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Harvard Electricity Policy Group

Power Sector Innovation: Creating the Future – Different approaches

Online

Prof. Laura Diaz Anadon

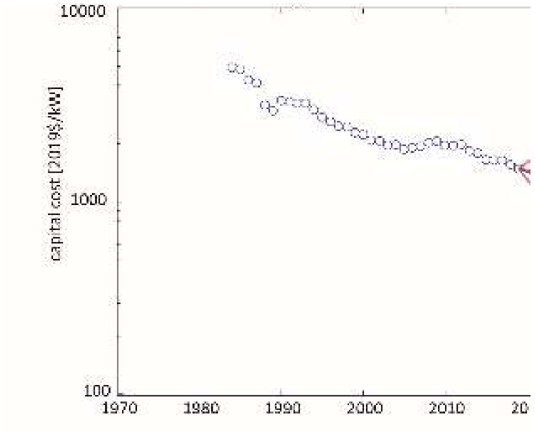
Chaired Professor of Climate Change Policy
Director of the Centre for Environment, Energy and Natural Resource Governance (CEENRG)
Department of Land Economy, University of Cambridge
Fellow Elect, St. John's College
Visiting Scholar, Belfer Center for Science & International Affairs, Harvard Kennedy School

Outline

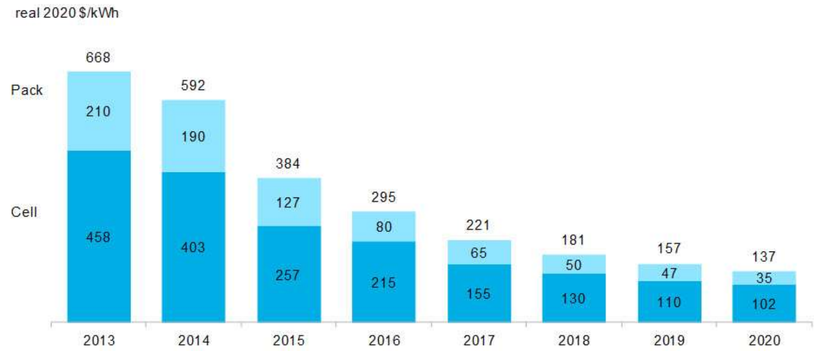
- Identifying promising technologies: what we know about forecasting
- Overview of the impacts of different policies
- Developments of tech push and market pull policies in the US and other countries

The costs of key climate mitigation technologies have come down really quickly

Onshore wind capital cost ($2019/kW)

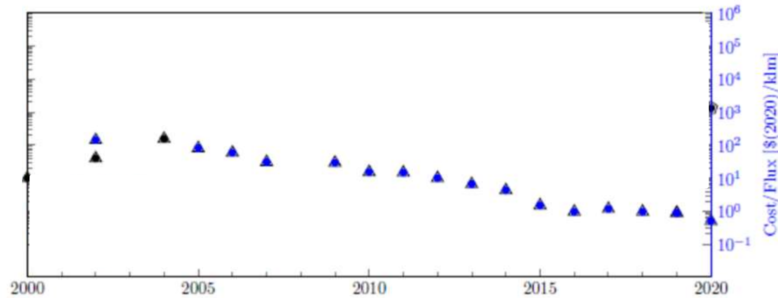


Lithium-ion v-weighted average price ($2020/kWh)



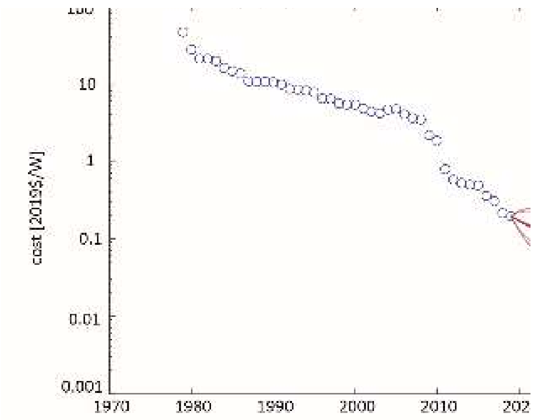
Source: BloombergNEF

LED lighting $/flux ($2020/klm)



Weinold, Kolesnikov and Anadon (2021)

Crystalline Si PV module cost ($2019/W)



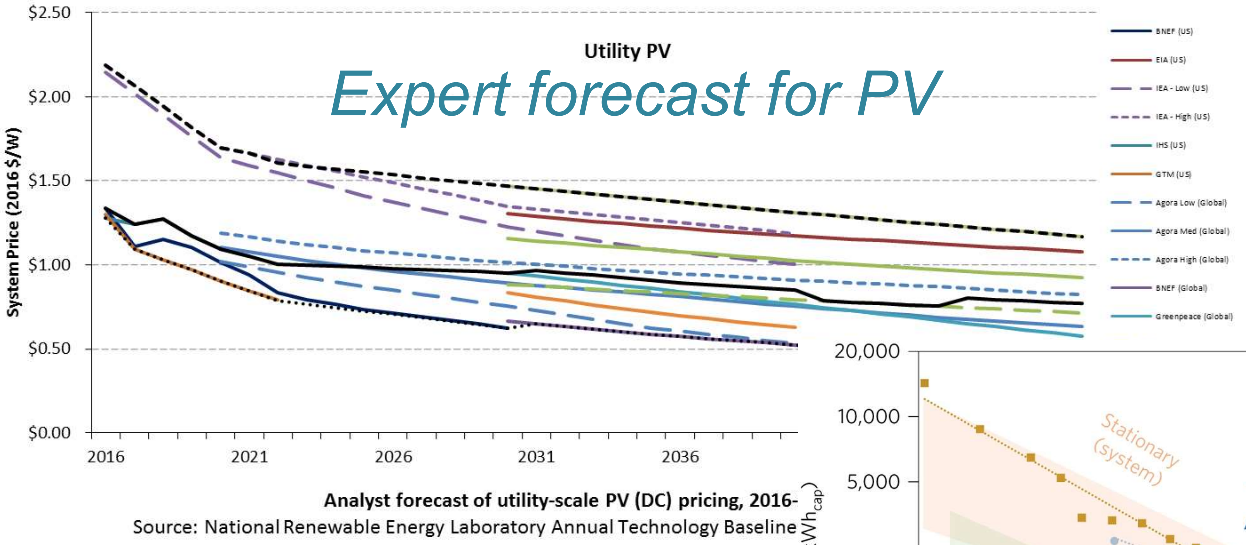
Meng, Way, Verdolini, Anadon (2021)

Offshore wind tender PPA and auctions ($2018/kWh)

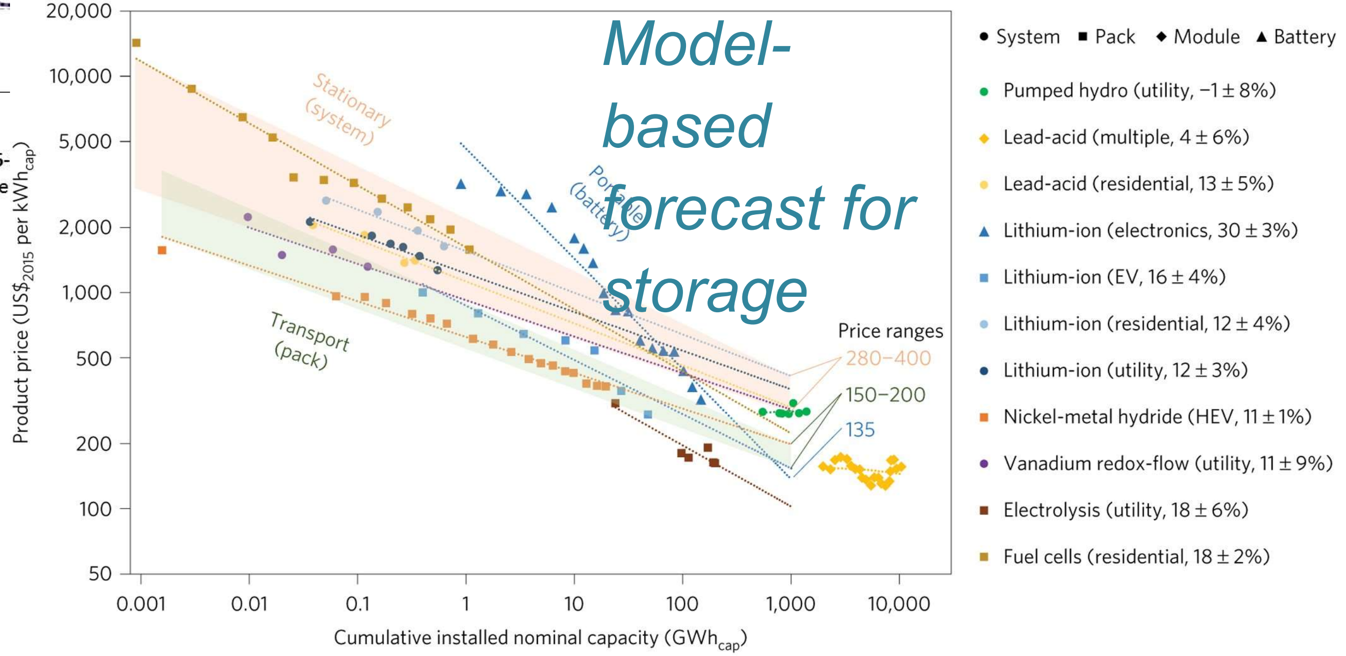
Carbon Brief (2019) using data from IRENA

- Over the past 10 years:
  - Cost of PV, LIB, SSL down by 80-90%
  - Cost of on- and off-shore wind down by around 50%

Did we see it coming? Expert- vs. model-based forecasting



NREL (2018)



Schmidt et al. (2017) *Nature Energy*

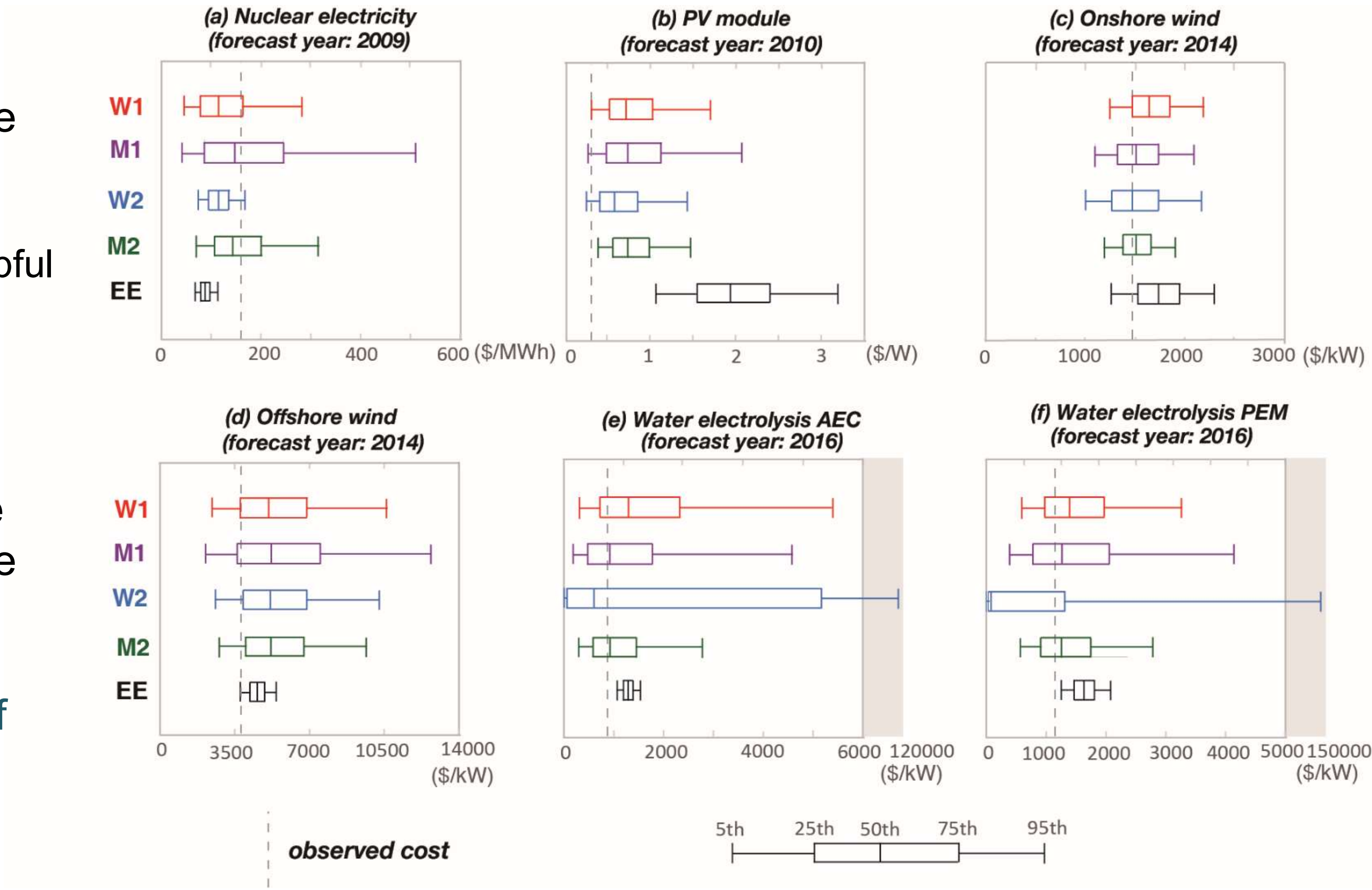
Systematic comparison of the accuracy of model- and expert-based 2019 forecasts

- Model forecasts much more likely to include observed value 6/6 vs 1/6
  - When data is available, probabilistic methods are helpful
  - When no data is available, larger uncertainty

- In all methods the **median forecast was higher than the observed value** (nuclear is the exception)

➔ Underestimation of the pace of technological change, but d

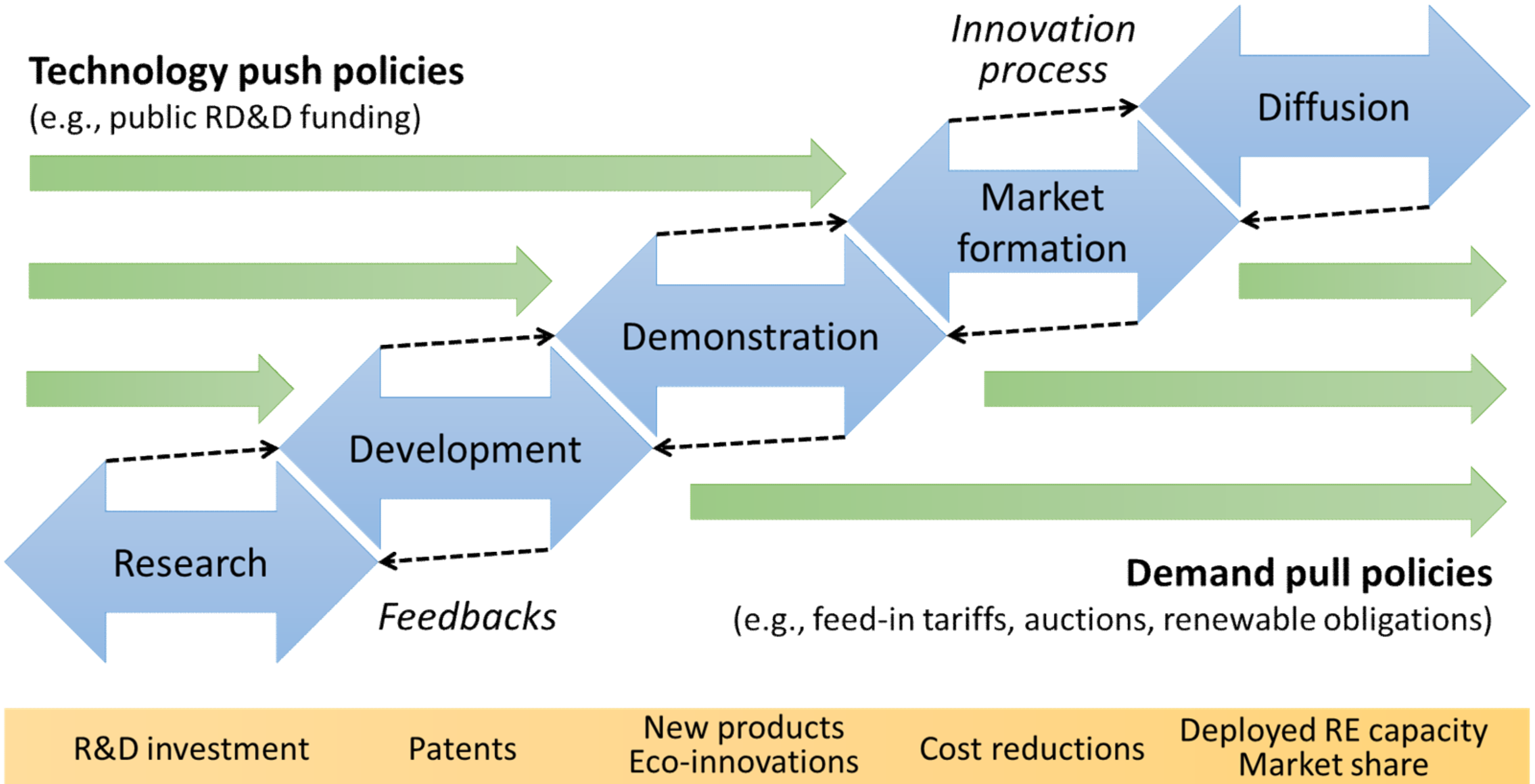
➔ 2030 forecasts also more optimistic using models



