EEIST

TEN PRINCIPLES FOR POLICYMAKING IN THE ENERGY TRANSITION:

LESSONS FROM EXPERIENCE

AUTHORS: LAURA DIAZ ANADON[*], ALED JONES[*], CRISTINA PEÑASCO[*], SIMON SHARPE[#], MICHAEL GRUBB[#], SANCHIT AGGARWAL[†], NELSON HENRIQUE BARBOSA FILHO[†], RAKTIMAVA BOSE[†], ANDREA CABELLO[†], SASWATA CHAUDHURY[†], PAUL DRUMMOND[†], DOYNE FARMER[†], CHRIS FOULDS[†], DANIELA FREDDO[†], CAMERON HEPBURN[†], VIDHU KAPUR[†], JIANG KEJUN[†], AILEEN LAM[†], JEAN-FRANCOIS MERCURE[†], LÚCIA HELENA MICHELS FREITAS[†], SARAH ROYSTON[†], PABLO SALAS[†], JORGE VIÑUALES[†], SONGLI ZHU[†]

[*]LEAD AUTHORS (LISTED ALPHABETICALLY), [#]KEY CONTRIBUTORS, [†]OTHER CONTRIBUTORS (LISTED ALPHABETICALLY)

EEIST

Executive Summary

Meeting the goals of the Paris Agreement requires a rapid worldwide transformation of our energy and land-use systems. The Glasgow Climate Pact of the United Nations Climate Change Conference (COP26) in November 2021 not only reaffirmed the commitment to limiting the increase in global temperature to well below 2°C, 'keeping 1.5°C alive' and building resilience, but it also emphasised the importance of additional government commitments and action through the Nationally Determined Contributions (NDCs). The Breakthrough Agenda, also launched at COP26, and supported by more than 40 countries, seeks to accelerate progress towards the Paris goals by making clean technologies in each of the most polluting sectors the most affordable, accessible and attractive choice for all by 2030.

Achieving a structural transformation in all the energy-consuming sectors in a just manner requires a stronger and more coordinated policy response across multiple policy domains and levels around the world. Increased engagement with civil society, businesses, youth, labour, media, Indigenous Peoples and local communities is also essential.[1] Getting right the policy efforts aimed at accelerating the energy transition can unlock significant opportunities including new industries, net generation of employment, liveable cities, positive health impacts and opportunities to tackle justice and poverty challenges simultaneously.

Given the scale, speed and interdependencies of the energy transition being pursued, this action will require from governments the application of an additional set of tools and principles to support policy-making and appraisal. Many of the economic principles, models, and decision-making tools used by governments are designed for use within contexts of 'marginal' or incremental change, where technologies, markets and other economic structures are relatively stable. Different tools are needed when, as in the energy transition, the aims and context of policy include widespread innovation and structural change.

The ***Ten Principles for Policymaking in the Energy Transition*** outlined in this report 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. We set out five '*Policy Design*' principles, all of which complement each other, and five '*Policy Appraisal*' principles that relate to how policy options are compared, and decisions made. These are summarised in the following table, alongside 'traditional principles', which are stylised versions of principles that are sometimes used to guide policymaking in situations of marginal change. When describing each principle we outline the usefulness of those traditional principles in their appropriate domains, point out some of their limitations and explain the need to complement them with the Ten Principles.

About

The Economics of Energy Innovation and System Transition (EEIST) project develops cutting-edge energy innovation analysis to support government decision making around low-carbon innovation and technological change.

By engaging with policymakers and stakeholders in Brazil, China, India, the UK and the EU, the project aims to contribute to the economic development of emerging nations and support sustainable development globally.

Led by the University of Exeter, EEIST brings together an international team of world-leading research institutions across Brazil, China, India, the UK and the EU.

The consortium of institutions are UK: University of Exeter, University of Oxford, University of Cambridge, University College London, Anglia Ruskin University, Cambridge Econometrics, Climate Strategies, India: The Energy and Resources Institute, World Resources Institute, China: Tsinghua University, Energy Research Institute, Brazil: Federal University of Rio de Janeiro, University of Brasilia, Universidade Estadual de Campinas (UNICAMP) EU: Scuola Superiore di Studi Universitari e di Perfezionamento Sant'Anna.

Contributors

EEIST is jointly funded through UK Aid by the UK Government Department for Business, Energy and Industrial Strategy (BEIS), and the Children's Investment Fund Foundation (CIFF).

Contributing authors are drawn from a wide range of institutions. For full institutional affiliations see www.eeist.co.uk

Acknowledgements

The authors wish to thank the UK Department for Business, Energy and Industrial Strategy (BEIS), the Children's Investment Fund Foundation (CIFF), the Quadrature Climate Foundation and Founders' Pledge for their support as sponsors of the EEIST project. We also wish to thank all those who contributed their time and expertise to developing and refining the analysis, concepts and ideas presented in this report, and in bringing it to publication. This includes, but is not limited to: Jacqui Richards and individuals from the Communities of Practice in EEIST partner countries, the EEIST Senior Oversight Group, and the UK government.

1 IPCC 6th Assessment Report. Working Group III. (2022). Summary for Policy Makers. www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf

	Traditional principle	Principle for the transition	
1	*Policy should be 'technology neutral'*	**Technology choices need to be made**	In a context of innovation and structural change, policies will almost always advantage some technologies more than others. It is better to choose deliberately rather than accidentally, supporting innovation in low-carbon directions. Some policies intended to be neutral can have a bias towards incumbents, and incremental change.
2	*Government interventions raise costs*	**Invest and regulate to bring down costs**	Well-designed investment and regulation policies can bring down the cost of clean technologies, by creating a 'demand pull' for innovation that complements the 'supply push' of research, development and demonstration, strengthening learning-by-doing feedbacks in technology development, deployment and diffusion.
3	*Markets on their own optimally manage risks*	**Actively manage risks to crowd-in investment**	Low-carbon transitions involve many sources of uncertainty. Efforts to reduce the risks of private investment in clean technologies, including public finance acting as a lead investor, can reduce technology risk and financing costs and greatly increase rates of investment and deployment.
4	*Simply price carbon at a level that internalises the damages of climate change*	**Target tipping points**	Well targeted interventions can activate tipping points in technology competitiveness, consumer preference, investor confidence, or social support for transitions, where a small input leads to a large change. This can inform the targeting and level of subsidies and taxes, as well as the stringency of regulations.
5	*Consider policies individually based upon distinct 'market failures'*	**Combine policies for better outcomes**	A combination of policies will be needed to drive each low-carbon transition. Since the effect of each policy depends on its interactions with others, assessing policies individually can be misleading. Assessing policies as a package can identify those that are mutually reinforcing, generating outcomes 'greater than the sum of the parts'.
6	*Policy should be optimal*	**Policy should be adaptive**	There are many paths along which economies can develop over time. It is often impossible in practice to identify which is 'best' in terms of public goals, or even 'least cost' economically, which implies there may be no single 'optimal' policy. Given also the potential to learn from experience, policy should be designed to be adaptive, so that it can more easily respond to unforeseen changes, exploit opportunities and manage risks.
7	*Act as long as total benefits outweigh the costs*	**Put distributional issues at the centre**	Low-carbon transitions inevitably involve transfers of economic resources. Distributional issues should be central to policy analysis, since they are important for environmental, economic and social goals, and are likely to have a strong bearing on social support for the transition.
8	*Link carbon markets to minimise current costs*	**Coordinate internationally to grow clean technology markets**	Countries should coordinate internationally to grow clean technology markets in each of the emitting sectors of the global economy. This can lead to faster innovation and larger economies of scale, accelerating the cost reduction of clean technologies, with benefits for all countries.
9	*Assess aggregate costs and benefits*	**Assess opportunities and risks**	Policy appraisal should consider risks and opportunities, not just costs and benefits, when unquantifiable or very uncertain factors are likely to be important. Where the aim is transformational change, appraisal should consider the effects of policies on processes of change in the economy, alongside their expected outcomes.
10	*Policy models and assessment are neutral*	**Know your biases**	The construction of economic models unavoidably involves many choices that will influence their outputs, in which there are no 'correct' answers. We should be aware of our biases, make model choices transparently and, where possible, use a range of models instead of a single one.

Introduction

The Economics of Energy Innovation and System Transition (EEIST) project was set up to bring together new economic understanding and analysis to inform policy decisions for deep decarbonisation, as set out in the goals of the Paris Agreement. The project's first report, '*The New Economics of Innovation and Transition: Evaluating Opportunities and Risks*',[2] launched at COP26, reviews evidence and theory to explain the limitations of traditional policy appraisal methods and the rationale for a new approach. In that report we concluded that policies central to some of the most outstanding successes in low-carbon transitions so far were generally implemented despite – not because of – predominant economic analysis and advice.

This report builds on that by setting out 10 principles to inform policymaking in the context of the energy transition, which we suggest can help governments to make successful choices more often. We will refer to these as 'the Ten Principles' or simply 'the principles'. These draw on experience and evidence from the academic literature[3] and from the work of EEIST partners in China, India, Brazil, the European Union and the United Kingdom. When presenting them, we discuss this empirical evidence and feature one specific illustrative case for each principle in a wide range of geographies.

We put forward and discuss each of the Ten Principles for Policymaking in the Energy Transition and set them alongside some principles often included in traditional economic guidance (typically as derived from equilibrium-based economics). This guidance frequently assumes that the goal of policy, particularly where markets are already established, is to make 'marginal' changes – i.e., incremental to existing systems without driving more fundamental changes in technologies and structures – in the most efficient way. We refer to this type of guidance as 'traditional principles'. There is a lot of variation in terms of the extent to which these 'traditional principles' are used and how they are implemented at different times and in different sectors and countries, as well as in how strongly they are recommended (or with how many caveats). Thus the traditional principles are necessarily somewhat stylised, albeit in ways often presented in economic textbooks as the 'ideal'. We present these traditional principles to sharpen understanding of how the proposed principles may bring new elements to decision-making.

Importantly, the Ten Principles are not necessarily intended to replace the traditional principles in all situations. We endeavour to briefly discuss the contexts in which the traditional principles emerged in the first place, and to differentiate where possible between their respective domains of applicability. We also explain how the Ten Principles incorporate the latest experience and empirical analysis in the literature from around the world over the last three decades of clean technology deployment, and thus provide relevant insights specifically in the context of the energy transition. As more researchers and policy analysts engage with this and other related work, and as even more evidence becomes available, the Ten Principles could serve as a useful starting point.

A general point of departure is that traditional approaches to policy appraisal are often essentially 'static'. By this we mean that traditional approaches typically aim to predict the effects of policy at a given point in time with an implicit assumption that these decisions would have little or no implications for the structure of existing markets and systems, normally assuming that, over time, the world changes but it does so in relatively small ways which are unaffected by the policy itself, and which would not disrupt the fundamental assumptions.[4]

2 Anadon, L.D., Barbrook-Johnson, P., Clark, A., Drummond, P., Ferraz, J.C., Gao, J., Grubb, M., Hepburn, C., Ives, M., Jones, A., Kelkar, U., Kolesnikov, S., Lam, A., Mathur, R., Mercure, J-F., Pasqualino, R., Penasco, C., Pollitt, H., Ramos, L., Roventini, A., Salas, P., Sharpe, S., Waghray, K., Xiliang, Z., Zhu, S. (2021). 'The New Economics of Innovation and Transition: Evaluating Opportunities and Risks', EEIST Report to COP26. UK Department for Business, Energy & Industrial Strategy. www.eeist.co.uk/reports

3 See e.g. Anadon, L.D., Peñasco, C., Verdolini, E. (2021). 'Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments.' *Nature Climate Change*. doi.org/10.1038/s41558-020-00971-x

4 Stern, N. (2022). 'A Time for Action on Climate Change and a Time for Change in Economics.' *The Economic Journal*, Volume 132, Issue 644, May 2022, Pages 1259–1289, doi.org/10.1093/ej/ueac005

Such approaches are thus more suitable for situations in which only marginal changes are either aimed for or expected, where, for example, existing industries, institutions and the market shares of incumbent technologies remain largely unchanged.

However, there is now strong evidence suggesting that decarbonisation through various policies advancing clean technology research and development, demonstration and deployment has led to the onset of a broad global economic transformation. We have seen the creation of entirely new global industries over the last 30 years and growing interdependencies across technologies and sectors, as demonstrated by the growing electrification of personal transport, among other examples. Increasingly, the least-cost options for decarbonisation in the medium to long-term may involve structural economic changes. This means that additional approaches to policy appraisal are needed: approaches that can consider structural change, and that can help policymakers manage transitions in a way that maximises opportunities and minimises costs and risks. Whereas traditionally, policy appraisal has often focused on allocating existing economic resources efficiently within fixed market structures, in this new context allocative efficiency analysis needs to be complemented with additional lenses, specifically concerning *dynamic efficiency* – how well policies achieve desired change over the course of time – as well as on questions of fairness.

To address the evolving needs of the policy community in the context of the energy transition, this report summarises the work by an international group of leading researchers and practitioners to distil what has been learned from the past three decades of different efforts to decarbonise the electricity generation and energy-consuming sectors, primarily focusing on power, transport and buildings. We developed the Ten Principles and grouped them into two topics: '*Policy Design*' (principles 1-5) and '*Policy Appraisal*' (principles 6-10). The former are aimed at helping design policy to galvanise and scale up clean technology development and deployment. The latter are concerned with the need to consider additional dimensions, opportunities and risks, as well as with the process of policy appraisal itself to ensure that, to the extent possible, it considers uncertainties, opportunities, local knowledge and context – something that necessarily involves continued engagement with a broad range of stakeholders, including vulnerable and marginalised communities.

While these Ten Principles could in theory inform policy making in a wide range of situations, we note that the context in which they are designed and implemented varies considerably across sectors and geographies. Therefore, a pragmatic approach to the detailed design and implementation should account for the different contexts and institutional and political cultures. For example, understanding the implementing stakeholders in different geographies and how they are involved, incentivised, empowered or marginalised is key. Other examples of where context matters include the fact that the impact and distribution of some policy changes in terms of innovation, decarbonisation, competitiveness and fairness will differ across countries that have diverse levels of public ownership of companies and industrial structures and capacities.

Our work also underlines the importance and complexity of finance in such transitions. In parallel to these principles, we have seen the importance of changing fiscal policy and financial regulation to ensure that institutional investors and others will deploy much larger amounts of capital into clean energy technology solutions. This may involve additional economic incentives and signals including fiduciary duty, capital requirements, use of quantitative easing and fund regulations. We do not attempt to cover the fiscal policy or financial regulation aspects of the energy transition in these principles as we focus on the necessary developments in energy policy.

The evidence reviewed in this report suggests that implementing these principles in appropriate ways could address many of the barriers identified in scaling up clean technology investment[5] and could help to refresh our way of thinking around what works and what doesn't in fostering a rapid zero-carbon transition.

5 Anger-Kraavi, A., Hafner, S., Jones, A., & Pohl, J. (2020). 'Closing the green finance gap: a systems perspective'. Environmental Innovation and Societal Transitions, 34, 26

PART 1

PRINCIPLES FOR POLICY DESIGN

Progress in energy innovation and towards low-carbon transition has often been driven by policies beyond those most recommended in traditional economic textbooks

PRINCIPLE 1:

Technology choices need to be made

Traditional principle: Policy must be technology neutral

Summary: In a context of innovation and structural change, policies will almost always advantage some technologies more than others. It is better to choose deliberately rather than accidentally, supporting innovation in low-carbon directions. Some policies intended to be neutral can have a bias towards incumbents and incremental change.

Rationale for the traditional principle

It is common to hear in the energy and climate policy arena that policies should be 'technology neutral' – in other words, that broad-based market incentives should drive technology choices to ensure cost-effective greenhouse gas emissions reduction.[6] The goal of technology neutrality is often invoked by arguing that policies and governments should not 'pick winners' and that they should allow competition between alternative technologies on an assumed level playing field.[7] It is also used in the context of concerns of 'regulatory capture' of public authority by private interests.

In the appropriate context, technology neutrality can be a powerful tool that can foster the emergence of new ideas (e.g., when having R&D funding rounds that are 'open' to different technologies, or providing some level of block funding[8]) and price discovery, flexibility and competition (for example, in the context of carbon pricing[9,10]). In addition, some classic empirical work demonstrates cases in which picking technologies can be driven by, or lead to, cronyism (the favouring of connected people for government roles or contracts on a non-competitive basis) or government failure[11] (in economic terms, governments as well as markets can be beset by failures, compared to the theoretical best).

Limitations of the traditional principle

In spite of the prominence of the concept of technology neutrality, it is often poorly defined and understood.[12] One reason for this is that, depending on the policy instrument, context and policy objective, technology neutrality is sometimes used to used to discuss avoiding favouring or 'picking' industry sectors, parts of the energy system (e.g., transport vs electricity), different technologies to generate electricity (e.g., wind vs. solar, or onshore vs offshore wind), or specific technology designs (e.g., a particular direct air capture project for demonstration). In other words, in some cases the 'technology' part seems to be referring to uses, in others to devices, and at different levels of granularity – thus the principle of technology neutrality is hard to define.

Technology neutrality is also a concept that is difficult to implement in practice – and in some circumstances impossible. Most obviously, in research and development, a programme may support a range of technologies, but it cannot support everything: something has to be researched, and something has to be developed. Some choices have to be made. Less obviously, but equally importantly, the effect of a market-shaping policy in a particular sector will have different impacts on different technologies. A policy that has the impact of encouraging the uptake of the least costly opportunities for short-term emissions reduction will tend to encourage the deployment (and therefore further development) of clean technologies that are relatively mature (and so lower cost) more than those that are less so.

6 Gawel, E., Korte, K., Lehman, P. (2018). Technology Neutrality: A Critical Assessment. Technology Neutrality in the Context of Transport. *Agora Verkehrswende. Helmholtz Centre for Environmental Research.* Available at: www.ufz.de/index.php?en=46374

7 Powell, J. (2011). Why politicians lose so much money trying to pick winners. *Forbes*. October 24. Available at: www.forbes.com/sites/jimpowell/2011/10/24/why-politicians-lose-so-much-money-trying-to-pick-winners/?sh=5ecf4cf742af

8 Anadon, L. D., Bin-Nun, A., Chan, G., Narayanamurti, V. (2017). 'The pressing energy innovation challenge of the U.S. national labs.' *Nature Energy* 1: 16117. doi:10.1038/nenergy.2016.117; Anadon, L.D., Bin-Nun, A., Chan, G., Goldstein, A.P., Narayanamurti, V. (2017) 'Six principles for energy innovation.' *Nature* 552: 25-27; Wang, J, Lee, Y-N, Walsh, J-P. (2018) Funding model and creativity in science: Competitive versus block funding and status contingency effects. *Research Policy* 47(6), 1070-1083.

9 Stavins, R. N. (1998). What Can We Learn from the Grand Policy Experiment? Lessons from SO2 Allowance Trading. *The Journal of Economic Perspectives*. Vol. 12, No. 3 (Summer, 1998), pp. 69-88; Schmalensee, R., Stavins, R.N. (2013). The SO2 Allowance Trading System: The Ironic History of a Grand Policy Experiment. *Journal of Economic Perspectives* (27)1, 103-122.

10 Metcalf, G. E. (2009). Tax Policies for Low-Carbon Technologies. *National Tax Journal*. Vol. 62, No. 3, pp. 519-533.

11 Cohen, L.R., Noll, R. (1991). The Technology Pork Barrel. Brookings Press. Washington D.C., USA. June 1, 1991.

12 Greenberg, B. R. (2016). Rethinking Technology Neutrality. *Minnesota Law Review* 207 (Vol. 100, page 1495.) scholarship.law.umn.edu/cgi/viewcontent.cgi?article=1206&context=mlr

The relative effect of a given policy on different technologies will vary not only according to those technologies' relative costs at that point in time, but also depending on factors such as the available infrastructure, market structures and costs of capital.

Since all these factors tend to weigh in favour of the more mature technologies, policy thought to be designed as neutral can end up discriminating against emerging or future technologies, and potentially even promoting or reinforcing a status-quo bias.[13] In situations involving structural change in particular, this tendency to favour incremental change can hinder the fast technology developments and cost reductions needed in key parts of the economy to meet climate change goals.

The case for Principle 1

Since policy cannot avoid supporting some technologies more than others, the policymaker must choose between technologies either deliberately or accidentally. Incumbent technologies tend to benefit from existing networks, asymmetries of information and institutional lock-in,[14] which normally reinforce their existing dominance. This path-dependent nature of technology and economic development means that apparently small choices in favour of one technology or another at one moment in time could have large consequences over a longer period. We propose that deliberate choice is preferable to accidental choice and suggest that, while uncertainties cannot be eliminated, there are some empirical grounds on which deliberate choices can reasonably be based.

Evidence shows that, at least to date, policy instruments that were *not* designed to be technology neutral are largely responsible for the large (and largely unexpected[15]) progress that the world has made reducing the costs and growing the deployment of key energy technologies, particularly in the context of incentives and regulations to foster early-stage deployment and market growth.[16]

Specifically, the rapid technological progress we have seen in areas like solar photovoltaics, on-shore and off-shore wind, concentrating solar power and lithium-ion batteries for electric vehicles, for example, was not driven by generic R&D investments and carbon pricing, but instead by 'innovation policy packages' which have enabled cost reductions and supported adoption[17] that involved a lot of deliberate technology choices made by governments in many countries over decades. These policies have included demand-pull policies such as standards on energy efficiency, renewable portfolio or fuel standards, feed-in tariffs and auctions, as well as R&D (both targeted and untargeted) and demonstration support.

The history of solar PV is now a classic example of countries putting in place different policies 'picking' solar PV – including R&D and procurement (US), niche market subsidies for residential deployment (Japan), feed-in tariffs (Germany) and further scale-up through subsidies (China) – resulting in costs coming down by a factor of over 10,000 since they were commercialised six decades ago.[18] At root, the reasons for dedicating attention and resources to solar in spite of initial high costs per unit energy include its potential: solar is by far the world's biggest, most intense and most widely distributed clean energy resource.[19]

There are also other reasons why policies deliberately focused on supporting specific technologies can be expected to lead to faster innovation and greater cost-effectiveness in a dynamic sense over time. Experimentation, production and installation can lead to cost reductions through learning-by-doing and economies of scale (see Principle 2). The process of learning by doing can be understood as a positive externality (firms deploying the technologies do not fully appropriate the benefits of the experience[20,21]) and as a reinforcing feedback: the more something is made, the more we learn to make it better; this leads to more demand, and more production.

13 Ibid.

14 Hepburn, C., Stern, N., Stiglitz, J. E. (2020). Carbon pricing. European Economic Review, 127, 103440.

15 Anadon, LD., Meng, J., Verdolini, E., Way, R. (2021). Comparing expert elicitation and model-based probabilistic technology cost forecasts for the energy transition. PNAS 118(27). doi.org/10.1073/pnas.1917165118

16 Anadon, L.D., Peñasco, C., Verdolini, E. (2021). 'Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments.' *Nature Climate Change*. doi.org/10.1038/s41558-020-00971-x

17 IPCC. (2022). Intergovernmental Panel on Climate Change 6th Assessment Report Working Group III on Mitigating Climate Change. Summary for Policy Makers. B.4. Also, Chapter 16. report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf

18 Nemet, G.F. (2019). How solar became cheap. *Routledge*. London and New York.

19 Anadon, L.D., Hoppmann, J., Narayanamurti, V. (2020) Why matter matters: how technology characteristics shape the strategic framing of technologies. *Research Policy.* 49:1, 103882. DoI: doi.org/10.1016/j.respol.2019.103882

20 Thompson, P. (2010). Learning by doing. Handbook of the Economics of Innovation 1(10), 429-476.

21 National Academies of Sciences, Engineering, and Medicine. (2016). The Power of Change: Innovation for Development and Deployment of Increasingly Clean Electric Power Technologies. Washington, DC: The National Academies Press. doi.org/10.17226/21712

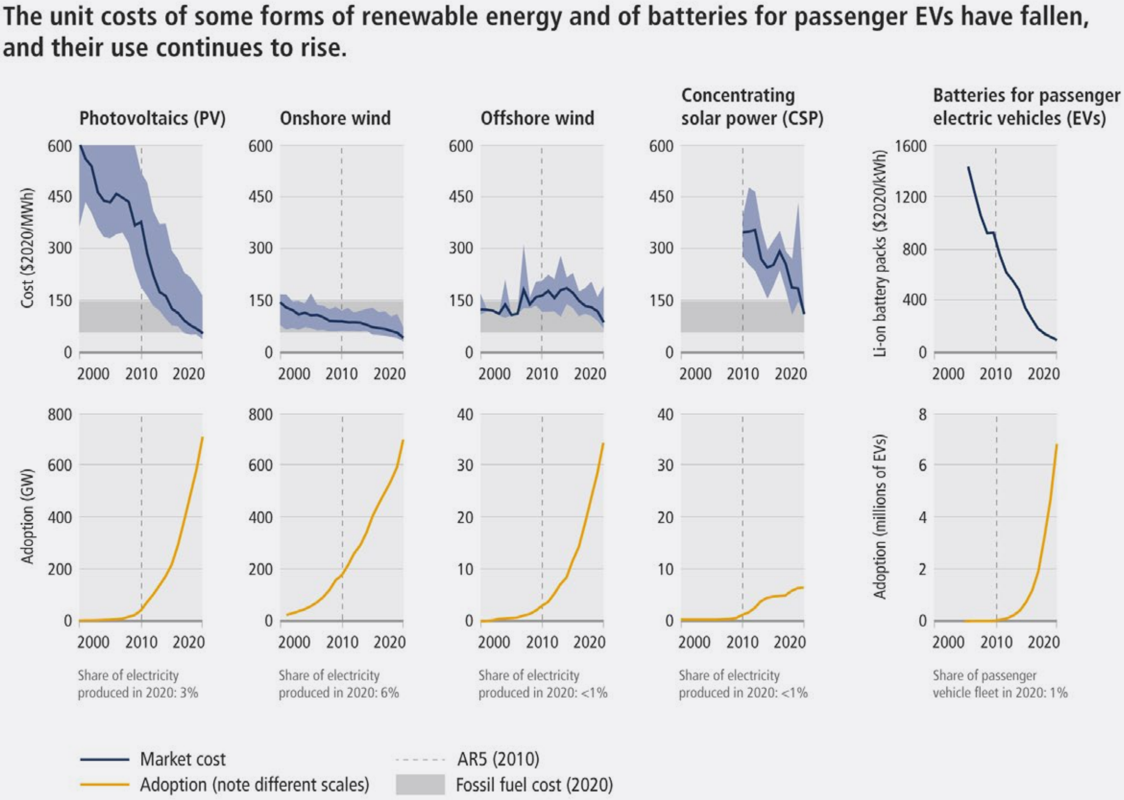


Figure 1. Unit cost reductions and use in some rapidly changing mitigation technologies. The top panel shows global costs per unit of energy (US$/MWh) for some rapidly changing mitigation technologies. Solid blue lines indicate average unit cost in each year. Light blue shaded areas show the range between the 5th and 95th percentiles in each year. Grey shading indicates the range of unit costs for new fossil fuel (coal and gas) power in 2020 (corresponding to US$55–148 per MWh). In 2020, the levelised costs of energy (LCOE) of the four renewable energy technologies could compete with fossil fuels in many places. For batteries, costs shown are for 1 kWh of battery storage capacity; for the others, costs are LCOE, which includes installation, capital, operations and maintenance costs per MWh of electricity produced. The literature uses LCOE because it allows consistent comparisons of cost trends across a diverse set of energy technologies to be made. However, it does not include the costs of grid integration or climate impacts. Further, LCOE does not take into account other environmental and social externalities that may modify the overall (monetary and non-monetary) costs of technologies and alter their deployment. The bottom panel shows cumulative global adoption for each technology, in GW of installed capacity for renewable energy and in millions of vehicles for battery-electric vehicles. A vertical dashed line is placed in 2010 to indicate the change since AR5. Shares of electricity produced and share of passenger vehicle fleet are indicated in text for 2020 based on provisional data, i.e., percentage of total electricity production (for PV, onshore wind, offshore wind, CSP) and of total stock of passenger vehicles (for electric vehicles). The electricity production share reflects different capacity factors; e.g., for the same amount of installed capacity, wind typically produces about twice as much electricity as solar PV. Similar fast cost reductions have been observed in solid state lighting.[22] Source: IPCC SPM3 Figure.[23]

22 Anadon, LD., Kolesnikov, S., Weinold, M. (2021). Quantifying the impact of performance improvements and cost reductions from 20 years of light emitting diode manufacturing. *Proceedings of the International Society for Optics and Photonics (SPIE). Light-Emitting Devices, Materials, and Applications* XXV: 1170611.

23 IPCC (2022). Intergovernmental Panel on Climate Change. 6th Assessment Report, Working Group III on Mitigating Climate Change. Summary for Policy Makers. Available at: www.ipcc.ch/report/ar6/wg3

In economic terms, learning-by-doing can generate benefits to companies and actors beyond the companies involved in manufacturing and/or installation and thus can result in 'spill-overs'. Economies of scale[24] can also create a reinforcing feedback: the more the unit scale of production increases, the more the cost of each unit falls; this tends to increase demand, leading to more production. Technology-specific policies can directly strengthen these reinforcing feedbacks, giving policy a self-amplifying effect, leading to dramatic technological progress over time for some technologies. In contrast, 'technology neutral' policies may in some cases simply incentivise the existing fossil-fuelled system to function more efficiently, in which case these feedbacks are not strengthened.

In addition, innovation, improvement and cost reduction are likely to be most strongly sustained over time when there is alignment between the 'technology push' of research and development, and the 'demand pull' of market-creating policies. An element of conscious technology choice can help policy achieve this alignment.

As illustrated in case study 1 on wind power in the UK, there were large public benefits in terms of innovation and cost reductions, and indeed opening up major new national resources, that emerged from creating technology-specific deployment policies, first for onshore wind and solar and later for offshore wind.

In short, some technology choices must be made. The extent to which technology choices are needed will depend largely (but not only) on expectations regarding learning by doing, economies of scale and costs of finance. In turn, the preferred policy instruments to decarbonise particular sectors should depend on the number and costs of the available technologies, the structure of the sector, the information and funding available, and the country context. For example, technology-neutral regulations or carbon prices may be sufficient to spur technology development and deployment in markets in which several alternative technologies are available that are nearly competitive with incumbents. In contrast, in areas of the economy in which alternatives are few and expensive, a carbon price may have limited effectiveness and specific demonstration and/or targeted demand-pull efforts appropriate for the particular sector and country context could be necessary to bring new technologies to markets.

To make progress in areas or sectors that are currently hard to decarbonise, significant investments, finance and policy attention are needed and this means that there are also practical limits to how many technologies, sectors or missions can and should be 'picked'. Particularly when it comes to deployment, it is important to select which still-expensive technologies to support for early adoption. Thus, a crucial criterion for designing policies is which technologies can reasonably be expected to make rapid progress and become competitive with cumulative investment. Research shows that, to date, the best predictor of future cost trajectories are not models or experts, but previous cost trajectories[25,26]. There is also some emerging evidence that technologies that are more granular or modular (such as those highlighted in Figure 1) have consistently seen faster cost declines (or learning rates) when compared to more bulky and bespoke technologies such as nuclear energy.[27] Notably, the more robust evidence points to the value of using prior cost reductions, especially those that occur after the very early commercialisation of technologies, to understand future ones considering uncertainty.

When a decision is made to support a specific technology with financial incentives, it can be useful to design programmes to ensure that the support can be easily removed once the objectives are reached, to avoid unduly locking-in technologies over the longer run or suffering from state or regulatory capture. (This point is explored further in Principle 6.)

In sum, technology choice and prioritisation must be strategic, transparent and accountable, and adaptable (see Principle 6). Where possible, it could make effective use of a portfolio approach[28] and involve a policy mix (Principle 5). *Strategic* choice refers to targeting substantial sources of emissions in which big technological leaps are needed, where the risk of failure in terms of technology performance or cost is too great and firms are less likely to invest without public sector intervention. Areas with these characteristics could also be identified using Principle 9 and may include green hydrogen, net-zero steel and cement production, long-term dispatchable power, and net-zero aviation and shipping. *Adaptability* is important both in terms of fostering innovation cost-effectively but also in reducing risks of uneven distributional impacts (see Principle 7).

24 Gillingham, K., and Sweeney, J. (2010). Market failure and the structure of externalities. In Harnessing renewable energy in electric power systems: Theory, practice, policy. Washington, DC: RFF Press. 69-91.

25 Farmer, J.D., Lafond, F. (2016). How Predictable Is Technological Progress? *Research Policy* 45, 647-655.

26 Anadon, L.D., Meng, J., Verdolini, E., Way, R. (2021). Comparing expert elicitation and model-based probabilistic technology cost forecasts for the energy transition. *PNAS* 118(27). doi.org/10.1073/pnas.1917165118

27 Wilson et al. (2019). 'Granular technologies to accelerate decarbonization.' Science 368(6486):36-39.; Anadon, L.D., Meng, J., Verdolini, E., Way, R. (2021). Comparing expert elicitation and model-based probabilistic technology cost forecasts for the energy transition. *PNAS* 118(27). doi.org/10.1073/pnas.1917165118; Malhotra, A., Schmidt, T. S. (2020). 'Accelerating Low-Carbon Innovation'. *Joule* 4(11):2259-2267.

28 Farmer, D., Lafond, F., Lillo, F., Panchenkof, V., Way, R. (2019). Wright meets Markowitz: How standard portfolio theory changes when assets are technologies following experience curves. *Journal of Economic Dynamics and Control* 101:211-238.

CASE STUDY 1:
UK offshore wind power [Summary largely from [29,30,31]]

Offshore wind had long presented an interesting opportunity for UK domestic energy development, given the resource potential in the North Sea and UK industry's offshore engineering capability. However, as late as 2008, early trials generated power at around £170/MWh, many times more than the cost of electricity produced by incumbent technologies.[32]

In 2002, to meet its target for 10% of power from renewables by 2010, the UK government introduced the Renewables Obligation (RO), a tradable green certificate mechanism providing subsidy in addition to the market price of electricity. The mechanism was originally technology-neutral (i.e. one certificate was issued per unit of power generated by any renewable generator) and the result was to favour the construction of mature, lowest-cost technologies (mainly onshore wind), with potentially excessive subsidy, while failing to incentivise investments into riskier and more expensive offshore wind projects.[33]

To tackle this problem, in 2009 the government introduced technology 'banding', through which a different number of certificates were issued – and therefore a differentiated subsidy provided – to technologies at different levels of maturity. This doubled the support levels for several immature technologies, including offshore wind, and reduced them for some of the most mature technologies. This was supported by two enabling policies: (a) the creation of the Offshore Wind Accelerator (developed and managed by the government-backed Carbon Trust), which brought together nine leading offshore wind developers to accelerate commercialisation and cost reductions; and (b) the auction of rights by the Crown Estate for seabed space that could serve over 32 GW of offshore capacity. The stability and generosity of the offshore wind RO subsidy gave developers space to experiment and develop and led to learning by doing and cost-reductions across the supply chain, including in the financial sector.

In 2013 the RO was replaced by fixed-priced Contracts for Differences (CfDs). The new renewable capacity to be awarded these contracts were divided into different technology 'pots' according to levels of maturity, reflecting the lessons learned with the RO, and the need to ensure support was channelled to a range of technologies, rather than just to those with already relatively low costs.

After an initial generous government-negotiated allocation, at a scale which attracted foreign investment into a UK manufacturing centre for wind turbines, the government then moved to competitive auctions, which yielded 'strike prices' (fixed revenue) of £120/MWh and £114/MWh in 2015 auctions, £75/MWh and £58/MWh in 2017, £42/MWh in 2019 and, in 2022, £37/MWh (all in 2012 prices) – a fall in costs of over two-thirds in less than a decade (see Figure 2). This has been delivered through large cost reductions across installation and commissioning, balance of plant and turbine costs, and, to a lesser extent, operations and maintenance, and development – induced by learning by doing and economies of scale. The result was that, just a decade after introducing technology 'banding' under the RO (essentially 'picking offshore wind'), the cost of offshore wind became competitive with fossil fuel generation, and can now be considered subsidy-free.

In the latest auction, in early 2022, new offshore wind was contracted at just £37/MWh (2012 prices), to begin generating in 2026[34] – less than one quarter of the price of electricity available from the wholesale market at the time the contracts were awarded. Under the CfDs, this means generators will be returning substantial revenue ultimately to electricity consumers, making offshore wind substantially 'subsidy *negative*' if anything like current electricity prices continue. This could not have been achieved if renewable support policy had remained technology neutral.

29 Grubb et al. (2021). The New Economics of Innovation and Transition: evaluating opportunities and risks. EEIST Report. eeist.co.uk/eeist-reports. Wind Energy in the UK and Brazil Annex.

30 Carbon Trust. (2006). Policy Frameworks for Renewables. Page 3. Available on: www.carbontrust.com/resources/policy-frameworks-for-renewables Accessed on July 5, 2022.

31 Daglish, J., Drummond, P., Grubb, M., Jennings, T., Tipper, H.A. (2020). Policy, innovation and cost reduction in UK offshore wind. The Carbon Trust, London.

32 Grubb et al. (2021) The new economics of innovation and transition: evaluating opportunities and risks. EEIST Report. eeist.co.uk/eeist-reports

33 Carbon Trust. (2006). Policy Frameworks for Renewables. Page 3. Available on: www.carbontrust.com/resources/policy-frameworks-for-renewables Accessed on July 5, 2022.

34 assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1088875/contracts-for-difference-allocation-round-4-results.pdf

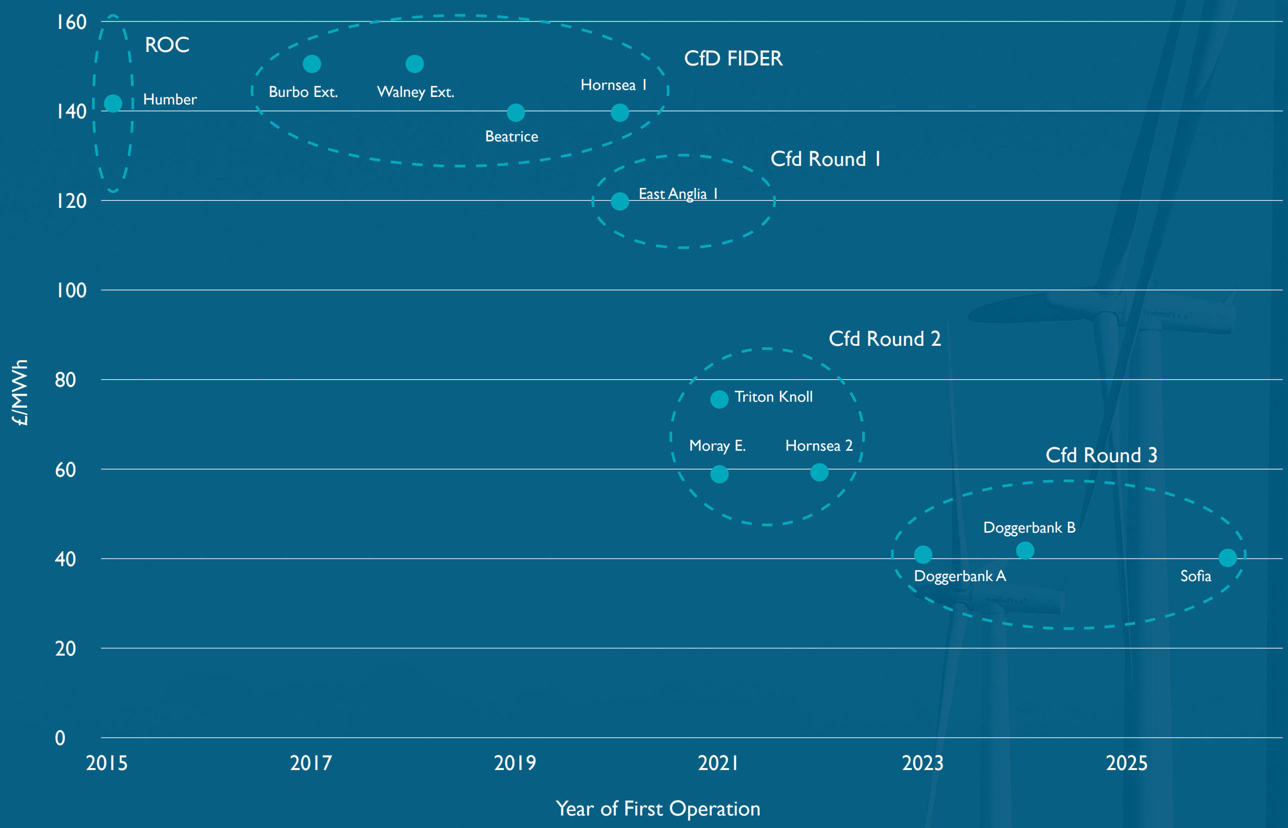


Figure 2. Development of offshore wind prices and costs in the UK. 'Strike prices' (in 2012 prices) are the lowest values awarded to offshore wind under CfD FIDER round (pre-defined prices, awarded in 2013), Auction Round 1 (held in 2015), Auction Round 2 (held in 2017) and Auction Round 3 (held in 2019). ROC (Renewable Obligation Certificate) is the estimated value of the subsidy under the RO mechanism. (Source: [35])

35 Daglish, J., Drummond, P., Grubb, M., Jennings, T., Tipper, H.A. (2020). Policy, innovation and cost reduction in UK offshore wind. The Carbon Trust, London.

PRINCIPLE 2:

Invest and regulate to bring down costs

Traditional principle: Government interventions raise costs

Summary: Well-designed investment and regulation policies can bring down the cost of clean technologies, by creating a 'demand pull' for innovation that complements the 'supply push' of research, development and demonstration, strengthening learning-by-doing feedbacks in technology development, deployment and diffusion.

Rationale for the traditional principle

Providing incentives or regulations for particular technologies is sometimes described, or seen, as 'inefficient' because it distorts more efficient allocations of capital by markets.

The theoretical basis for this argument is that, in equilibrium, a market ensures the optimal allocation of economic resources. Any policy intervention, unless specifically addressing a market failure, will by definition lead to an allocation of resources that is inferior. More practically, this argument partly relies on analyses suggesting that, over the long run, competition can generate high productivity and economic growth and growing prosperity through improvements in business efficiency and innovation incentives.[36] It also implicitly assumes that regulation or incentives will decrease competition and 'efficient' allocation.

There are also policy and country-specific empirical analyses that illustrate how, in the short term, fiscal or regulatory policies typically result in increases in some specific costs. For example, one study suggested that periods of rapid increases in (mainly defence) US federal R&D funding between 1968 and 1994 contributed to substantial increases in scientists' wages.[37] Another study showed that local content regulations for solar PV in India over three years led to short-term increases in technology costs compared to a similar projects without such regulations, during a time of deployment in which the costs of the technology in auctions with and without local content requirements were coming down.[38]

Limitations of the traditional principle

The assumption that government intervention raises costs does not actually reflect societal goals (or all costs, benefits, risks and opportunities), the dynamics of technological change over time, or the practical realities of markets. It is well established that markets do not deliver public goods (such as defence or energy security[39]) by themselves or always work efficiently because of various externalities including learning by doing, information problems and market power.[40]

More fundamentally, the idea of 'optimal allocation of economic resources' is a static one. Over the course of time, there are many different development pathways that an economy can take – more than can ever be explored – and none of them can meaningfully be described as 'optimal'. Over time, economies undergo persistent technological and structural change. Most jobs today did not exist in 1940,[41] many sectors that are thriving now did not exist a few decades ago. Even though in the short term there were often associated costs, government interventions of various forms, including but not limited to state R&D funding, procurement, targeted investment and regulation, have been crucial in creating new economic sectors and enhancing wellbeing.[42]

36 Aghion, P., Blundell, P., Griffith, R., Howitt, P., Prantl, S. (2009). The Effect of Entry on Incumbent Innovation and Productivity. *Review of Economics and Statistics* 91(1), 20-32.

37 Goolsbee, A. (1998). Does Government R&D Policy Mainly Benefit Scientists and Engineers?. *American Economic Review* 88 (2): 298-302.

38 Anadon, L.D., Anatolitis, V., Kontoleon, A., Probst, B,. (2020). The short term costs of local content requirements in the Indian solar auctions. *Nature Energy* doi.org/10.1038/s41560-020-0677-7.

39 Golthau, A. (2012). A public policy perspective on energy security. *International Studies Perspectives* 13, 65-84.

40 OFT. (2009). Government in Markets. UK *Office of Fair Trading*. Available at: assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/284451/OFT1113.pdf

41 Autor, D., Mindell, D., Reynolds, E. (2020). The Work of the Future. *MIT Task Force on the Work of the Future*. Available at: workofthefuture.mit.edu/wp-content/uploads/2021/01/2020-Final-Report4.pdf

42 Mazzucato, M. (2013). The Entrepreneurial State. Debunking Public vs. Private Sector Myths. *Anthem Press*. New York, NY, USA.; Janeway, W. (2012). Doing Capitalism in the Innovation Economy: Markets, Speculation and the State. *Cambridge University Press*. Cambridge, UK.

The case for Principle 2

The extensive data from decarbonisation policies reviewed provides strong evidence of a link between 'demand-pull' policies – those that shape markets to increase demand for clean technologies, including some fiscal incentives and some regulations,[43] (e.g., tax incentives, portfolio or efficiency standards, feed-in-tariffs, public procurement, demand aggregations and auctions) and reductions in the costs of key clean energy technologies (e.g., solar PV, onshore and offshore wind power, lithium ion batteries, and solid state lighting).[44] As we highlighted in our last report, '*The New Economics of Innovation and Transition: Evaluating Opportunities and Risks*':

- Market-creating policies, in particular feed-in tariffs and portfolio standards, notably in Germany and China but also in many other countries, have been central to the dramatic cost declines that have made solar power 'the cheapest electricity in history'.
- In India, public procurement was central to cutting the cost of efficient lighting by 85% in four years, and bringing electric lighting to millions of homes for the first time.
- In the UK, targeted subsidies cut the cost of offshore wind by around 70% over a decade, making it a cheaper source of electricity generation than gas (See Case Study 1).

Most of these policies – some fiscal incentives, some regulations – did initially raise system costs (most notably, electricity prices), in the sense that they supported new technologies that were at first more expensive than the incumbents. But over time, they led to deep cost reductions. While the many individual studies reviewed, by themselves, are not fully able to isolate the impact of specific policies on cost reductions, taken as a whole and with the fact that many of them control for important possible confounding factors, they provide overwhelming evidence that supporting deployment at scale leads to technology and sectoral cost reductions through learning-by-doing, economies of scale and spill-overs (see case study 2 on onshore wind technology cost reductions in Brazil).

This effect can be understood in the terms described under Principle 1: targeted investment and regulation can directly strengthen learning by doing and economies of scale (i.e. reinforcing feedbacks) and foster new networks and business models, all of which accelerate technology innovation, development, cost reductions and diffusion. For the best effects over the long term, these policies should be strategic (see Principle 1), complementary (Principle 5), adaptive (Principle 6) and just (Principle 7).

Broader studies on innovation further show that innovation is cumulative[45] and path-dependent.[46] Policy plays an important role in steering the direction of development. Without any such steering, markets are likely to unduly favour incumbents. Indeed, the concern about regulatory capture,[47] a common criticism of demand-pull policies, can apply also to existing institutions and regulations favouring fossil-fuel incumbents.

As hinted at in the 'rationale for the traditional principle', supporting clean energy technologies is a form of industrial policy that has been referred to as 'green industrial policy'[48] and usually involves (at least) some short-term costs. Industrial policy is a complex area in which there are legitimate concerns about government failures, capture and efficiency, but also lessons about how to do it well (see various references here[49]).

43 Regulation can be broadly defined as the imposition of rules by government backed by the use of penalties. They are "intended specifically to modify the economic behaviour of individuals and firms in the private sector" and can involve rules about prices, output, rate of return, disclosure of information, particular performance or other standards, etc. OECD. (2002). Glossary of Statistical Terms. Available at stats.oecd.org/glossary/detail.asp?ID=3295

44 Anadon, L.D., Peñasco, C., Verdolini, E. (2021). 'Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments.' Nature Climate Change.

doi.org/10.1038/s41558-020-00971-x; Dechezlepretre, A., Drummond, P., Gillingham, K., Glachant, M., Grubb, M., Hassall, G., McDowall, W., Mizuno, E., Pavan, G., Peñasco, C., Poncia, A., Popp, D., Samadi, S., Smulders, S., Rubin, E.S. (2021). Induced innovation in energy technologies and systems: a review of evidence and potential implications for CO2 mitigation. *Environmental Research Letters*. iopscience.iop.org/article/10.1088/1748-9326/abde07; Anadon, L.D., Hoffmann, V.H., Stephan, A. (2021). How has external knowledge contributed to lithium-ion batteries for the energy transition?' *iScience* doi.org/10.1016/j.isci.2020.101995; and Anadon, L.D., Weinold, M., Kolesnikov, S. (2021). 'Quantifying the impact of performance improvements and cost reductions from 20 years of light emitting diode manufacturing.' *Proceedings of the International Society for Optics and Photonics* (SPIE). Light-Emitting Devices, Materials, and Applications XXV 2021: 117061I.

45 Arthur, B. (2007). The Nature of Technology: What it is and how it evolves. *Simon & Schuster*. New York, NY, USA.

46 Unruh, G.C. (2000). Understanding carbon lock-in. *Energy Policy* 28(12), 817-830.

47 Dal Bo, E. (2006). Regulatory Capture: A review. *Oxford Review of Economic Policy* 22(2), 203-225.

48 Altenburg, T., Rodrik, D. (2017). Chapter 1: Green industrial policy: Accelerating structural change towards wealthy green economies. In Green Industrial Policy: Concepts, Policies, Country Experiences. Eds. Altenburg, T, and Assmann, C. Geneva, Bonn: UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitk (DIE). Available at: drodrik.scholar.harvard.edu/files/dani-rodrik/files/altenburg_rodrik_green_industrial_policy_webversion.pdf; Accessed on July 5, 2022.

49 Green Industrial Policy: Concepts, Policies, Country Experiences.' Eds. Altenburg, T, and Assmann, C. Geneva, Bonn: UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitk (DIE). Available at: drodrik.scholar.harvard.edu/files/dani-rodrik/files/altenburg_rodrik_green_industrial_policy_webversion.pdf; Accessed on July 5, 2022; Grubb, M. (2014). Planetary Economics, Section 9.11. Routledge, London.; Rodrik, D. (2014). 'Green Industrial Policy.' *Oxford Economic Review*.30 (3) :469-491

50 Peñasco et al (2021) Systematic review of the outcomes and trade-offs of ten types of decarbonisation policy instruments, *Nature Climate Change*. 11, 257-265

In some cases there is evidence of policy having some 'business-stealing effects' (i.e., of investments that help one firm get ahead without improving productivity), and in some other cases there is evidence of decarbonisation policies having relatively small short-term adverse effects on competitiveness.[50] However, these effects can be small compared to the transformational gains described above.

50 Peñasco et al (2021) Systematic review of the outcomes and trade-offs of ten types of decarbonisation policy instruments, *Nature Climate Change*. 11, 257-265

CASE STUDY 2:

Wind turbines in Brazil [For additional background, see[51]]

The first wind turbine generator installed in Brazil was in the Fernando de Noronha archipelago, in 1992. It was a result of a partnership between the Brazilian Center for Wind Energy (CBEE) and Pernambuco State Power Company (CELPE) and it was financed by Folkecenter, a Danish research institute. Because of high technological costs, ten years later wind-power plants were still an insignificant part of the Brazilian total power supply. At that time (around 2001) the weighted average total installed cost of wind power in Brazil was still above US$3,300/kW (2020 US$/kW)[52] with a LCOE of US$0.097/kWh (2020 US$/kWh) (see Figure 4).

In 2001, an intense period of drought resulted in lower levels of power generation capacity from hydropower plants, which had historically accounted for around three quarters of power generation in the country. This drought period was a tipping point for wind power from the perspective of policymakers. To solve the problem, following a failed attempt in 2001 to design an Emergency Programme of Wind Energy (Proeólica) by the Electric Energy Crisis Management Chamber (GCE), the government created the Incentive Programme for Alternative Sources of Electric Energy (Proinfa) in 2002. It had the objective of increasing the share of wind energy, biomass and small hydroelectric power plants in the generation of electricity in the National Interconnected System[53] and it consisted of both fiscal and regulatory measures.

Proinfa was fully operational in 2004, when it created a power purchase agreement (PPA) for three alternative renewable energy sources to last for 20 years from the start of operations of the plants in December 2011. The promotion system was based on feed-in tariffs, with prices higher than those paid by hydro and thermal plants, financed by extra fees paid by all users of the system[54] and the establishment of power quotas by type of renewable energy (1,100 MW for each of the three alternative sources).

Independent producers not controlled by electricity generation, transmission or distribution concessionaires were subject to preferential treatment in the programme, and the financing – supported by the National Bank for Economic and Social Development (BNDES) – was made conditional on 60% of the production chain coming from domestic manufacturing facilities.[55,56]

The government intervention in the 2000s created incentives to develop infrastructure and make onshore wind generation cost competitive in the country. The impact of Proinfa and subsequent specific auctions for renewable energy in the process of adoption and consolidation of wind energy in Brazil was especially significant. In 2004 the Brazilian government started a second phase of reforming the electricity market by requiring distribution companies to engage in long-term contracts through competitive auctions, following the Proinfa PPA that same year.[57] It created an exclusive auction for wind energy in December 2009 and a specific auction for alternative power sources, in which wind power was included, in August 2010. These efforts continued to support learning by doing in project development and installations. In August 2011, wind energy ventures won contracts in auctions that were open to a wide range of energy sources, including natural gas, biomass and hydroelectric power plants. Since then, the wind sector has continued to be highly competitive in energy auctions open to other energy sources and deployment has grown to over 21 GW[58,59] (see Figure 3).

At constant April 2013 prices, the price of wind energy in Proinfa in 2004 was US$182.6/MWh, while almost a decade after, in an auction held in December 2013 the price had dropped to US$59.5/MWh.[60]

51 Grubb et al. (2021). The New Economics Of Innovation And Transition: Evaluating Opportunities And Risks. EEIST Report. November 2021. eeist.co.uk/eeist-reports. Wind Energy in the UK and Brazil Annex.

52 IRENA. (2021). Renewable Power Generation Costs in 2020, International Renewable Energy Agency, Abu Dhabi.

53 Nogueira, L. P. P. (2011). Estado atual e perspectivas futuras para a indústria eólica no Brasil. Dissertação de Mestrado. Universidade Federal do Rio de Janeiro.

54 Castro, N., Dantas, G. (2008). Lições do PROINFA e do leilão de fontes alternativas para a inserção da bioeletricidade sucroalcooleira na matriz elétrica Brasileira. In *Congresso Internacional de Bioenergia* (Vol. 30)

55 Nogueira, L. P. P. (2011). Estado atual e perspectivas futuras para a indústria eólica no Brasil. Dissertação de Mestrado. Universidade Federal do Rio de Janeiro.

56 Diniz, T. B. (2018). Expansão da indústria de geração eólica no Brasil: uma análise à luz da Nova Economia das Instituições. *Planejamento e Políticas Públicas*. 50.

57 Rosa, et al. (2013). The evolution of Brazilian electricity market. In Evolution of Global Electricity Markets. 435-459.

58 Ibid.

59 Ferreira, A. C., Blasques, L. C. M., & Pinho, J. T. (2014). Avaliações a respeito da evolução das capacidades contratada e instalada e dos custos da energia eólica no Brasil: do PROINFA aos leilões de energia. *Revista Brasileira de Energia Solar*. 5(1).

60 Diniz, T. B. (2018). Expansão da indústria de geração eólica no Brasil: uma análise à luz da Nova Economia das Instituições. *Planejamento e Políticas Públicas*. 50.

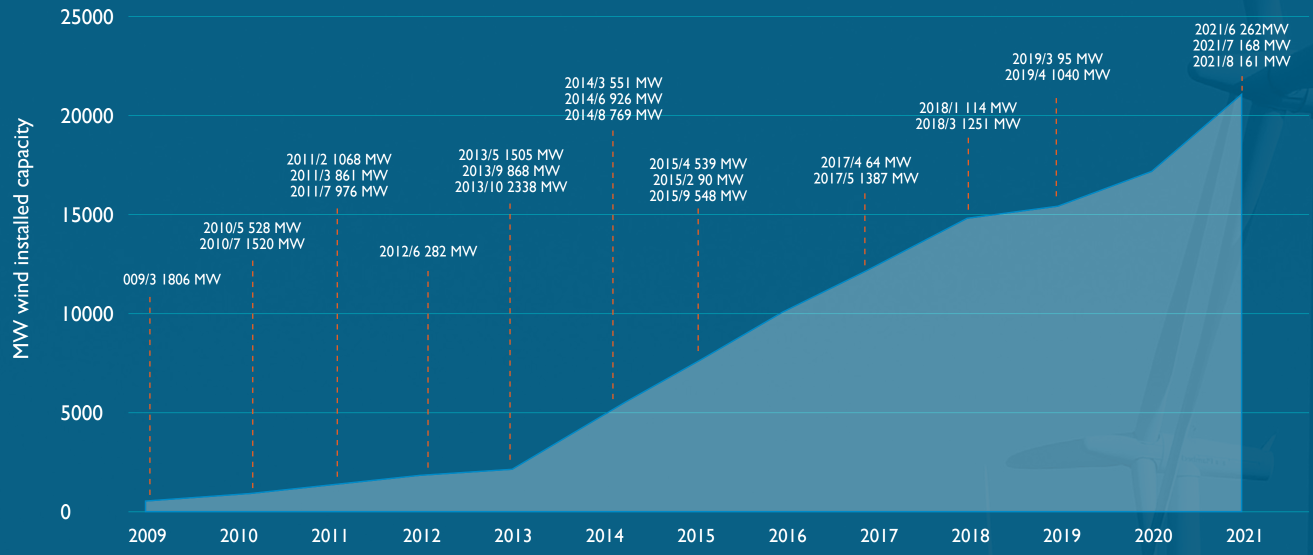


Figure 3. Wind installed capacity in Brazil (MW) and different wind energy auctions. Own elaboration with data from IRENA (2022)[61] and ANEEL(2022)[62].

Note: Figures along the graph represent the wind power capacity awarded in each auction round in MW

These regulations and fiscal incentive policies, combined with the availability of finance from the Brazilian Development Bank (BNDES) – which took riskier positions to provide finance for renewable energy as a policy priority to foster local industrial capacity development – have been a success: the cost of installed wind power capacity fell by 57% between 2001 and 2020 (IRENA reports costs around US$1400/kW) in less than 20 years. As shown in Figure 4, the levelised cost of onshore wind energy (LCOE) also fell significantly: from 1999 to 2020 it went down by approximately 70%.

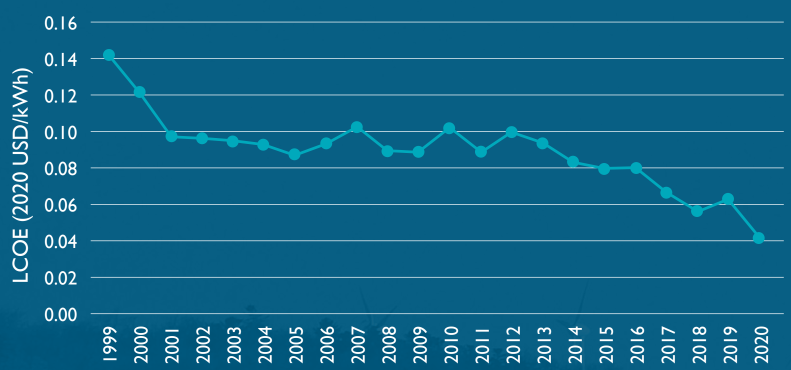


Figure 4. LCOE of onshore wind power in Brazil (USD/kWh)
Source: Own elaboration with data from IRENA (2021)[63].

Wind now provides around 11.9% of Brazil's electricity generation[64] and has become the second-largest energy source in the national electricity matrix. The policies have also contributed to industrial growth: Brazil now has six turbine factories and hundreds of companies in the wind-power supply chain, and the sector supported more than 150,000 jobs by 2016.[65] More recently, in January 2022, the Brazilian government expanded its policy and regulation to include offshore windfarms, which are expected to fall in cost and increase the country's power capacity substantially in this decade.

61 IRENA. (2022). Renewable capacity statistics 2022. International Renewable Energy Agency, Abu Dhabi.

62 ANEEL. (2022). Resultados dos leilões de expansão da geração. Relatório interativo. Dados por Empreendimento. Access: app.powerbi.com/view?r=eyJrIjoiYmMzN2Y0NGMtYjEyNy00OTNlLWI1YzctZjI0ZTUwMDg5ODE3IiwidCI6IjQwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9. Last accessed July 2022.

63 IRENA. (2021), Renewable Power Generation Costs in 2020, International Renewable Energy Agency, Abu Dhabi.

64 Ministry of Mines and Energy. (2022). https://www.gov.br/mme/pt-br/assuntos/secretarias/spe/publicacoes/boletins-mensais-de-energia/2022-2/ingles/4-boletim-mensal-de-energia-abril-2022/view

65 Associação Brasileira De Energia Eólica. (2020). Boletim Anual de Geração Eólica 2019. São Paulo.

PRINCIPLE 3:

Actively manage risks to crowd-in investment

Traditional principle: Markets on their own optimally manage risks

Summary: Low-carbon transitions involve many sources of uncertainty. