Do long-term projections of technological change in E3 models capture rates of historical transitions? What should we capture?

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Achieving 2°C climate stabilisation: macroeconomic benefits or costs?

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Wilson et al. (2013): Are scenarios consistent with historical evidence?

- C. Wilson, A. Grubler, N. Bauer, V. Krey & K. Riahi (2013), ‘Future Capacity Growth of Energy Technologies: are Scenarios Consistent with Historical Evidence?’ *Climatic Change* 118:381–395
  - Energy system scenarios under GHG emission constraints depict dramatic growth in energy technologies.
  - The paper’s methodology allows projected capacity expansions of low carbon energy technologies to be compared against historically-evidenced diffusion
  - Offering a first-order verification of model output against the observed historical record

Wilson et al. (2013): argument & findings

- Historical time series data reveal a relationship between how much a technology's cumulative installed capacity grows (*extent)* & how long this growth takes (*duration*)
- This *extent-duration relationship* is both consistent across 8 energy supply & end-use technologies and across established & emerging technologies
- Power generation technology data from two integrated assessment & energy-economic models (MESSAGE-IAMF & REMIND-AME) yield a consistent extent-duration relationship across technologies & scenarios
- The scenarios depict longer capacity growth durations to reach a given extent of growth than the historical pattern
- The findings are largely robust across technologies, regions & times

Wilson et al: 6-stage method for comparing past & future energy technology growth trajectories

I. Compile global time series of cumulative capacity (MW) of energy technologies, historically & in IAM scenarios
II. Disaggregate global data into core, rim & periphery regions, defined by sequence of widespread diffusion
III. Fit logistic functions subject to appropriate criteria
IV. Extract logistic function asymptote parameter (K) (saturation level) & time variable (Δt), as proxies for extent & duration of capacity growth
V. Normalise asymptote parameter K for changes in energy system size
VI. Plot & compare relationships between extent of growth (normalized K) & duration of growth (Δt), both historically & in future scenarios, at global & regional scales.

Historic capacity growth, 8 energy technologies (a); fitted extent (k) vs. duration of growth (Δt) (b)

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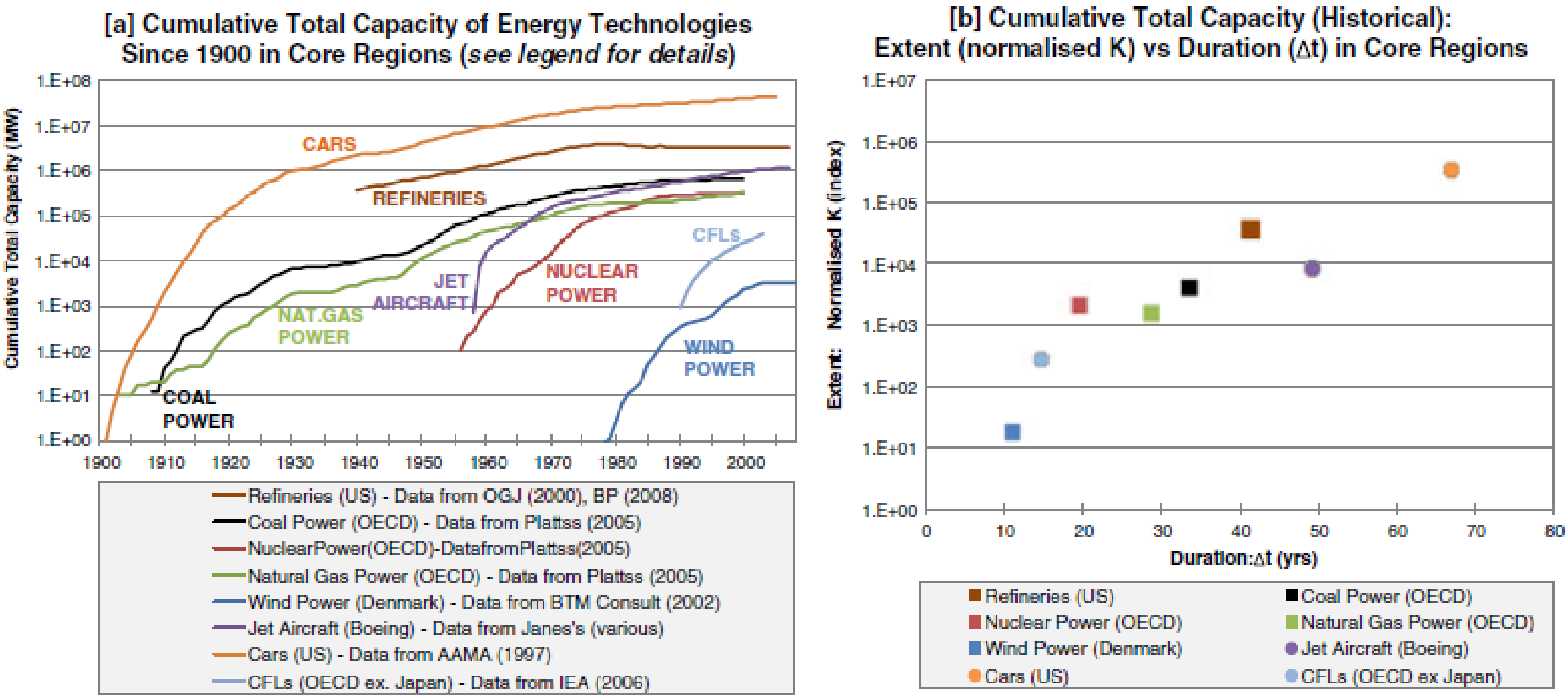