Meng, Way, Verdolini, Anadon (2021). *PNAS*

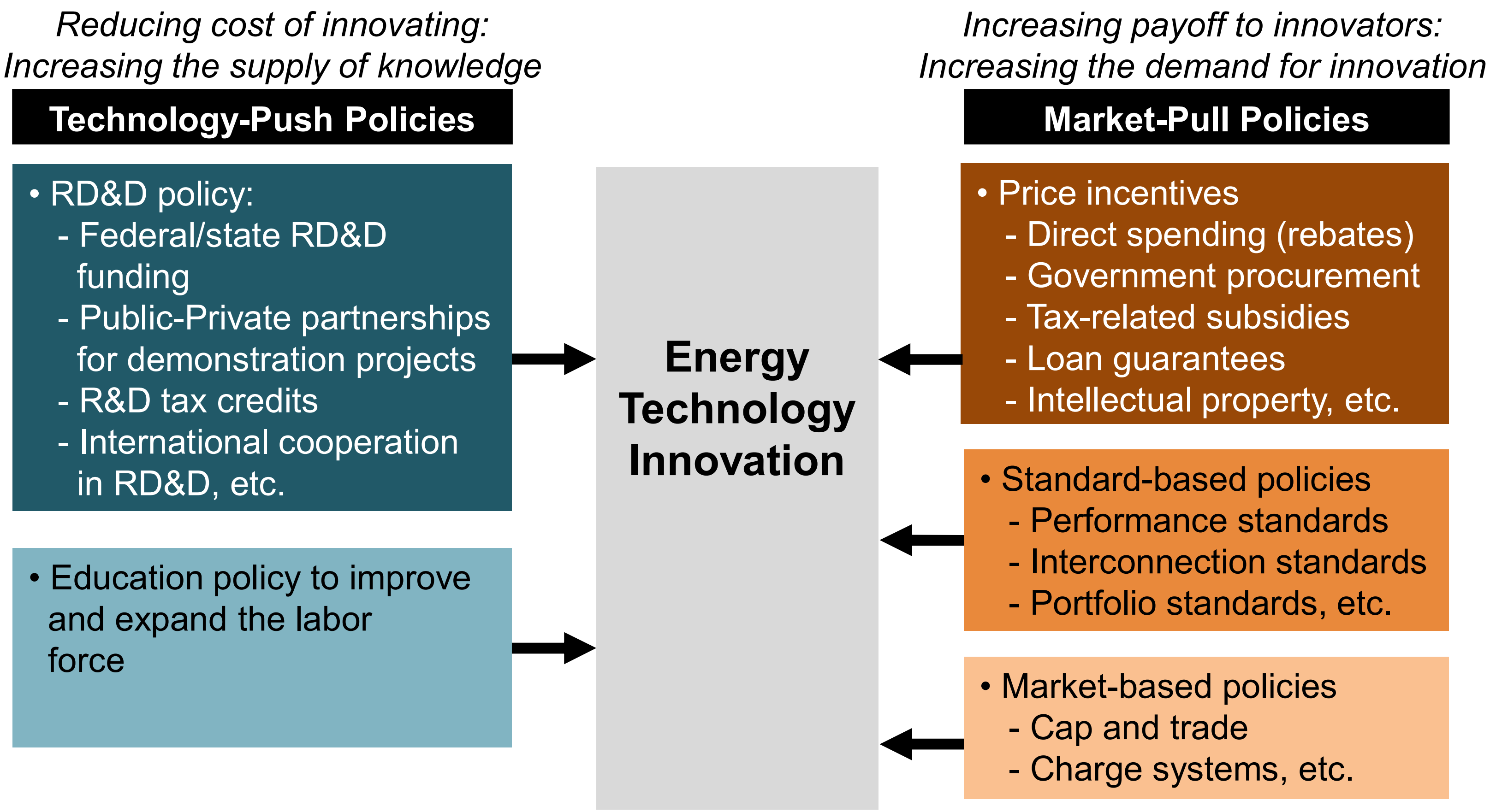
Innovation spans from research to diffusion

- **Innovation:** the process by which technology is conceived, developed, codified, and deployed (Brooks, 1980)
- Different indicators used to assess efforts across the different stages



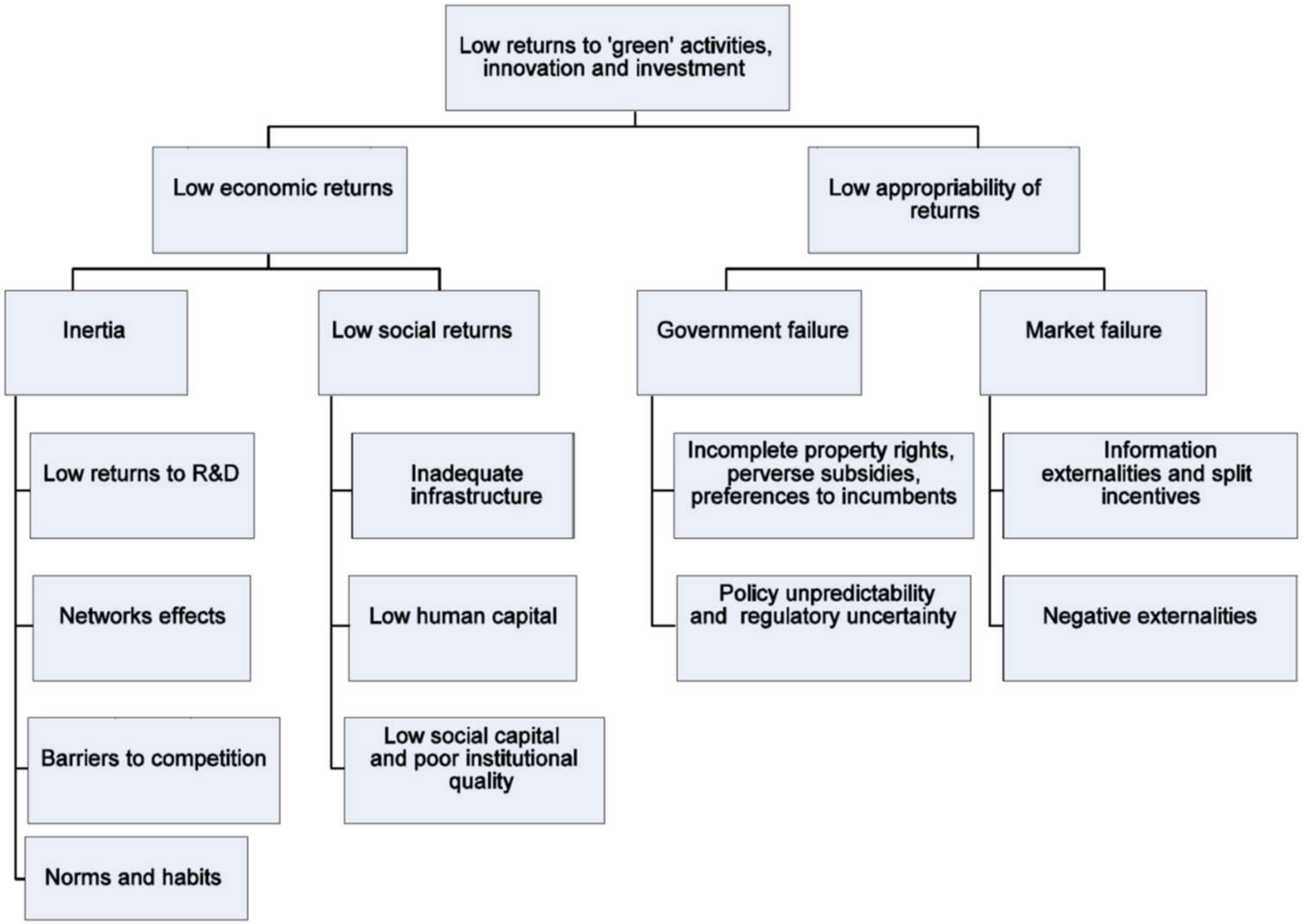
Source: Adapted from Grubler et al. (2012) by Peñasco, Kolesnikov and Anadon (2021)

Many policies shape direction and pace of energy innovation



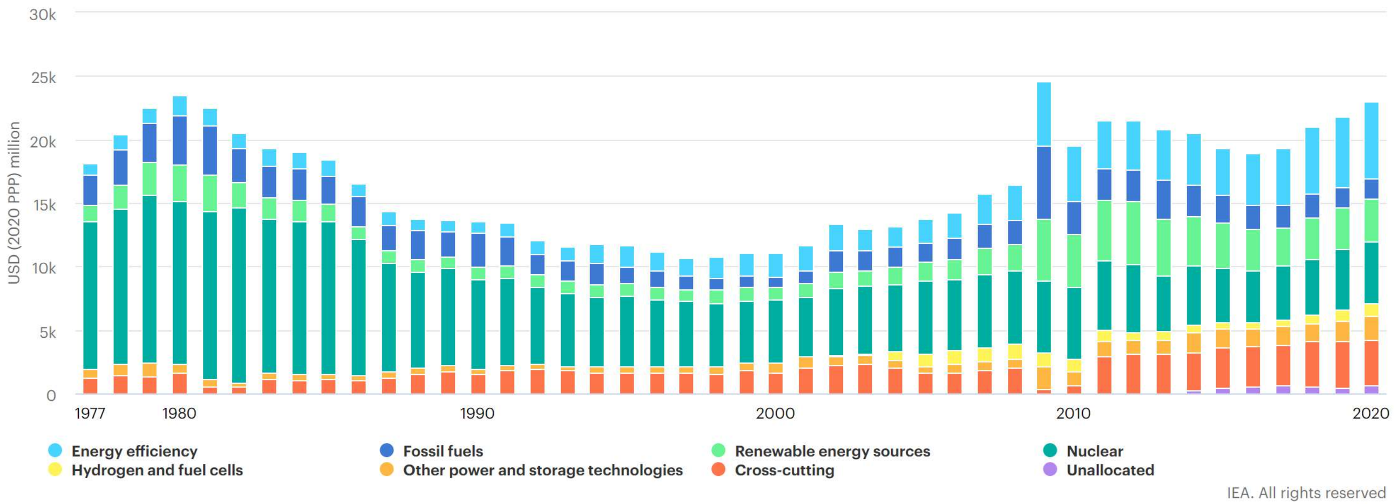
Adapted from Mowery and Rosenberg (1979) and Anadon and Holdren (2009), *Brookings Press*

Typology of reasons explaining for low investment in innovation in green technologies



Hausmann, Velasco and Rodrik (2008), “Growth Diagnostics” in J. Stiglitz and N. Serra, (eds)

Public energy RD&D investments in OECD countries
Getting close to oil crisis levels – China playing a growing role



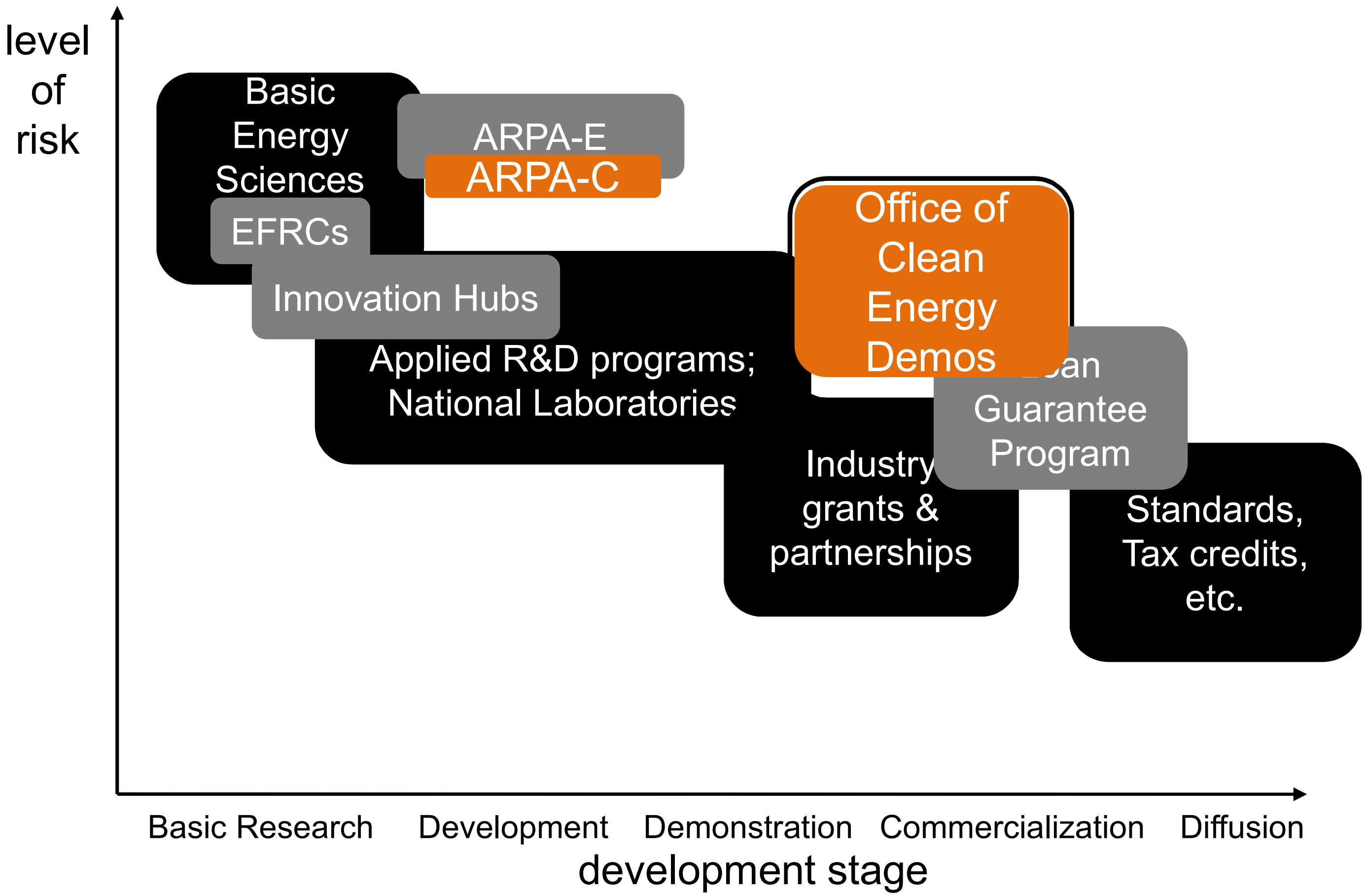
Data from IEA (2020)
Work on energy R&D investments in Anadon et al (2017) Nature Energy; Chan & Anadon (2017); Anadon et al (2014), etc

- OECD plus China and India in 2018 were at $25 bn
- China made up 5% of total in 2008 and 24% in 2018
- Largest number of **institutional changes** for RD&D at the turn of the century and the financial crisis, not so much with Mission Innovation

Meckling et al. (2022) Under review

The United States has an ecosystem of public programs

- Some **conduct** research
  - EFRCs, Innovation Hubs, National Labs
- Some **finance firms**
  - SBIR, industry grants, industry-public cooperation, loan guarantees, R&D tax credits
- Some allocate R&D funds in **novel ways**
  - ARPA-E, now ARPA-C, OETC, etc



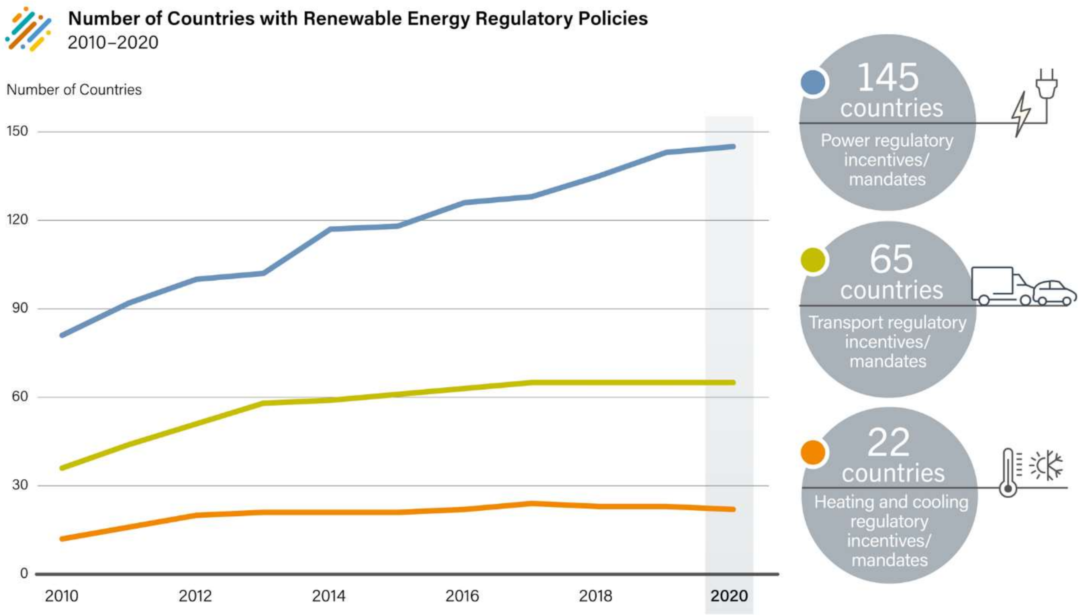
Updated from Anadon, Bunn, Narayanamurti (2014). *Cambridge University Press.*

What have we seen elsewhere in the tech push side? A selection

- **ARPA-E model**
  - Japan: Moonshot - around $900 m over 5 years)
  - UK: ARIA - $1.2 bn over first few years
  - Canada: CARPA - starting wiht $2bn
  - EU: European Innovation Council introducing an 'active management' model
- **National lab model**
  - Germany: its own version with Max Planck and Fraunhofer Institutes (the latter with closer industry connections (Hoppmann, Anadon, Narayanamurti 2021, *Research Policy*)
  - China: expanding (from 200 to 700) and restructuring its national lab system (Shenzen Grubb Institute)
  - UK: (no labs) experimenting with Catapults and the Faraday Institution (storage)
- **Support for R&D in firms**
  - UK has something similar to SBIR, R&D tax credits lead to 'additional' R&D in small firms (Pless, 2020)
- **Missions approach** (novelty for Horizon programs 2021-2027)
  - EU: 5 'missions' (4 of them environment-related) to guide and complement policies at different levels

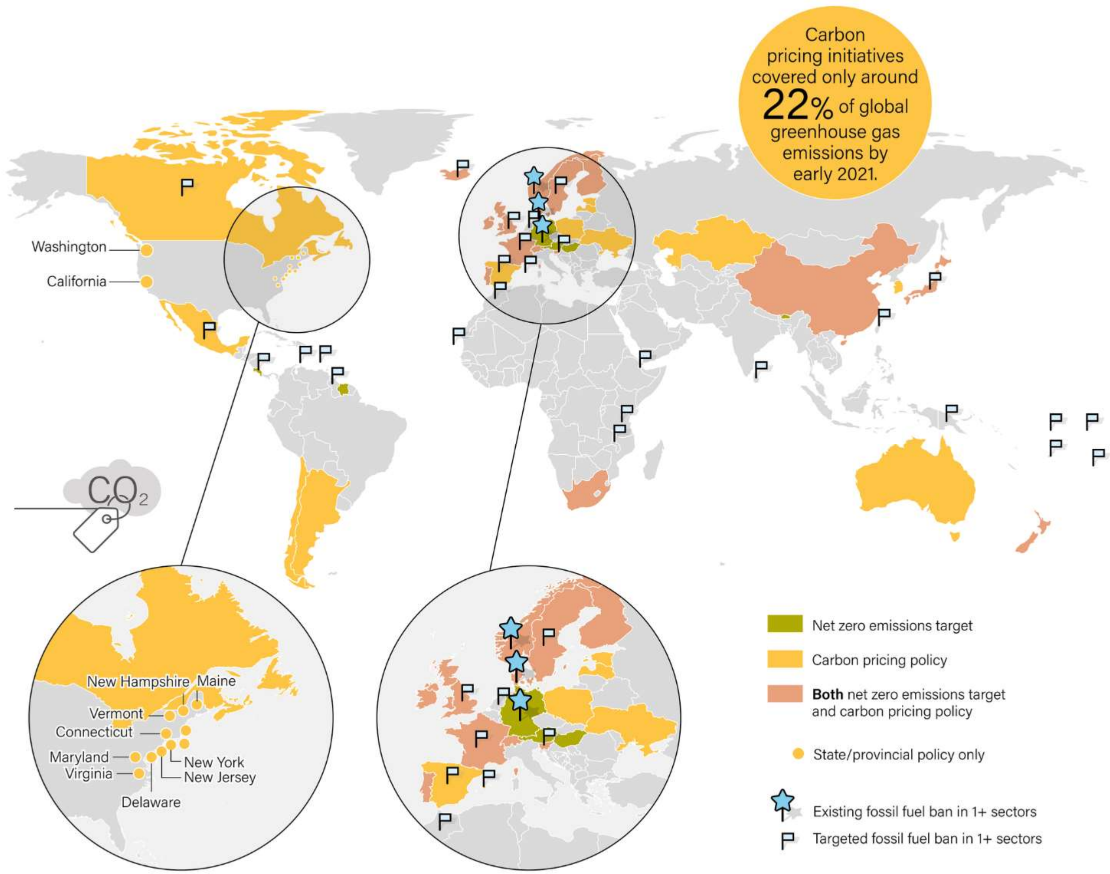
Many countries have put in place demand-pull fiscal and regulatory policies, carbon pricing and targets (as of 2020-21)

