The economics of energy transformation:

the 3-pillar approach, the UK experience, and some global implications

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Four topics

- Dynamics of energy Innovation & transformation – general features
- Why policy, what policy? A Three Domains & Pillars approach to innovation
- A practical application: The UK Electricity Transition
- A model application: transforming *DICE*

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

Technology costs decline *with both time and investment*

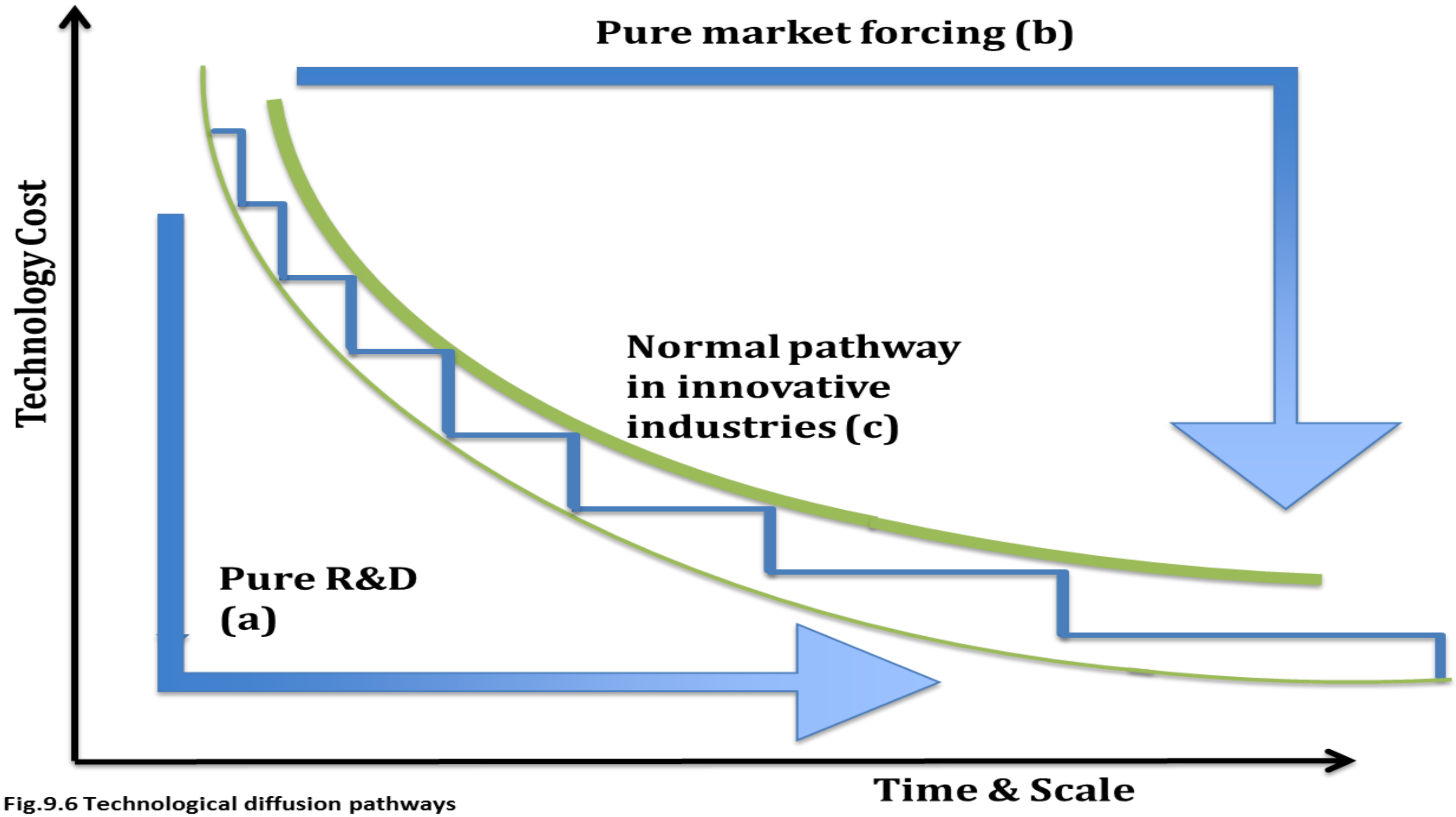


Fig.9.6 Technological diffusion pathways
Source: CIRED, France

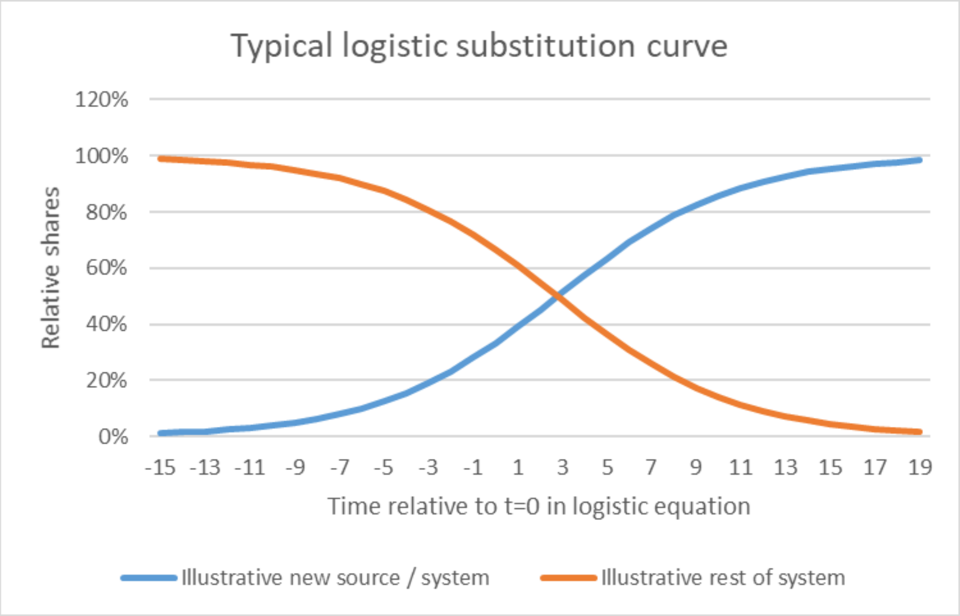
… The reality is that most technologies have to evolve through repeated cycles of market growth, learning, scale economies and supply chain development

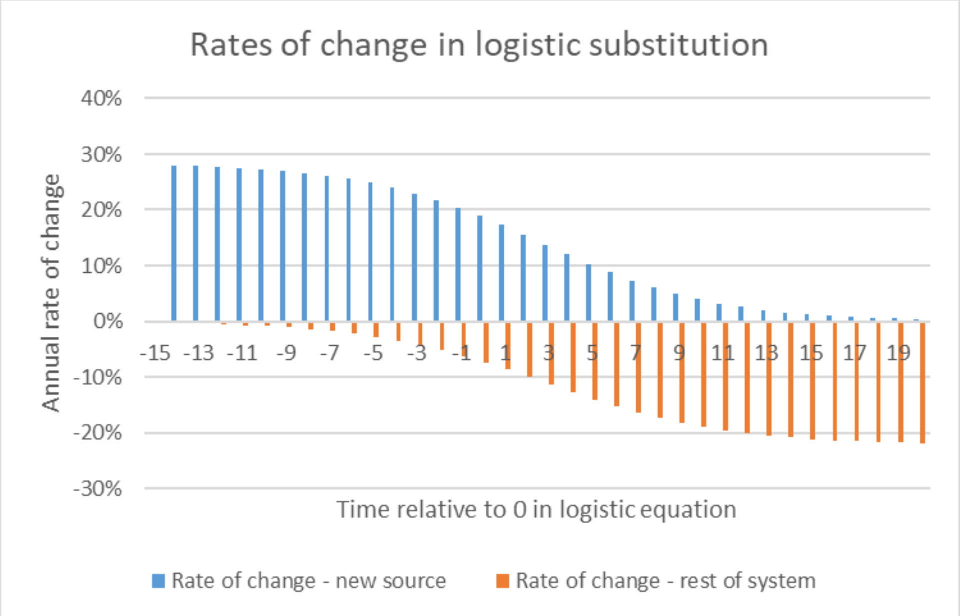
..process typically culminates with *transformation*

Major sectoral transitions typically occur through logistic ('S-curve') substitution with self-reinforcing *induced innovation*

With various timescales:

- Lag from R&D to 10% can be decades
- Energy technologies, historically c. 30 years from 10 to 90% of penetration in natural evolution of markets (may be accelerated with policies)
- Key infrastructures may be even slower (think cities, roads, buildings)