Fig. 1 Capacity growth of 8 energy technologies in the 20th century in their respective core regions (**a** *left panel*) with extent vs. duration of growth using fitted logistic parameters (**b** *right panel*). Source: see figure legend (and Online Resource 1 for details)

Source: Wilson et al. (2013)

REALISING TRANSITION PATHWAYS

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Capacity growth of 6 electricity technologies in 8 MESSAGE scenarios: extent vs. growth

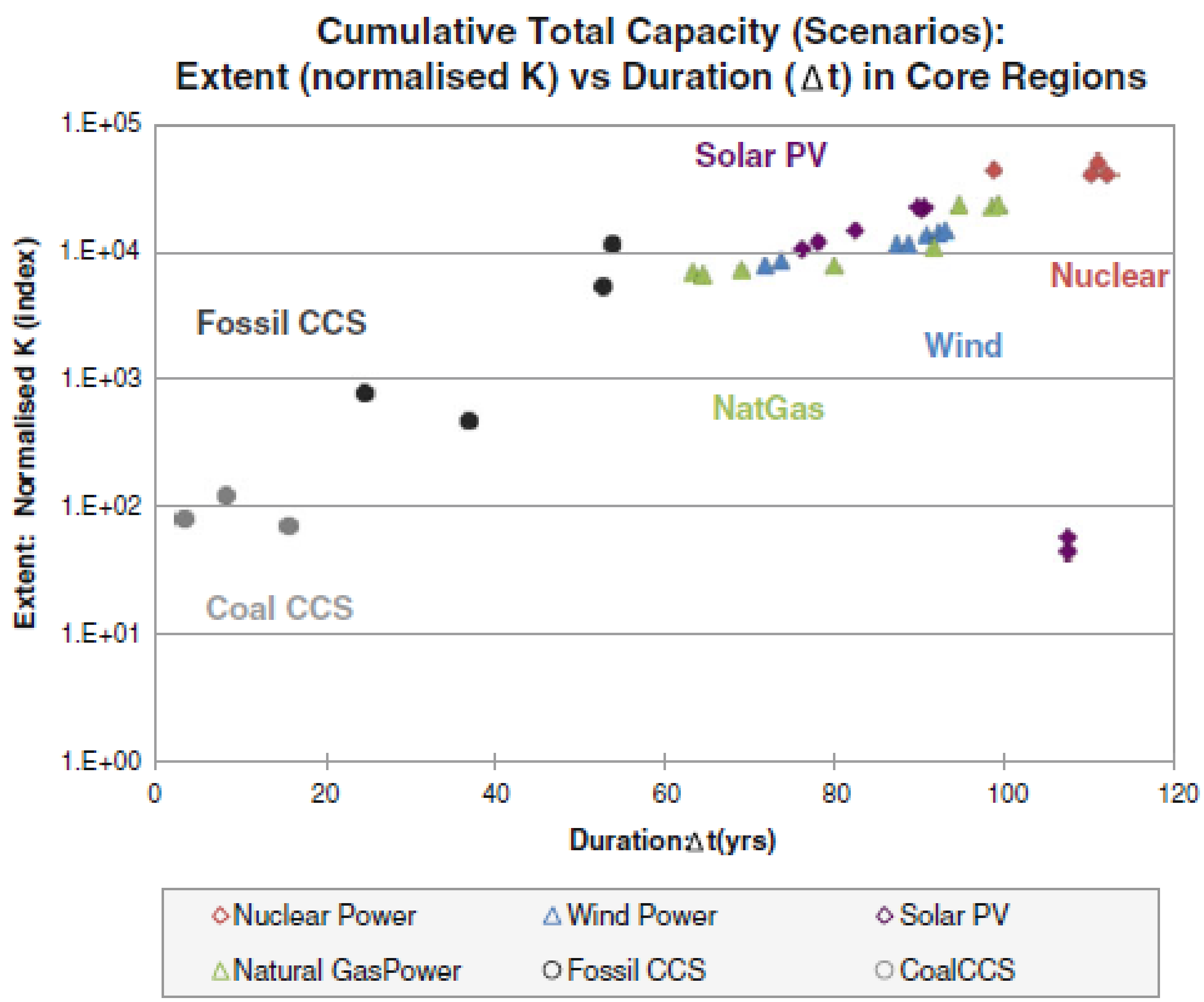


Fig. 2 Capacity growth of 6 energy technologies in 8 future scenarios of the 21st century in their respective core regions: extent vs. duration of growth using fitted logistic function parameters