Countries with regulatory incentives and mandates



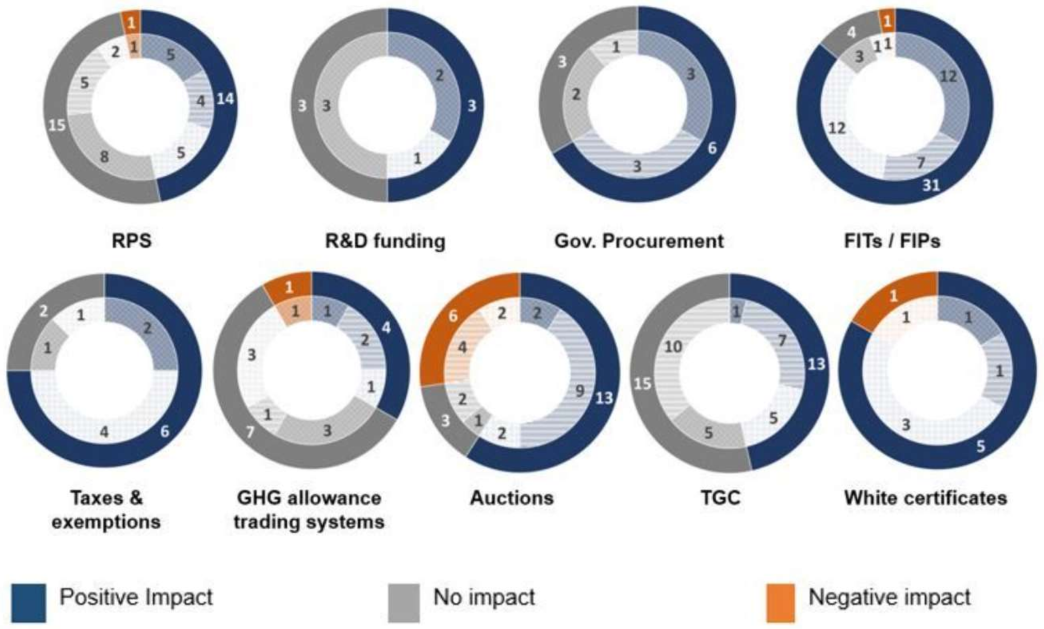
REN21 2021 Report

Carbon pricing and Net Zero targets

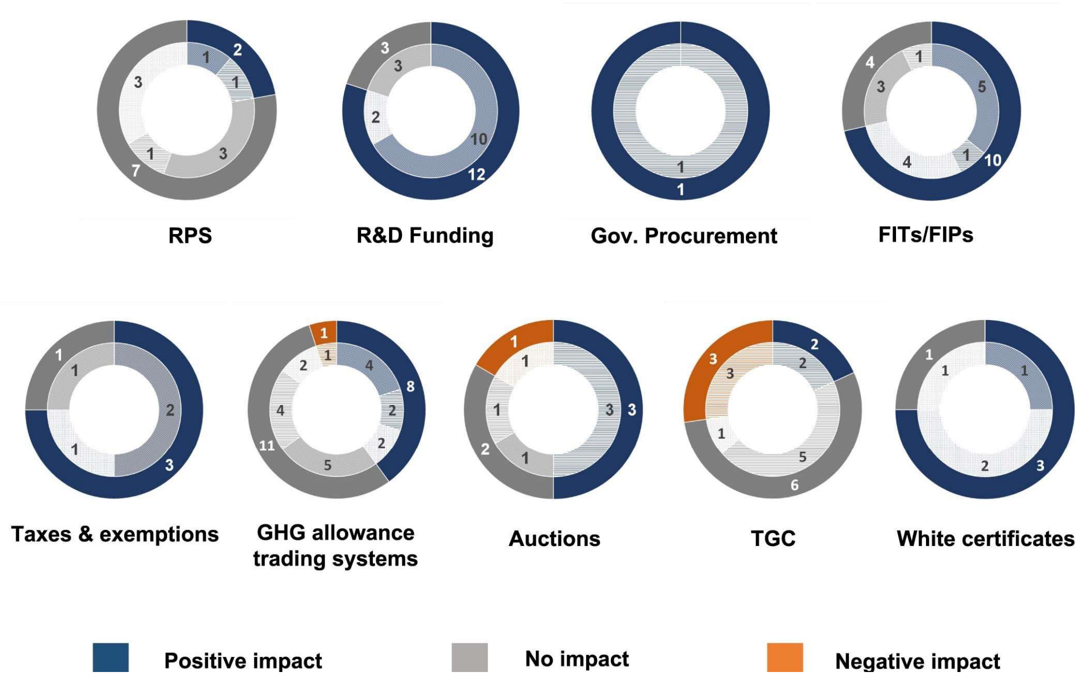


Direction of policy impacts by policy instrument on...

deployment



other innovation indicators

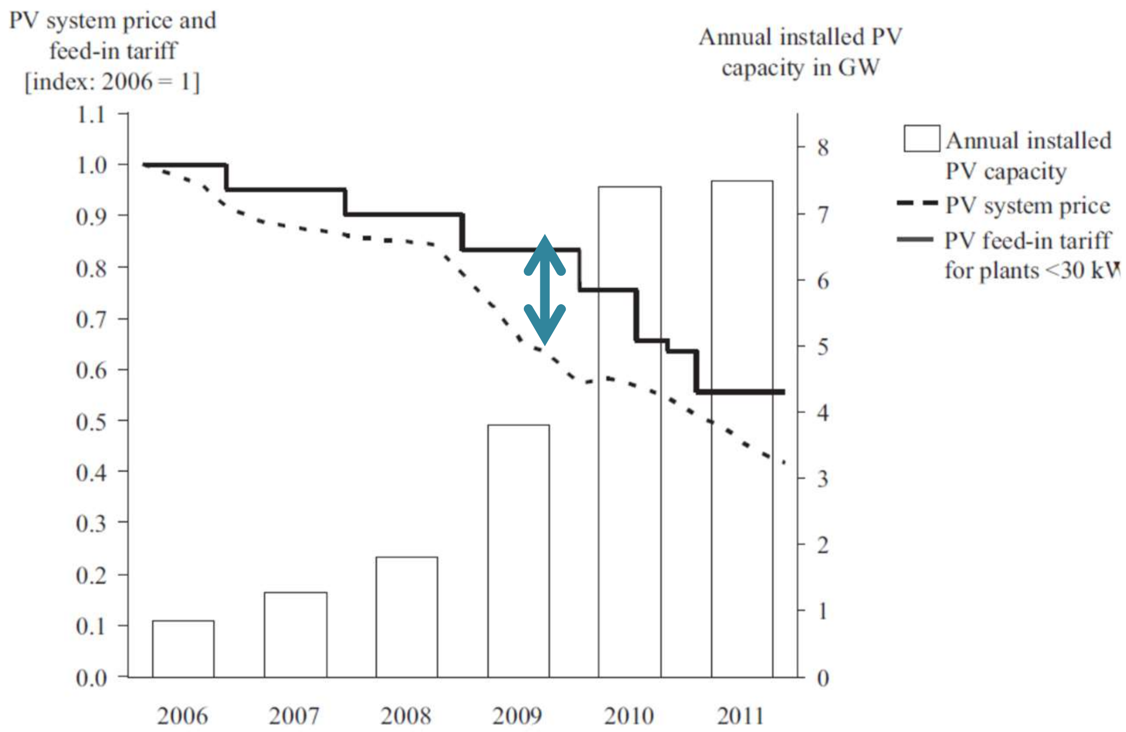


Quantitative methods   Qualitative methods   Theoretical/ex ante

- The major cost reductions driven by fiscal and regulatory policies, not carbon prices

Peñasco, Anadon, Verdolini (2021) *Nature Climate Change*

Providing certainty about profits incentivizes private investments and innovation – evidence also about FITs vs RPS



Hoppmann et al (2014). *Research Policy*

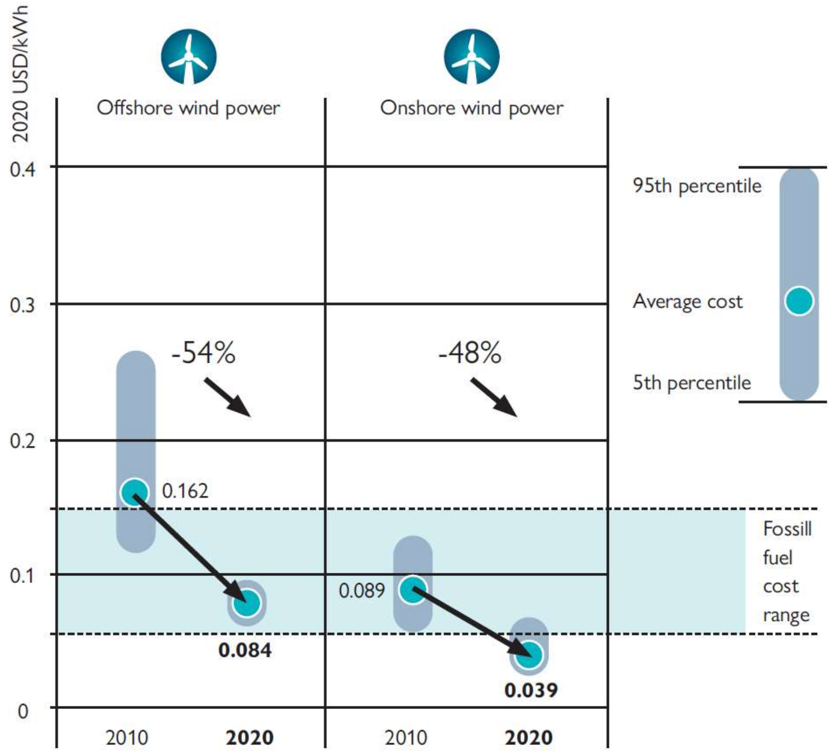


Figure 2: Range in of wind energy generation costs, 2020 vs 2010
Source: IRENA, Renewable Power Generation Costs in 2020 (p. 15).[32]

Grubb et al. (2021) *EEIST Report*

- German feed-in-tariffs guaranteed returns for solar PV
- UK contracts for differences reduced uncertainty for on- and offshore wind

What have we seen elsewhere in the market pull elsewhere?

A selection from Europe

EU

- Emissions trading scheme
  - Carbon Border Adjustment
- 'Fit for 55 package' package to deliver 55% reduction from 1990 levels by 2030
  - emissions standards for cars & vans, revision of Energy Taxation Directive
  - €72 bn fund to help distributional impacts

UK

- UK ETS + Carbon Price Floor
- Doubling down on offshore wind (CfDs)
- Ofgem Regulatory Sandboxes and evaluation
- Heatpump subsidies to come…

Germany and the Netherlands:

- Green procurement, competence centers

Case: Green H2 for industry

EU:

€ 2bn R&D partnership for green H2

4/7 demos of € 1bn on green H2

At a national level, supporting demand:

- E.g.: HyDeal: Green H2 for Mittal and Fertiberia with Enagas in Spain (7.5 GW of electrolyzer power), guaranteeing H2 purchase at €1.5/kg (generation supported with EU funds)

Anadon, Bunn, Narayanamurti (2014). *Cambridge University Press.*

Some high-level policy conclusions

1. We are seeing rapid change resulting from both push and pull policies

2. **Sustained and targeted support for deployment** is needed in some areas: some technologies need to be 'picked'

3. Policy sequencing matters, early action important
   - E.g. shifting to EVs with more renewable electricity decreases emissions further
   - E.g., preferences are endogenous and there is path dependency; action now determines options & paths

4. Given urgency international coordination can help
   - E.g. Carbon border adjustment, technology standards, etc

5. New approaches to policy appraisal beyond CBA needed to account for systemic, non-marginal, change
   - adaptive governance and monitoring (including independent evaluation)

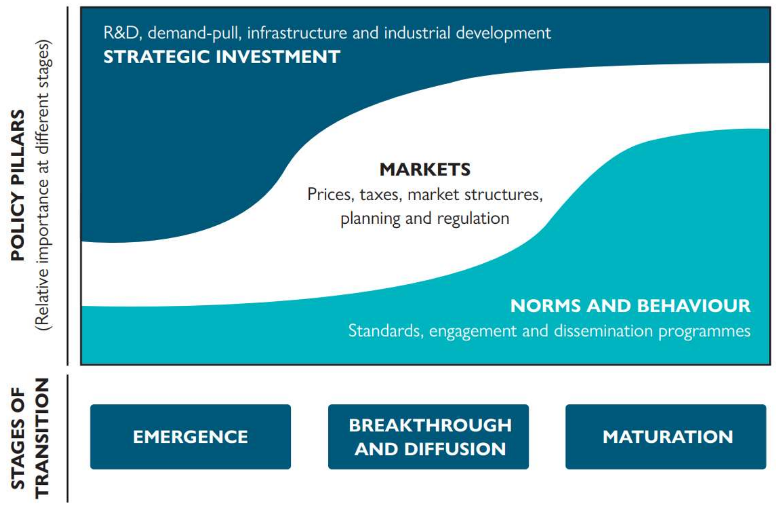


Figure 9: Indicative evolution of policy mix over the course of a transition

Grubb et al. (2021). *EEIST Report*

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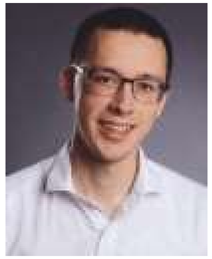

Prof. Elena Verdolini Dr. Jing Meng Dr. Cristina Peñasco Michael Weinold

Thank you for your attention!
And thanks also to my co-authors!

@l_diaz_anadon




Dr. Benedict Probst Prof. Christian Binz Dr. Deyu Li Dr. Sergey Kolesnikov

https://eeist.co.uk/

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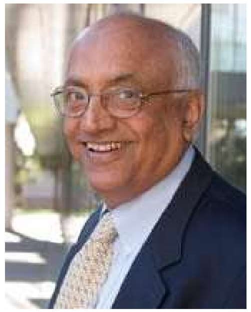
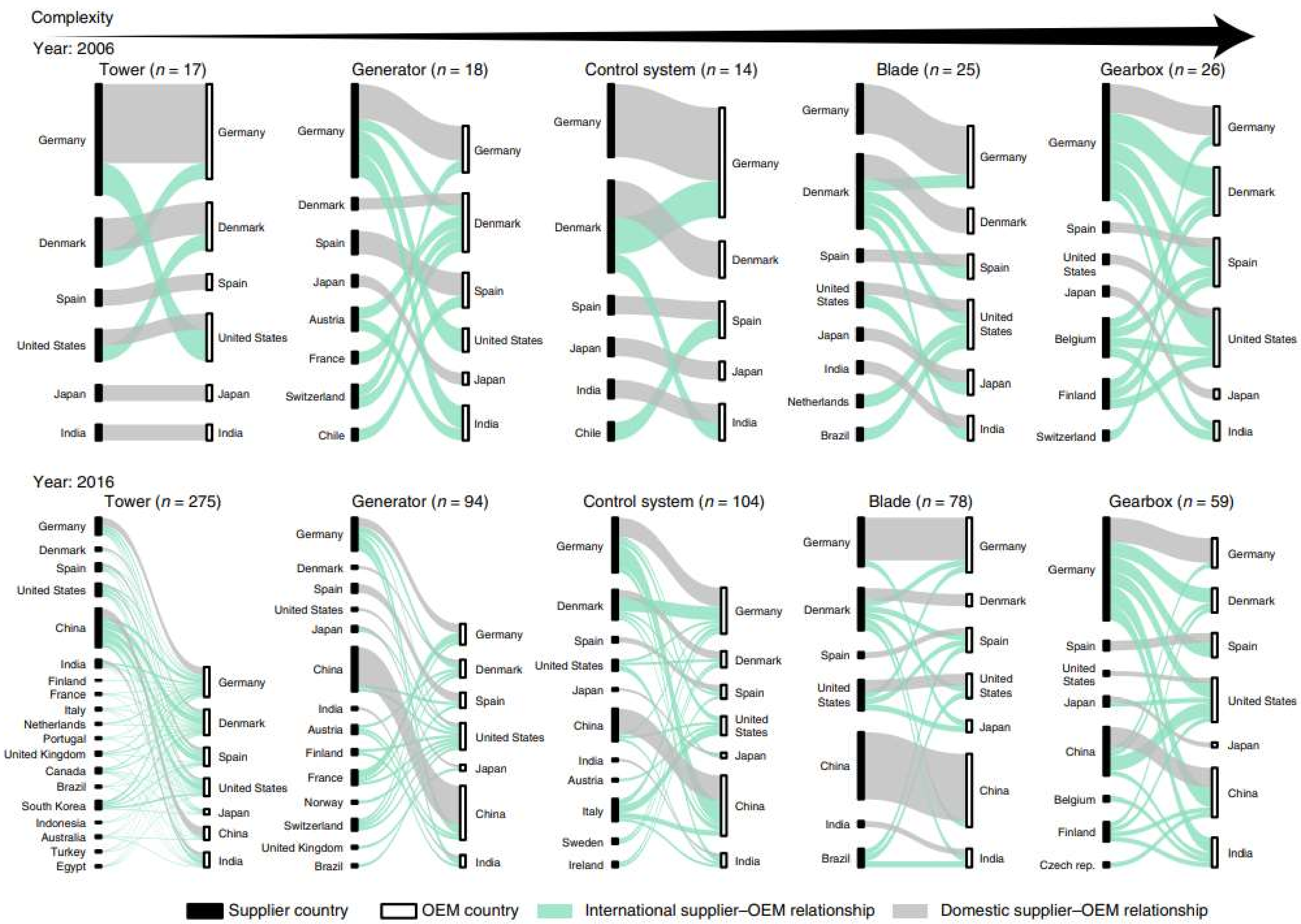



Dr. Anna Goldstein Dr. Kavita Surana Prof. Claudia Doblinger Dr. JF Mercure Prof. Venky Narayanamurti Dr. Clara Galeazzi

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730403

ECONOMICS OF ENERGY INNOVATION AND SYSTEM TRANSITION

Not all technologies and countries are equal in terms of economic development opportunities

