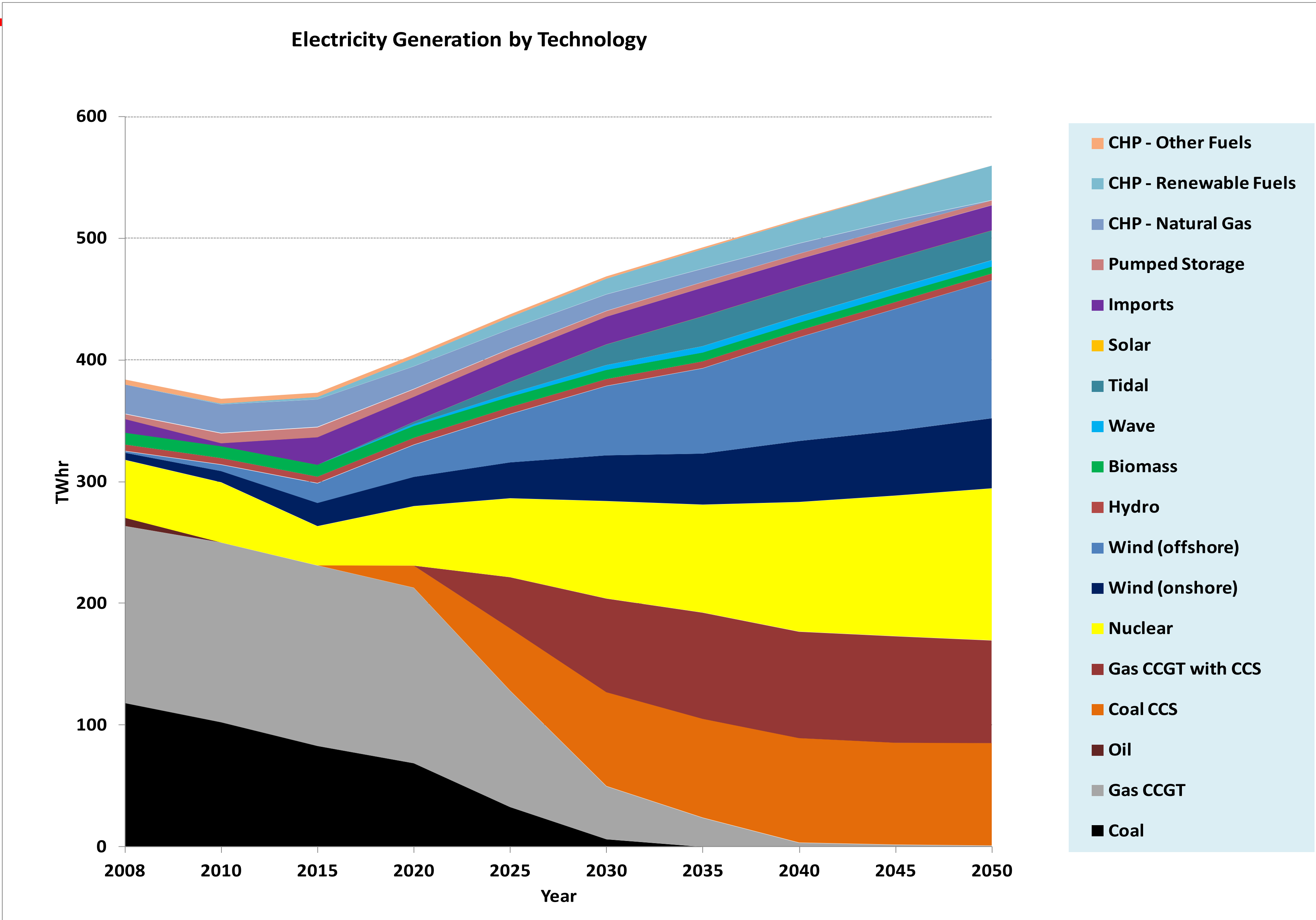
Simulating electricity generation

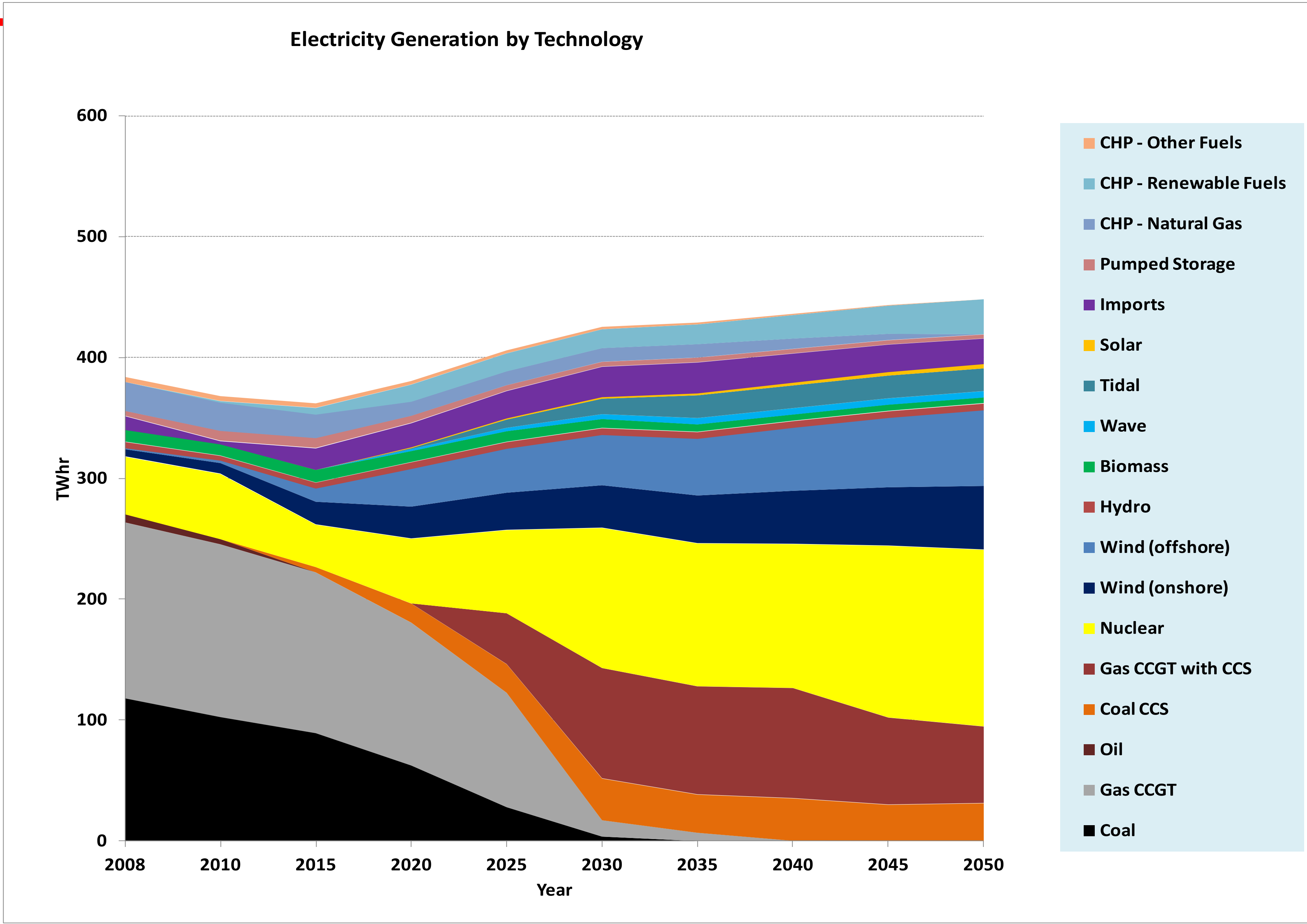
- FESA combined with other research at Strathclyde