Source: Wilson et al. (2013)

Extent-duration: historically & in future scenarios

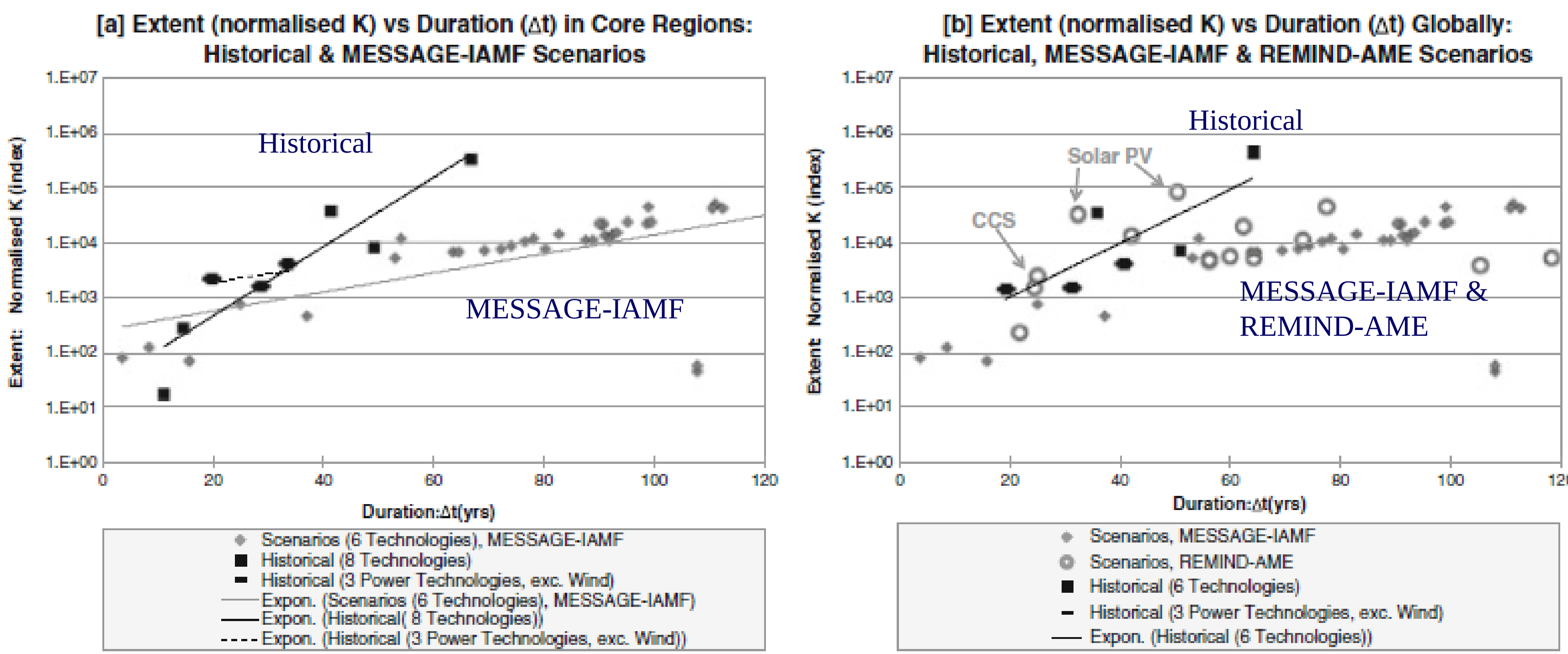


Fig. 3 Extent - duration relationships of capacity growth historically & in scenarios using fitted logistic function parameters. *Left panel* **a** shows core region data historically and for MESSAGE-IAMF scenarios. *Right panel* **b** shows global data historically and for MESSAGE-IAMF and REMIND-AME scenarios

Source: Wilson et al. (2013)

The scenarios depict longer capacity growth durations to reach a given extent of growth than the historical pattern

Explanations for scenario conservatism?