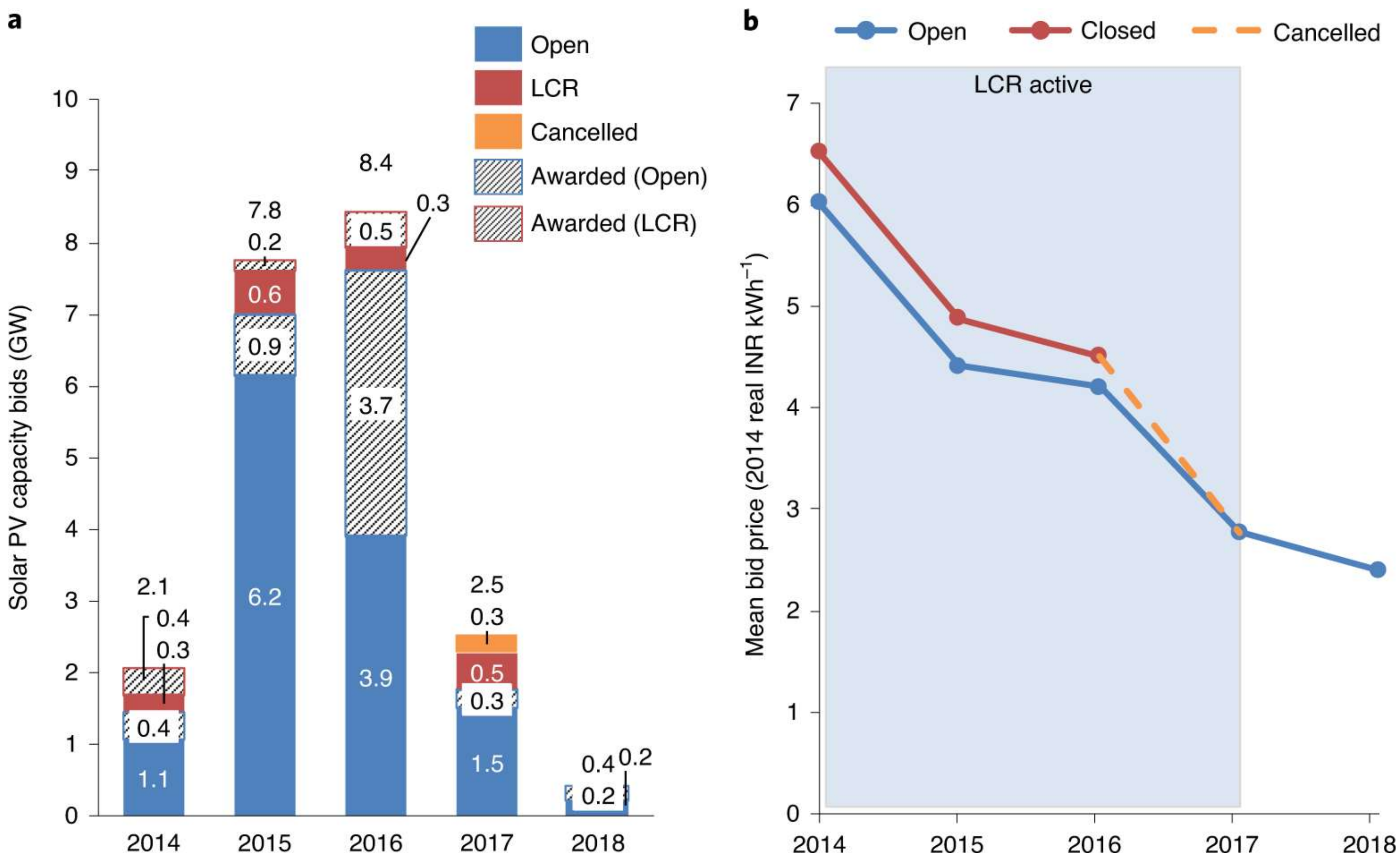


- Less internationalization for more complex components in the value chain

Surana et al. (2020) *Nature Energy*

Sustained and systemic policies are needed to deliver multiple benefits – e.g. local content requirements (LCRs) in India

- LCRs in India from 2014-2017 for some solar auctions
- 6% increase in kWh from LCR
- Short-term increases in manufacturing capacity but little impact on market share or export markets



Probst et al. (2020) *Nature Energy*

Market creation and aggregation essential
But so is a dynamic approach

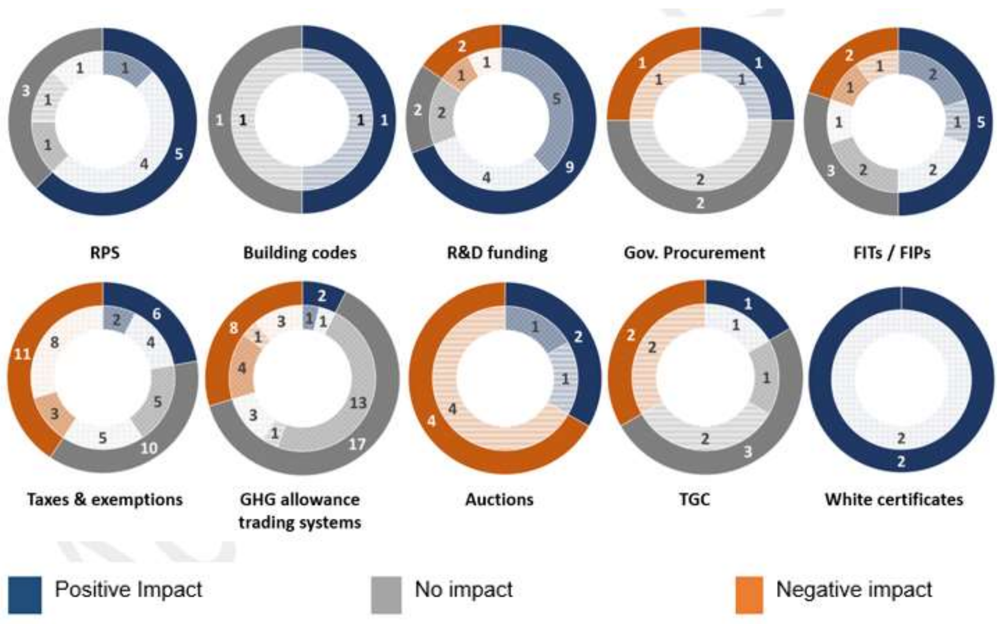
Carbon prices not enough because:

- Urgency, timescales
- Missing markets
- Other externalities including spillovers and learning-by-doing
- Lock-in

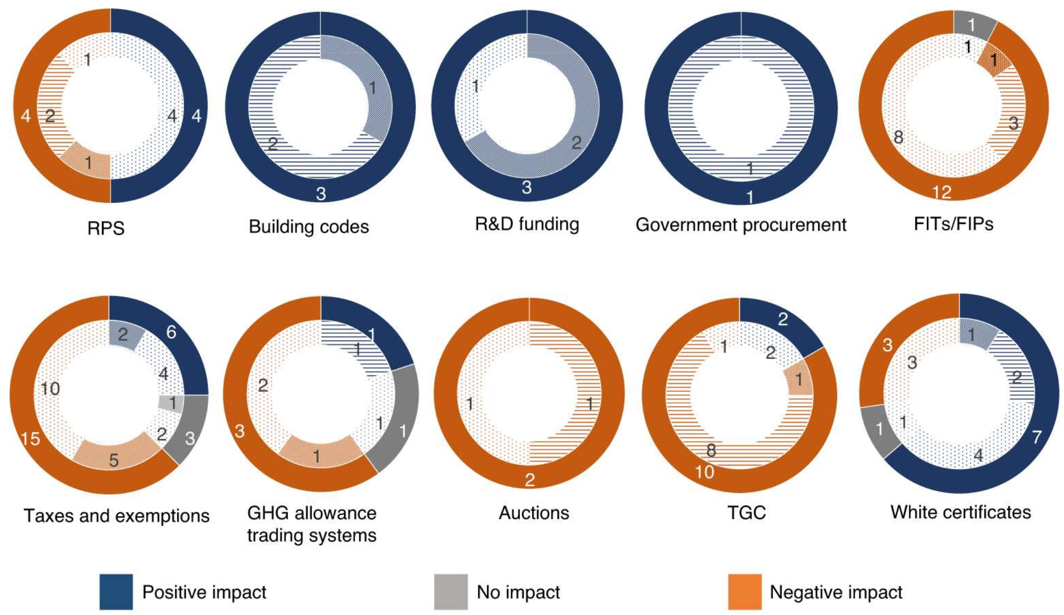
- … and political feasibility

The picture depends more on context and policy design for...

competitiveness impacts



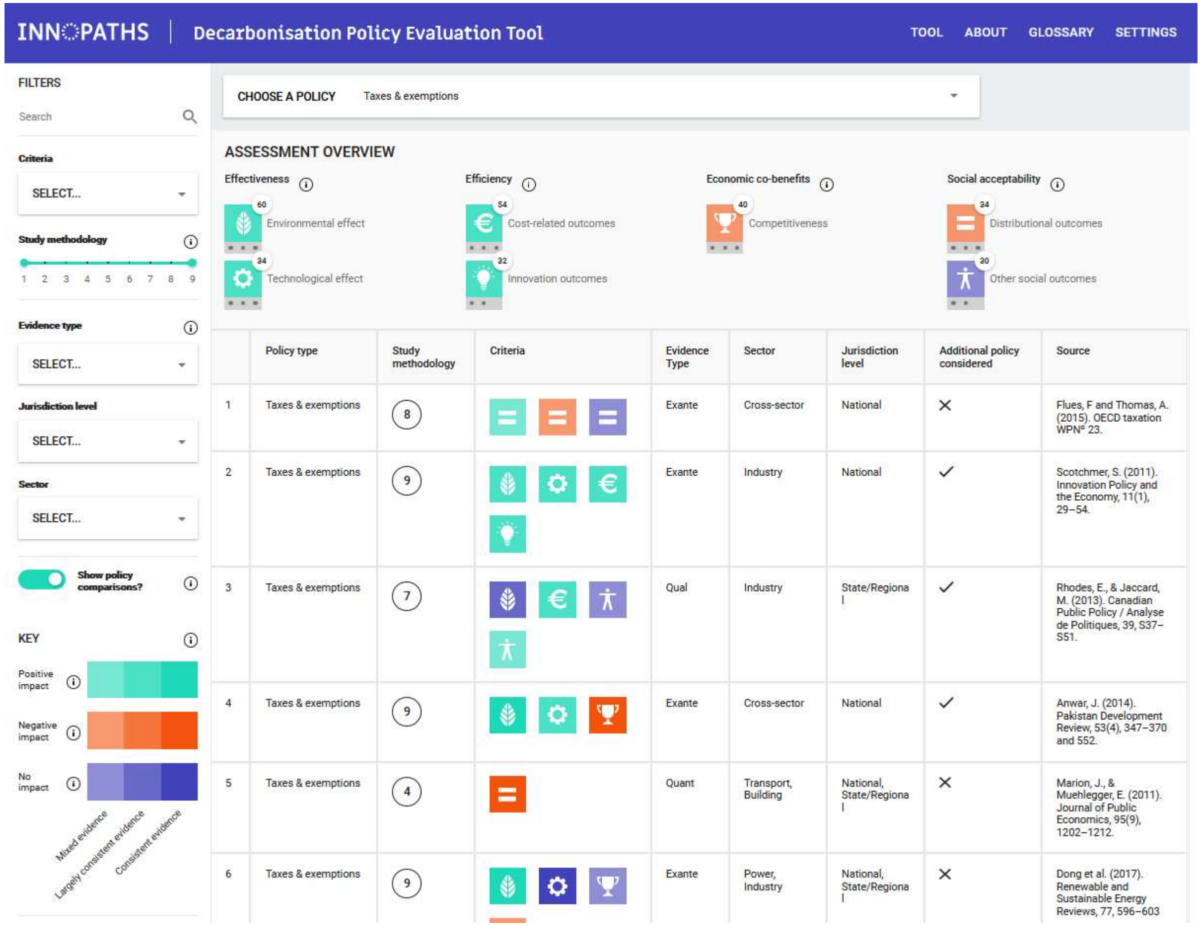
distributional impacts



Quantitative methods   Qualitative methods   Theoretical/ex ante

Peñasco, Anadon, Verdolini (2021) *Nature Climate Change*

Decarbonisation Policy Evaluation Tool (DPET) to explore the evidence in more detail



http://dpet.innopaths.eu/#/

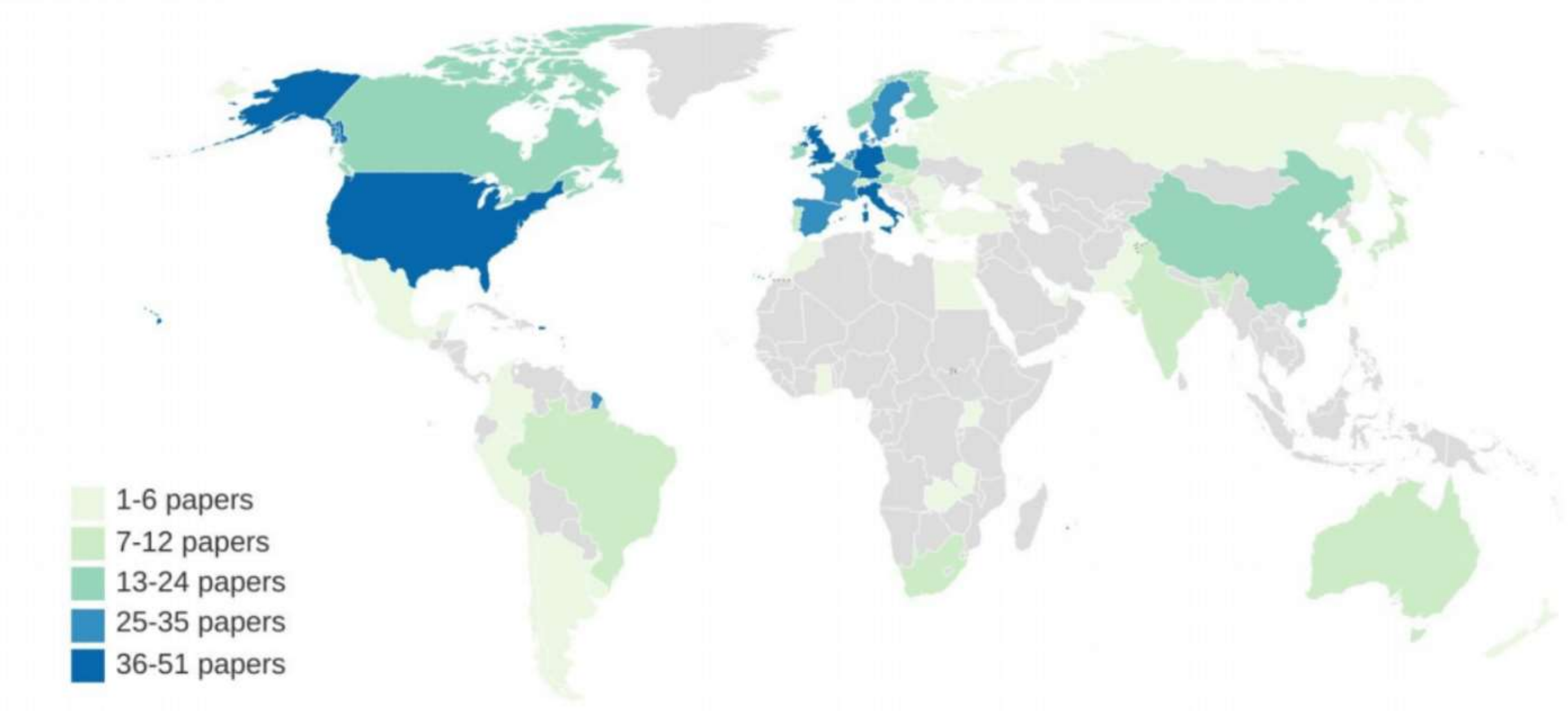
- Some of the **competitiveness and distributional impacts were most pronounced in startups and small and medium enterprises**

INNOPATHS has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730403

Peñasco, Anadon, Verdolini (2021) *Nature Climate Change*

Geographical scope of the publications identified in the systematic review

UK: 48 papers



Penasco, Anadon, Verdolini (2021) *Nature Climate Change*

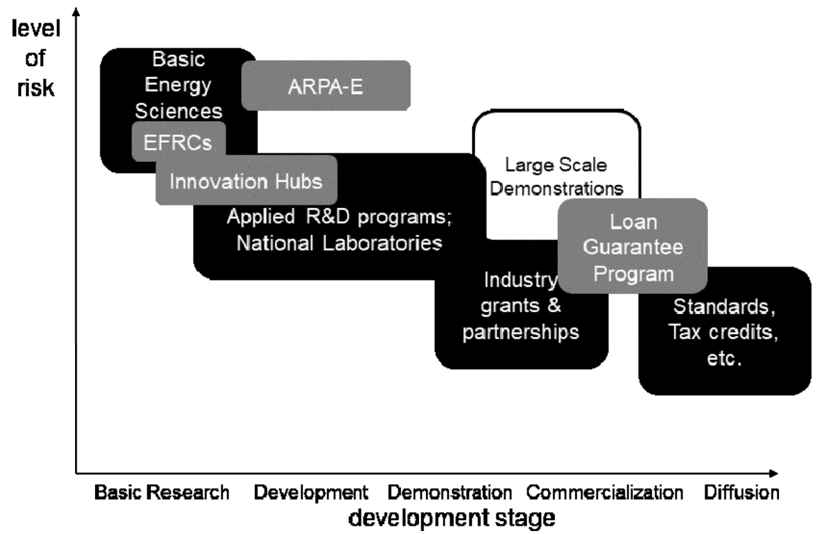
- Ongoing work with colleagues to assess experiences in developing countries

Broad consensus on the need to increase public funding for green RD&D for climate and economic development (& recovery)

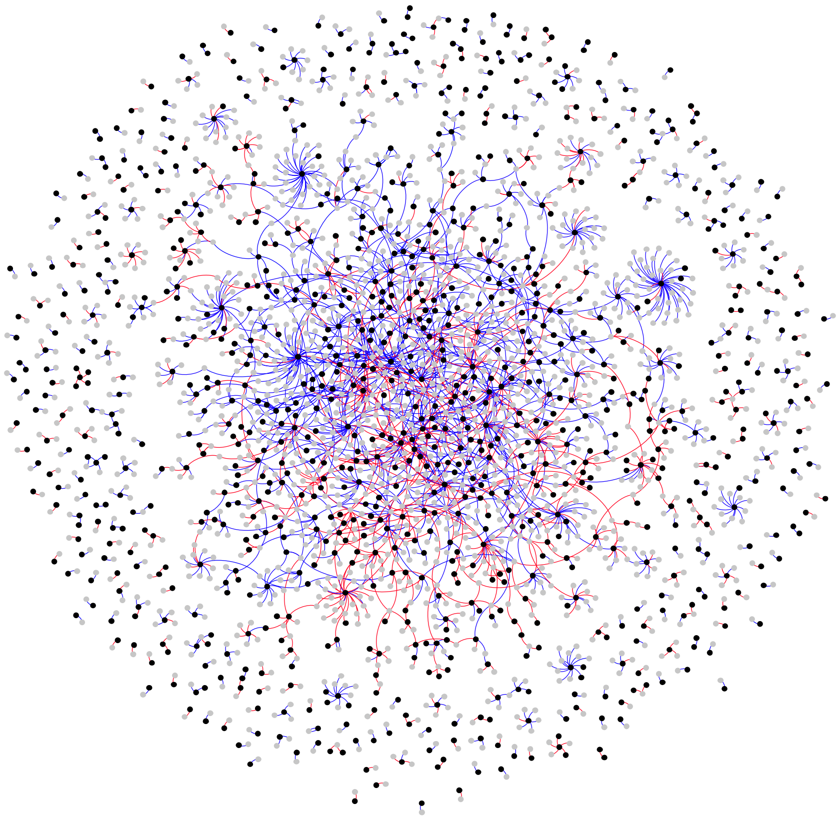
- Public energy RD&D globally around 30 bn USD, up from 25 bn in 2015 (IEA, 2020)
- Increased interest in how to manage and allocate funding (Anadon et al. 2016, Nature Energy)
- Growing interest in the role of new players, startups, small companies

➔ What is the role of **public R&D institutions (e.g. labs)? Have they enhanced US cleantech startup innovation and growth**?