to derive generation capacity & despatch required to meet hourly loads



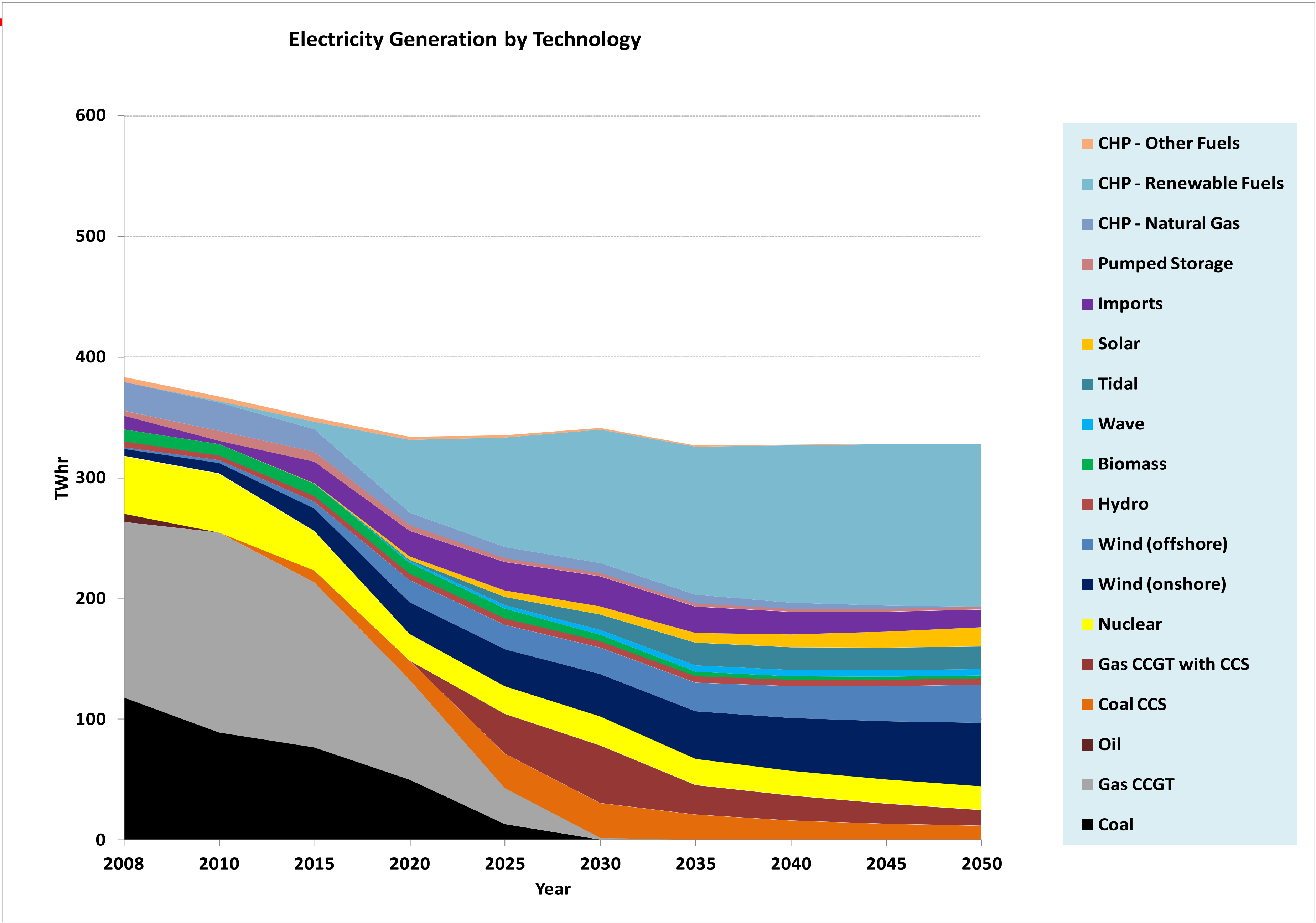
Electricity generation mix in 'Market Rules' pathway



Electricity generation mix in ‘Central Co-ordination’



Electricity generation mix in 'Thousand Flowers'



Demand, Energy Use and Behaviour

- Greater energy efficiency & use of non-electric heating sources (mostly CHP) in Thousand Flowers cuts peak demand to 38GW.
- But with significant 'excess' generation locally at times of low electricity demand.
- Load shifting through greater use of DSM, with widespread acceptance of automatic appliance control &/or deep behaviour changes, could address this,
- But our longitudinal study of responses to visual energy displays showed how quickly households returned to pre-existing use levels.
- Most early adopters used displays to picture the household's 'normal' energy use pattern - & tended to resist external appeals to change.
- The closer engagement of end users with energy system governance in Thousand Flowers suggests one way to overcome these barriers.

Whole systems appraisal of pathways

- Establish a 'sustainability appraisal framework', including the identification of key technical, environmental, economic & social constraints

- Identify key constraints or risks that may limit such pathways – risk assessment of the UK *Electricity Supply Industry*

- Provide quantitative & qualitative 'whole systems'/ 'full fuel cycle' energy & environmental appraisal of the pathways

- Map environmental & carbon implications of the pathways using aggregate footprints

UPSTREAM EMISSIONS

- **Upstream from delivered fuel**
  - Extraction, refining, transport, …. etc.
- **Two main GHG burdens**
  1. Additional energy requirements to ‘fuel’ upstream activities
  2. Methane leakage
     - Coal mining activities – quite a significant contribution
     - Natural gas pipelines

Fuel	DEFRA GHG Combustion - per kWh	GHG Upstream – per kWh	Resulting Increase
Coal	0.33 kg CO_2e	0.06 kg CO_2e	+18%

TECHNOLOGY COMPARISON (kg CO_{2e} per kWh)

- **Ranked by GHG emission order …**
- **A comparison of 'Gas' with 'Coal CCS' *downstream* emissions**
  - ❖ Coal CCS has 1/3 lower GHG emissions compared to NGCC plant
  - ❖ Coal CCS can therefore be viewed as a relatively attractive environmental proposition
    - ➢ It is also a 'cheap' fuel, readily available, flexible generation, …. etc.
  - ❖ The impact of 'upstream emissions' on the carbon performance of some technologies (such as CHP and CCS) and pathways distinguish the present findings from those of other analysts, e.g., the CCC and DECC.

Technology (mix)	GHG (CO_{2e})
Coal	1.09
Grid Average, 1990	0.90
Grid Average, 2008	0.62
Gas	0.47
Coal CCS	0.31
Gas CCS	0.08
Nuclear	0.02

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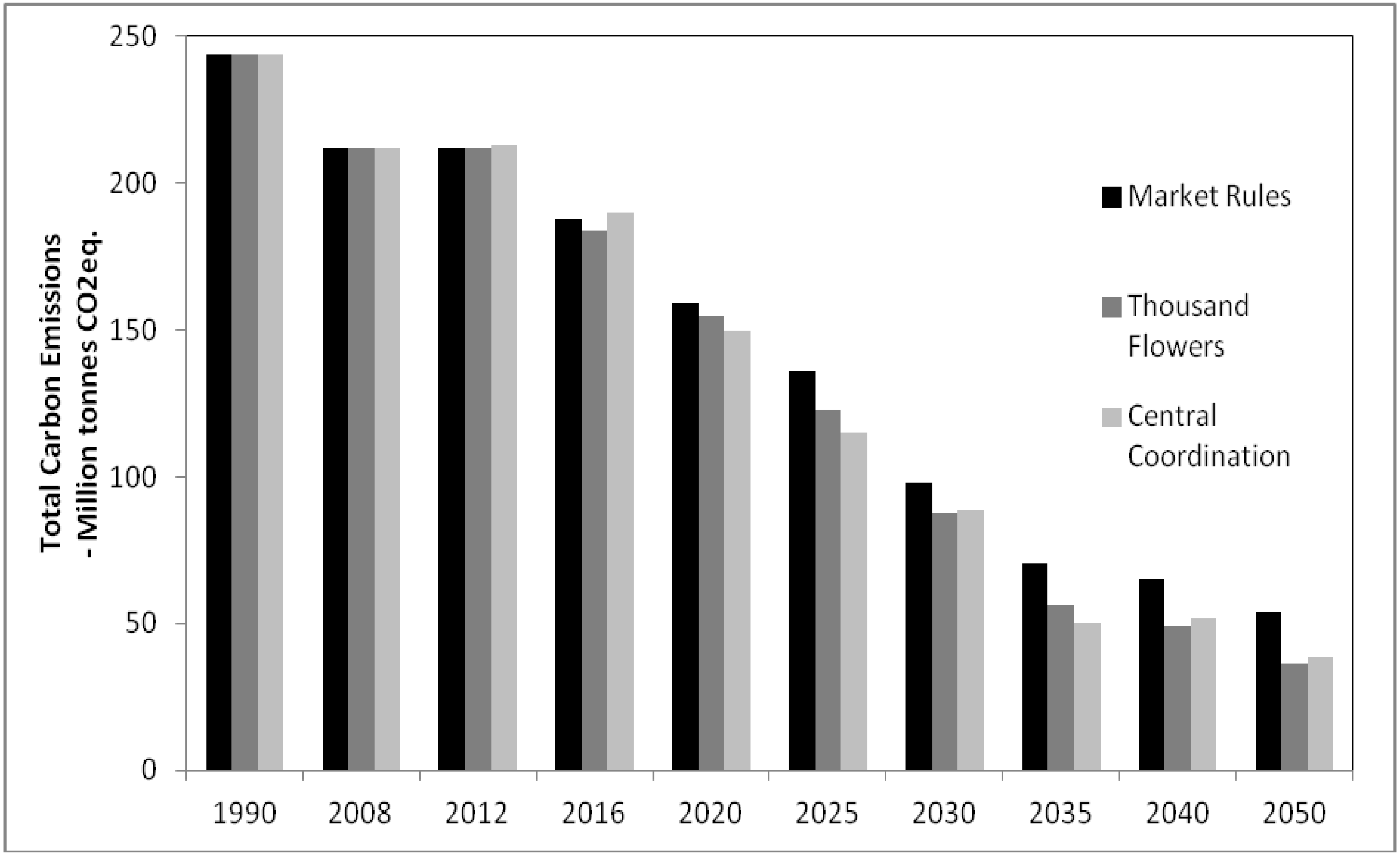
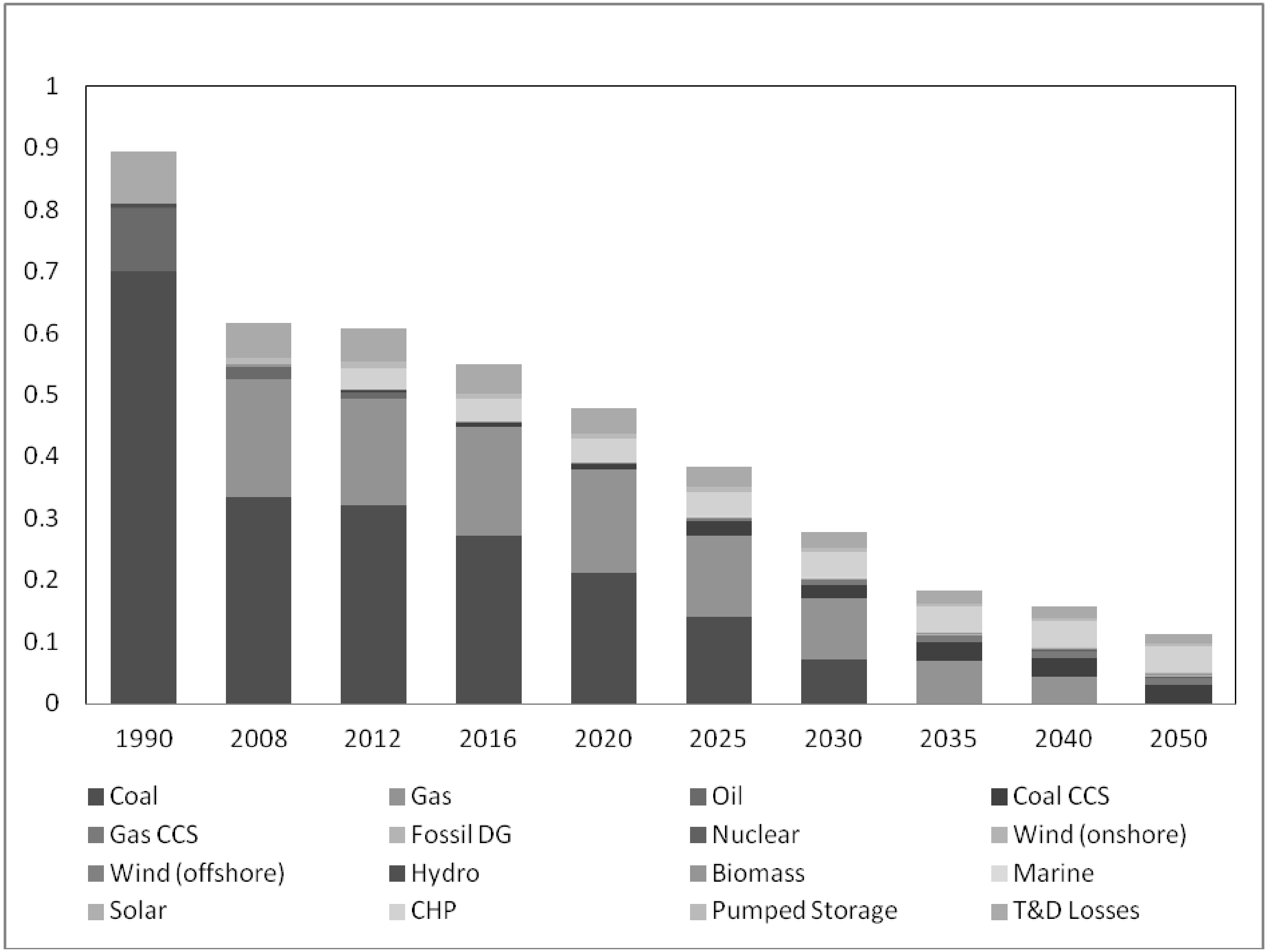
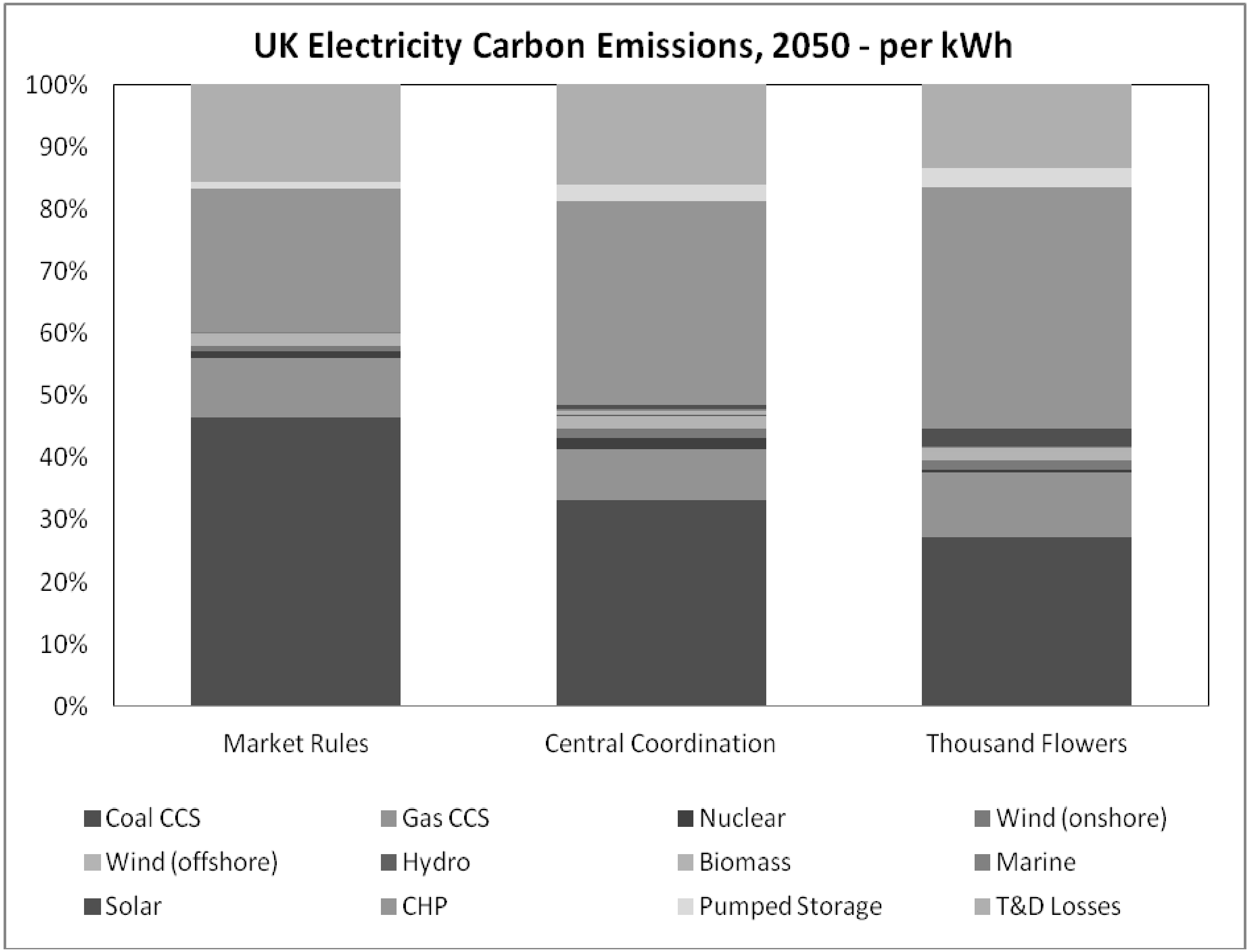
Total UK Carbon Emissions (MtC_e) from the Electricity Sector under the Three Transition Pathways



UK Power Network Carbon Intensities (kg CO2e/kWhe) under the ‘Market Rules’ Pathway



Shares of UK Electricity Sector Carbon Intensities (kg CO_2e/kWhe) in 2050 under the Three Transition Pathways



Whole systems appraisal – Key Findings

- The impact of 'upstream emissions' distinguishes our findings from those of CCC & DECC.
  - None of the pathways yield zero GHG emissions by 2050, because of this
  - UK ESI cannot realistically be decarbonised by 2030-2040, as CCC advocated
  - Real requirement is for more dramatic ESI carbon reductions
  - CCS technologies likely to deliver only 70% reduction in carbon emissions on whole system basis (cx. normal 90% assumed)
  - Biomass co-firing with CCS may mitigate upstream emissions on full life-cycle basis: needs careful study in future
- Particulate Matter Formation (PMF) & Human Toxicity (heavy metal emissions) may need attention, especially with CCS technologies

Branching point analysis

- *Branching point*
  - Point where endogenous (national/local) or exogenous (international) pressures /tensions mean actors make choices determining whether & how pathway is followed
- Actors' choices could lead to 3 responses on pathway:
  a) Logic *reinforced* - pathway continues same trajectory;
  b) Logic *challenged* – branches to new trajectory with hybrid logic;
  c) Logic *vanquished* – pathway fails & moves to new logic
- Identify & analyse branching points
  i. Pathway specific - identify choices leading to (a), (b) and (c)
  ii. Key branching points across all pathways – compare & contrast responses across pathways
- Initial branching points based on stakeholder & internal workshops & informed by historical analyses

Past Transitions and Branching Points

- Although much is different, insights from past transitions & branching points can inform low carbon challenges
- Experiences from earlier centuries & other countries give us the broader view (2011 Cardiff International Workshop)
  - They illustrate that transitions often take many decades & encounter resistance
  - Suggest that as yet the low carbon transition & its technologies do not amount to an 'industrial revolution'
- Experiences of C19 & C20 transitions offer valuable nearer-term insights into how transitions might occur under different governance regimes, technologies & circumstances

Historical Analyses of Past Transitions (i)

- The responses of incumbents (inc. end-C19 gas industry), to the threat of new competition
- How UK gas & electricity industries sought to encourage, shape & manage energy uses & habits in C19 & C20
- The survival of the Bristol Water Company against C19 municipalisation attempts
- C20 transition of the UK liquid fuels & chemicals sectors from coal-based to petrochemical-based feedstocks
- The 1960s scaling up & rolling out of electric power plant by CEGB & partners
- The transition from town gas to natural gas, 1948-77

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Historical Analyses of Past Transitions (ii)

- Analyses of the market-led C19-C20 transition to greater use of gas cooking & heating in face of new competition from electricity,
- And the government-led 1960s transition from town gas to LNG & N Sea gas
- Help understand the governance & socio-technical challenges of past transitions & branching points:
  - They illustrate the co-evolution of technologies, infrastructures & institutions, the power of incumbents & challenges of scaling-up technologies.
  - While multi-actor, market-led transitions offer useful chances for experimentation, government-led transitions with fewer actors & centralised decisions may sometimes be easier to achieve.
  - This may help explain why recent governments have moved towards a hybrid pathway with greater government involvement.
  - Though balancing centralised & market approaches & involving civil society in decisions remain significant challenges.

Potential branching points

- **Market Rules:** CCS assessed commercially unviable by 2020
  - a) Market actors decide to continue investing in CCS, driven by expectations of big export markets for CCS technology;
  - b) Market mechanisms judged incapable of delivering – branch to Central Co-ordination;
  - c) Doubts about hitting carbon targets plus energy security concerns lead to renewed investment in unabated generation
- **Central Co-ordination:** Strategic Energy Agency fails
  - a) Government re-nationalises key electricity assets;
  - b) 'Bureaucratic interference & incompetence' blamed for failure – move to Market Rules but with time delays & higher costs;
  - c) Lack of co-ordination leads to a 'two-tier' price driven electricity system
- **Thousand Flowers:** 'Too much to carry' in terms of actions needed
  - a) Community groups take ownership of local electricity networks;
  - b) National govt. or big energy companies step in to manage problems
  - c) Patchwork of local problems results in targets being missed

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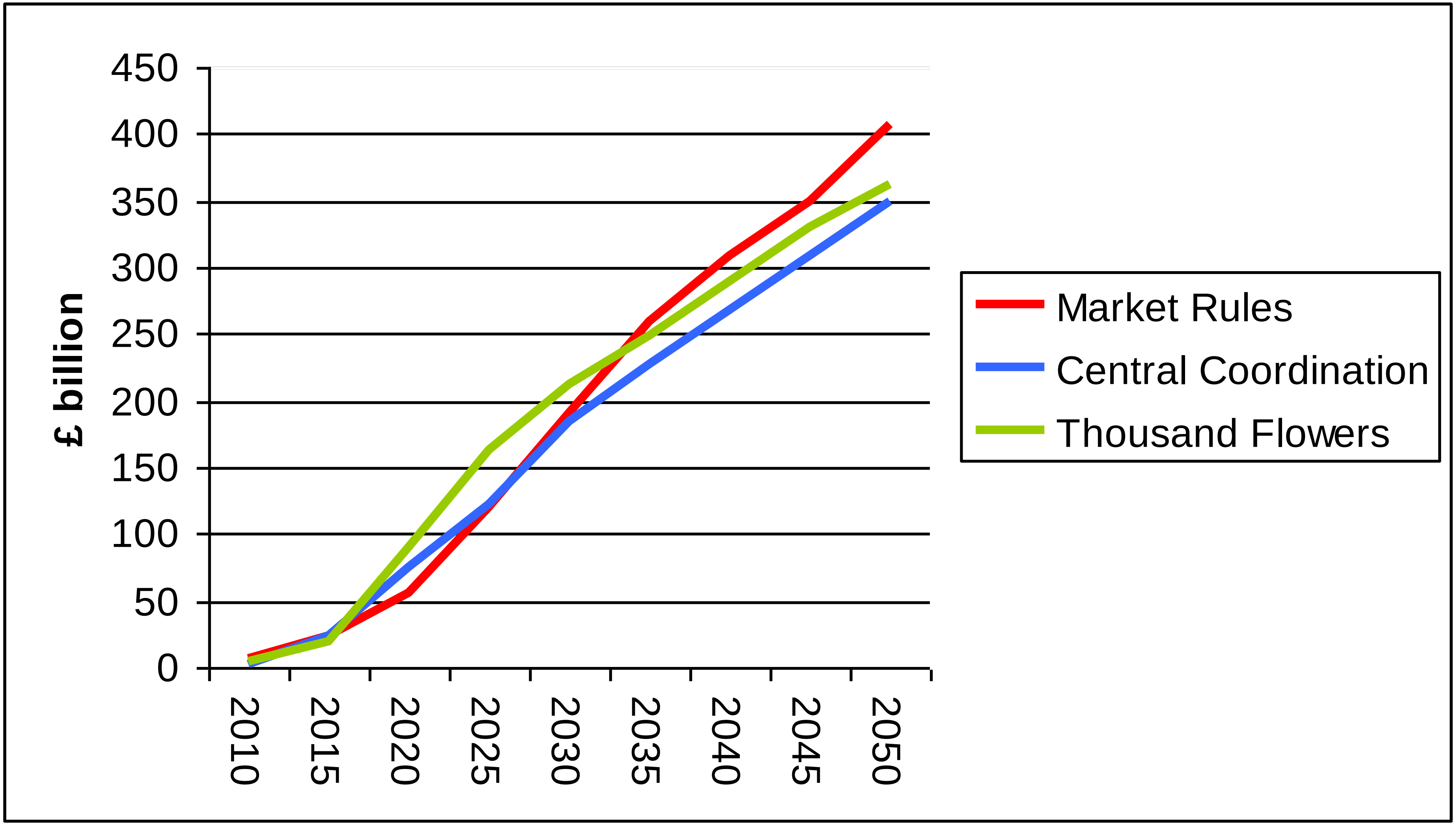
Branching point: Smart grid/control visions

- Disputes about the development of ‘smart grid/smart control’
  - Do benefits go mainly to producers or consumers - triggered by competing visions of smart grids?
  - Consumers might interpret developments as unwarranted intrusions or infringements of liberty by market &/or government actors
- Potential responses:
  a) Large market actors see potential benefits from a more effectively managed electricity system & invest in smart grid & control technologies;
  b) Smart grid seen more as enabling technology to incorporate distributed generation, microgen. & demand side developments, led by new entrants, like ICT & user interface companies;
  c) Discordant visions of smart grid & smart controls delay developments & prevent realisation of their benefits.

Calculating investment costs for pathways

- Calculate investment costs of additional & replacement generating capacity for each pathway
- Based on Ofgem (2009) Project Discovery methodology
- Caveats:
  - Costs not discounted back to present values
  - Not included: demand side investment costs; learning rates for technologies; operation, maintenance & decommissioning costs
- Results:
  - Similar cumulative investment costs to 2050
  - Thousand Flowers: higher investment costs up to 2030, from more rapid transition to distributed generation
  - Market Rules: higher investment costs 2030-2050 from continuing investment in CCS, nuclear & offshore wind needed for rising demand

Cumulative investment costs for pathways



Challenges facing individual energy users/ households

- Realising pathways requires households & energy users to play more active roles in energy service provision/use:
  - Facilitating energy saving choices via more ‘visible’ energy use (e.g. smart meters) - but household dynamics influence responses
  - Changes in habits/routines/lifestyles (e.g. reduced car use, increased car sharing)
  - Changes in shared understanding of ‘proper’ energy use (e.g. awareness of increases in showering frequency)
  - Increasing demand/new uses for low-carbon/more-efficient technologies (potentially leading to some rebound)
  - Increasing policy action to ensure any energy use limitations are shared fairly across different groups
- Dependent on wider social attitude changes, focusing on ‘quality of life’ benefits

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Challenges facing social movements

- Carbon targets imply radical changes to meet light, heat & power demands - inherently politically-charged
- Social movements might play multiple roles:
  - Lobbying government to introduce stronger targets, policies & measures, countering lobbying by big energy firms & others
  - Demonstrating viability of alternative solutions
  - Creating wider coalition of progressive energy users, generators & analysts
  - Proposing alternative visions for a future low-carbon society
- Suggests need for wider public debates on alternative visions & pathways to a low-carbon future

TRANSITION PATHWAYS

Challenges facing market actors

- Costly investments in low-carbon generation technologies
- New modes of engagement with government & civil society actors, inc. customers
- Development of new skills & capabilities
- Strategic choices:
  - How much effort/investment in UK rather than other markets?
  - Engagement with/resistance to market developments like ESCOs
  - Responses to changes at landscape & niche levels
- High levels of social & technological uncertainty suggest value of business strategies that:
  - Engage constructively with a range of actors
  - Keep options open, both for technology mix & business models

Challenges facing policymakers

- Balancing low-carbon, security & affordability objectives, in face of multi-faceted risks & uncertainties
  - *Central Co-ordination* pathway would give direct influence but require much political leadership
  - Main risks In *Market Rules:* technical/economic feasibility & social acceptability of delivering large-scale low-carbon generation options
  - Main risks in *Thousand Flowers:* technical/economic feasibility of distributed generation; realising behavioural & technological changes to reach & sustain big demand reductions
- Key to any successful low-carbon transition
  - Trust in policymakers to stick to & deliver credible policies/incentives
  - Willingness of market & civil society actors to engage constructively

Value of 'Transition Pathways' analysis

- Exploration of pathways & branching points informs actions needed & consensus building for common goals
- Shows pathways with different/shifting roles for government, market & civil society actors
  - And how they might lead to alternative visions & realities of a low-carbon electricity system
- Identifies challenges raised for different actors
- Shows implications of risks & uncertainties, including
  - Future progress in different energy technologies & portfolios
  - Whole system sustainability challenges for technologies & pathways
  - Role of ICTs to help facilitate change through smart grid/controls
  - Demanding role of changes in actors' habits, practices & wider social values, & how actors might interact well or badly with technologies
  - Role of policies & incentives

TRANSITION PATHWAYS

Selected Publications

- Foxon, T J, Hammond, G P and Pearson, P J (2010), ‘Developing transition pathways for a low carbon electricity system in the UK’, *Technological Forecasting and Social Change* **77**,1203-1213.
- Hammond, G.P., Harajli, H.A., Jones, C.I. and Winnett, A.B. (2012), ‘Whole systems appraisal of a UK Building Integrated Photovoltaic (BIPV) system: Energy, environmental, and economic evaluations’, *Energy Policy* **40**, 219-230.
- Hargreaves, T, Nye, M and Burgess, J (2010), ‘Making energy visible: A qualitative field study of how households interact with feedback from smart energy monitors’, *Energy Policy* **38**, 6111-6119.
- Nye, M, Whitmarsh, L and Foxon, T J (2010), ‘Socio-psychological perspectives on the active roles of domestic actors in transition to a lower carbon electricity economy’, *Environment and Planning A* **42**, 697-714.
- Torriti, J., Hassan, M.G. and Leach, M. (2010). ‘Demand response experience in Europe: Policies, programmes and implementation’, Energy **35**, 1575-1583.

- 2 forthcoming special issues of *Energy Policy* in process, covering technical, social and environmental analysis of pathways, and insights from past transitions
- Further working papers and presentations available on project website:

  www.lowcarbonpathways.org.uk