- No single explanation for the scenario conservatism
  - The centennial timescales of future scenarios or the use of historical energy technologies to build a comparator for future electricity technologies may mean this finding is a *methodological artefact*
  - Or energy system models may be *parametrically conservative* (in terms of growth constraints or other exogenous technology parameters)
  - And/or *structurally conservative* (e.g. endogenous drivers of & constraints on rapid capacity expansion).

Wilson at al: three important caveats

1) Potential explanatory variables for observed & modelled growth dynamics, inc. relative costs, efficiencies & technology turnover rates, not addressed
   – Cross-technology analysis => observed consistency of historical & scenario extent-duration relationships is inherently general
2. More historical data for more technologies needed, to provide reliable trend to compare with scenarios; scenario data could include end-use technologies from models with more detailed end-use sector resolutions
3. Use of logistic functions a strength in providing common form with extent & duration parameters allowing cross-technology comparisons. Its weakness: excluding technologies in early lifecycle &/or growing exponentially

So what does Wilson et al. tell us?

- Suppose Wilson et al. are right & findings survive greater scrutiny, better data, more explanatory variables, etc.
  - The scenario models are wrong & transitions to low carbon technologies could be quicker (& cheaper?)
  - *Implication:* models should better reflect observed historical processes; they remain relevant despite changes in socio-technical context & the externality/ public good nature of the climate change problem
- Or one or more caveats mean the results don't hold, so
  - History isn't a direct guide to the future;
  - The models are right & reflect, maybe inadvertently, the difficulties of ensuring growth & penetration of low carbon technologies, under current policies

Why might the transition be slower?

- Path dependence & inertia, technological & institutional lock-in – see innovation & sustainability transitions literature
- Responses by incumbent industries & technologies: Sailing Ship/Last Gasp Effects of obsolescent technologies
- Issues with the fitness for the market of low carbon technologies & their attributes
- Issues of governance (government/market/civil society logics)
- Energy & climate policy issues

Sailing Ship and Last Gasp Effects (SSE/LGE)

- The ‘sailing ship’ effect or ‘last gasp’ effect of obsolescent technologies
  - Where competition from new technologies stimulates improvements in incumbent technologies/industries
- Examples (sometimes with hybridisation)
  - sailing ship improvements after competition from steam ships
  - Eventual adoption of Welsbach gas mantle in response to incandescent electric lamps (late C19)
  - Carburettor enhancements in response to fuel injection
  - Hybrid electric/ICE vehicles
  - Disk drives with SS flash memory

Sailing ship and last gasp effects

- As well as responding with performance enhancements, high carbon actors also lobby to resist institutional changes that favour low carbon technologies
  - Example: efforts of large German utilities in the 1990s to lobby for repeal of renewable energy FiTs
- So sailing ship and last gasp effects can act to delay or weaken low carbon transitions and network decline
- *Note:* the threat here is from low carbon technologies promoted by government rather than purely by the market
  - As yet not all such technologies have attributes that are superior &/or cost-competitive with incumbents
  - Placing incumbents in strong position to respond

UK Gas Industry Transition 1945-1967*

- By World War II, 800 private & municipal firms supplying 'town gas' from coal
- Industry fragmented, uncoordinated & 'incoherent'
- Struggling to compete & with a costly feedstock
- 1948 nationalisation, reorganisation & new processes
- State-owned company, led by Gas Council
  - Rationalised industry structure - regional Area Boards & vertical integration
  - R &D investment & experiments with niche technologies:
    - Lurgi coal gasification, reforming oil & imported LNG from Algeria

* **Source:** Arapostathis et al. (2013)

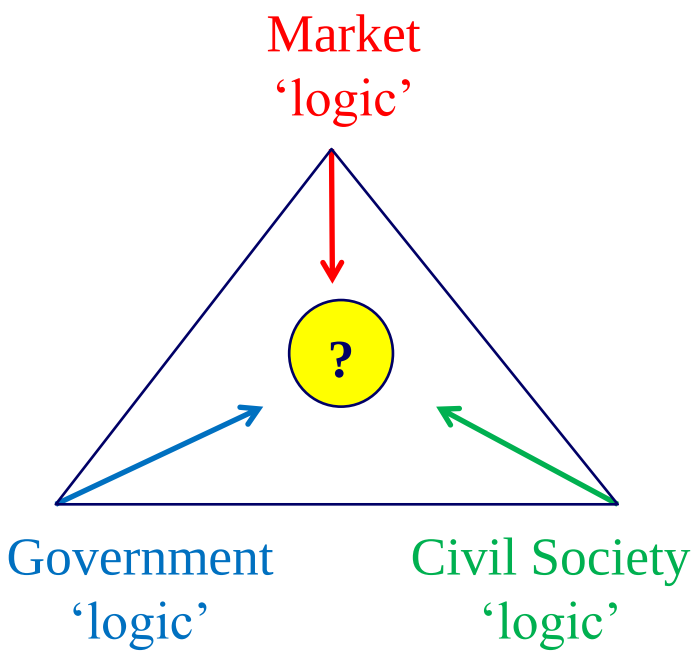
Example: UK Gas Industry Transition 1945-1967

- 1966: bold move to new North Sea natural gas
  - Reorganised industry & actors, developed terminals & national gas grid from LNG pipeline ‘backbone’
- Challenging 10-year conversion of appliances of 6 million consumers by 1977 required new skills & training
- So in less than 20 years, the industry
  - Reorganised itself twice
  - Undertook R & D & niche experimentation
  - Scrapped production assets, changed (fossil) supply feedstock/technology & end-use technologies
- But this was under a government-led mode of governance in an industry that had already recognised its challenges
- Is today’s gas industry ready for the low carbon challenge?

What we might capture, drawing on the past

- Historical case studies like that of the UK natural gas gas transition illustrate that
- The conduct & outcomes of energy & climate policy depend on the interplay within & between 3 ‘trilemmas’:
  - Energy system governance
  - Energy policy objectives
  - Technologies & their attributes
- And many other things too…
- But let’s start with these three

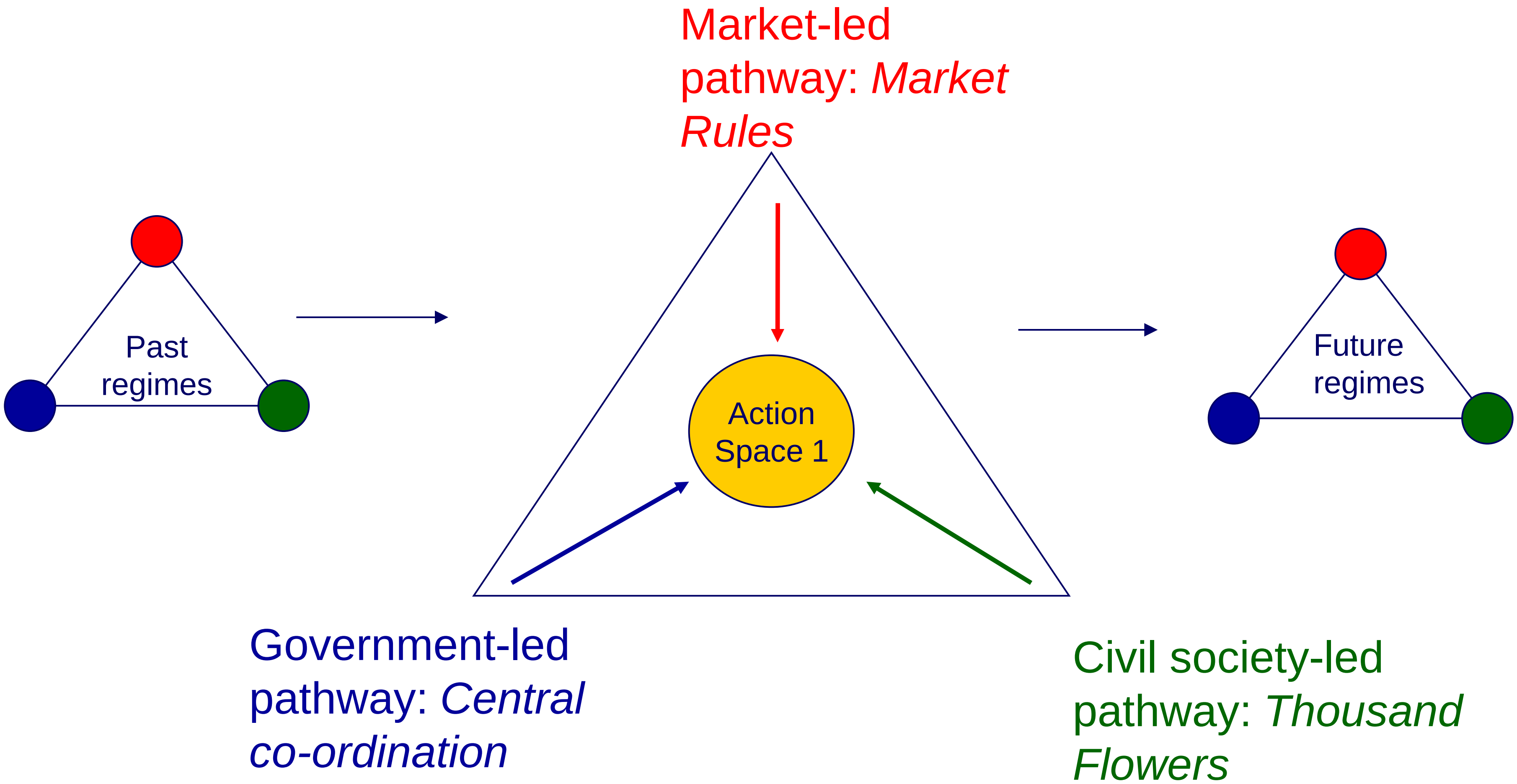
Action-Space Approach to Governance – 3 Key Actor Groups: Market, Government & Civil Society