➔ **What has been the impact of ARPA-E in small firms?** It is a high risk, actively managed, and mission-oriented agency founded 2009 (>$3.1bn investments since then)



Analysis of the impact of different technology development and licensing partnerships of US cleantech firms



- Startups
- Partners
- Technology-based relationship
- Market-based relationship

- 2,015 alliances
- Patents
- Financing deals
- Variables: degree centrality, age, size, location, prior patents, prior financing deals, sector

➔ Technology-based <u>government partnerships</u> with startups increased patenting activity and follow-on financing the most

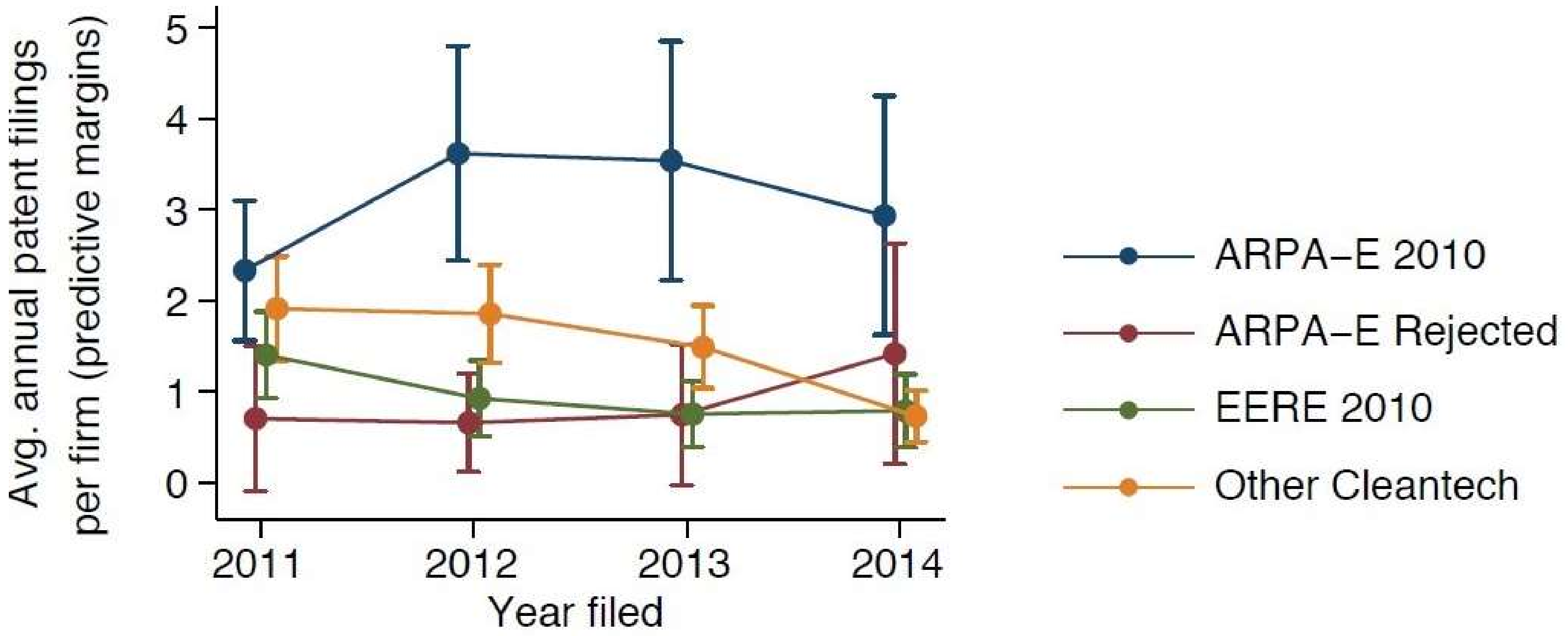
Doblinger, Surana, Anadon (2019) *Research Policy*

Public energy innovation institutions have complementary <u>resources</u>

- **Expertise and networks**:
  critical mass of employees with insights on technology development, complementary technologies in the energy system, or future developments
- **Infrastructure:**
  physical infrastructures and facilities for experimentation, demonstration, and testing facilities
  - DOE has over 200 facilities available for external users
  - DOD also provides extensive shared infrastructure and test beds
- **Inventions available for licensing**
- **Investors take it as an extra quality check**

Doblinger, Surana, Anadon (2019) *Research Policy*

Analysis of the impact of ARPA-E awards for first cohort of funded start-ups



- Enhanced patenting post-ARPA-E compared to other groups controlling by sector, pre-patenting, and other firm level covariates

Goldstein, Doblinger, Baker & Anadon. (2020) *Nature Energy*

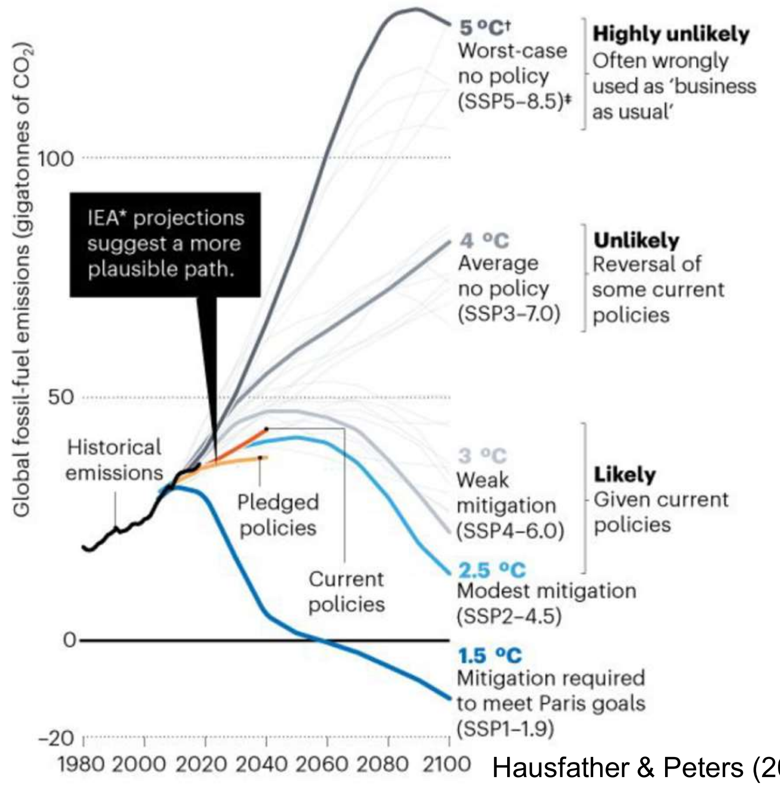
- The EU has created 5 missions, five of them related to environment
  - – Climate adaptation and societal transformation
  - – Climate-resilien cities
  - – Soil regeneration and food
  - – Regeneration of oceans and water ways

➔ Inspired by Apollo 11 mission

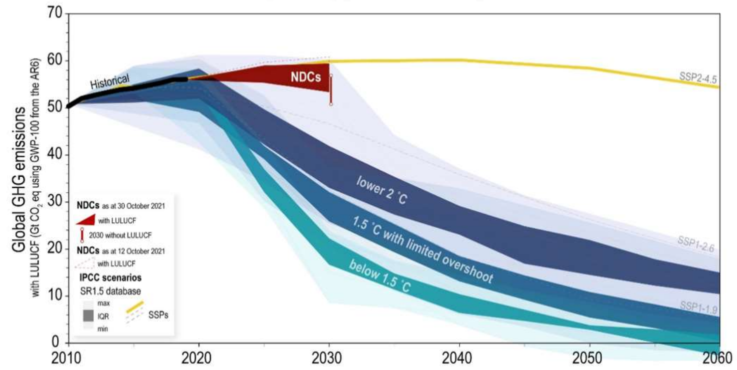
- £800 million ARIA UK
- Canadian ARPA
- EU ARPA
- Spain Green H2

Current emissions trajectories are not consistent with the goals of the Paris agreement

- Already 1.1 ^{o}C over pre-industrial
- Since 1997 the global carbon intensity has been declining at about 1% year
- To get to the 1.5 ^{o}C Paris aspirational goal (which was emphasized more strongly in Glasgow) we would need to increase the rate of the rate of decrease in the carbon intensity of the economy by over one order of magnitude

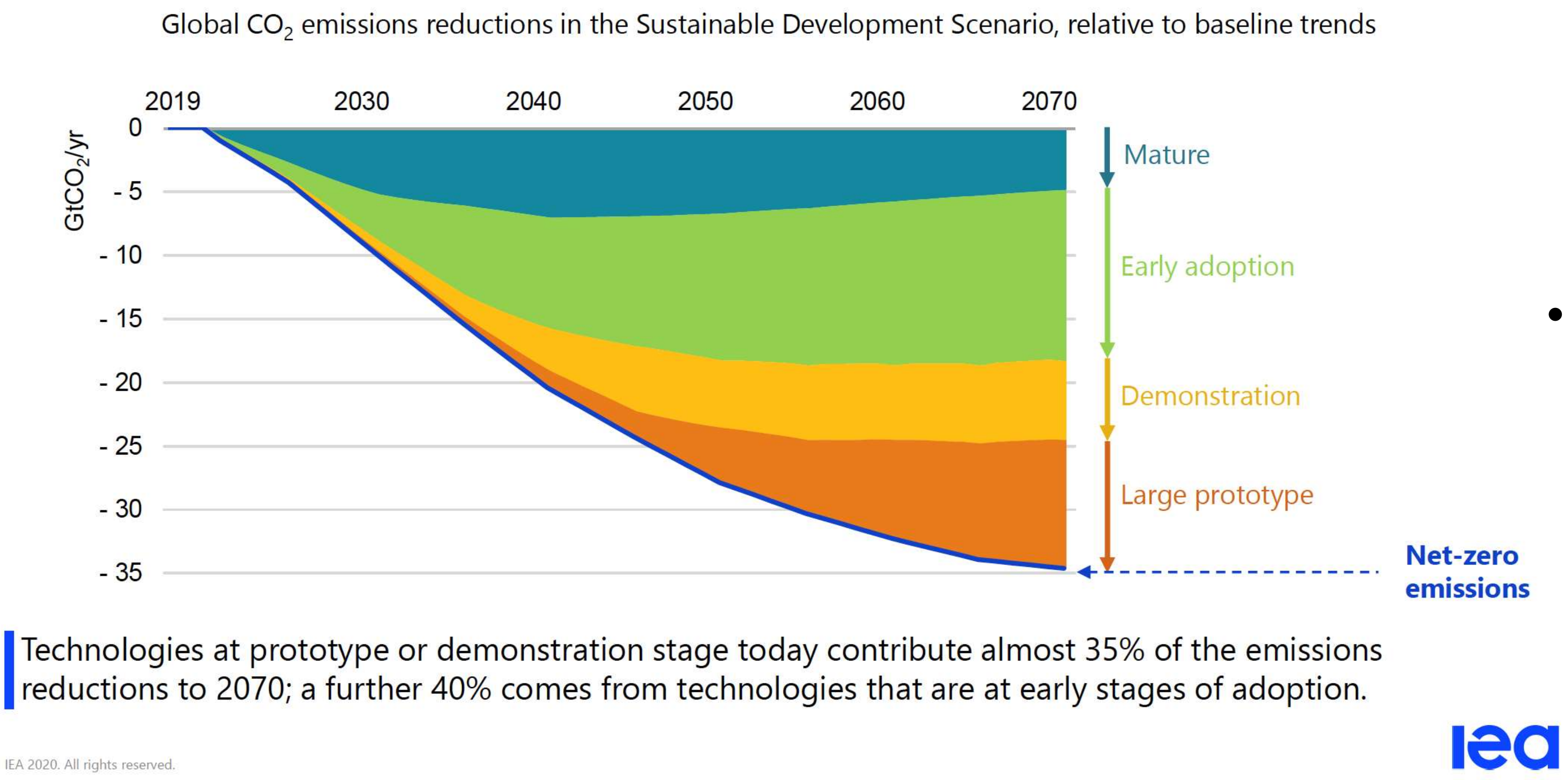


Hausfather & Peters (2020)



UNFCCC (2021) Nov 4.

Net Zero emissions is not viable without more & faster innovation



- 130 countries have announced or are considering net zero targets between 2050-2070 (Climate Action Tracker, 2021)
- Some technologies are in the early stages of innovation, particularly in freight, aviation, firm power, energy intensive industries, and green house gas removal

Energy innovation affects various drivers of emissions: the IPAT/Kaya identity

$$CO_2 = Population \times \frac{GDP}{Population} \times \frac{Energy}{GDP} \times \frac{Carbon}{Energy}$$

Income per capita

Energy intensity of GDP

Carbon intensity of energy

Politics, public policy and innovation studies research suggest the value of a strategy emphasizing innovation & competitiveness

- **Competitiveness co-benefits of decarbonisation policies shape public support**

Competitiveness, health and other co-benefits (e.g. biodiversity) can change public opinion and sustain effort

It is also a particularly relevant policy goal right now

[Stokes and Warshaw, 2017; Ansolabehere and Konisky, 2014; Deng et al., 2018; Hulme, 2009; Roberts and Zeckhauser, 2011]

- **New players and actors can counter balance the power of the incumbents**

New industries create new actors (‘winners’), which form new interest groups that can make policy ‘sticky’ and overcome lock-in

[Geels 2014; Meckling et al. 2015, Breetz, Mildenberger, & Stokes 2018; Schmidt & Severin 2016; Schmidt & Huenteler 2016; Surana & Anadon 2015; Stokes & Breetz 2018; Turnheim & Geels 2019; Sovacool et al. 2020…]

Strategic investments, regulation, green industrial policy

Expert-based forecasting approaches

- We cover **expert elicitations** because:
  - they are probabilistic
  - they have been increasingly used
  - they do not assume that previous trajectories will continue and do not preclude the identification of technology surprises or discontinuities

High-level approach	***Subtypes*** *for expert-& model-based methods*	***Rationale or intuition and comments on practice.***	***Example References*** *when possible, these references covered energy technology cost forecasts, but it was not always possible*
Expert-based forecasts: experts rely on information available to them, including observed data, as well as on their tacit knowledge and mental models.	Un-structured expert input	It involves asking experts informally about cost parameters in the future. This method is used in many exercises. It is the simplest and least resource intensive method. Information about the consulted expert(s) is often not provided, which leads to a lack of transparency.	Deterministic forecasts: Most IAM scenarios, e.g. [1-3]. Some of the examples cited and others have 'high' and 'low' forecasts (sensitivity analysis or scenarios), but they are often not probabilistic. Probabilistic forecasts: N/A. Calls for increased transparency.
	Expert elicitations	Highly structured formal processes aimed at reducing different psychological biases from individual experts. Very interactive and resource-intensive. In some cases, multiple expert answers are aggregated although there are pros and cons of this [4,5].	Deterministic forecasts: Not applicable, since this approach was designed to elicit probabilistic estimates. Probabilistic forecasts: E.g. [6-11]
	Group methods - Delphi method	Structured iterative group process aiming to lead to a convergence of opinion, a group response.	Deterministic forecasts: E.g. [12] Probabilistic forecasts: E.g., some applying to non-cost technology attributes[13,14,15]
	Prediction markets	It assumes that trading in futures contracts (or betting) by large groups of people may help predict events better than individuals or smaller groups of experts.	Method could be applied to make both deterministic or probabilistic forecasts[16]. No examples related to technology costs or availability were found, although the use of this method has been suggested [17].

Meng, Way, Verdolini, Anadon (2021). *PNAS*

Model-based forecasting approaches

- We cover **Wright's and Moore's law** because:
  - they are most widely used
  - there is more data available
  - to date shown to be more accurate than other model-based methods

Meng, Way, Verdolini, Anadon (2021). *PNAS*

High-level approach	***Subtypes*** *for expert-& model-based methods*	***Rationale or intuition and comments on practice.***	***Example References*** *when possible, these references covered energy technology cost forecasts, but it was not always possible*
Model-based forecasts: forecasts based on mathe-matical relationships between selected observed parameters	**Wright's law**	Evolution of costs as a function of cumulative production or deployment (learning by doing). Link to induced innovation	Deterministic forecasts: E.g. [18-20] Probabilistic forecasts: E.g. [19,21,22]
	Moore's law	Evolution of costs as a function of time	Deterministic forecasts: E.g. [23] Probabilistic forecasts: E.g. [21,22]
	Goddard model	Evolution of costs as a function of economies of scale	Deterministic forecasts: N/A Probabilistic forecasts: E.g. [21]
	Nordhaus model [24]	Evolution of costs as both a function of time and deployment (combining Moore and Wright)	Deterministic forecast: E.g. [25] Probabilistic forecasts: E.g. [21]
	SKC model	Evolution of costs as a function of scale (unit costs) and deployment (combining Goddard and Wright)	Deterministic forecasts: E.g. [24] Probabilistic forecasts: E.g. [21]
	Two-factor learning curve (R&D and deployment)	Evolution technology costs is represented as a function of both R&D investments and deployment (Wright).	Deterministic forecasts: E.g. [26] Probabilistic forecasts: N/A

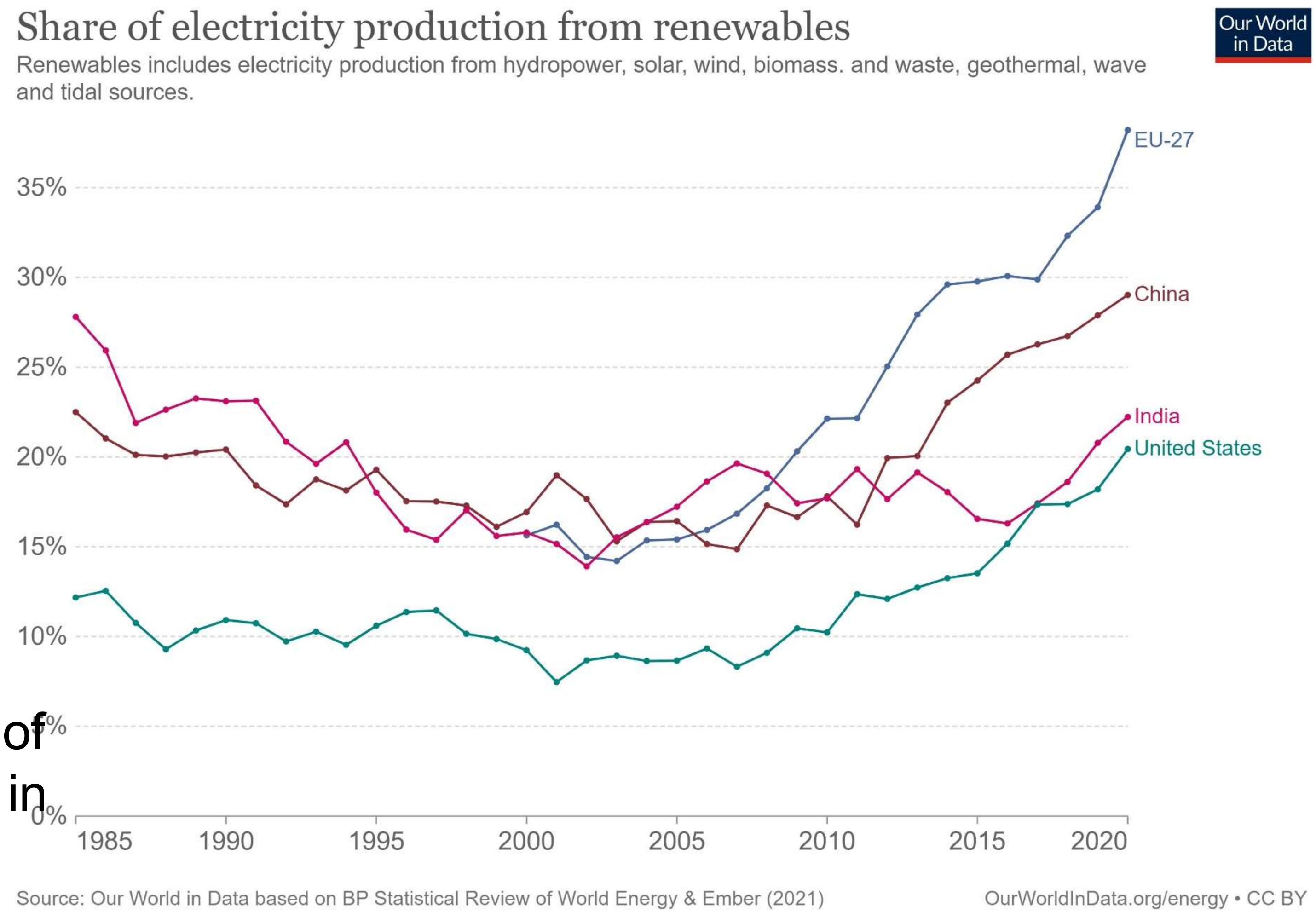
Systematic assessment of the performance of forecasting methods

- We **collect, harmonize, and make available** a large number of data points on the costs of **32 energy technologies**
  - 25 sets of data from expert elicitations conducted between 2007 and 2016
  - 25 sets of observed technology data
- We **generate** forecasts using EEs and the four model-based approaches (the Stochastic Exponent approach is a modified version of previous work)
- We **compare 2019** probabilistic expert- and model-based **forecasts with observed 2019 costs**
  - For 6 technologies for which this is possible
- We compare **2030 model- and expert-based forecasts** to each other
  - For 10 technologies for which this is possible

Meng, Way, Verdolini, Anadon (2021). *PNAS*

Renewables are contributing to larger shares of electricity production

- While there has been progress in electricity, fossil fuels still generate around 80% of total final energy consumption (Ren21)—it has not changed much between 2009-2019
- We understand what explains the evolution of costs and deployment in clean technologies



In spite of the evidence of the positive impact of various policies across the innovation indicators…

- **Only 8 out of 16 energy economic models in recent survey include innovation outcomes** that may represent the impact of decarbonisation policies on innovation

- Other innovation outcomes (e.g., new products and eco-innovations, patenting, R&D investment) are rarely represented

- Most models also do not account for endogenous technological change or knowledge spillovers

➔ Models generally underestimate the economic benefits of decarbonisation policies because **only some positive impacts** are captured

Kolesnikov, Penasco, Anadon (2021). CEENRG Working Paper 2021-06

Case study: growing evidence on the impact of specific public support tools for energy innovation: startups and SMEs

ARPA-style funding was not designed to fill all gaps in the innovation system

- On **post-award business success**, ARPA-E awardees performed better than rejected applicants
  - it helped riskier technologies get closer to commercialization
  - for the first cohort financing outcomes not better than the wider set of cleantech startups

- Given policy interest, possible areas for future research include:
  - Increasing the timeframe (long-term nature of innovation)
  - Including additional metrics
  - Considering subsequent cohorts and awardees
  - Qualitative work to understand mechanisms that may have been at play related to markets and demonstration

Goldstein, Doblinger, Baker & Anadon. (2020) *Nature Energy*

Resources and funding for R&D in startups and SMEs in energy can help advance both technologies and economic development

- Research on the government-startup partnerships and ARPA-E adds to body of evidence indicating that public R&D support (resources and funding) can help cleantech startups and small firms in the energy sector thrive [e.g., Howell, 2017; Pless, 2019]

- Additional support mechanisms (demand pull) also needed in many areas to further de-risk technologies before the private sector can fully take them on—e.g., preferential financing, efficiency regulation, financial and fiscal deployment incentives, carbon pricing, and possibly requirements to disclose the carbon content of products

Energy innovation/green industrial policy should consider technology and context

Different research streams investigating determinants of where different clean industries emerge – development benefits

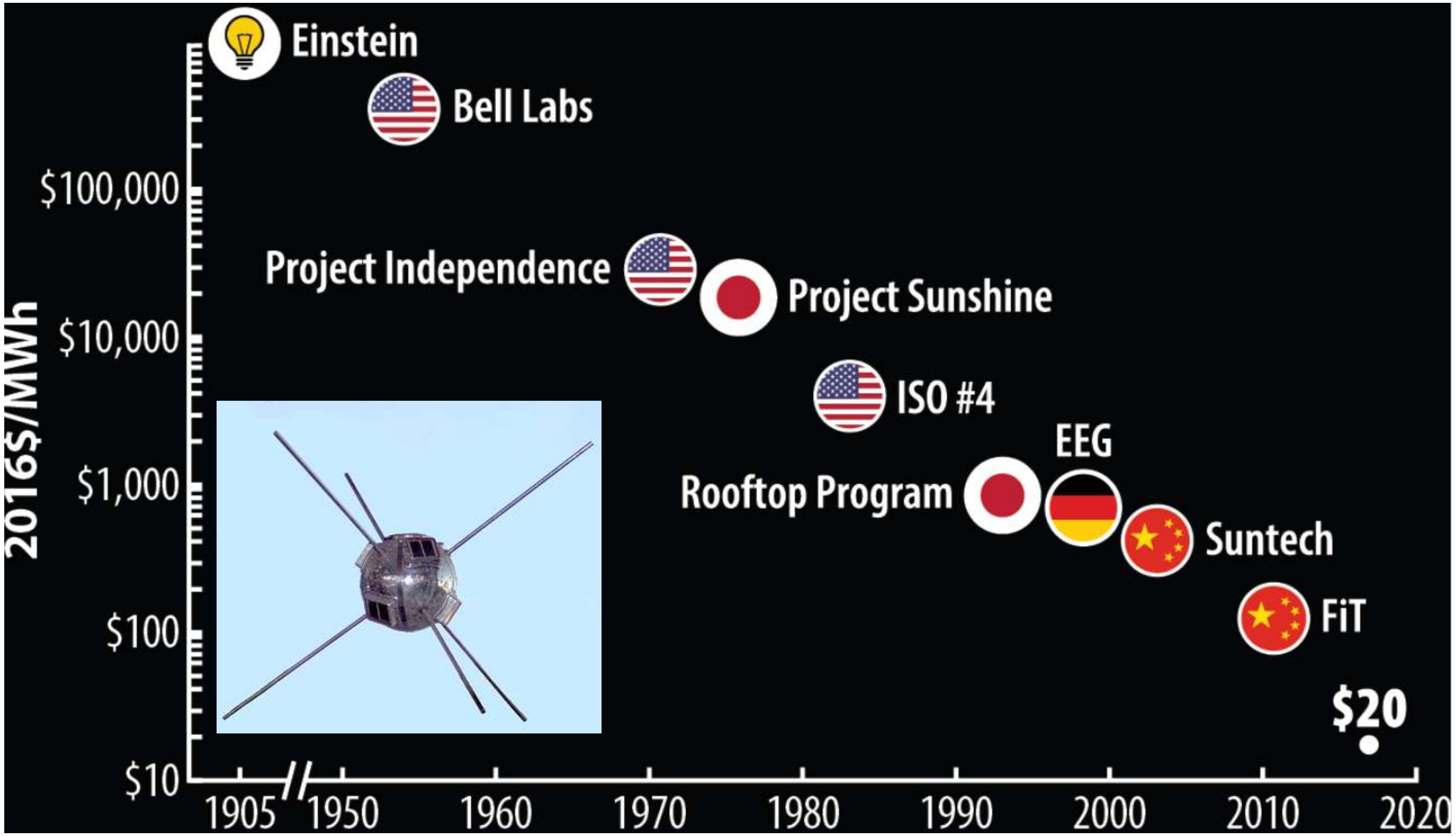
- **Technology complexity and industry structure:** higher complexity of wind components is associated with less internationalization of manufacturing given differences in country capabilities [e.g., Hidalgo et al. 2007; Hausmann et al. 2013; Surana et al. 2020; Mealy & Teytelboym, 2020]

- **Design and manufacturing complexity, mass production, and related capabilities** [e.g., Huenteler et al. 2015; Huenteler & Schmidt, 2016]

- **Standardization, doing/using/interacting, global innovation system** [e.g., Binz et al. 2020; Binz & Anadon, 2018; etc]

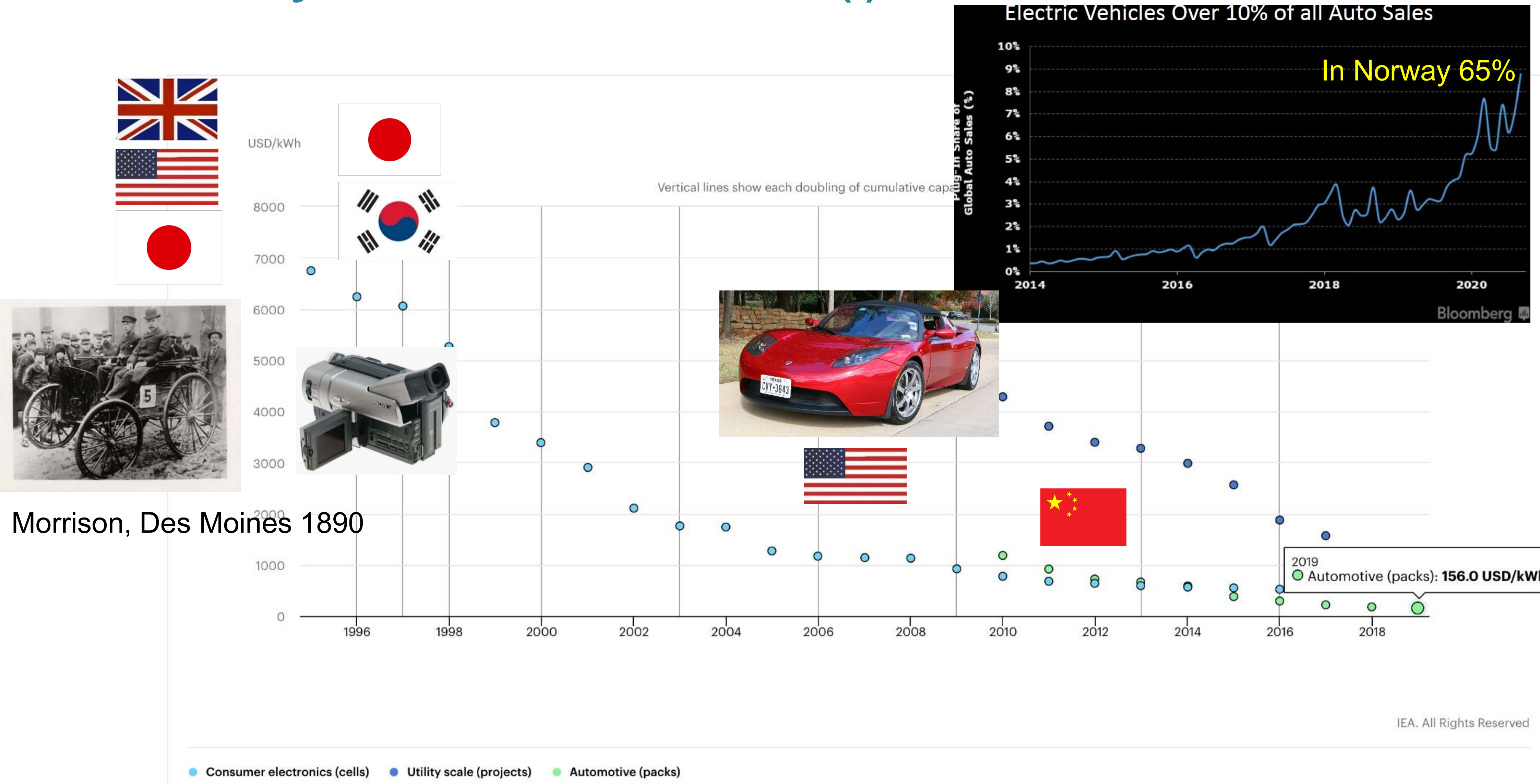
The history of solar PV at a glance

- 1905 Einstein discovered photons
- Bell Labs 1954, first cell studying seminconductors
- First solar panel in spage, 1958 Vanguard I



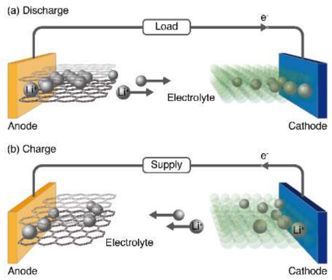
Nemet (2018); Kolesnikov, Anadon et al (2022) In prep.

The history of Lithium ion batteries (I)



Morrison, Des Moines 1890

The history of Lithium ion batteries (II)



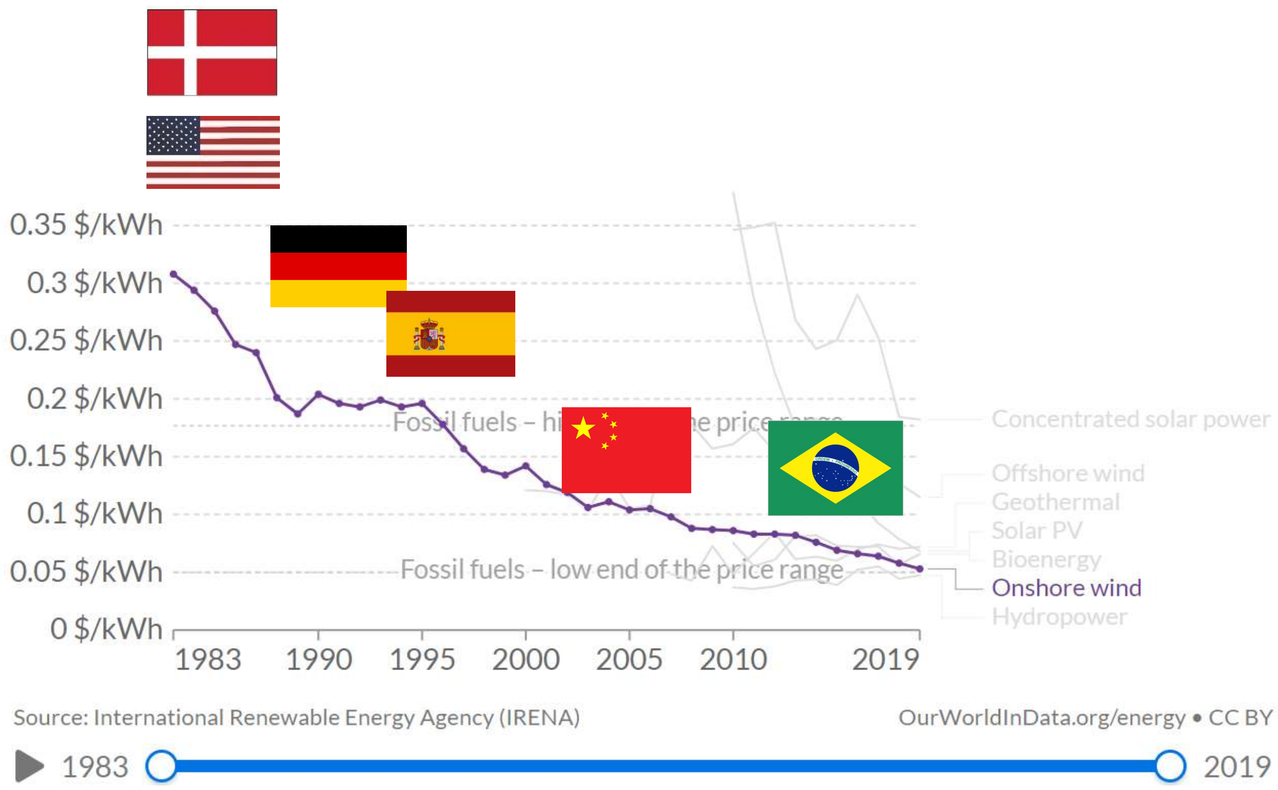
- Enabling breakthroughs (1-5) happened in the wake of the oil crisis thanks to DoD funding in the US and in the UK, flexible funding for researchers in France, as well as from firms (Exxon and Asahi Kasei)
- In the early 1990s Sony put them together to manufacture batteries for personal electronics (still too expensive for vehicles)
- Other process inventions as manufacturing for vehicles scaled up

Stephan, Anadon, Hoffmann (2021). *iScience*

Table 1. Overview of the analyzed breakthrough and additional (mainly process) LIB innovations (#) with associated spillovers sources (a–d)

#	Innovation	Spillover sources from other technology (T), sector (S), and scientific discipline (SD)	Short description of how spillover came about
1	Electrochemical intercalation (cathode)	a) NaS (sodium sulfur) batteries (T)	S. Whittingham had worked on NaS batteries in Stanford before he transferred the mechanisms of intercalation that he and his colleagues discovered at Exxon to the battery field
		b) Superconductors (T,S)	S. Whittingham worked in superconductors at Exxon and discovered the mechanisms of electrochemical intercalation. He was able to transfer this idea to LIBs and discovered TiS_2 as a cathode material
2	Cathode (LCO, lithium cobalt oxide)	a) Solid-state physics (SD)	J. Goodenough, who was trained as a solid-state physicist, often worked with solid-state chemists
		b) Digital data storage (T,S)	J. Goodenough, inspired by the Ford Motor Company, wanted to apply his research ideas related to digital data storage in the battery field
3	Anode (graphite)	a) Material science (SD)	R. Yazami was trained in the two scientific fields of material science and electrochemistry
		b) Physical chemistry (T,S)	R. Yazami built upon the interdisciplinary knowledge and funding existing in his research group. Physical chemistry, including thermodynamics, was one of the foci of R. Yazami's group
		c) Heat storage (T,S)	R. Yazami built upon the interdisciplinary knowledge and funding existing in his research group. Heat storage was one of the foci of R. Yazami's group
4	Cathode (LMO, lithium manganese oxide)	a) Crystallography (SD)	M. Thackeray was trained as crystallographer
		b) ZEBRA (sodium/metal chloride) batteries (T)	M. Thackeray further developed his knowledge from materials used in high-temperature ZEBRA batteries to those used in room-temperature LIBs
		c) Digital data storage (T,S)	J. Goodenough knew about spinels from his prior work in digital data storage
		b) Nature (geology) (SD)	M. Thackeray's ideas have built on his interest in the structural stability of materials produced in the geological world.
5	Electrode coating	a) Cassette/magnetic tape production (T,S)	Sony produced the first LIB electrodes on cassette-tape manufacturing equipment that had been standing idle Leclanché produced battery electrodes at an old BASF manufacturing plant for magnetic tapes. Leclanché furthermore used the trained personnel who were available
6	Battery slurry manufacturing	a) Printing-ink production (T,S)	Bühler, a Swiss technology provider, had developed a revolutionary electrode slurry manufacturing process, which originated from the organization's knowledge in developing printing-ink production equipment

