UCL Institute for Sustainable Resources

The Economics of Innovation & Transition

Lessons and principles for policymaking

ECONOMICS OF ENERGY INNOVATION AND SYSTEM TRANSITION

Presentation to **LCS-RNet 13th Annual Meeting**

New Scientific Challenges for Strengthening Actions Based on IPCC AR6

16th December 2022

Michael Grubb, Professor of Energy and Climate Change, UCL

Strategy Director, *Economics of Energy Innovation and System Transition (EEIST)*

Convening Lead Author, IPCC Sixth Assessment Report – Mitigation

- Energy innovation: recent breakthroughs
- Case studies and lessons learned
- A broadened theory of innovation processes
- The stylized dynamics of transition
- The UK electricity transition
- A generalized view on transition dynamics and policy

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Q: What two things do the following energy technologies have in common?

- Offshore oil extraction
- Shale gas
- Combined cycle gas turbines
- Solar PV
- Wind energy
- High efficiency lighting (LED lights)

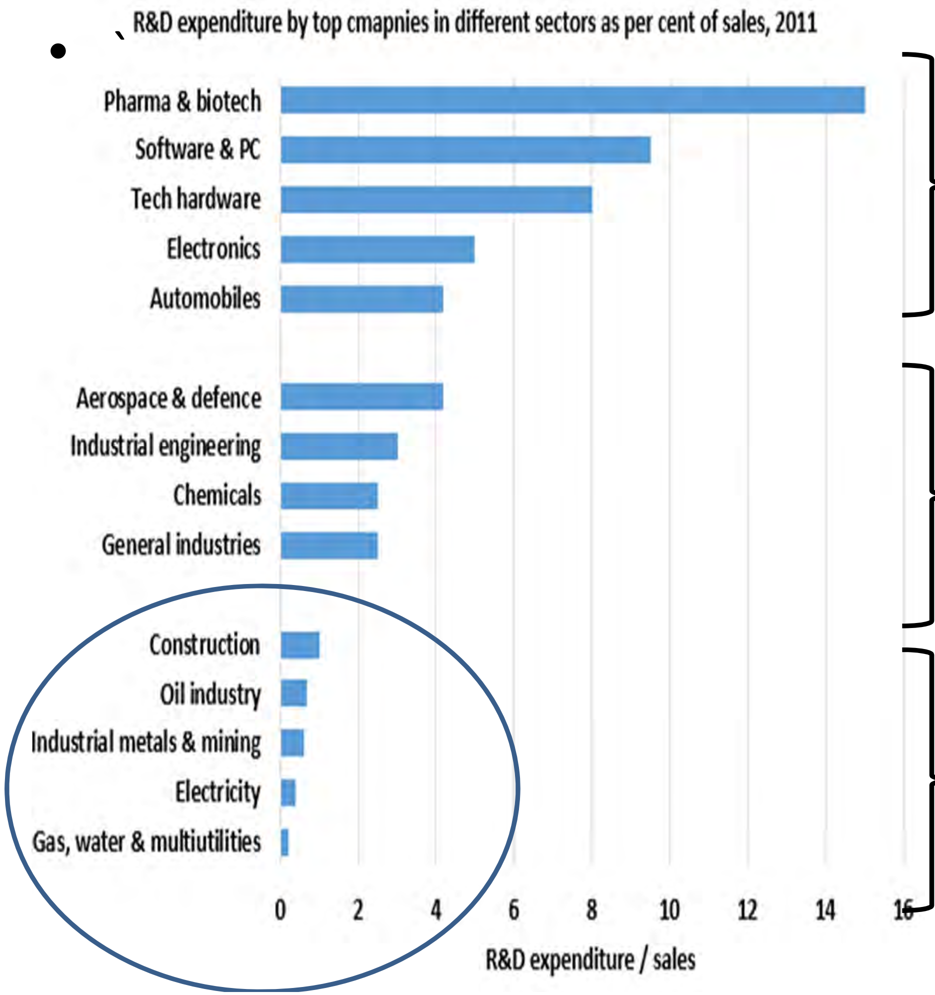
[1] They all turned out to be ***much cheaper*** than anyone expected

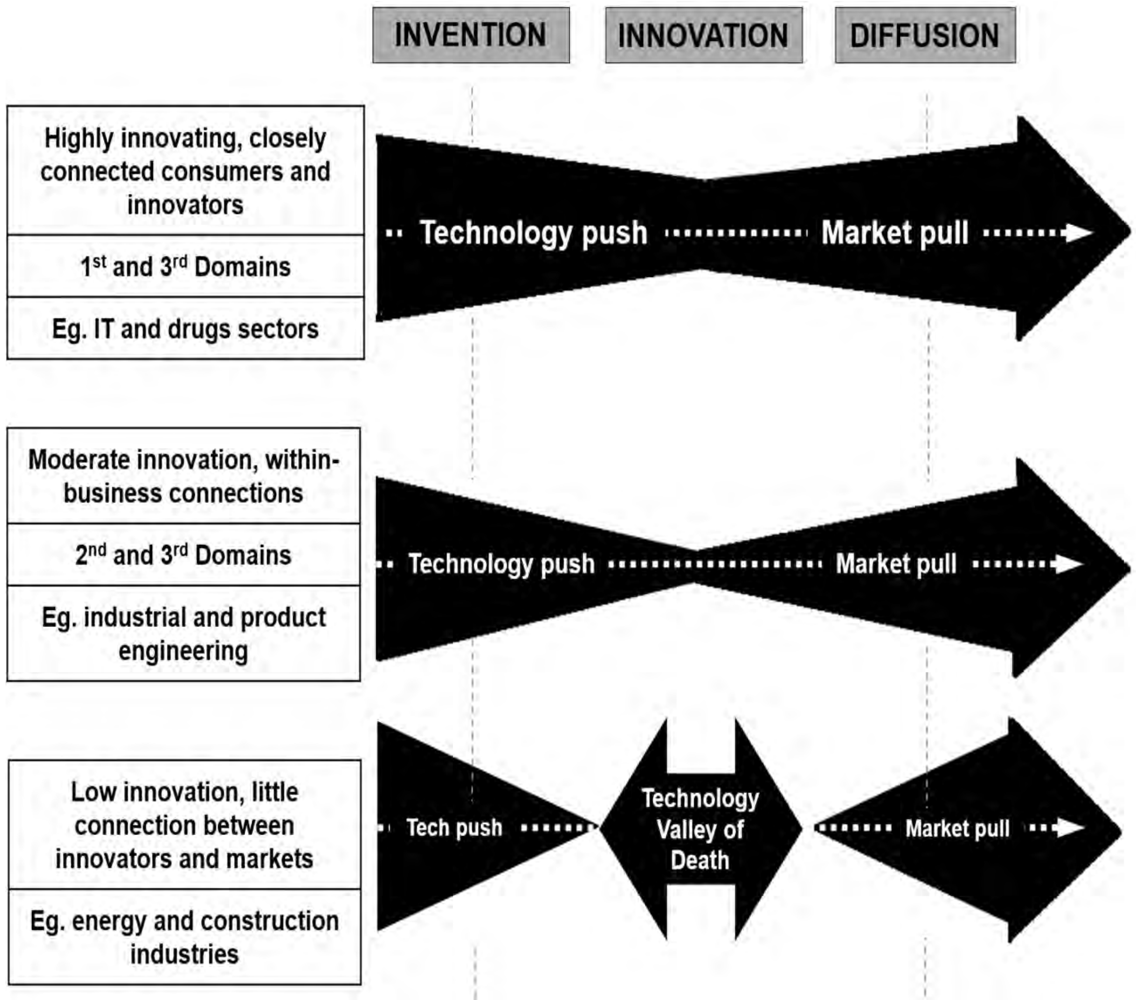
[2] They all involved government action at scale over many years

- On both technology/resource development, and demand/price

The energy-climate challenge – seek radical change in …

… some of the historically least innovative sectors of our economies

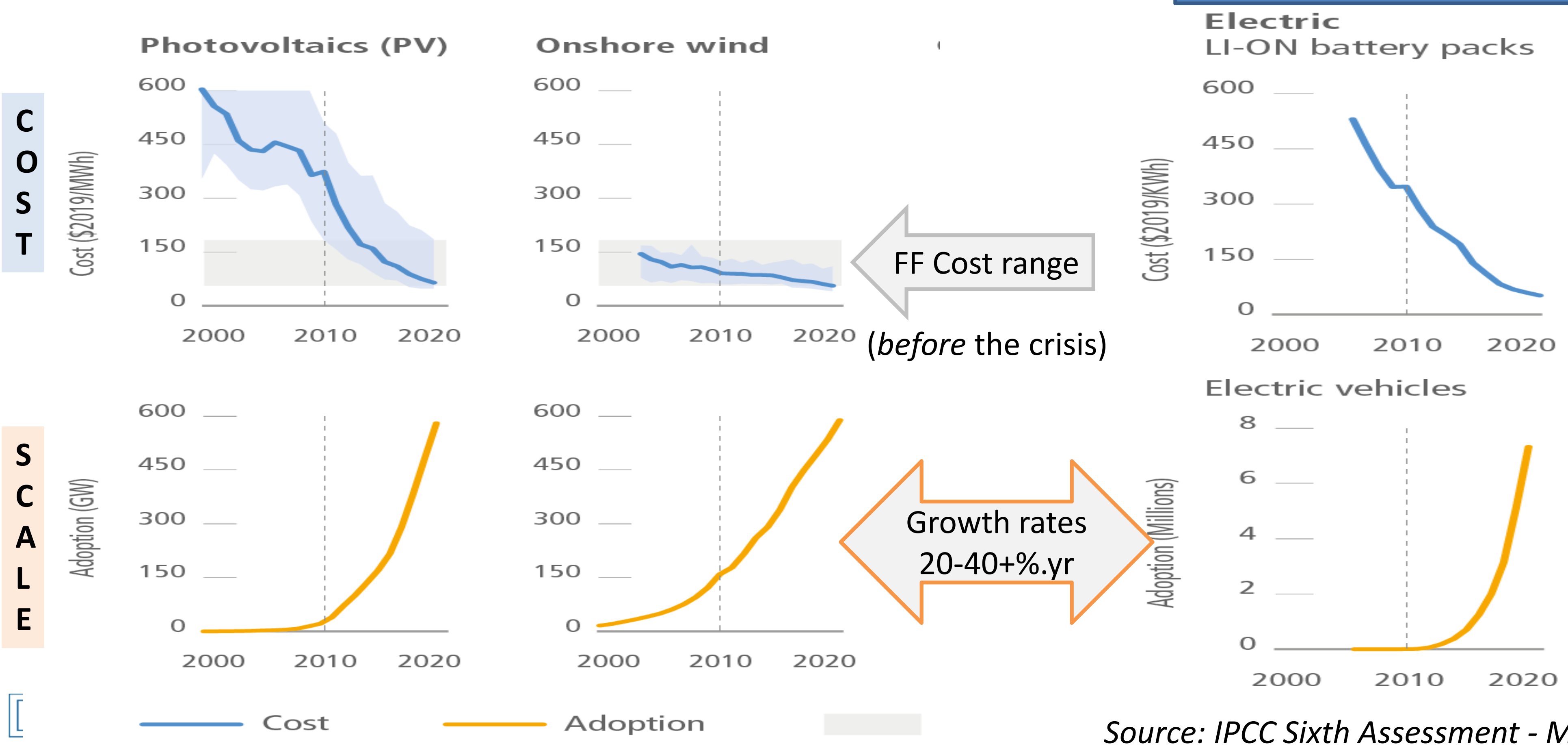




Innovation is *not* just R&D – but way beyond …

PV is most dramatic – now at bottom of range of cost of new fossil fuel (like wind) … but not the only one ..

Batteries & Vehicles



Source: IPCC Sixth Assessment - Mitigation

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THE NEW ECONOMICS OF INNOVATION AND TRANSITION: EVALUATING OPPORTUNITIES AND RISKS

A REPORT BY THE ECONOMICS OF ENERGY INNOVATION AND SYSTEM TRANSITION (EEIST) CONSORTIUM

MICHAEL GRUBB, PAUL DRUMMOND, JEAN-FRANCOIS MERCURE, CAMERON HEPBURN, PETER BARBROOK-JOHNSON, JOÃO CARLOS FERRAZ, ALEX CLARK, LAURA DIAZ ANADON, DOYNE FARMER, BEN HINDER, MATT IVES, ALED JONES, GAO JUN, ULKA KELKAR, SERGEY KOLESNIKOV, AILEEN LAM, RITU MATHUR, ROBERTO PASQUALINO, CRISTINA PENASCO, HECTOR POLLITT, LUMA RAMOS, ANDREA ROVENTINI, PABLO SALAS, SIMON SHARPE, ZHU SONGLI, PIM VERCOULEN, KAMNA WAGHRAY, ZHANG XILIANG

Key Findings

- Evidence
- Principles
- Implications

Evidence: Learning from Successes

Wind: from 1 to 10-15% in Brazil and Europe in a decade

Policy support 'both push and pull' – R&D, collaboration, industry-building, public-backed banks and contracts

Cumulative improvements

Globalisation of the *market*

Financial involvement crucial

Big breakthroughs also in offshore wind costs

Solar PV: from 'the most expensive' to 'the cheapest electricity in history'

Long evolution from R&D through niche commercialisation

Breakthroughs from strategic commitment driving market scale

Internationalisation of *production*

Prompting Chinese domestic ambition and globalisation of diffusion

Energy efficient lights: from high-tech gadgets to lighting the poor

Indian energy-efficiency institutions stimulated by Kyoto's Clean Development Mechanism

Linked to drive for 'modern energy services'

Bulk public procurement and smart policy though electricity suppliers drove **85% cost reduction *in four years***

'The cheapest lighting in history'

These + forward looks at EVs and low carbon steel, now at eeist.ac.uk

UK Offshore wind - the components of cost reduction

Offshore wind in the UK – A remarkable success story

£170 MWh (2008) → **£40** MWh (completion 2023)

R&D

Predominantly private R&D incorporated learning from one generation/size of turbine into the next

Larger turbines in turn required R&D across balance of plant, installation and O&M technologies which, whilst still industry-led, benefited from some public R&D support

Learning-by-doing

Learning-by-doing gained through each successive generation/size of turbine

Economies of scale

Economies of scale are principally from the larger turbines, whose increase in size has delivered the greatest cost reduction, requiring half the installation and less balance of plant and O&M

Finance costs

Finance costs have plummeted as the industry has achieved scale and confidence in each generation/size of turbine and its associated installation and operation

Driven through strong, sustained and well-targeted ***government support***

See: *Jennings et al (2020) Policy, innovation and cost reduction in UK offshore wind, Carbon Trust, London*

Big themes from case studies

- Led by strong government action; all are now largely self-sustaining
- Would not have been pursued under traditional economic cost-benefit assessment
- Common themes include:
  - ***Cumulative progress.*** Built upon previous progress, not blue-skies lab breakthroughs (innovation is '*cumulative,* and *path-dependent')*
  - ***Market-based innovation*.** market-based innovation and cost reduction, particularly associated with the deployment phase.
  - ***Sustained and targeted support beyond R&D****.* involved sustained support for deployment, mostly for 1-2 decades beyond the period dominated by public R&D.
  - ***Substantial uncertainties*,** at least in the earlier stages of deployment until critical thresholds were passed.
  - ***Strong international dimensions.*** It was indeed internationalisation that often sustained the growth of the technologies and helped them pass critical thresholds.

Induced by scale & incentives: systemic review

Search-Links	Findings
energy / carbon prices -> innovation indicators/outcomes	- **clear evidence of a positive** link between energy price increases and patenting across these sectors – although strongest effects are usually **lagged**, often by several years - commonly **path-dependent** and based on previous knowledge stock – e.g. firms previously involved in 'clean' patenting (e.g. renewables, electric vehicles) vs. 'grey' patenting - **induced *incremental* innovation** (e.g. more efficient processes), and mostly when prices were high, or increasing stringency (and thus price) was expected in future.
targeted policy -> innovation indicators/outcomes	- Clear evidence **Feed-in Tariffs (FiTs)** induced patenting for solar PV - **Renewable Portfolio Standards** induced patenting in more mature renewables - **Regulatory (i.e.energy & CO_2) standards** induced patenting in energy efficient & low-carbon
Learning Curves	- **Unambiguous correlation** between deployed scale and cost reduction in almost all of > 1000 studies, reasonable evidence of causal relationship scale -> cost reduction
Macro -> Outcomes	- **Oil shocks** switched technical change from energy-increasing to energy-saving. "by 2000, 40% of fall in aggregate energy intensity attributable to induced technical change" - **Asymmetric price elasticities** ('what goes down doesn't necessarily come back up …') .. "almost all of the preferred models for OECD industrial energy demand incorporate both a stochastic underlying energy demand trend and asymmetric price responses"

BOTTOM LINE: "HICKS (1932) WAS RIGHT": Induced Innovation is real and important

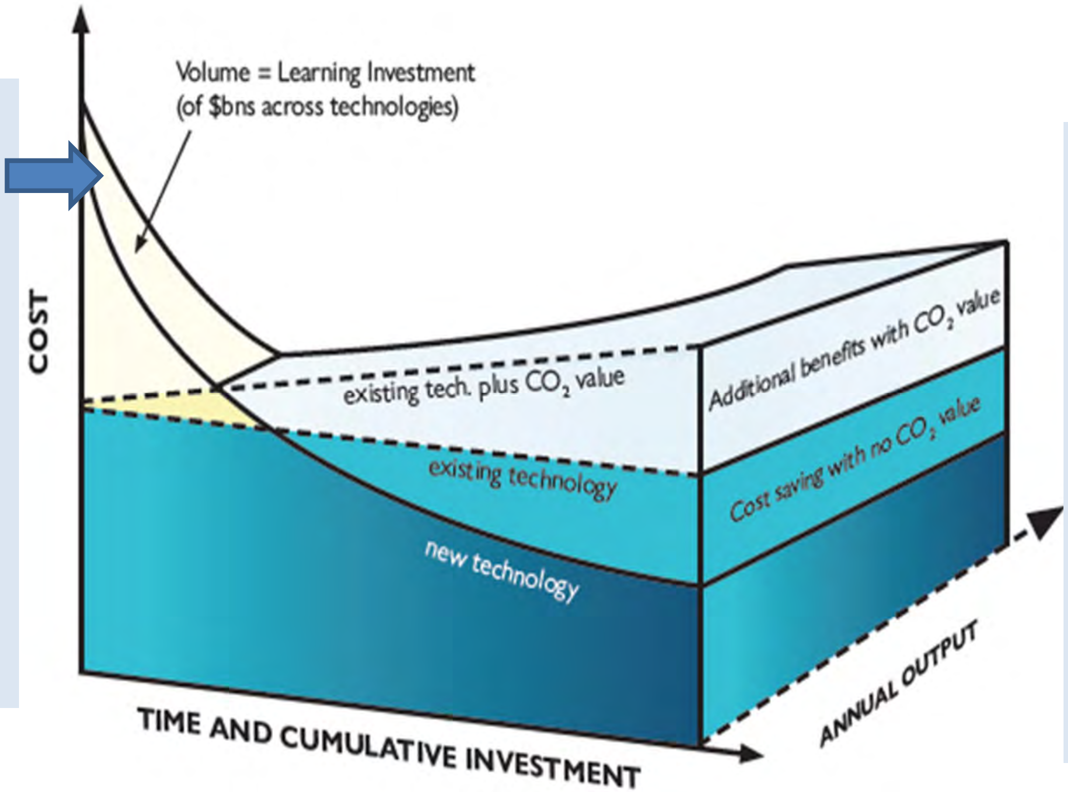
Grubb M., P.Drummond, A.Poncia et al, (2021). Induced innovation in energy technologies and systems: a review of evidence and potential implications for CO2 mitigation, Environ. Res. Lett. https://doi.org/10.1088/1748-9326/abde07

Dynamic framework for Strategic Investment

Innovation beyond RD&D - can be costly but the returns can be huge,
particularly when integrated with energy/externality pricing

North-Sea oil investments in the 1970s cost UK c.£100bn, remarkable cost reductions emerged

Offshore wind, a similar story, but driven by UK government (not OPEC!)



Rising carbon price could

Help fund innovation

Shift capital from clean to dirty

Give strategic direction

(but could never have driven the breakthroughs)

Both costs and benefits come with sizeable up-front uncertainties

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The extreme caricatures are usually unhelpful

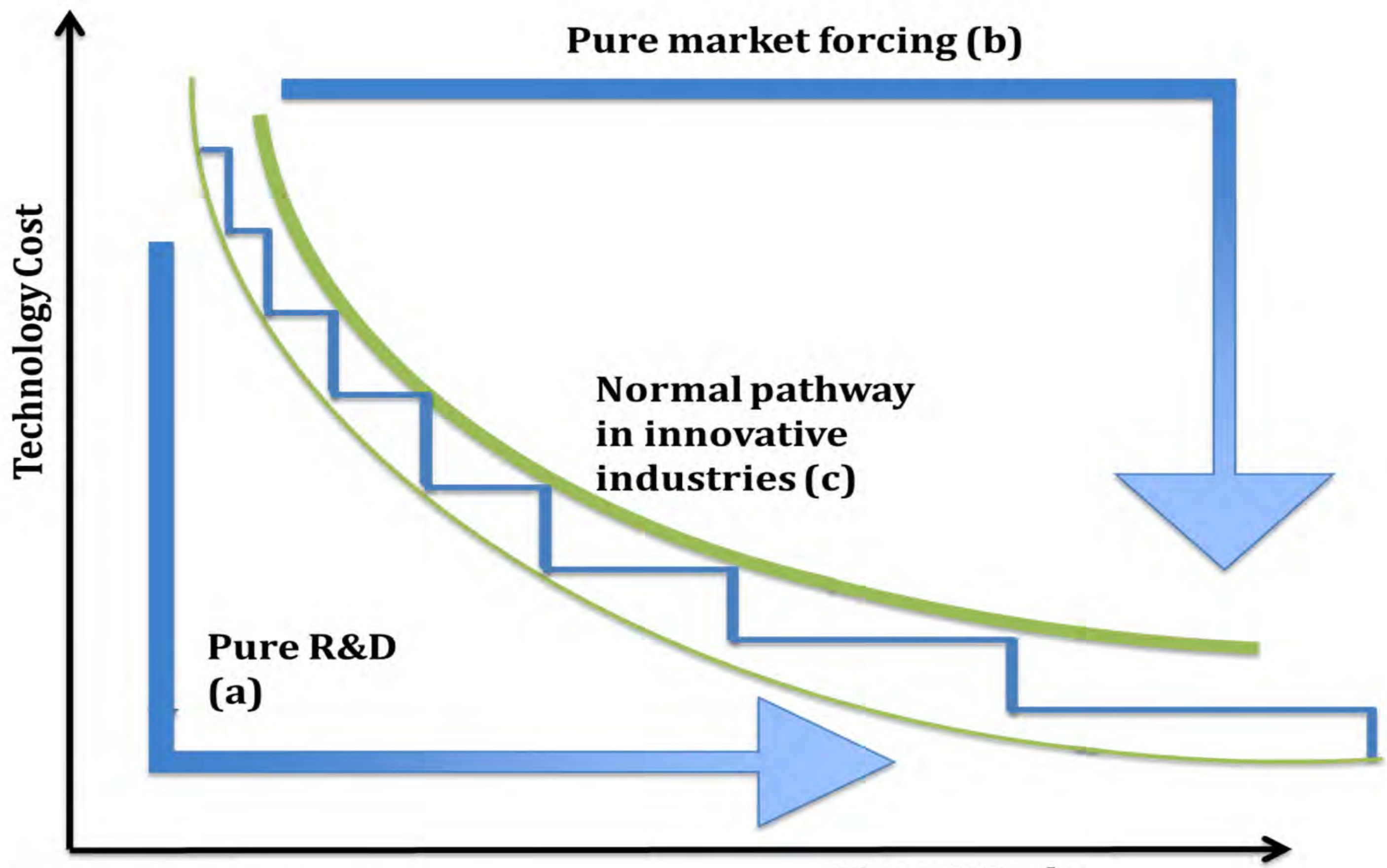
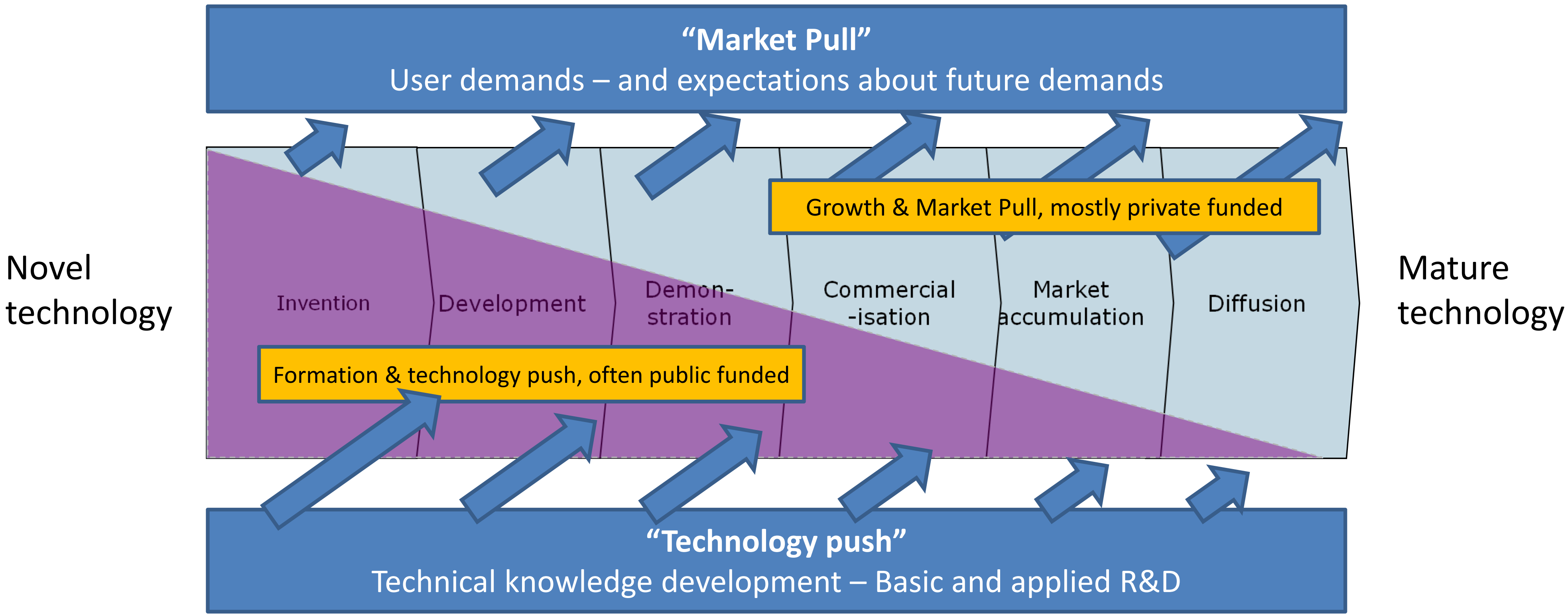


Fig.9.6 Technological diffusion pathways
Source: CIRED, France

… The reality is that most technologies have to evolve through repeated cycles of market growth, learning, scale economies and supply chain development

Real innovation is complex ...

Push *and* Pull, Private *and* Pubic, in many dimensions



Grubb M.J., W.McDowell and P.Drummond (2017), On order and complexity in innovations systems: Conceptual frameworks for policy mixes in sustainability, transitions, Energy Research and Social Sciences, Vol.33:pp21-34

Successful innovation must span a complex multi-domain journey

Technology journey	Basic R&D	Technology RD&D	Demonstration	Commerciali-zation	Market accumulation	Wide diffusion
Organisation & supply chain	1 or 2 individuals	Venture or new unit	First outsiders	Recruit specialists, Develop supply chain	Grow operational staff	Mature company or independent division
Customers and standards	No market defined	first targeting of possible markets	Choosing Market of commercial-ization	Early adopters and niches, basic standards	Expanding range of customers	Well defined customer Profile, trusted brand
Financing	Public or Internal funding	Internal funds or project grants	Internal funds, project grants, angel or VC investors	First sales, internal or external funds still needed	First profits	Financing through private equity, banks, etc.
Market Regulation	Neutral or negative regulation	Neutral or negative regulation	Neutral regulation	Specific positive regulation	Positive general regulation	Fully adapted regulatory environment
Institutional	Research institutions	Bespoke tech institutions	First sector associations	Eg. first IPO, licence acquisitions	Lobbying, corporate expansion	Stable role of associations in negotiating sector policy
Infrastructure	Research infrastructure	Test centres	Negative or neutral	'Piggybacking'/ First enabling infrastructure investments	Barriers from existing infrastructure	Adapted or dedicated infrastructure

1st

2nd

3rd

Growing social scale and role of higher domains

Source: Grubb, McDowell and Drummond (2017), On order and complexity in innovations systems, Energy Research & Social Science; derived from Fig.9.8 in Grubb et al (2014) *Planetary Economics*

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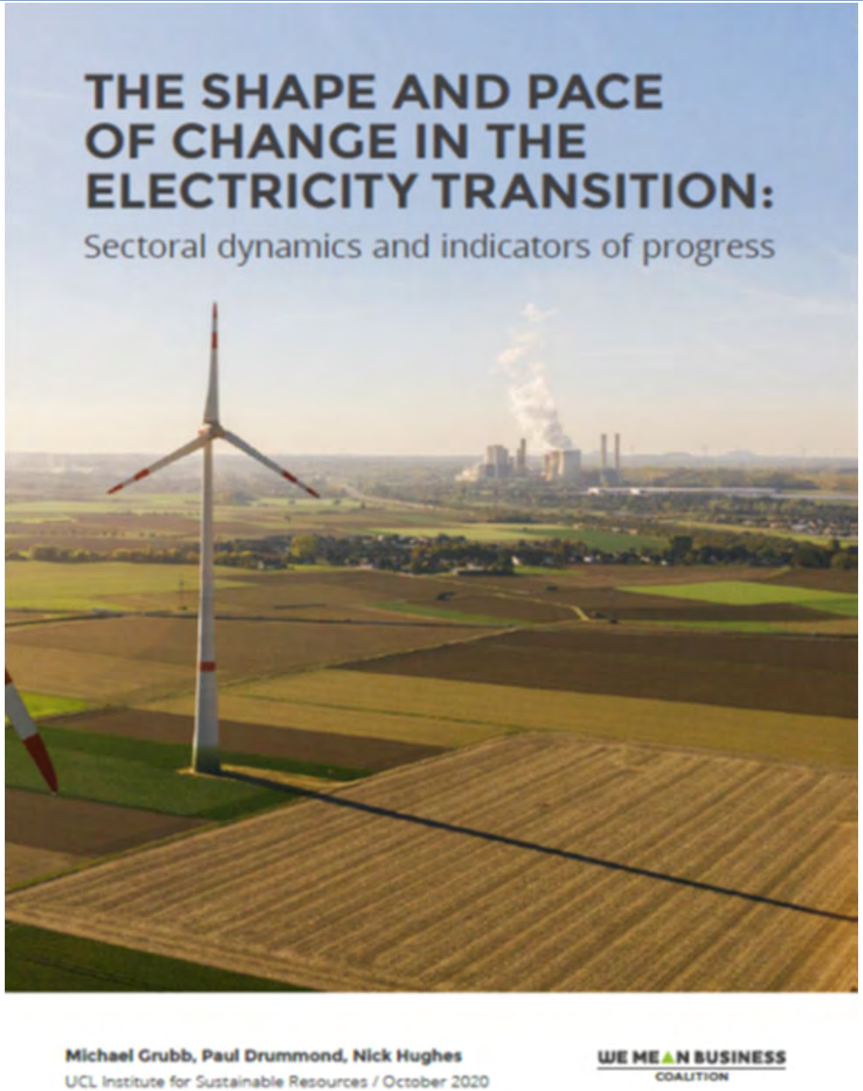
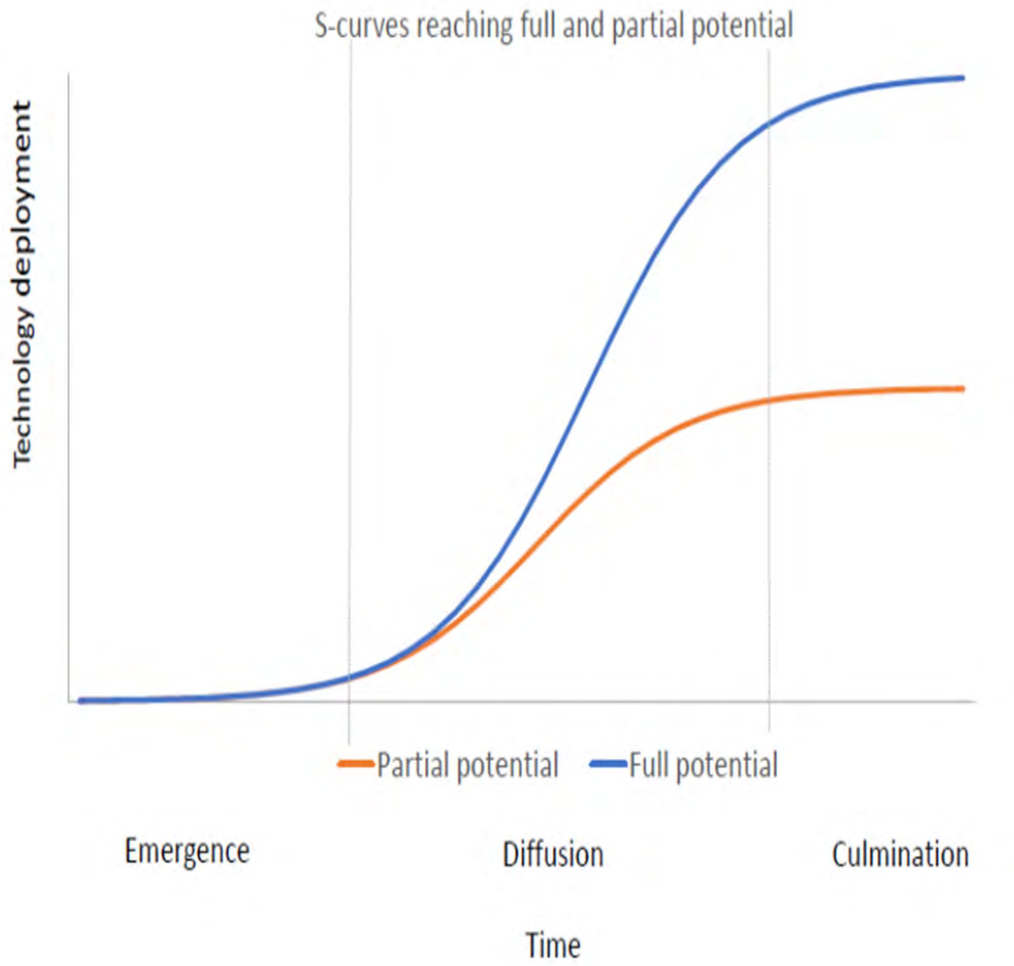
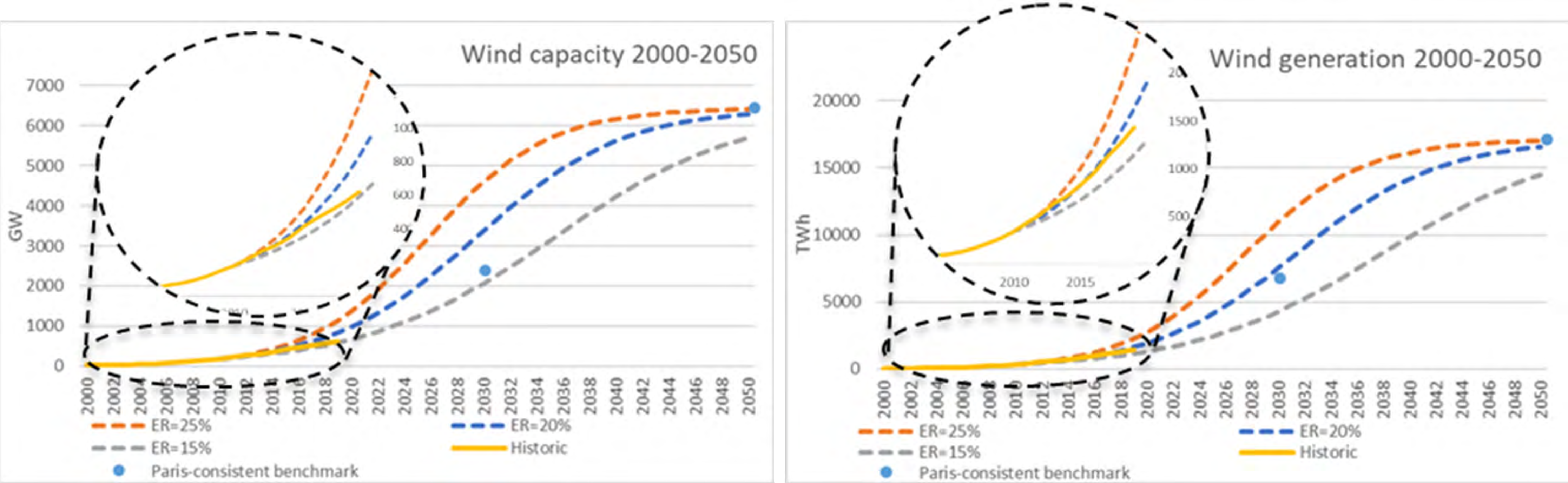




https://www.wemeanbusinesscoalition.org/s-curve-power-report/

The power of exponential / S-curve growth: wind

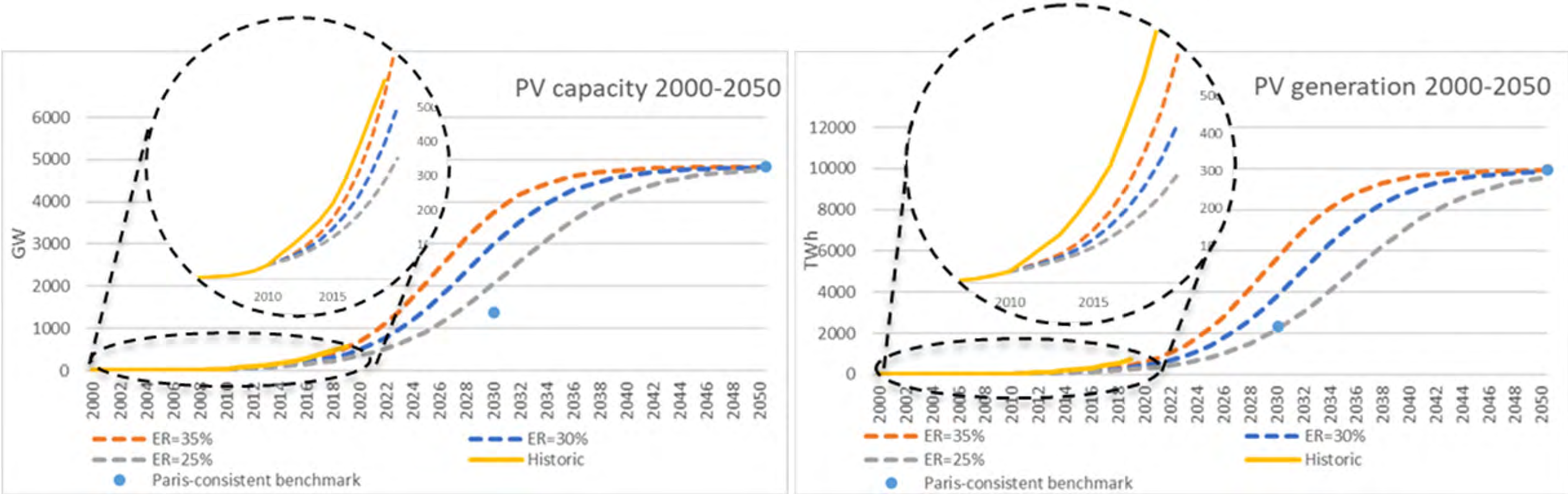
Wind installed capacity and generation – historic trend and S-curve projections



Notes: Historic values for 2000-2019, from IRENA (2020a) and BP (2020). S-curve projections start from 2010 values. Saturation point of S-curves set at relevant 2050 Paris-consistent benchmark. Left-hand panel shows capacity, right-hand panel shows generation. Call-outs focus on 2000-2020.

The power of exponential / S-curve growth: PV

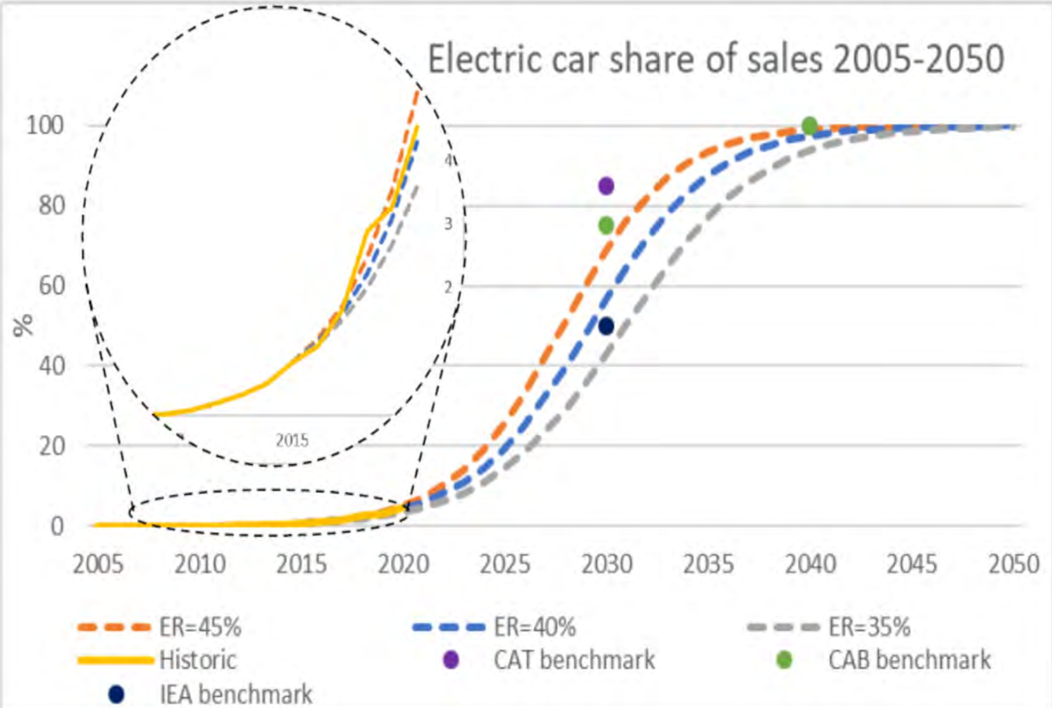
Solar PV installed capacity and generation – historic trend and S-curve projections



Subsequent report (*Shape and pace of change in transport)* also identified exponential growth in electric vehicles, and traced implications

Notes: Historic values from 2000-2019, from IRENA (2020a). S-curve projections start from 2010 values. Saturation point of S-curves set at relevant 2050 Paris-consistent benchmark. Left-hand panel shows capacity, right-hand panel shows generation. Call-outs focus on 2000-2020.

Electric vehicles too …



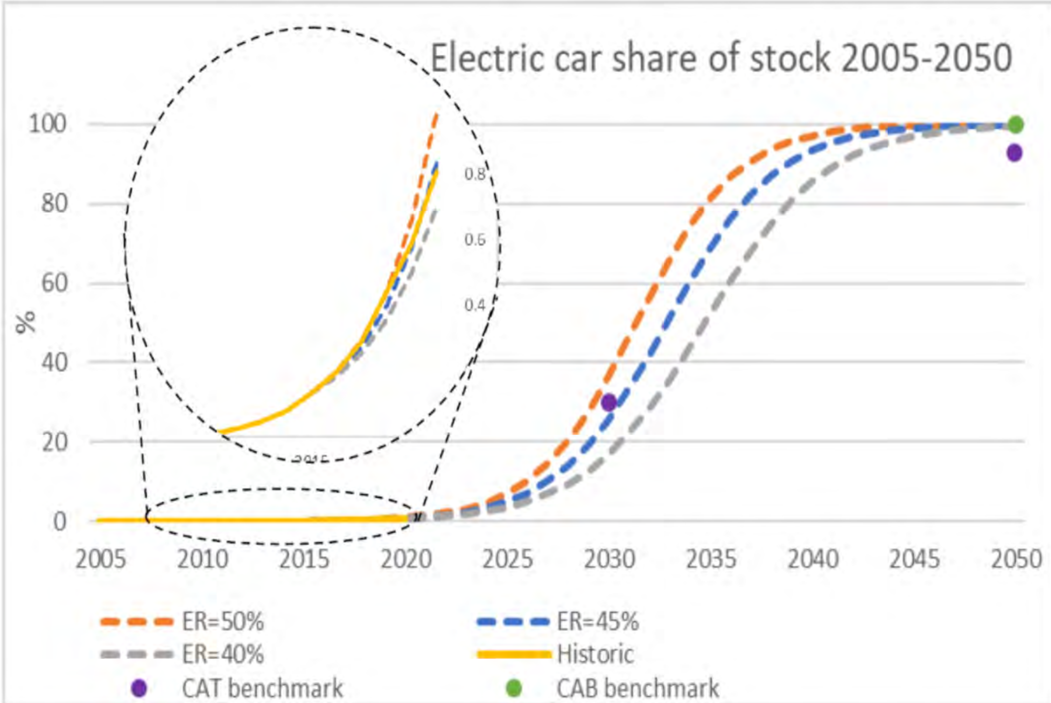


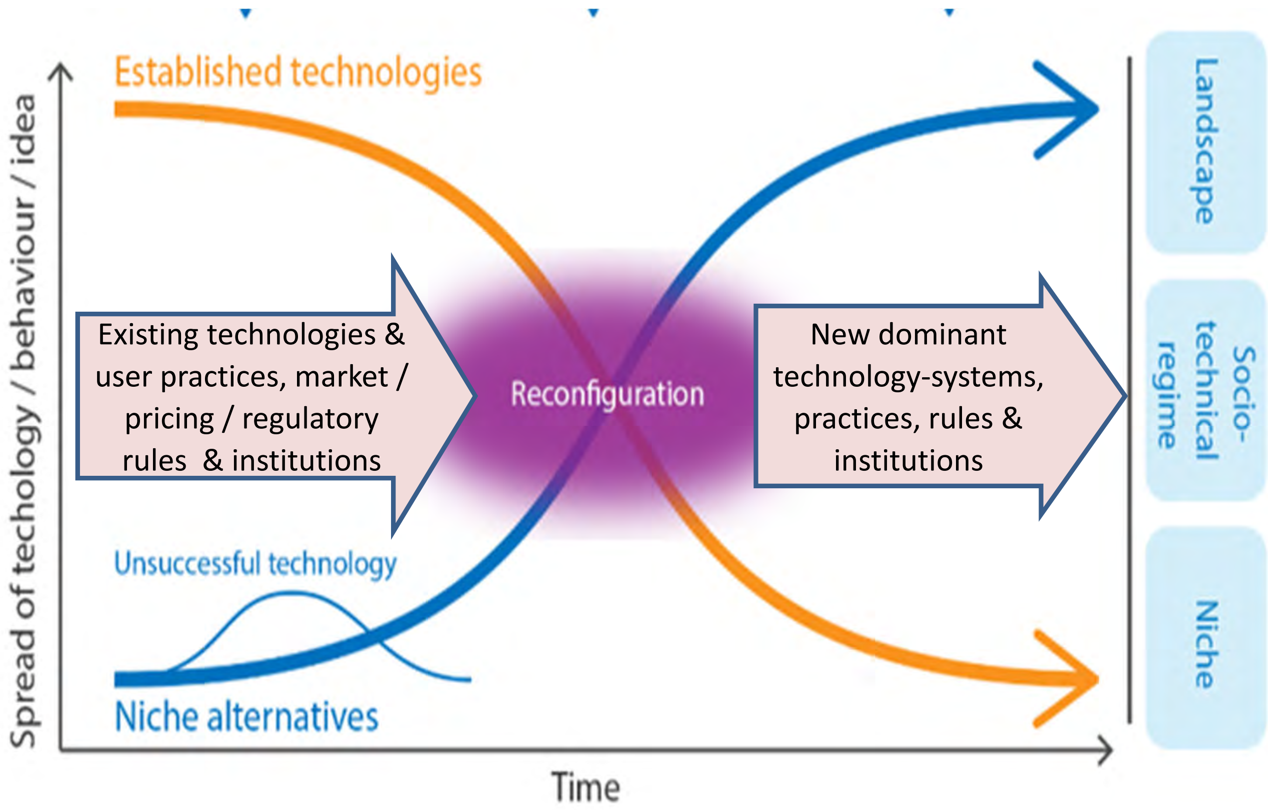
Figure 5: Electric car share of sales. Historic values from 2005-2020. Total sales of electric cars for 2005-2019 from IEA Global EV Outlook (IEA, 2020c), Statistical Annex, Electric Car New Registrations (BEV and PHEV) by country. Total sales of passenger cars for 2005-2019 from OICA (OICA, 2020a), Sales Statistics, New Passenger Car Registrations. 2020 electric car sales and total car sales calculated based on Irle (2021) and IEA (2020b). Share calculated from these data. S-curve projections start from 2015 values. CAT benchmark refers to LDVS, and 2030 value is the mid-point of the range. CAB benchmark is >95% in 2040, has been set here as 100%, and refers to LDVs. IEA benchmark refers to passenger cars and is based on the Net-Zero Emissions by 2050 (NZE2050) scenario from the World Energy Outlook (2020e). Saturation point of S-curves set at 100%.

Transitions are complex dynamic processes …

Impact on incumbent technologies / businesses initially modest, but …

…. over time may involve substantial reconfiguration of existing infra/market structures

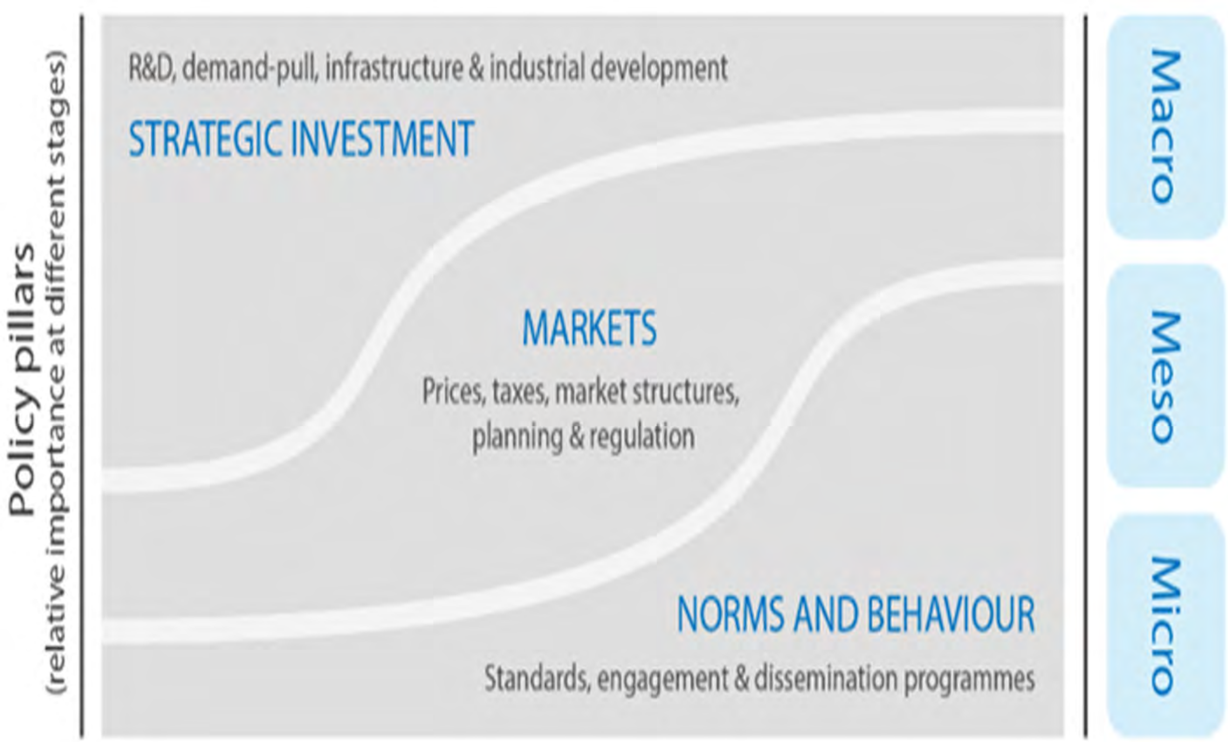
May start small, and take many years, *technology* emergence followed by *market* emergence



Source: IPCC Sixth Assessment Report – Mitigation (Chapter 1 / Technical Summary)

A mix of complementary policy instruments, evolving with transition

- Strategic Investment to foster emerging technologies and businesses, 'leaders'
- Evolve or reconfigure infrastructure, market structures suited to new tech
  - scale in lead markets & supply chains
  - accelerate global diffusion
- Expand with attention to standards, norms, behaviour, to support widespread adoption and 'laggards'



Source: IPCC AR6 - Mitigation Report, Figure TS-31. Developed in M.Grubb, P.Drummond and A.Poncia, "*Different therefore equal*: economic diversity and the paradox of carbon pricing", Paper for Swedish Entrepreneurship Forum and KTH Royal Institute of Technology workshop "The Political Economy of Climate Change", *In Review*

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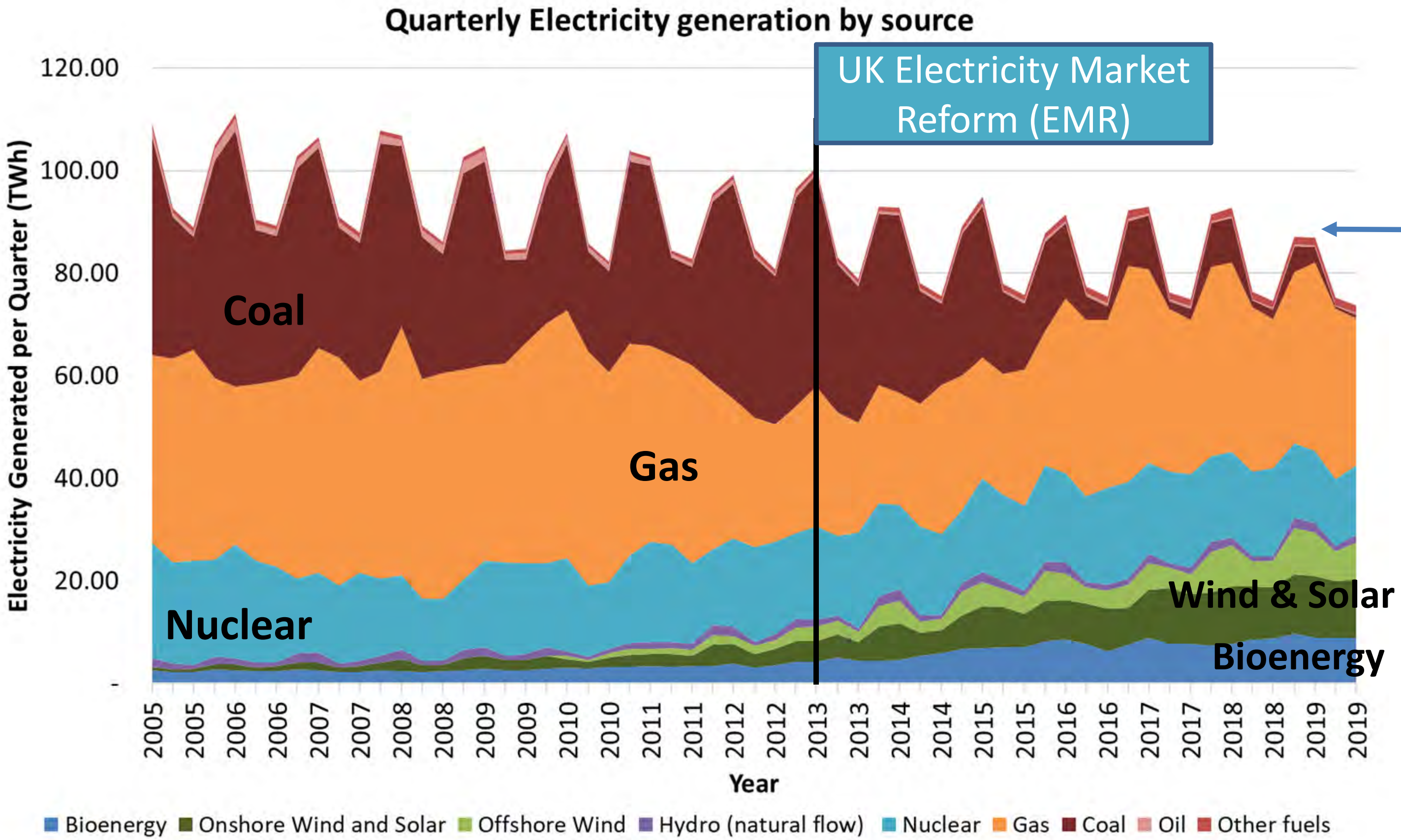
UK 'island of coal in a sea of oil and gas' – no longer

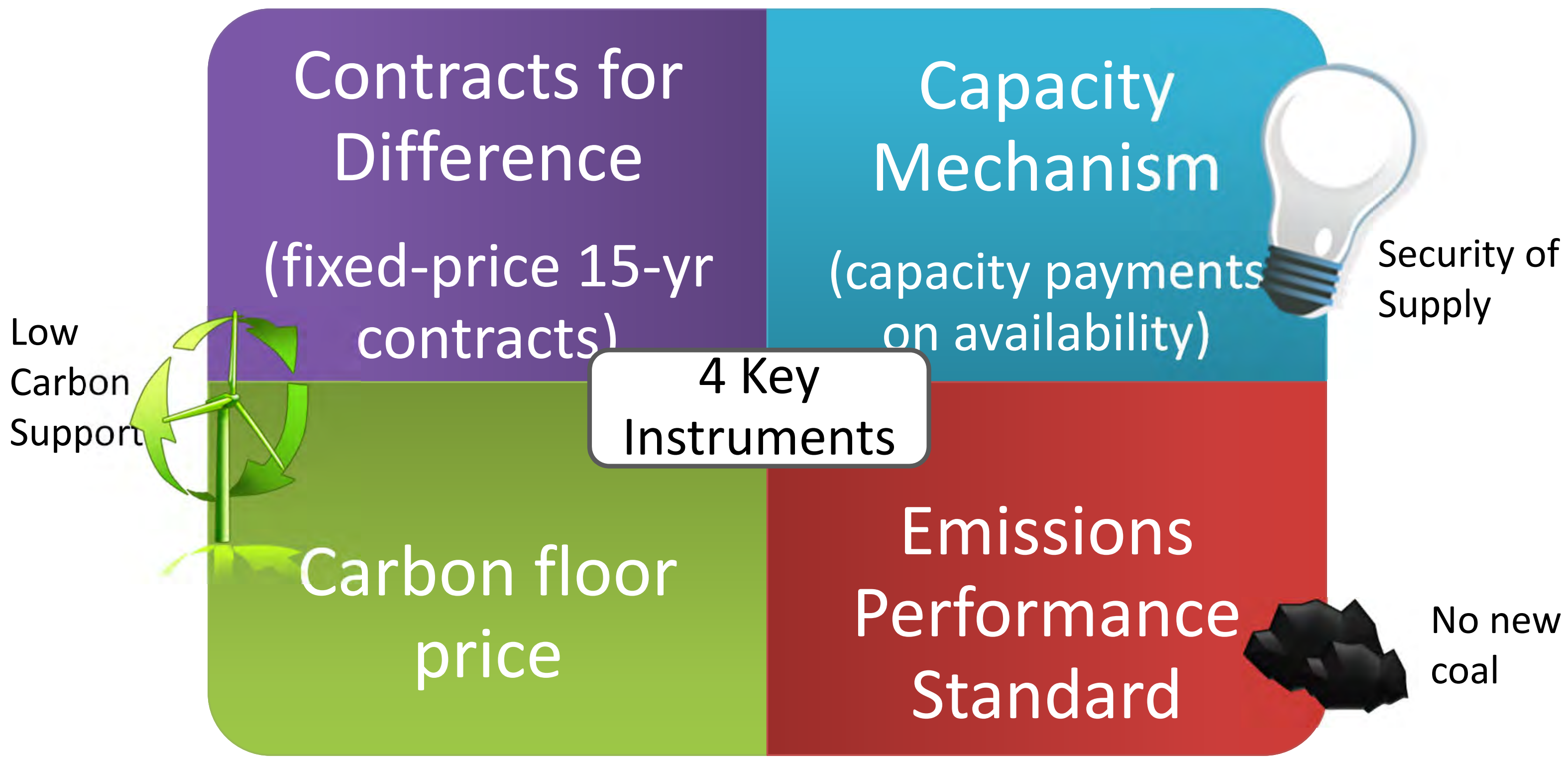
.. moved through a 'sea of gas', now rapidly rising renewables –



Stabilised / declining demand reflects energy efficiency standards and programmes from c. 2000-2015

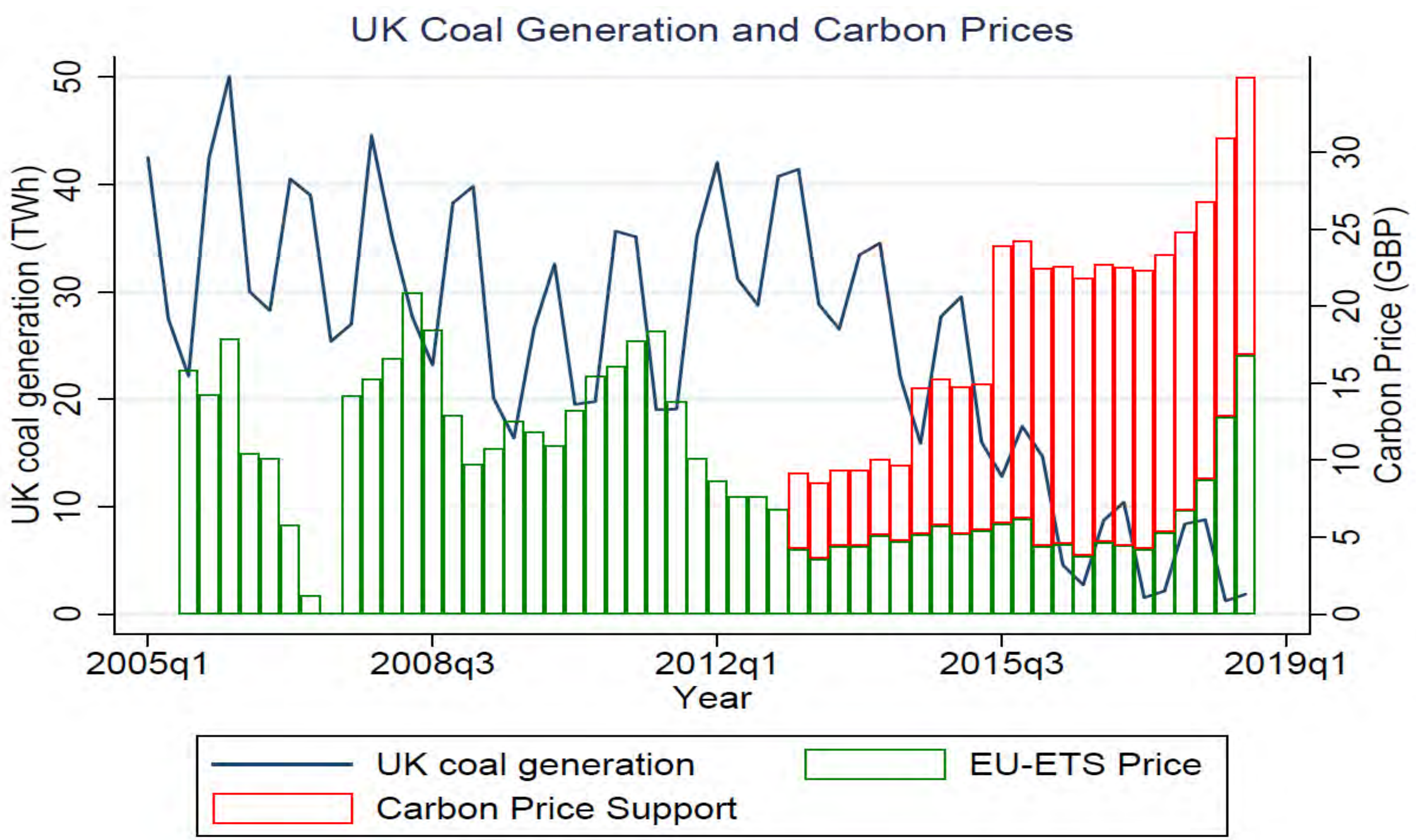
UK Electricity Market Reform (EMR) 2013

Four instruments



... with significant challenges in overall institutional design.

UK electricity – carbon pricing and the demise of coal



UK power sector emissions ***halved*** since 1990, coal collapse.

C price drives *operation and closure* not new investment or efficiency. Impact since 2014 much bigger than before due to price+ **and** :

- energy efficiency policies, demand declining since 2010
- Rapidly rising share of renewables:aim 50GW offshore for 2030

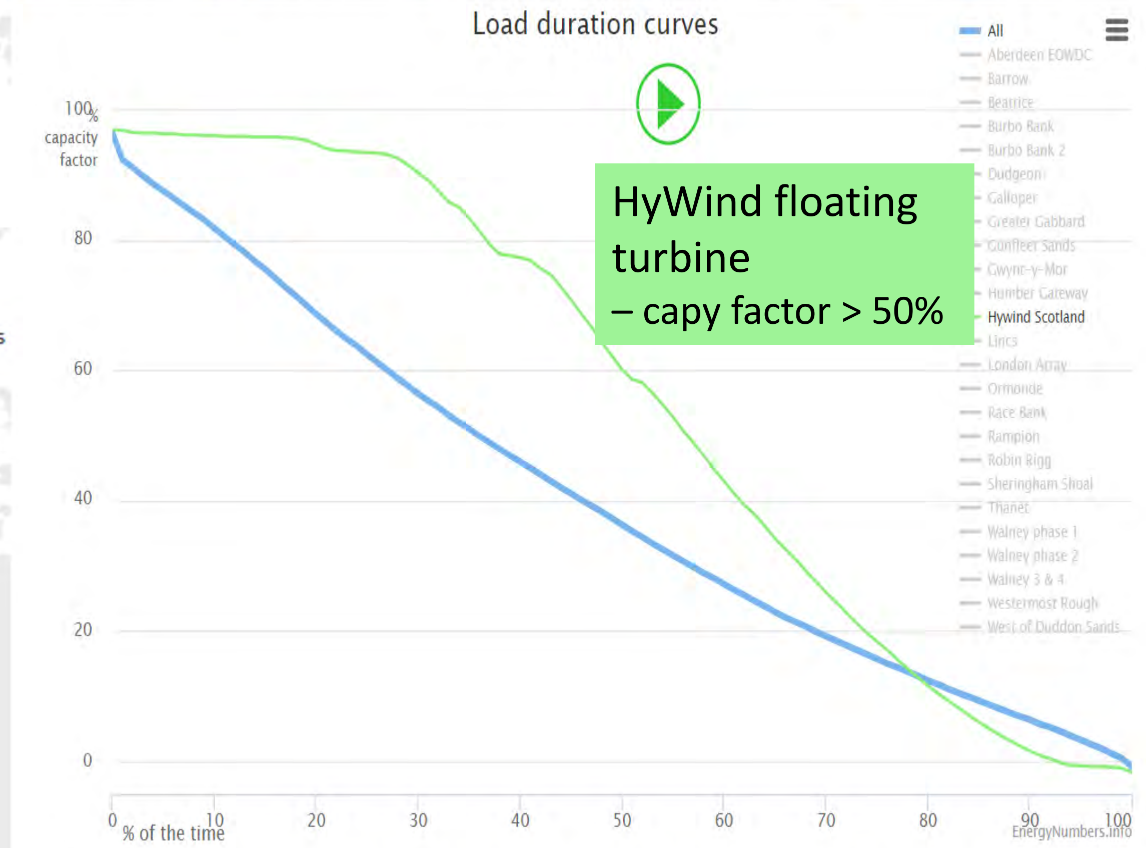
April 2017 - first hours without coal power for over a Century, driven by rising carbon price, declining gas price, and increasing renewables and efficiency. Now weeks at a time ..
UK total CO2 emissions now lower than a century ago, coal just occasional reserve

Trajectory for zero carbon electricity system by 2035

Offshore Wind: north Europe’s new energy frontier

‘Shallow’ water?

Or floating ?



Note that for each individual windfarm, its curve is based on data starting from either January 2009, or from the date that the windfarm was fully commissioned, whichever is more recent. The curve for *all* windfarms is for the last five years.

Three Domains – fundamental analytic concepts

First Domain

- Behavioural, organisational and social perspectives
- Focus on 'capacity'
- Lots of wider evidence around theoretical potential
  - Energy and wider resource efficiency*,
  - Increasingly sophisticated measures of 'distance from frontier'**

Second Domain

- Market perspectives, usually assumption of economy-wide rational discount rate with risk premia
- Equalise marginal costs, internalise external costs, *separability*
- *Equilibrium:* Optimum defined in terms of marginal (maths: *partial* derivatives))

Third Domain

- Long term / Hyperbolic discount rate, or fundamental risk aversion;
- Finance interplay between 2nd & 3rd domain type investments
- Minimise scenario-based total costs, focus on option values & risks
- Component (or subcomponent) costs may be *inseparable – systems perspective*
- *Evolution*: Decisions at margin need to be based on total (maths: *total derivative*)

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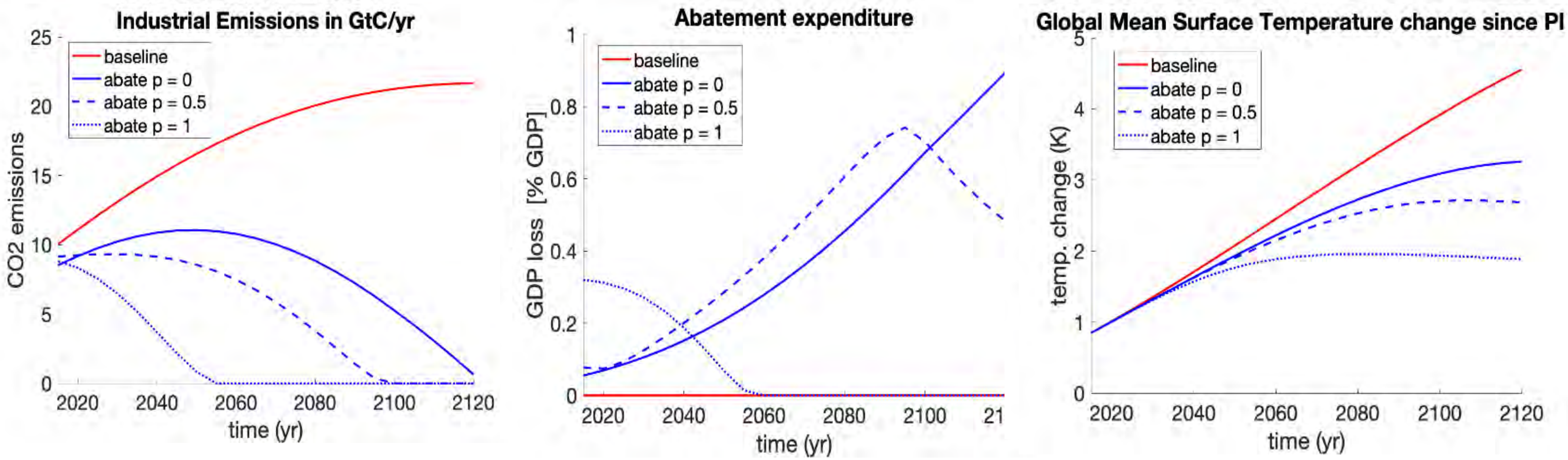
Optimal trajectories with ‘pliable’ emitting system

Impact of system pliability and adjustment timescales on global abatement expenditure, emissions and temperature change in DICE-PACE.



With high pliability and relatively short ‘half life’ characteristic transition time, the optimal response comprises:

Abatement: approx. linear reduction, to near zero around mid-Century

Effort: about four times bigger than in classical case (> 0.3% GDP)

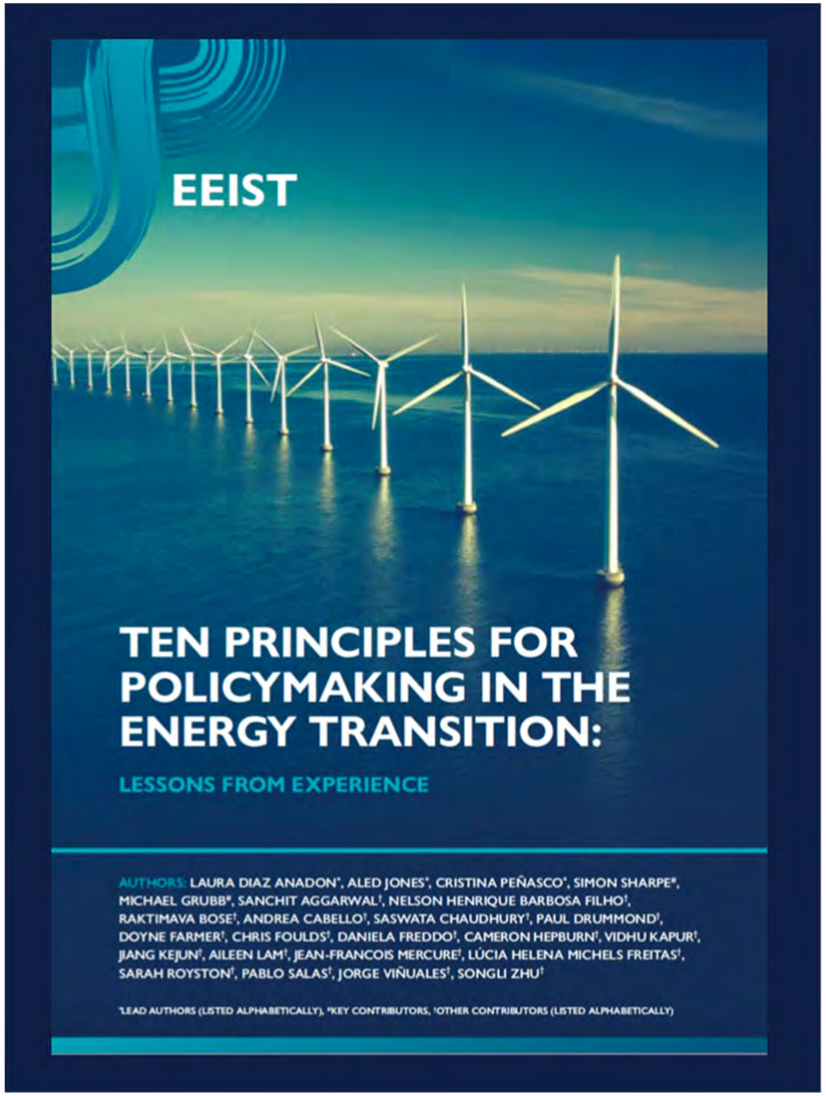
Outcome: instead of > 3 deg.C, stays under 2 deg.C global temp change

Source: Grubb and Weiners (2020), *Modelling Myths: On the need for dynamic realism in DICE and other equilibrium models of global climate mitigation*, in review at Wiley Interdisciplinary Reviews (WIRES) – Climate Change

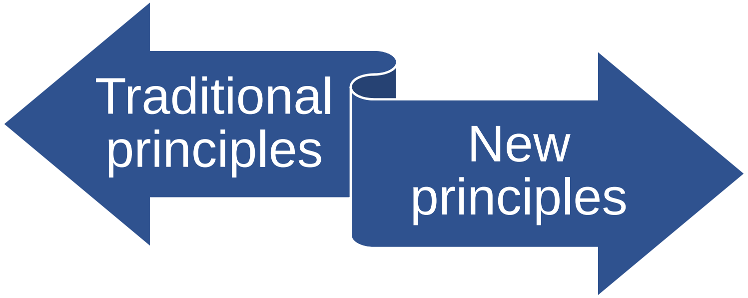
Approaches to policy evaluation

	Where the aim or expectation is **marginal change**	Where the aim or expectation is **non-marginal change**	Reason for difference (in non-marginal case)
Purpose of the policy intervention	Allocative / static efficiency	Dynamic effectiveness	Primary concern is not how efficiently resources are allocated (optimisation), but how effectively economic structures are changed or created (steering)
Rationale for policy	Market failure	Market shaping	Over periods or scales of concern, existing markets are changing, or new ones emerge, so that optimal states cannot be reliably identified
Appropriate analysis	CBA	ROA	Fundamental uncertainty makes precise expected future costs and benefits unknowable
Appropriate models	Equilibrium / optimising	Disequilibrium / simulating	Need to assess effect of policy on processes of change, not just on destination
Theoretical basis	Equilibrium / welfare economics	Complexity economics	Need theory that can explain non-marginal, irreversible and transformational change where relevant

Table 2: Choosing the appropriate set of economic concepts and tools



In the context of dynamic processes and structural change like the energy transition, **new general principles for policymaking are needed.**

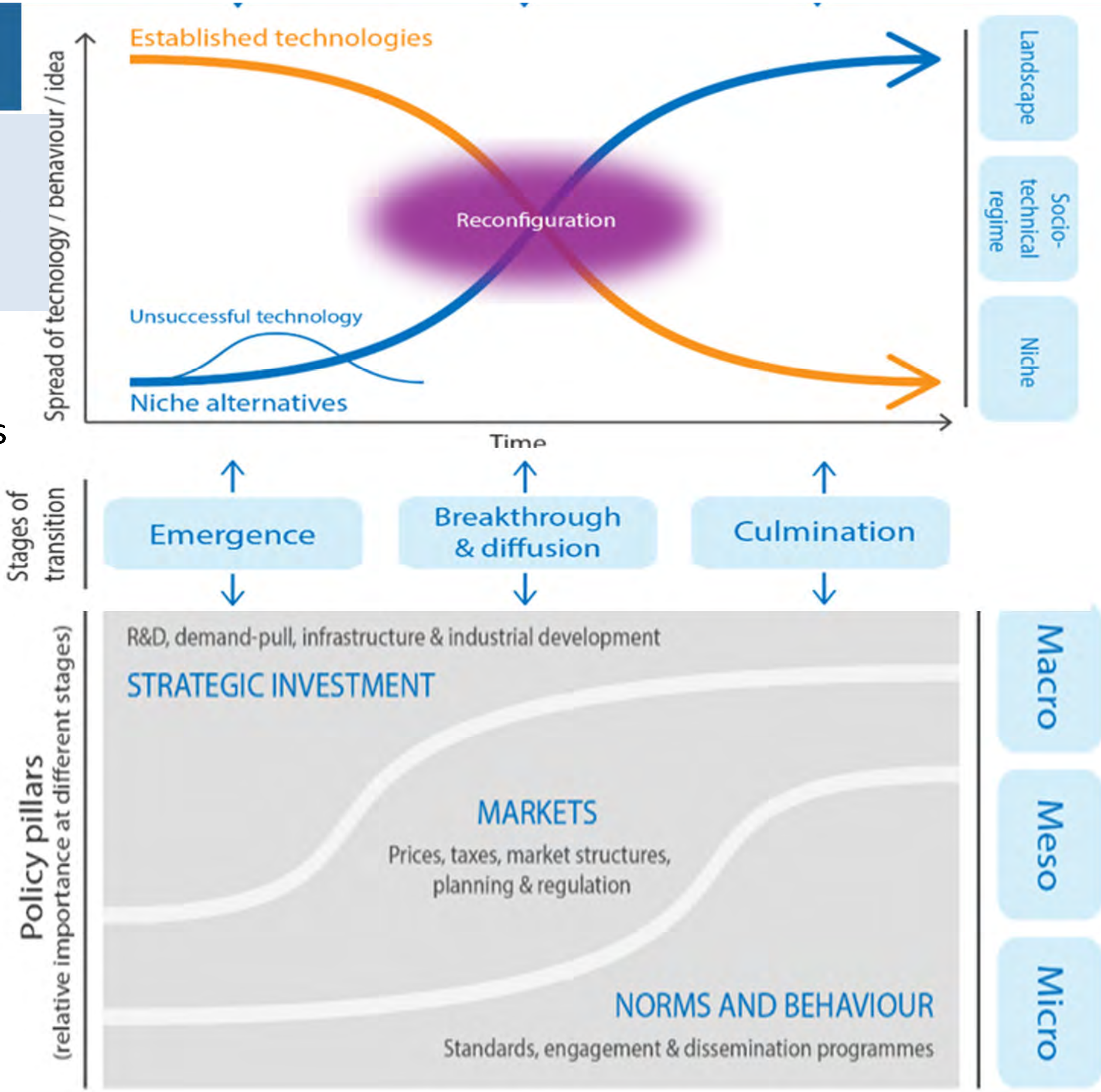


This New Principles are built on a wealth of **experience and analysis gathered over the last three decades** where policy has induced rapid innovation and growth in clean energy technologies.

Conclusions

Innovations take investment, experimentation, can lead to transitions with *evolution of policy packages*

- The “10 principles” reflect experience of sustained innovation in technologies *and* systems, ultimately leading to major transitions
- Opportunities obvious, risks arise not just from tech uncertainties but from incumbent interests and challenge of declining industries
- link with the qualitative transitions literature emphasises *reconfiguration*
- … and potential ‘tipping points’ into new systems
- Transitions require *policy combinations that also need to evolve*
- **With imagination, experimentation, commitment and investment, we can create *very* different, low-carbon energy futures**



Conclusions

'Ignoranti quem portum petat nullus suus ventus est' -

Lucius Annaeus Seneca

No wind favours those who don't know where they are going

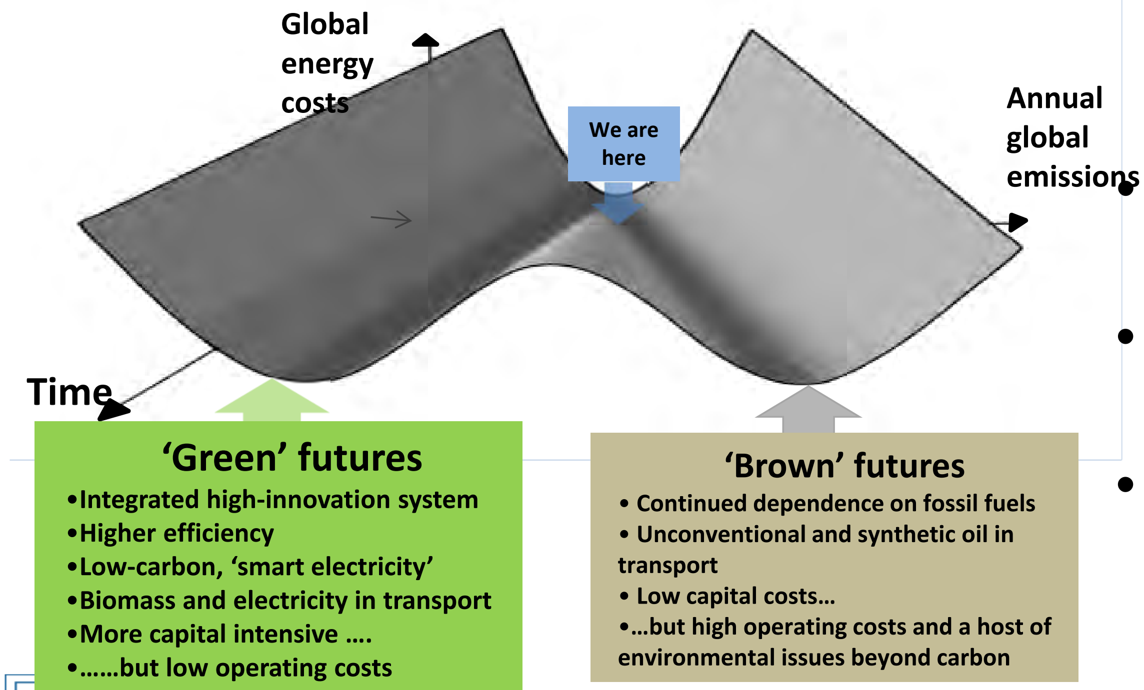


Figure 10-6: Two kinds of energy future – the carbon divide
Source: Upper panel: Gritsevskyi and Nakićenović (2000); lower panel: authors

- 21st Century energy systems will be radically different from 20th Century
- Transition is already under way, so far driven far more by non-pure-market policies
- Need the Three Domains & associated Pillars of Policy designed as a mutually reinforcing package
- Harnessed for *industrial and development* strategies, "shifting development pathways"
- Including fresh consideration of carbon pricing as a *tool for change*
- Clear policy direction with all three pillars can shift risk, lower finance costs, and increase the economic gains from innovation and infrastructure

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- The UK electricity transition
- A generalized view on transition dynamics and policy

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