Source: Jacquie Burgess & Tom Hargreaves – Transition Pathways Project (see Foxon, T.J. 2013)

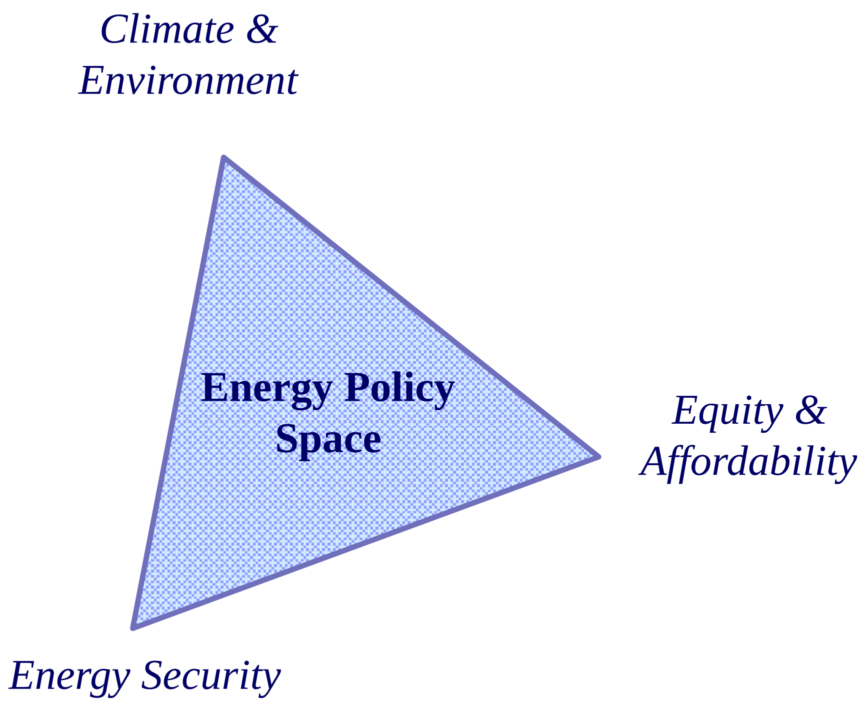
- Choices depend on actors' competing 'logics': messy, dynamic, interactive
- Action-space maps shifting relationships
- Via their *interactions,* each actor tries to '*enrol*' the others in their logic
- The dominant actor – i.e. best 'enroler' - defines that period's action-space
- Influencing the pathway & its branching points
- Recently we've seen UK moves from the market towards the government logic – Electricity Market Reform, etc.
- And questions about role of civil society, especially in the heat transition

The Action Space for Transition Pathways



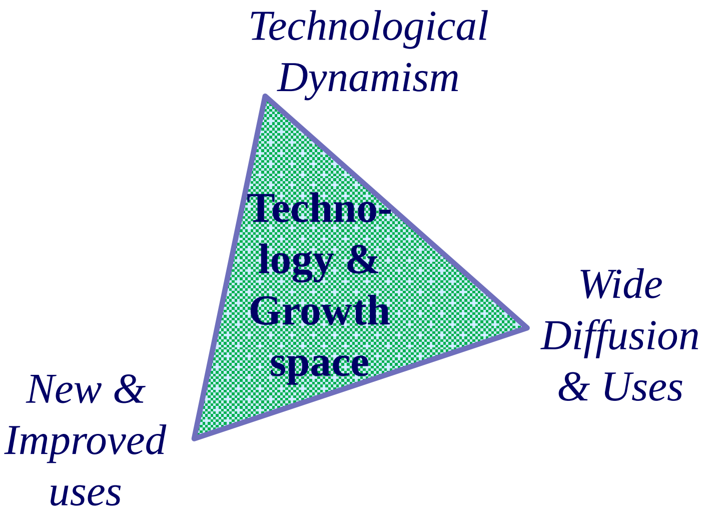
The Energy Policy Trilemma

- In the UK & other countries we have seen changing priorities between these three objectives



Technology: General Purpose Technologies (GPTs)

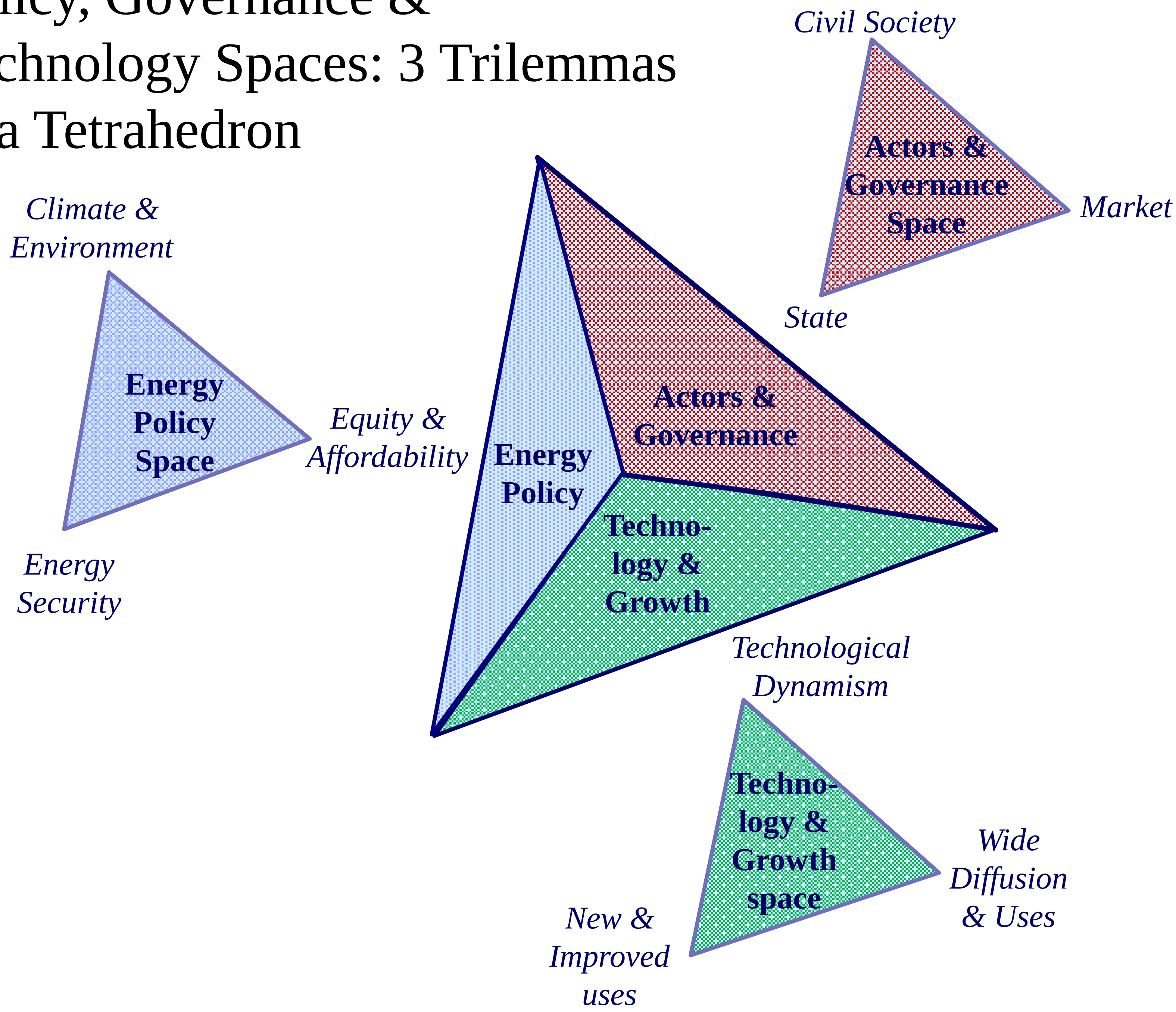
- GPTs help explain why the Industrial Revolution's technical progress went on instead of petering out
- Three core properties:
  - Capacity for continued innovation: costs fall & quality rises
  - Wide range of general uses
  - Users improve own technologies & find new uses (examples: steam engine, electrification, ICE & ICT)



Bringing the trilemmas together

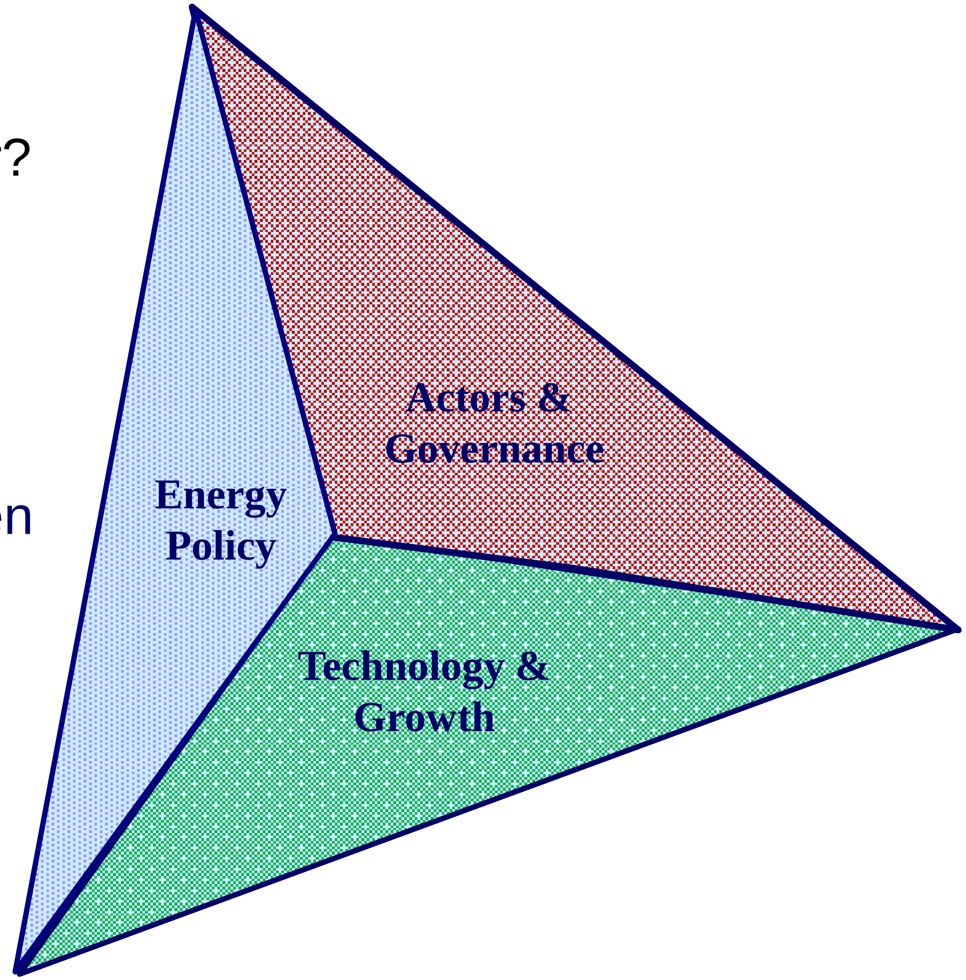
- Successful conduct of energy & climate policy determined not only by how a country resolves each trilemma, i.e.
  - The ranking of its policy objectives,
  - The logic & mode of governance it chooses & how it engages with key actors,
  - The properties of the energy supply & use technologies it develops
- But by how these three elements interact with & feed back onto each other

Policy, Governance & Technology Spaces: 3 Trilemmas & a Tetrahedron



Policy/Governance/Technology Space

- This reminds us to think about
  - What are policies aiming for?
  - Who is aiming for it & with what forms of governance?
  - With what technologies & practices?
- How might the interplay between energy policy, governance & technology play out (locally, nationally, globally) in future pathways?



Conclusion

- The Wilson et al. paper offers a useful reminder of the importance of drawing on historical experience – without necessarily trying to replicate it (should we expect high carbon transitions to be close analogues for a low carbon transition?)
- Scenarios can learn from past transition experiences, without trying exactly to replicate them in a changed and changing world
- History matters and, from the Industrial Revolution onwards, illustrates the interplay between policy, governance & technology – an interplay we should explore in scenarios of the future.

Sources & Notes

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