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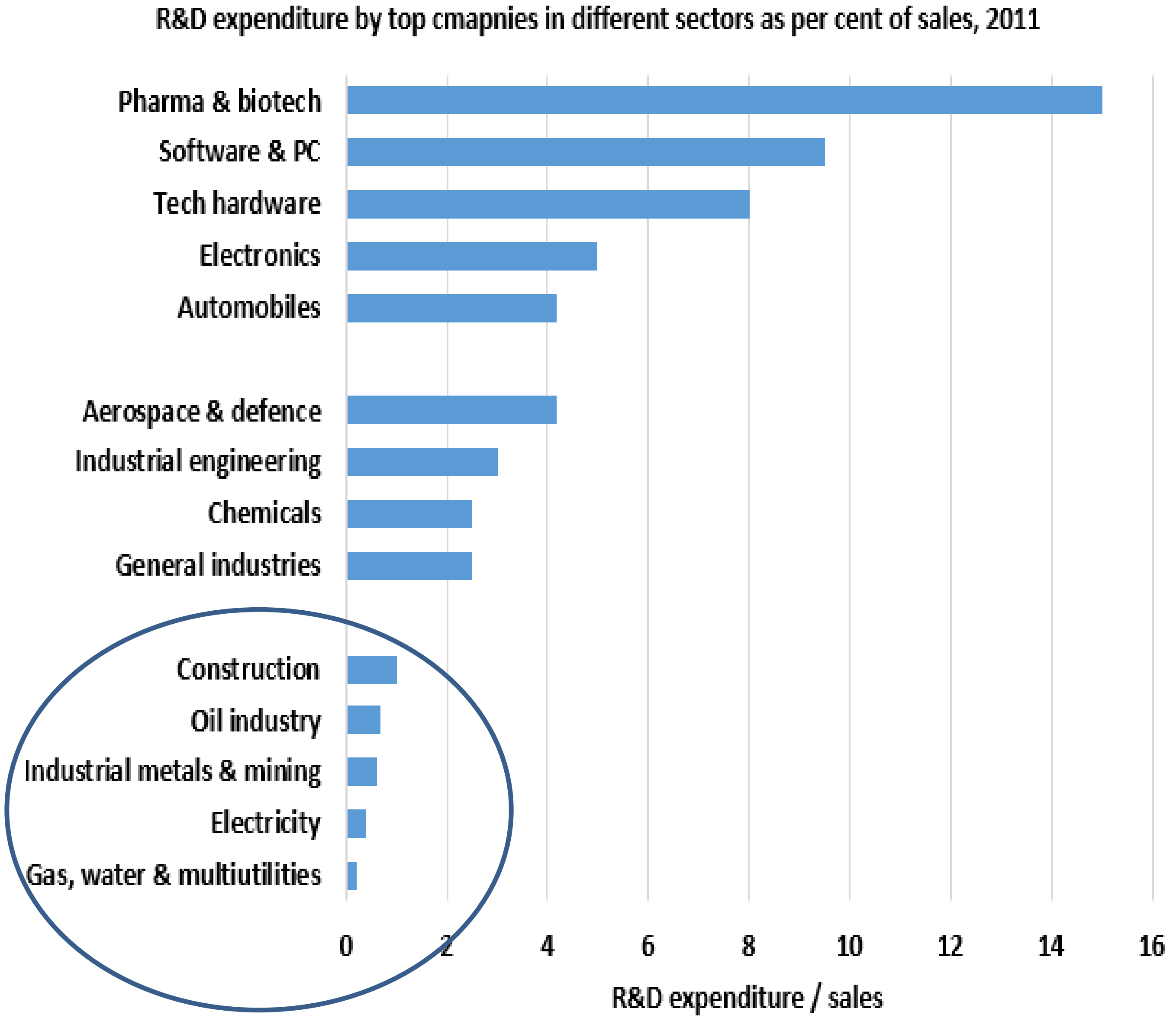
Energy-climate challenge – seek radical change in …

… some of the historically least innovative sectors of our economies



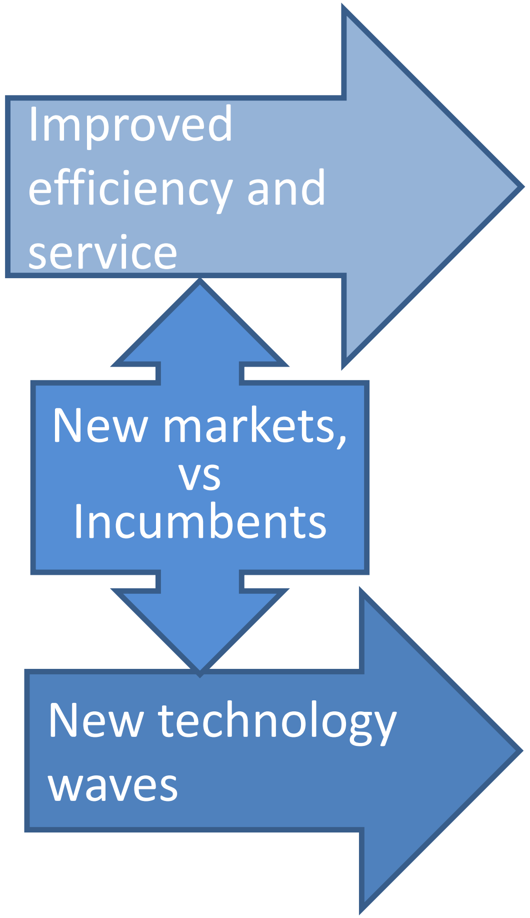
Three Domains of decision-processes

with different characteristics and theoretical foundations, apply at different scales

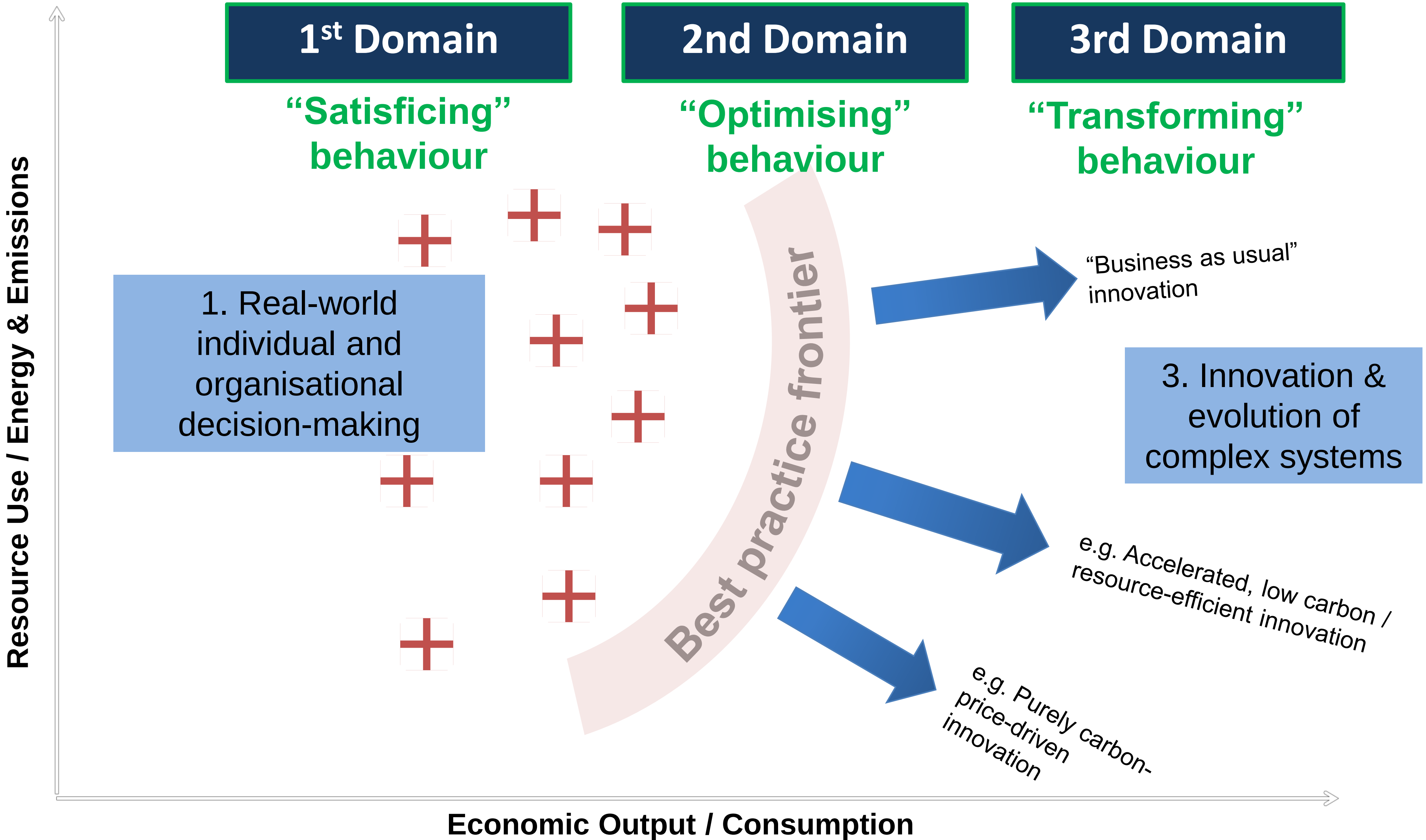
DOMAIN	Characteristics	Theoretical foundations
1. Satisficing	Habits, myopia/present-bias, risk aversion, inattention to incidental / intangible costs & opportunities, individual diversity & experimentation, malleable preferences; network effects	**Behavioural and organisational economics**
2. Optimising	Economic optimisation based on relative prices, 'representative agents' with 'rational expectations', stable preferences and tech trends	**Neoclassical and welfare economics**
3. Transform-ing	Structural, technological, institutional and behavioural change, typically from strategising, innovation, infrastructure investment	**Evolutionary and institutional economics**

SOCIAL SCALE

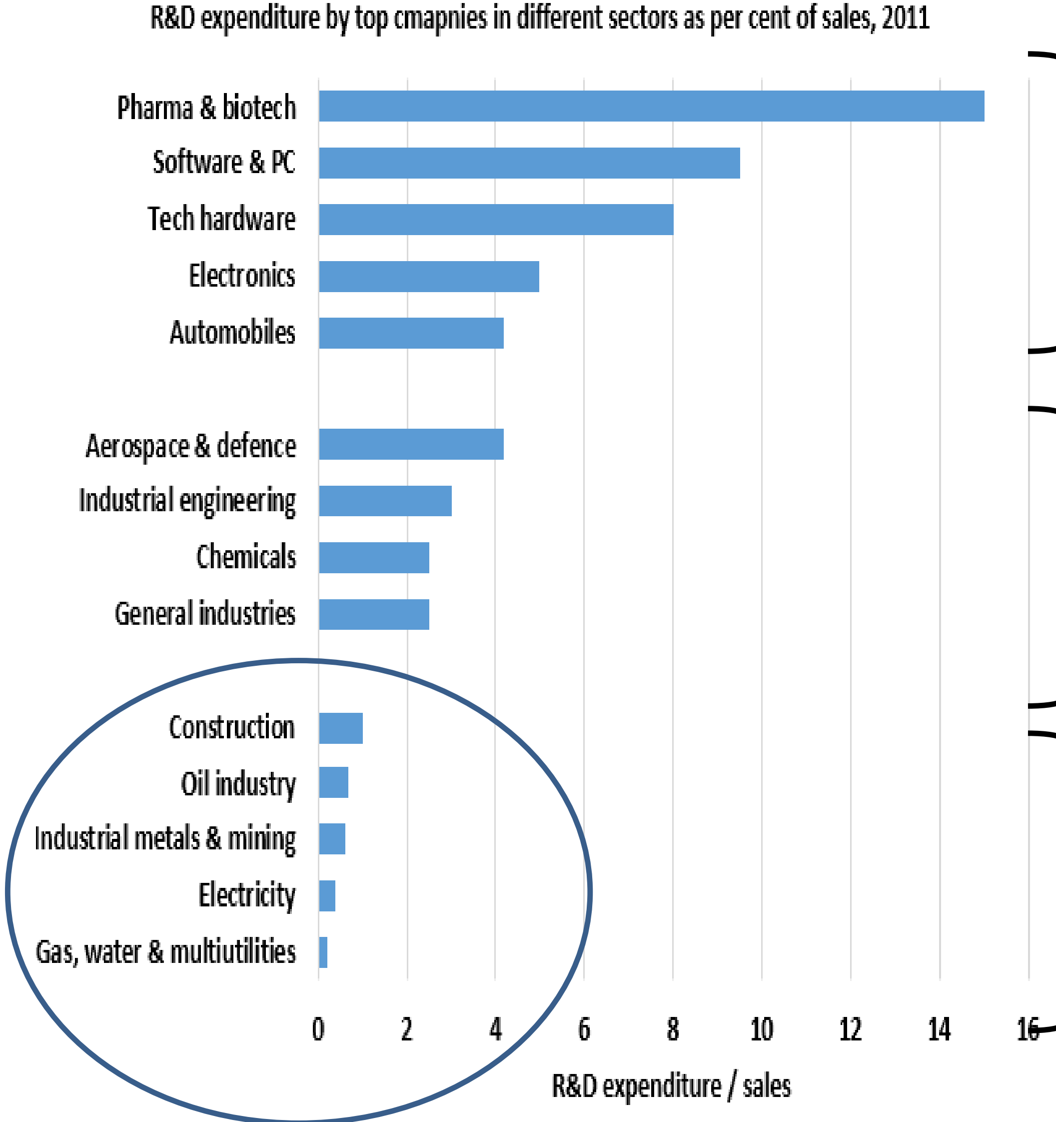
TIME HORIZON



The Three Domains form a *dynamic system*



Energy-climate challenge – need to *invest* and *connect*



Highly innovating, closely connected consumers and innovators

1st and 3rd Domains

Eg. IT and drugs sectors

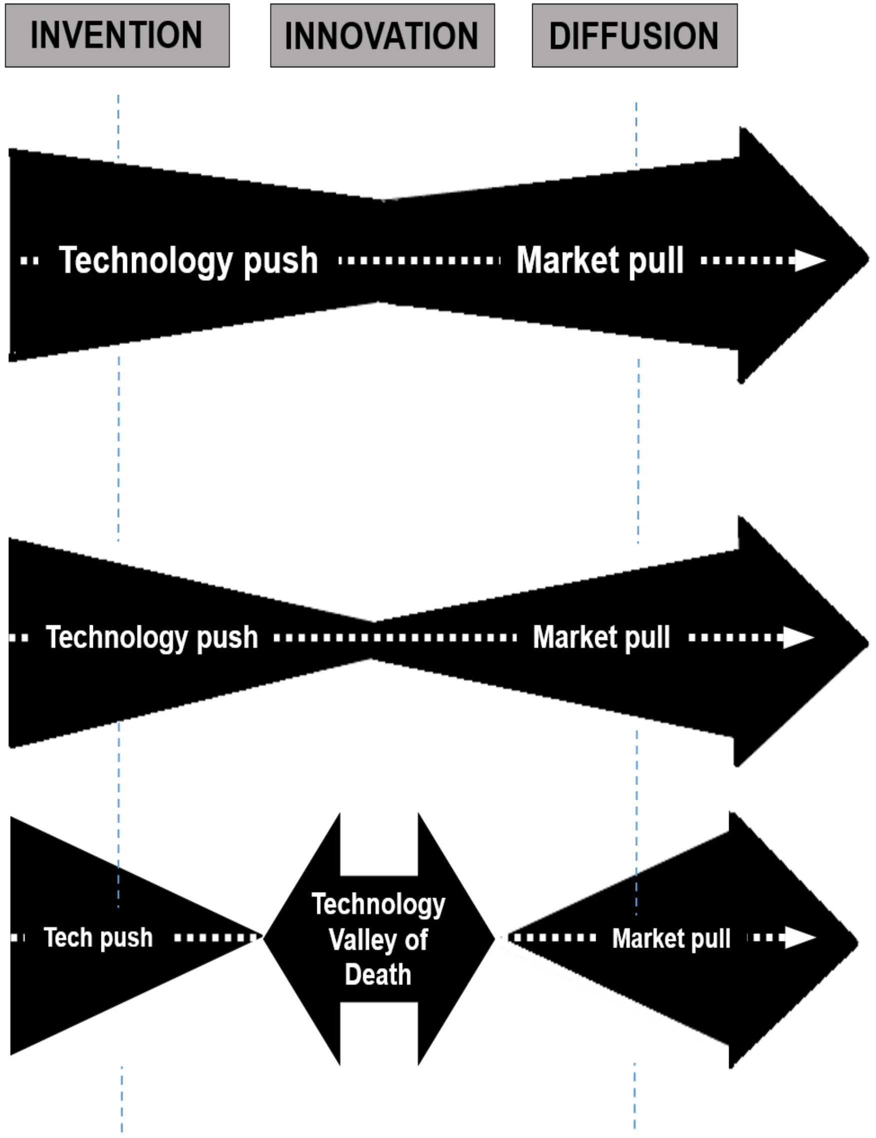
Moderate innovation, within-business connections

2nd and 3rd Domains

Eg. industrial and product engineering

Low innovation, little connection between innovators and markets

Eg. energy and construction industries



Ideal policy comprises a package …

"Other policies such as feed-in tariffs, industry regulation and subsidies, are far less economically preferable than carbon pricing to reduce emissions… " (OECD, 2013)

I beg to differ …

Key is to match the best instrument to the respective domain of decision-making

Policy pillars

Domain	1 Standards & Engagement	2 Markets & Prices	3 Strategic Investment	
Satisfice	H	L/M	L	'Smarter' individual & corporate choices
Optimise	M	H	M	Cleaner products & processes
Transform	L	L/M	H	Innovation & infrastructure

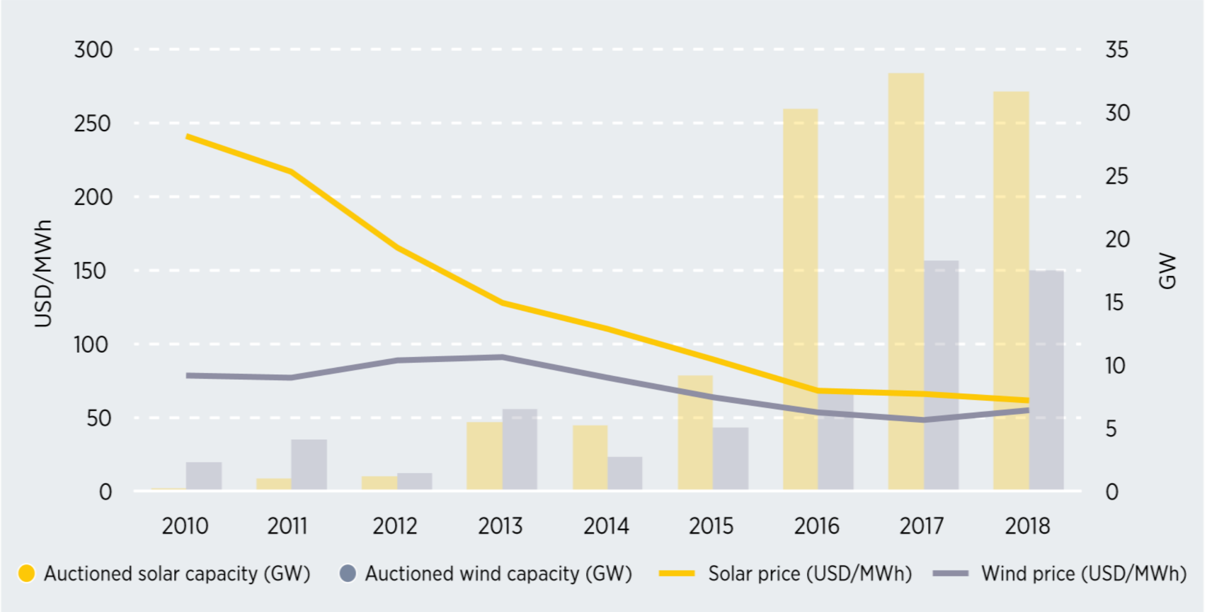
H Highest relevance
M Medium relevance
L Lowest relevance

Induced innovation – example,the Solar Revolution

“Solar power is by far the most expensive way of reducing carbon emissions - *The Economist,* **2014.**

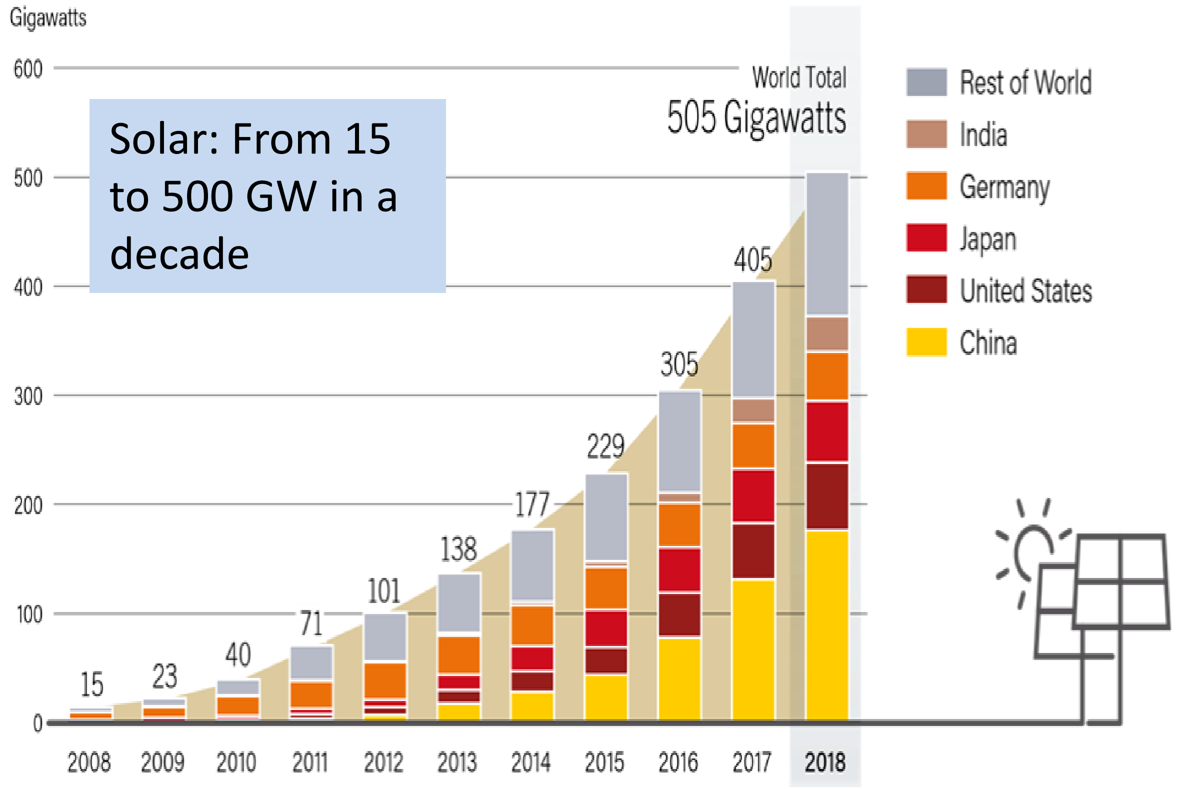
“.. in Germany, like growing pineapples in Alaska.” - J. Grossmann, then CEO of RWE, **2012**

Source: IRENA (2019), Renewable Energy Auctions: Status and Trends Beyond Price



Global *average* prices resulting from auctions, 2010–18

Solar: From 15 to 500 GW in a decade



Auctions in summer 2019 broke three times the world record of cheapest solar PV tariff:

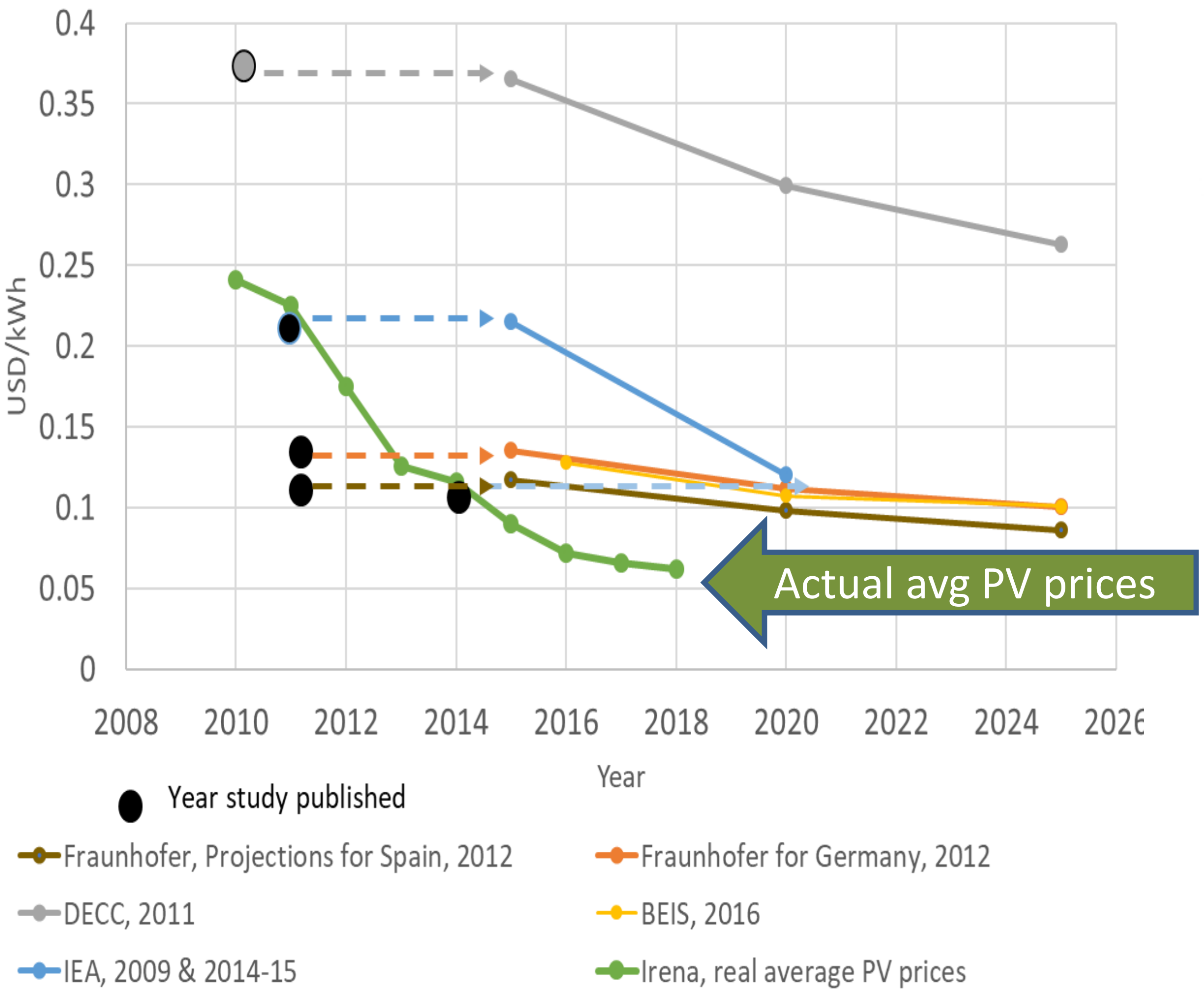
Los Angeles, USA - $20/MWh
Brazil - $17.5/MWh
Portugal - $16/MWh

Portugal’s July 2019 world’s cheapest PV.

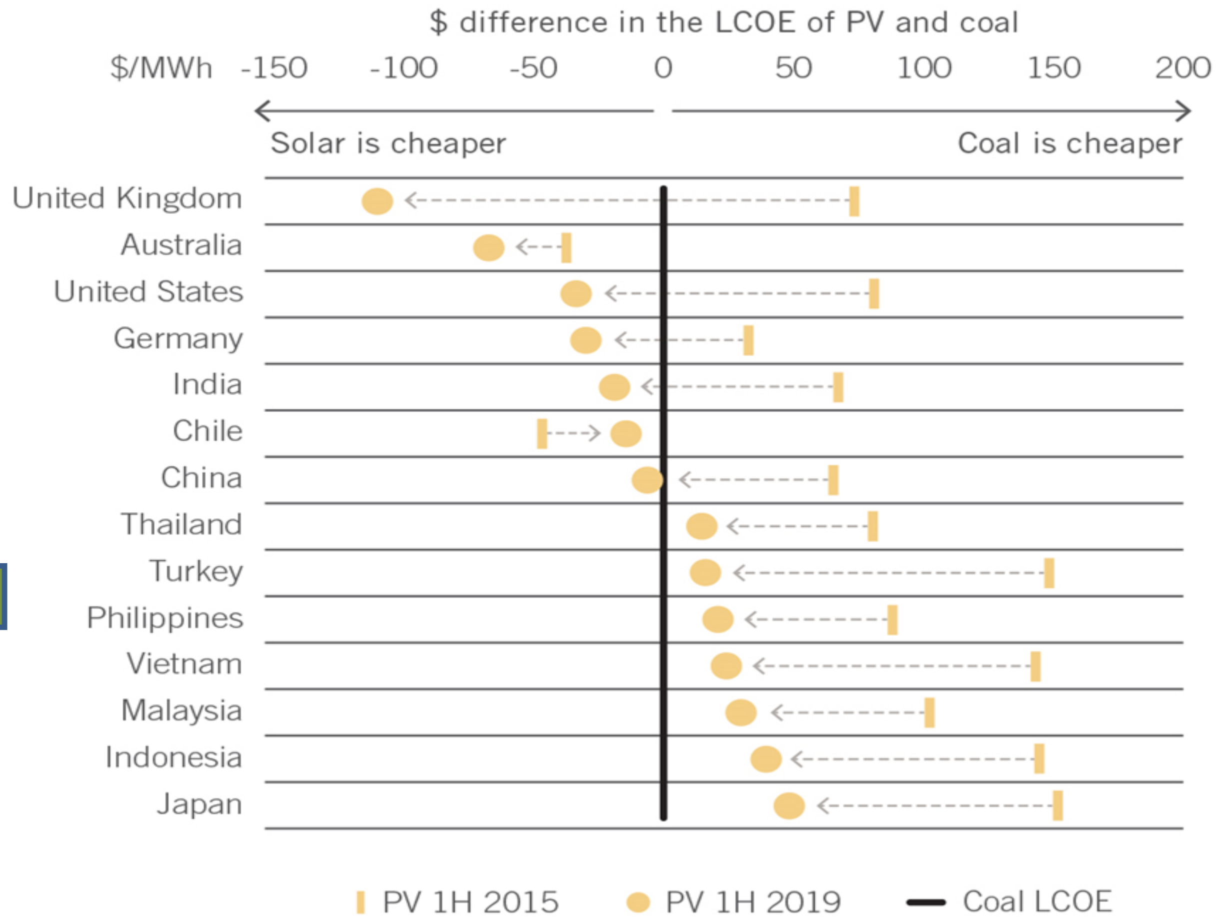
Ethiopia Sept 2019, Africa’s cheaper PV to date @ $25/MWh

Actually, emerging as the cheapest widespread high-grade energy source in human history

Innovation – dramatic changes, far faster than projected



Projections for levelized cost of energy for large-scale solar PV vs realised global average prices from auctions



Note: H = Semester (data from first semester, 2015 cf. 2019).
Costs are life-cycle cost of energy (LCOE)
Source: Bloomberg data, chart as presented from Figure 6 in CFLI (2019).

Evolution of the relative life-cycle cost of new solar PV and coal plants, 2015-2019 – local learning and efficient policy important

Source: Authors, from data sources as shown

Successful innovation must span a complex multi-domain journey

Technology journey	Basic R&D	Technology RD&D	Demonstration	Commercial-ization	Deployment	Wide Diffusion
Organisation & supply chain	A few 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 technology institutions	First sector associations	Eg. first IPO, licence acquisitions	Lobbying, corporate expansion	Stable associations 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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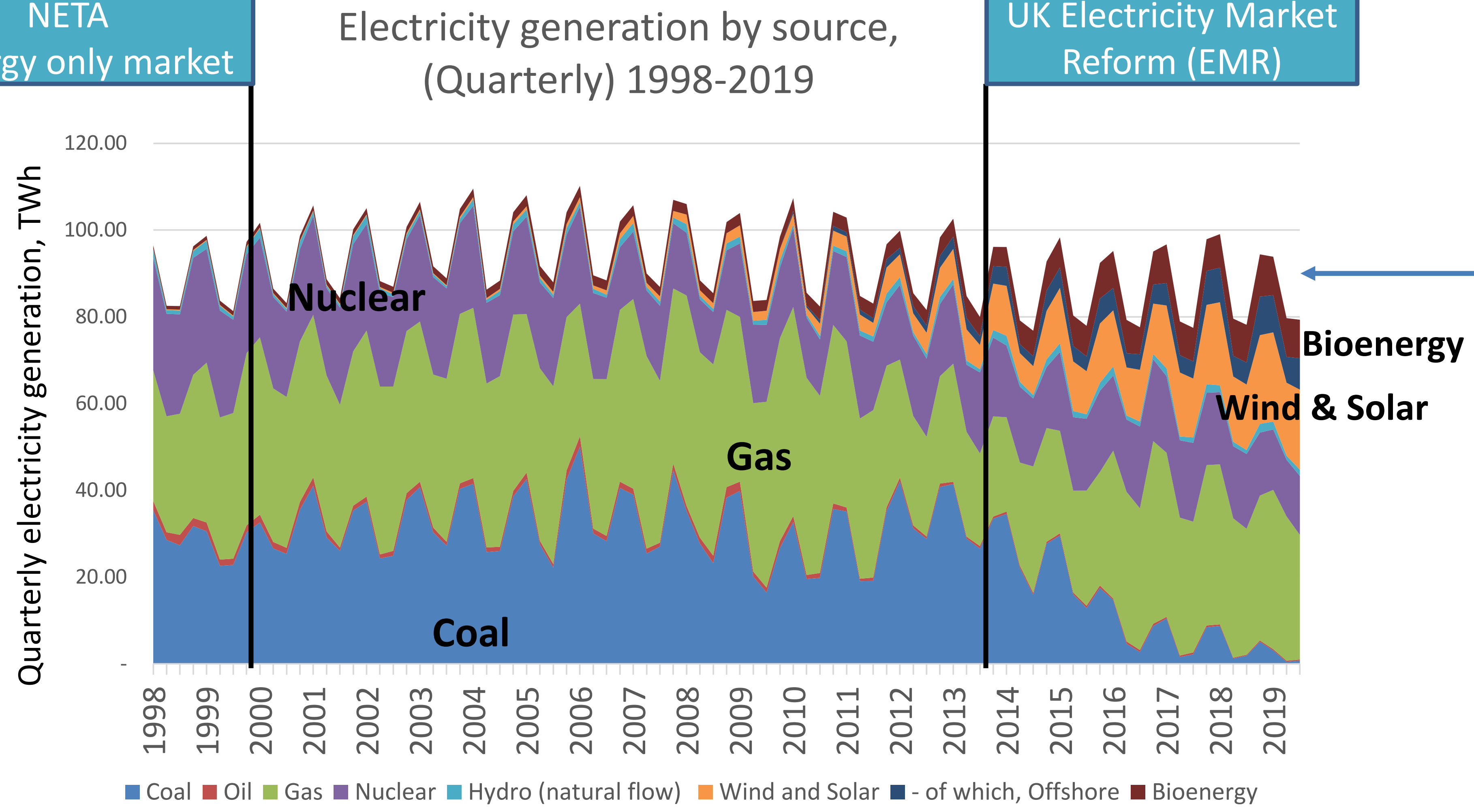
UK 'island of coal in a sea of oil and gas' – no longer

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

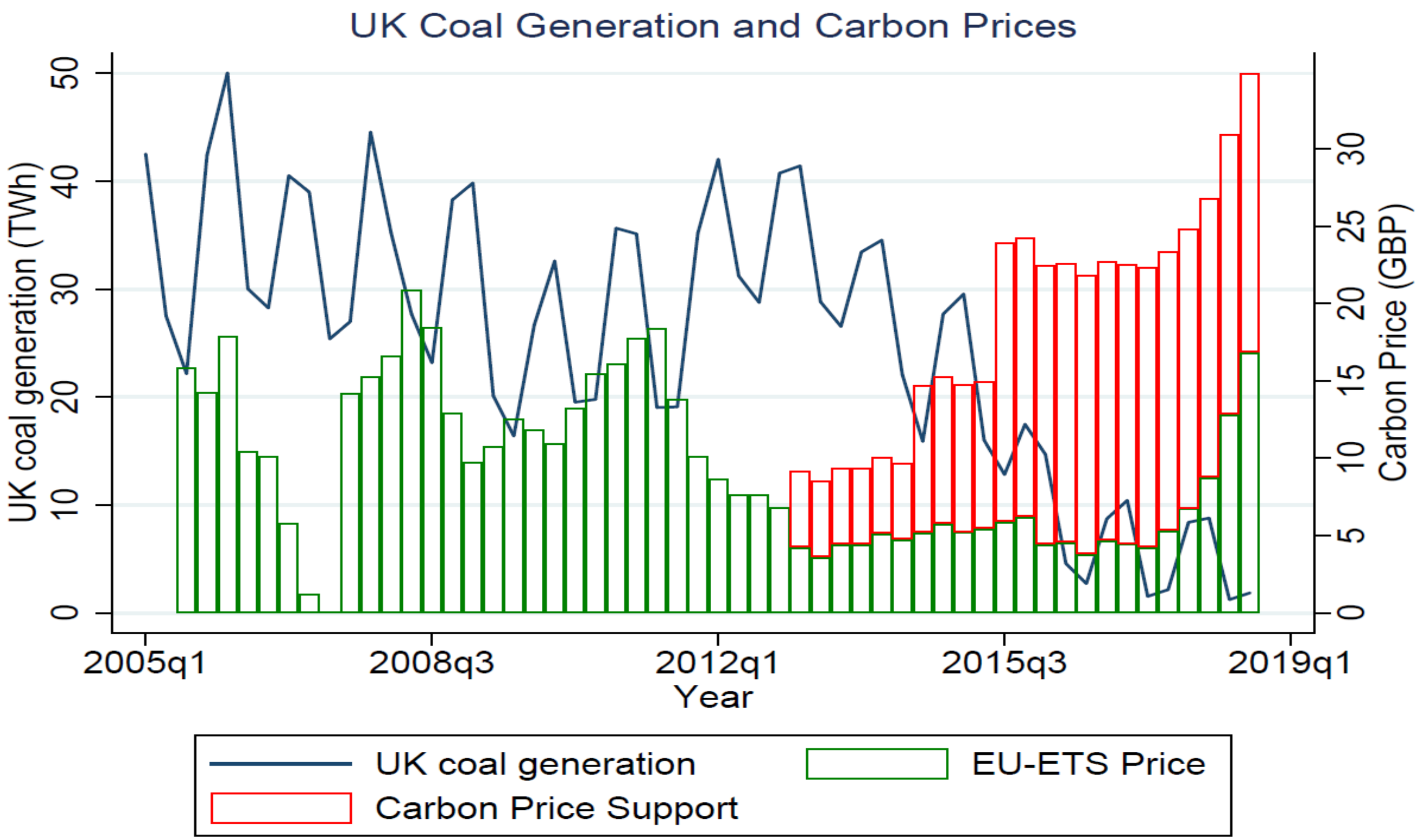
NETA
– Energy only market

UK Electricity Market Reform (EMR)



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

UK electricity – carbon pricing and the demise of coal



UK power sector emissions ***halved*** since 1990, coal now below 10% of generation.

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

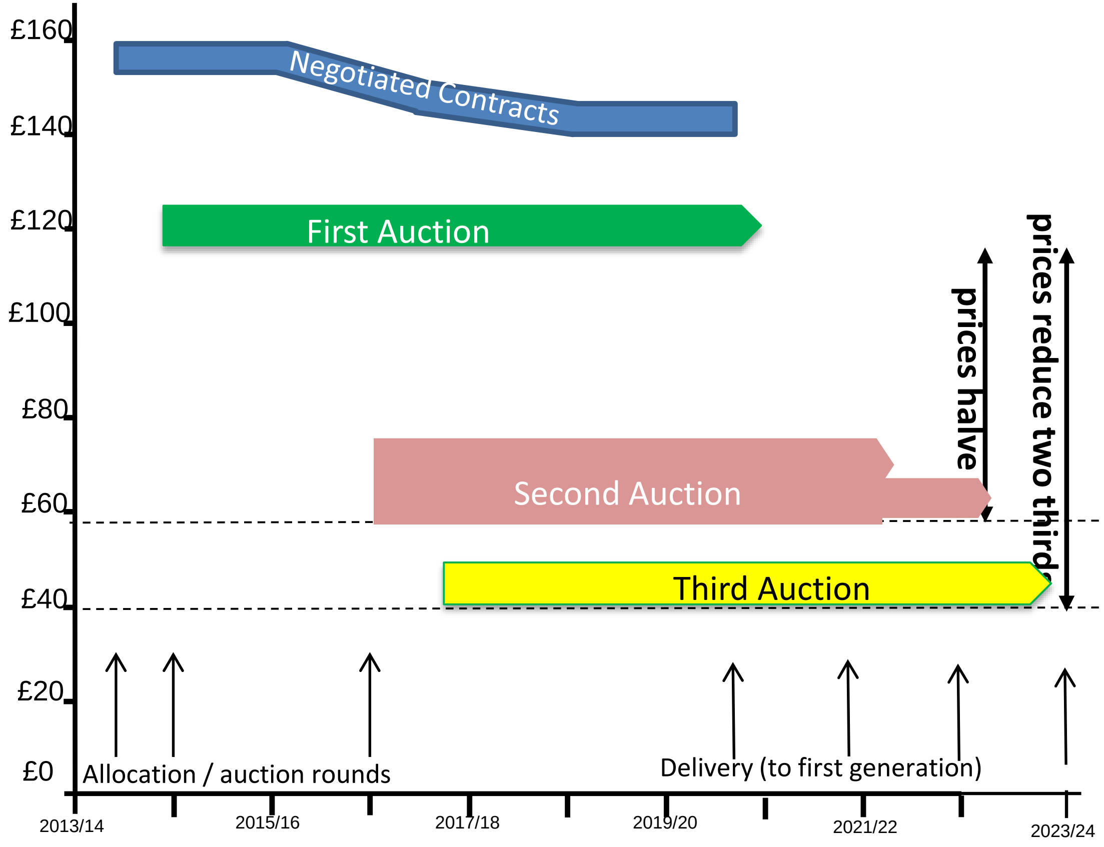
- Lower gas – coal price differential
- energy efficiency policies, demand declining since c. 2010
- Rapidly rising share of renewables

April 2017 - first hours without coal power for over a Century, driven by rising carbon price, declining gas price, and increasing renewables and efficiency.
UK total CO2 emissions now lower than a century ago, all coal to be closed by 2025

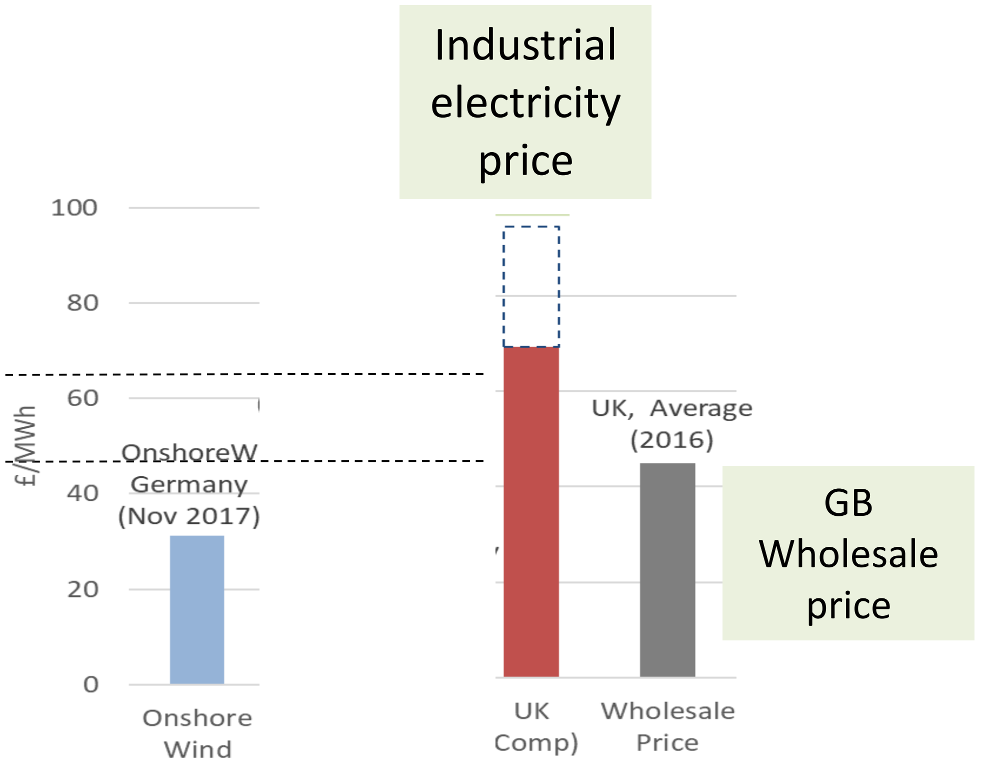
Offshore wind: the big breakthrough

Huge gains from long-term contract auctions & pan-European industrial development

Offshore wind contracts under UK EMR



… now c. half industrial elec price and around recent wholesale elec price



Sources: M.Grubb and D.Newbery (2018), 'UK Electricity Market Reform and the Energy Transition: Emerging Lessons', MIT-CEEPR working paper; Updated

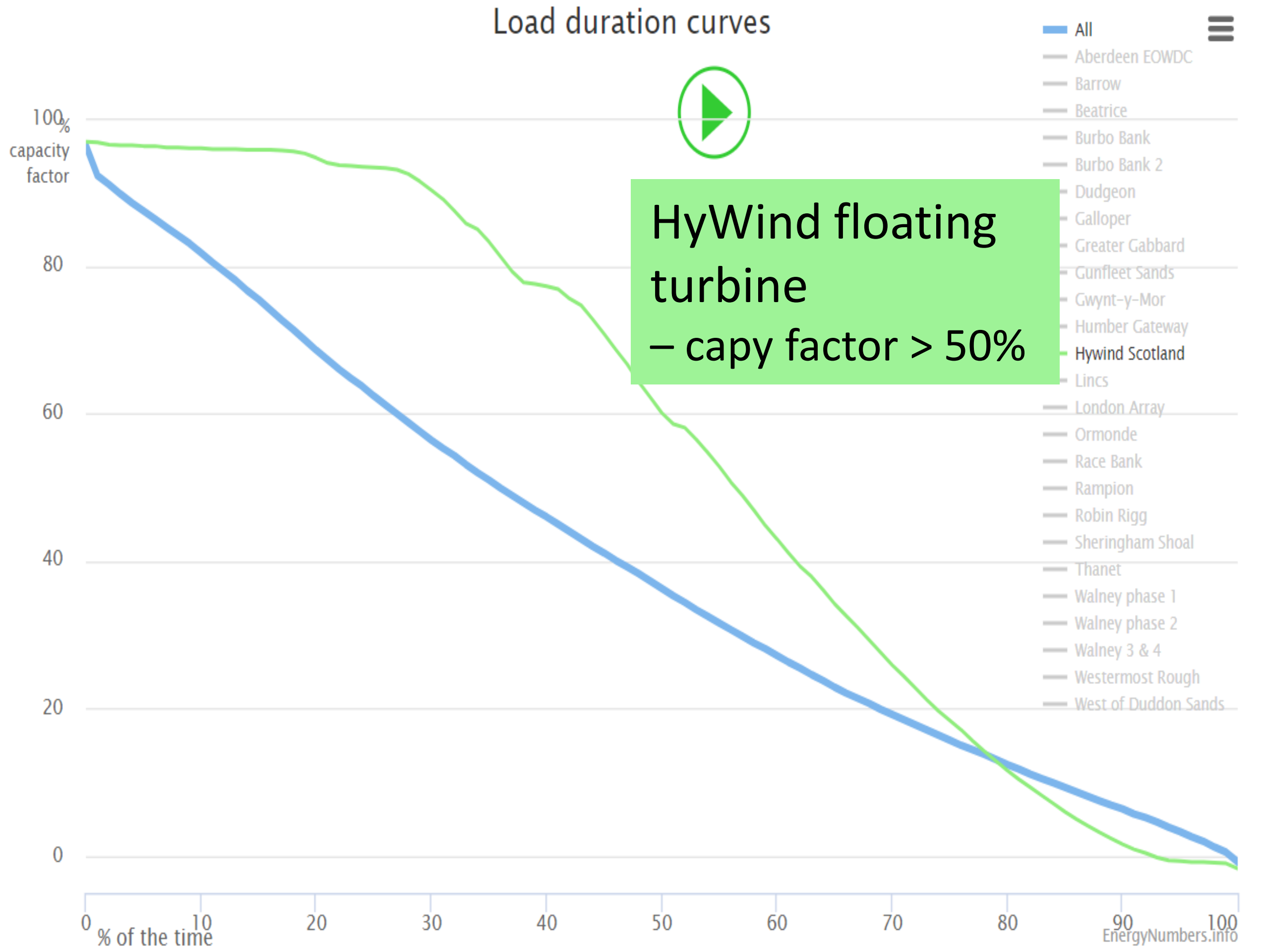
Grubb & Drummond (2018), UK Industrial Elec Prices, UCL/Aldersgate Group

Emerging as a UK and North European resource as large and valuable as North Sea Gas

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.

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Standard Economic Approach to "Integrated Assessment …"

…. seeks to balance abatement costs and climate benefits

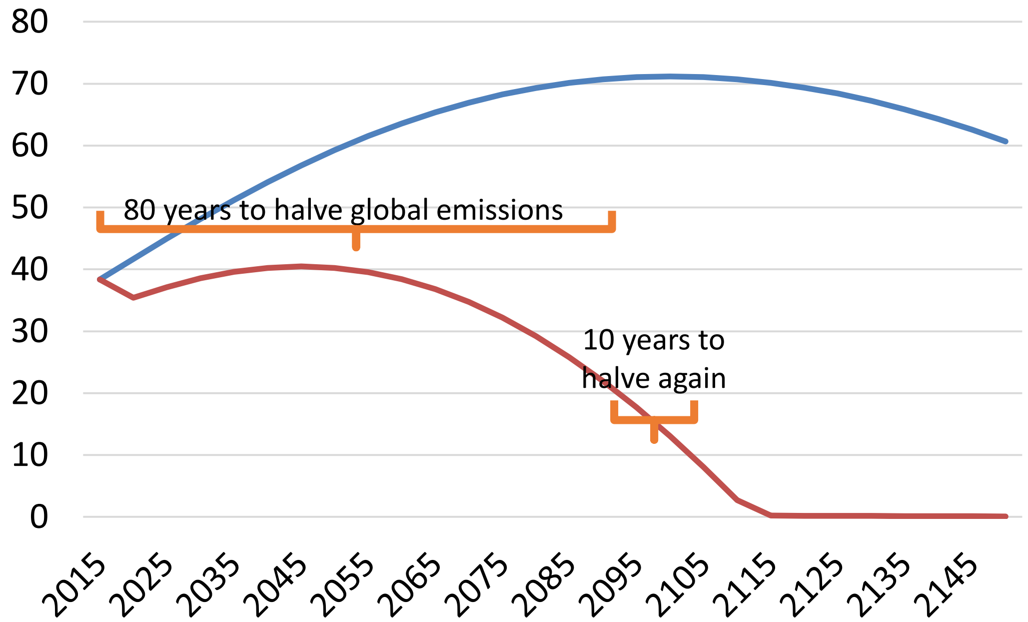
Abatement Costs
(of cutting emissions given today's projections)

Balance

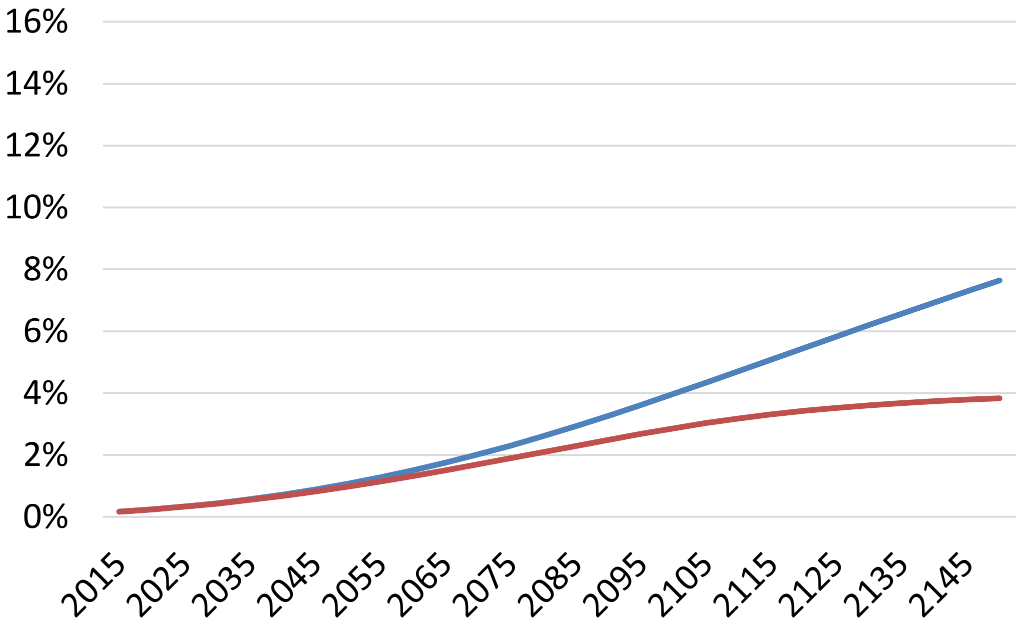
Climate Benefits
(of avoided climate damages)

Nordhaus' DICE model with his "standard" assumptions

a. "Optimal" Emissions ($GtCO_2$)



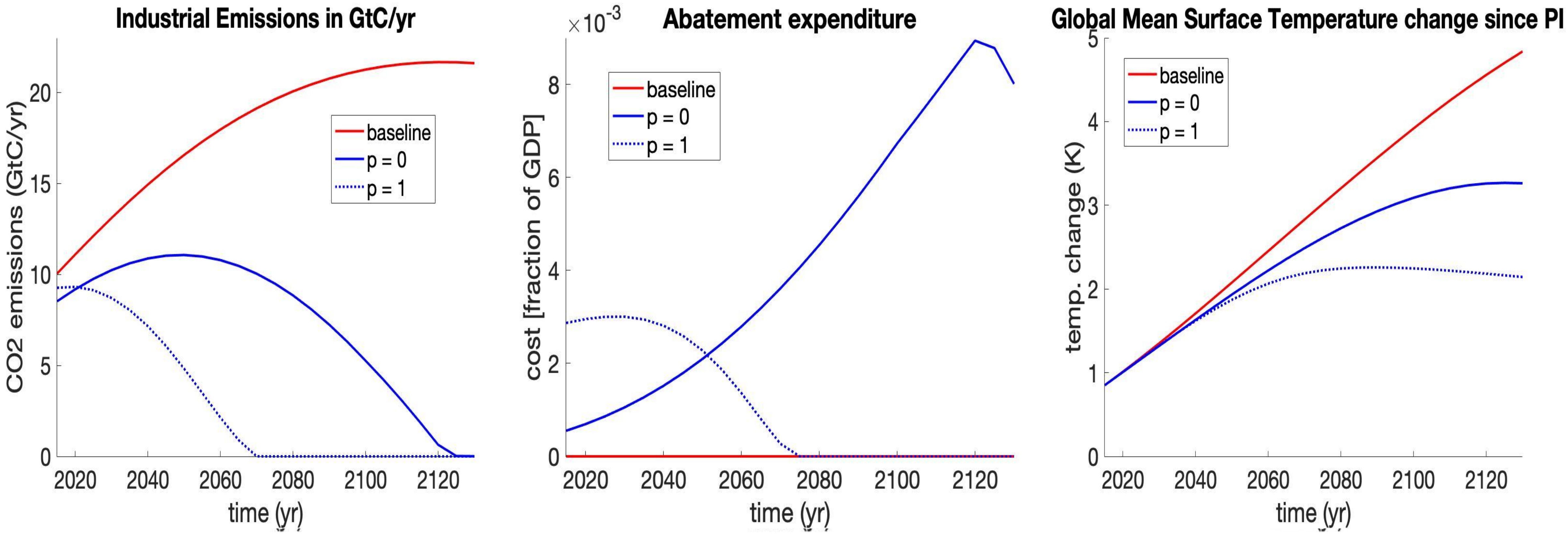
b. Damage fraction of GDP(%)



…. Classical Computable General Equilibrium model, assumes globally perfect foresight with discounted damages. Attracted huge range of criticisms, for assumptions on damage evaluation

(b) DICE-PACE model – behaviour with pliable abatement system

Impact of inertia and induced innovation on global emissions, expenditure, and temperature change in DICE-PACE: $\hat{t}$= 30yrs.



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

Abatement: steady reduction towards net zero

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

Outcome: stays c. 2 deg.C despite weak damage / risk assumption

Source: Grubb and Wieners (2020), *Modelling Myths: On the need for dynamic realism in DICE and other equilibrium models of global climate mitigation*, https://www.ineteconomics.org/perspectives/blog/modeling-myths-of-climate-change

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Four topics: conclusions

- Dynamics of energy Innovation & transformation – general features
  - *Logistic substitution with self-reinforcing induced innovation*
- Why policy, what policy? A Three Domains approach
  - *Need engagement, market instruments and strategic investment*
- A practical application: The UK Electricity Transition
  - *A radical transformation, >50% CO_2 reduction & major new energy resource*
- A model application: transforming *DICE*
  - *Dynamics realities including induced innovation transform the global economics*