The history of wind power



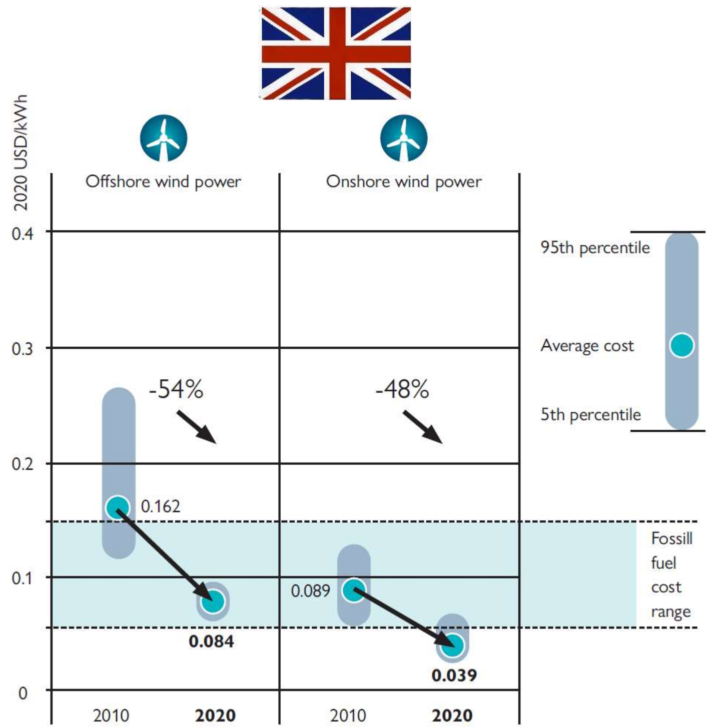
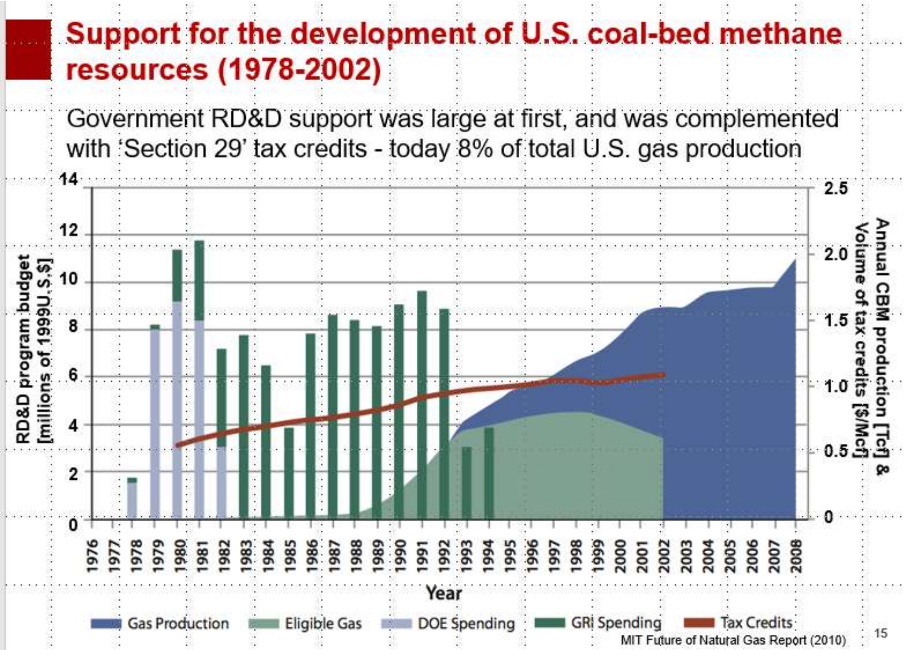
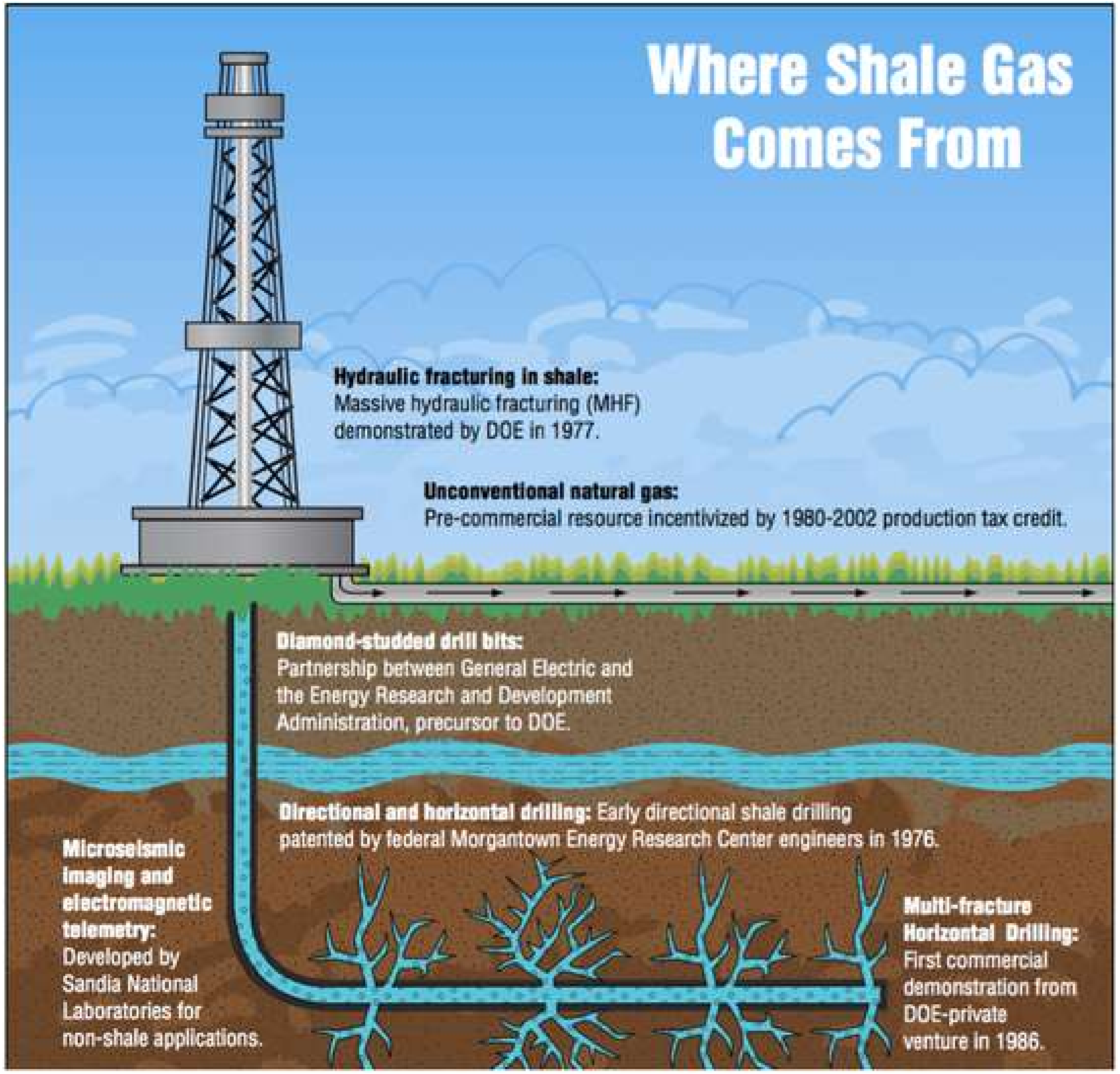


Figure 2: Range in of wind energy generation costs, 2020 vs 2010
Source: IRENA, Renewable Power Generation Costs in 2020 (p. 15).[32]

Key shale gas innovations: technology push and market pull policies



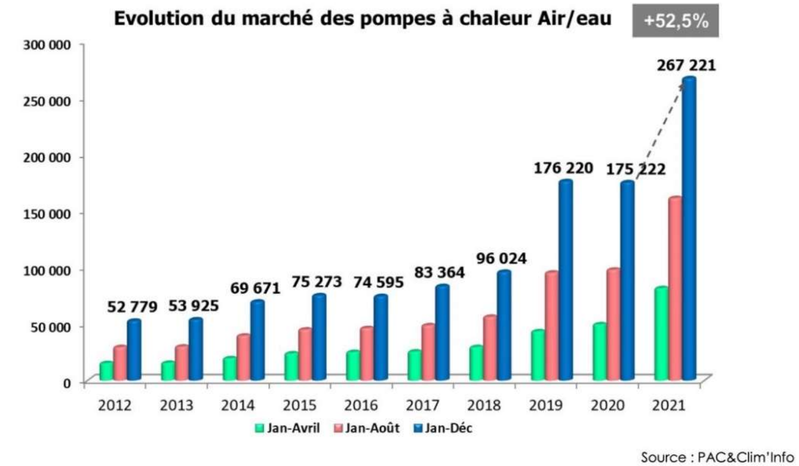


- Diamond-studded drill bits, microseismic imaging, and horizontal drilling

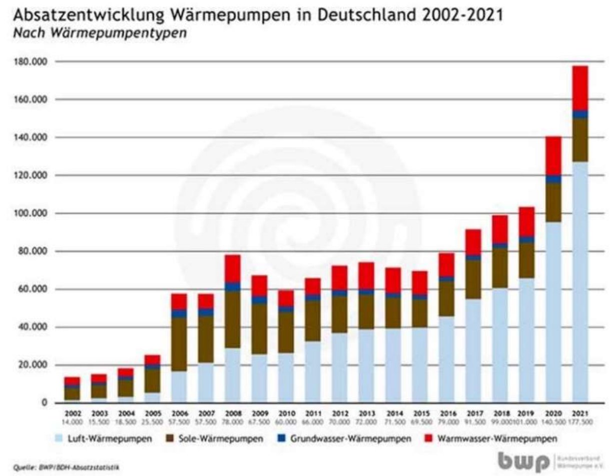
Growth in four major heat pump markets (change in 2021)

- Long prominent in Finland and Norway
- Deployment driven by information, grants, training, word of mouth
- Higher rates of return required for new technologies, particularly when they are capital intensive

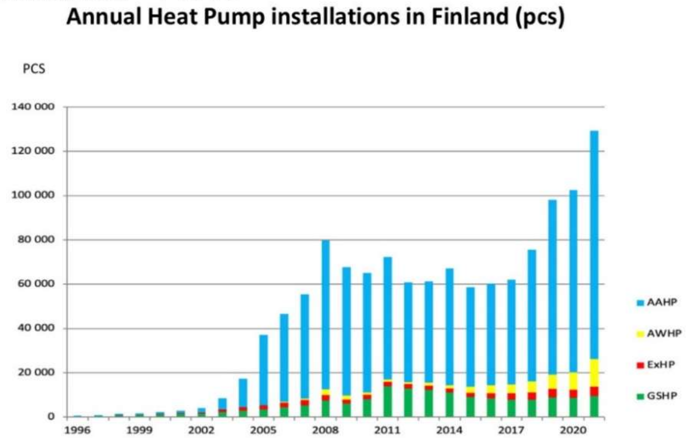
France: +53% (air source)



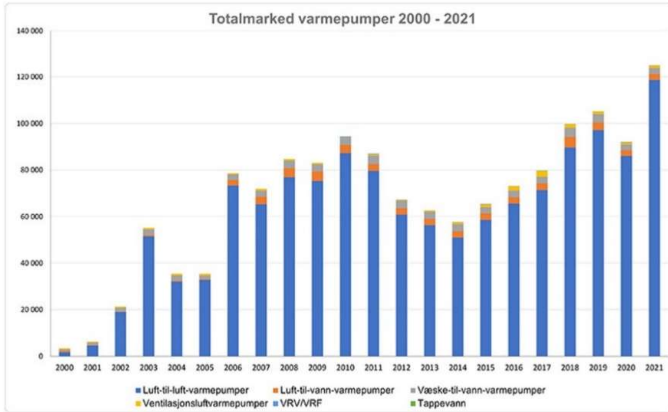
Germany: +28%



Finland: +25%

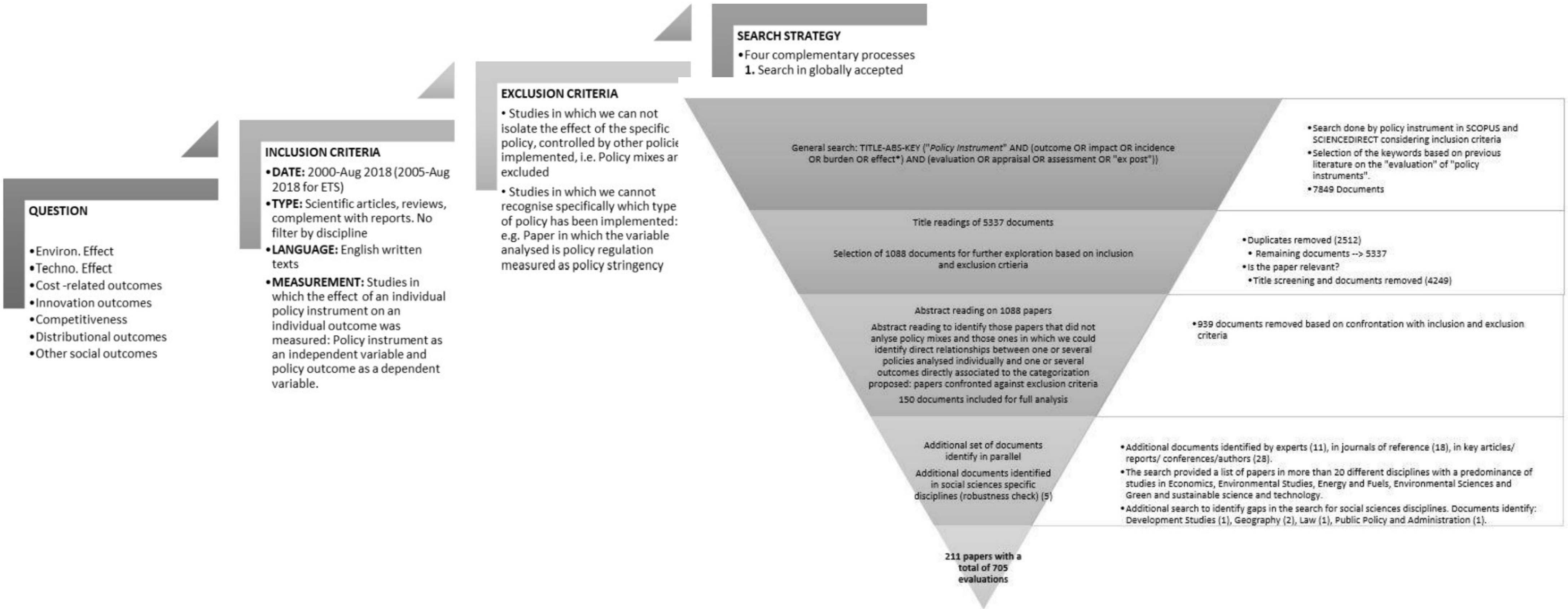


Norway: +36%



Rosenow (2022)

Systematic review to understand what is known about the impact of decarbonization policies on different outcomes

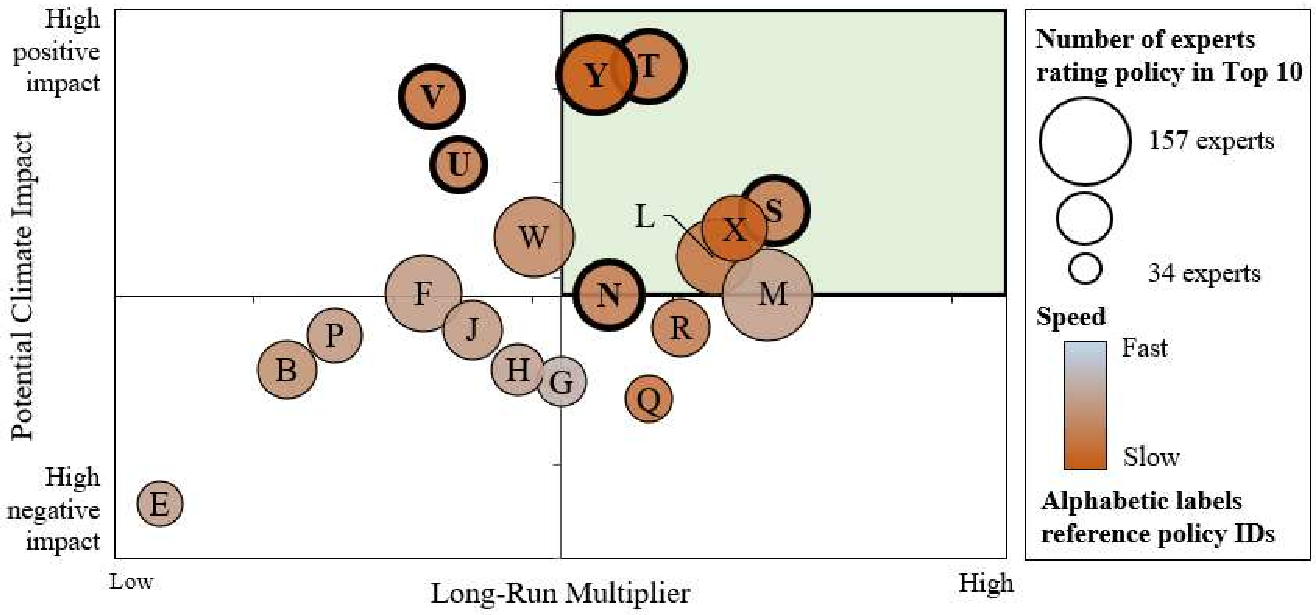


Peñasco, Anadon, Verdolini (2021) *Nature Climate Change*

Insights consistent with recent survey of experts about recovery policies

- 231 central bank officials, finance ministry officials, and other economic experts from G20 countries
- Vertical axis: direction and size of the climate impact
- Horizontal axis: direction and size of economic multiplier
- Colour denotes the speed: dark brown is slow)

Global Survey of Fiscal Recovery Policies

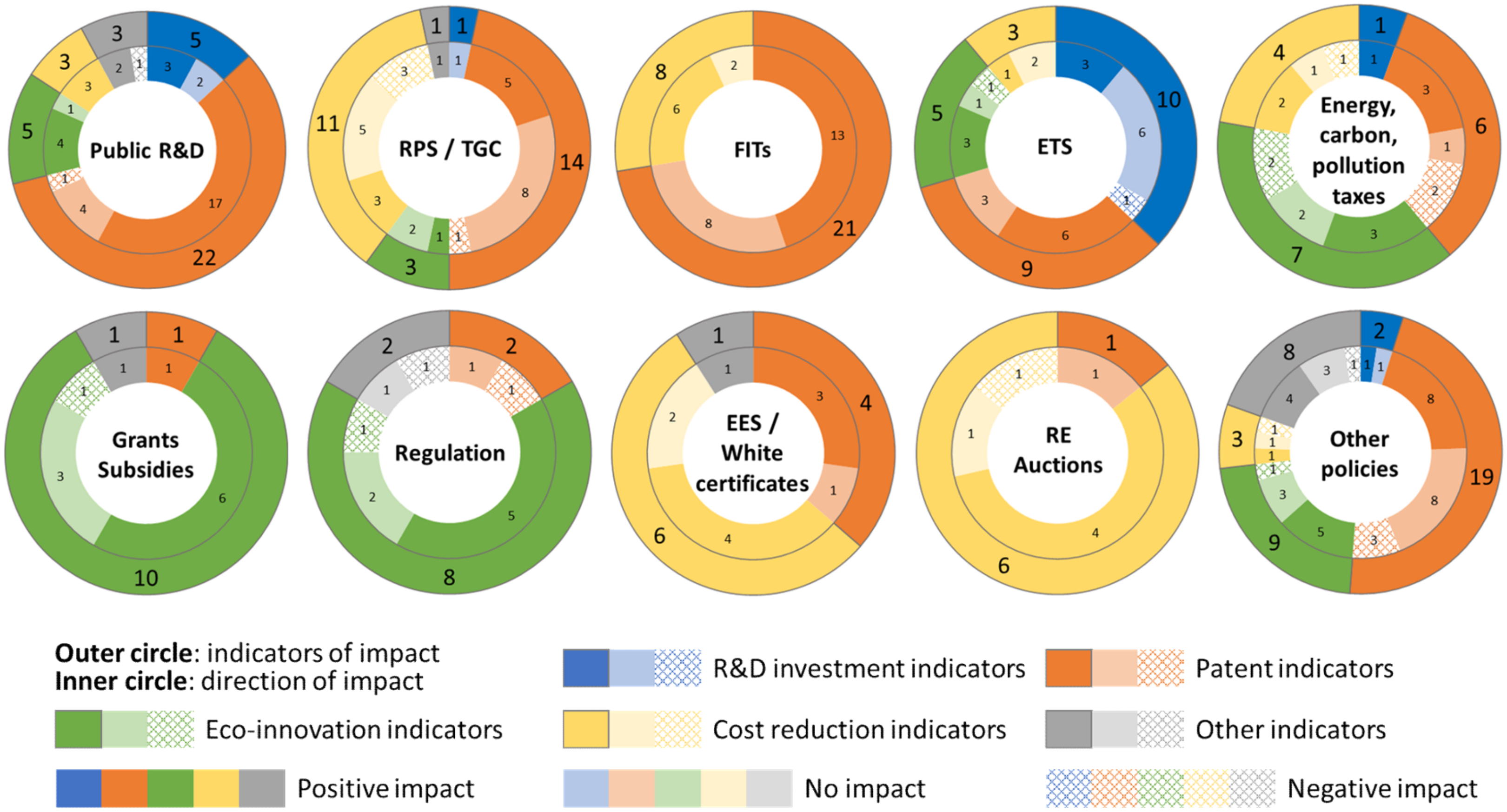


B Assisted bankruptcy (super Chapter 11)
E Airline bailouts
F Not for profits, education, research, health inst. bailouts
G Reduction in VAT and other goods and services taxes
H Income tax cuts
J Business tax relief for strategic and structural adj.
L Education investment
M Healthcare investment
N Worker retraining
P Rural support policies
Q Traditional transport infrastructure investment
R Project-based local infrastructure grants
S Connectivity infrastructure investment
T Clean energy infrastructure investment
U Buildings upgrades (energy efficiency)
V Green spaces and natural infrastructure investment
W Disaster preparedness, capacity building
X General R&D spending
Y Clean R&D spending

Hepburn et al. (2020) *Oxford Review of Economic Policy*

Evidence of a positive impact on innovation indicators

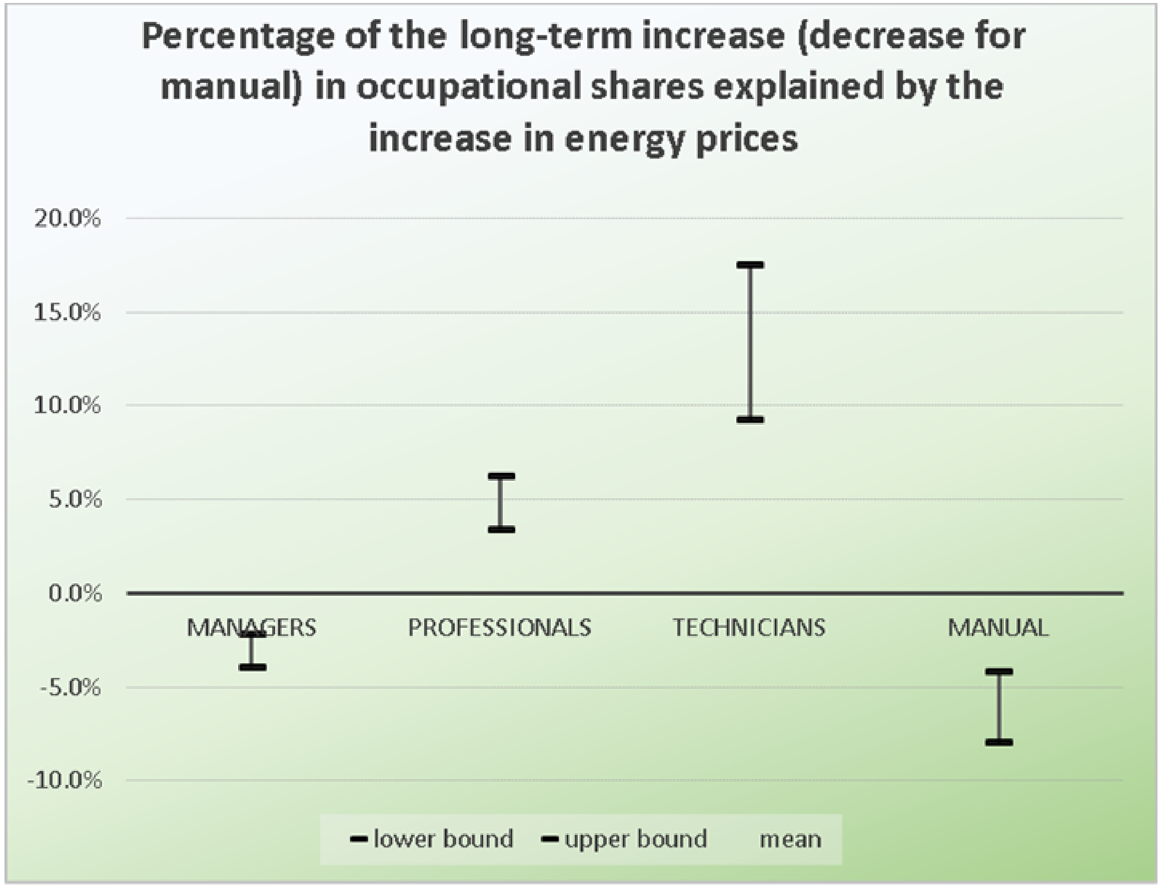
1. Evidence on **positive impacts** of public R&D funding on innovation → **patenting and R&D investment**. Public R&D play a role as catalysers of R&D investment in the private sector.
2. FITs, RE auctions, energy efficiency standards (EES) and white certificates → **positive impacts** on clean technology **patents and cost reductions**. **Mixed evidence** for renewable portfolio standards (RPS) / tradeable green certificates (TGC).
3. More research needed for RE auctions as an instrument that is being increasingly used.



Peñasco, Kolesnikov and Anadon (2021). CEENRG Working Paper

Evidence on market pull policies points to the need to support manual workers as part of the energy transition

- Energy price increases have had a negative impact on the demand for manual workers, favouring technicians
- Data from 14 European countries and 15 industrial sectors (1995-2011)
- **Training and upskilling programs are essential**



Marin and Vona (2019), *JEEM*

INNOPATHS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730403

Measuring and mapping the wind energy global value chain

1. **Structuring GVC data** from unstructured wind industry reports*

- 389 Suppliers
- 9 Components
- Over 1,000 relationships with 13 OEMs between 2006 and 2016

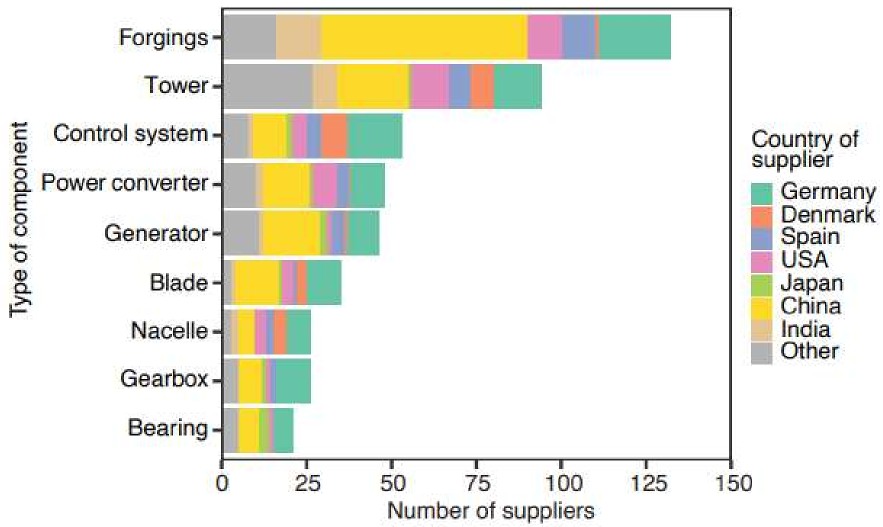
*Navigant Research. Supply Chain Assessment Reports

OEM	Supplier	In-house / Acquire / Outsource	Component	Origin Country of Supplier	Actual Location of Supplier	Start Year	End Year	Capacity (annual MW)
Vestas	Windcast	Acquire	Castings	Norway	Norway			
Vestas	VTC	Outsource	Castings	Germany	Germany	2013		
Vestas	Titan Wind	Outsource	Towers	China	Denmark			500
Vestas	Vestas	In-House	Nacelles	Denmark	Italy		2013	

2. Verification and additional data on **supplier firms****

- Home location of firms
- Size, founding year
- M&A
- Specialization in wind

**using Factset, Orbis, Bloomberg



Strategic investment and green industrial policy

- **Industrial policy**: "government actions to alter the structure of an economy, encouraging resources to move into particular sectors that are perceived as desirable for future development." [Altenburg & Rodrik, 2017]

- **Green industrial policy**: "government measure(s) aimed to accelerate the structural transformation towards a low-carbon, resource-efficient economy in ways that also enable productivity enhancements in the economy." [Altenburg & Rodrik, 2017]

➔ GIP focus and framing can help, at least in the short- to medium-term, with the politics, innovation and covid recovery…

Broad guiding principles for public cleantech RD&D

Evidence from high income countries on innovation and competitiveness

1. **Giving researchers and technical experts autonomy and influence over funding decisions** (e.g., lab-directed research at labs, ARPA-E)

2. **Incorporating technology transfer in research organizations** (researcher mobility, investment on tech. transfer and reducing friction, joint development)

3. **Focusing demonstration projects on learning** (decades of projects)

4. **Incentivizing international collaboration**

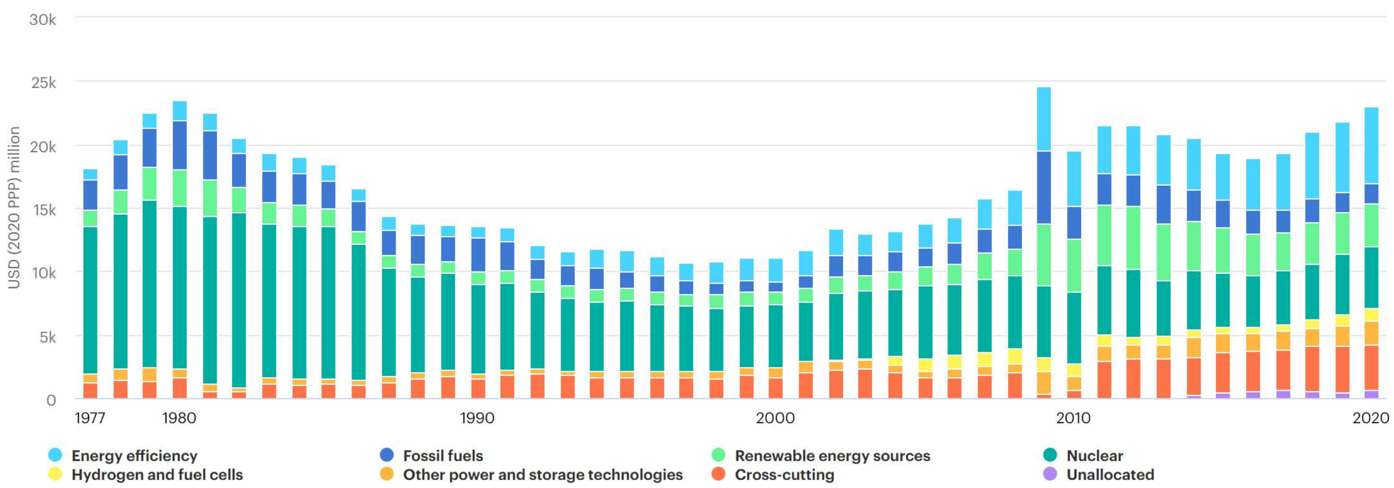
5. **Adopting an adaptive learning strategy** (monitoring & data collection, analysis, incorporation of uncertainty)

6. **Keep funding stable and predictable**

Chan, Goldstein, Bin-Nun, Anadon, Narayanamurti (2017), *Nature;* Goldstein et al (2020) Under review

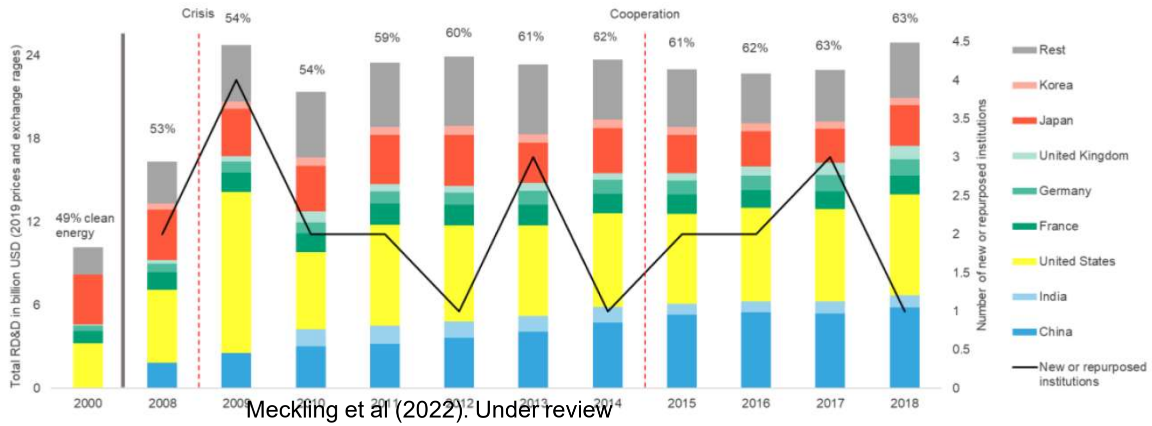
7. **Public R&D funding and collaboration (in the form of technical or business expertise, facilities, and legitimacy) helps cleantech SME outcomes** (Doblinger, Surana & Anadon, RP 2020; Howell AER 2017; Pless 2020)

Public energy RD&D investments in OECD countries
Higher investments are needed



Data from IEA (2020)
Work on energy R&D investments in Anadon et al (2017) Nature Energy; Chan & Anadon (2017); Anadon et al (2014), etc

- In market exchange rates, including China and India we are at 25 billion USD. China makes up from 5% in 2008 to 24% in 2018 (Meckling et al, 2022)



Meckling et al (2022). Under review

But green industrial policy needs to...

- be designed to help the **most vulnerable workers and communities** [Peñasco et al. 2021]

- Account for differential impacts across firms of **firms of different sizes and capabilities** [Peñasco et al, 2021; Pless, 2019]

- consider the role that **global value chains, complexity** [e..g., Surana et al. 2020] and **sector** [Schmidt & Huenteler, 2016; Binz and Anadon, 2018; Binz et al. 2020] can play in reaping competitiveness benefits

- provide a **long term comprehensive framework** considering the full innovation system and policy mixes [e.g. Probst et al. 2020; Ossenbrink et al. 2019; Rogge & Reihardt, 2016; del Rio & Howlett, 2013] and the SDG context

Criteria, outcomes and common indicators to evaluate the impact of decarbonisation policy instruments.

	Environmental effectiveness outcomes	Technological effectiveness Outcomes	Cost-related outcomes	Innovation outcomes	Competitiveness outcomes	Distributional outcomes	Other social outcomes
INDICATORS	GHG emission reductions (tCO2eq) Meeting targets Total energy savings	Installed capacity RE Electricity generated with RE* Deployment of EE** systems buildings Number electric vehicles	Cost installed capacity RE Total costs indicators €/avoided tCO2eq €/saved KWh Difference cost to comply with targets with and without policies	Time series cost-effectiveness indicators Patents Learning rates Reduction technology abatement costs	Industry creation Net job creation Export of RE technology equipment Economic growth (GDP, GNP) Productivity Investments	Incidence of support costs Change in spending on electricity as a % of total household spending Participation of stakeholders International equity (tCO2eq/capita) Inequalities among big and small producers	Concentration of facilities leading to public opposition Perceived transparency from consumers Contributions to the participation of new actors Emergence of not in my backyard (NIMBY) movements

Source: Own elaboration based on EC, 2015; IPCC, 2007; IRENa, 2014; Neil and Astranj 2006; Kondari and Mavrakis 2007, Del Rio et al., 2014; Scheneider and Wagner, 2002; Spree, 2013, Field and Olewiler, 2011.

Penasco, Anadon, Verdolini (2021) *Nature Climate Change*

Rationales for government role in fostering the transition to a zero-carbon economy (in addition to addressing pollution, access, security....)

- Two market failures (environmental and knowledge externalities) (Jaffe et al. 2005)
- Market shaping and creation (Mazzucato, 2013), mission-orientation / multiple missions (Foray, Mowery, Nelson, 2012; Mazzucato, 2013; Anadon, 2012)
- Other system failures:
  - coordination failures
  - information asymmetries
  - institutional capacity
- In addition, in the energy and industrial sectors we have
  - technology development cycles that can take up to several decades
  - significant system lock-in (interest groups, politics, regulation favoring incumbents)
  - undifferentiated/commoditized products

Types of "partnerships" or alliances

Alliance Type		Example
Technology- based alliances	Technology development	Arcos Silicon and Broadcom Corporation partnered to improve the interoperability of their power-over-ethernet (PoE) products. Sapphire Power has partnered with University of California, San Diego to demonstrate the viability of saltwater algae in the production of biofuels.
	Licensee	Natcore has been granted a patent license agreement from the NREL to develop and commercialize a line of black silicon PV products.
Additional forms of alliances (included as controls)	Procurement or customer	As part of a purchase agreement, Sustainable Green will become exclusive distributor of MagneGas fuel over a two-year period in Pacific Northwest. Avista Corp. is buying the power produced by the Palouse Wind project under a 30-year power purchase agreement and will take delivery of the power through a direct interconnect to the Avista 230 kV Benewah-to-Shawnee transmission line.
	Licensor	ABB has signed a licensing agreement with ECOtality to use ECOtality's technology for ABB's EV charging network.
	Project development	Obsidian Renewables partnered with Swinerton Builders to develop the Black Cap Solar facility.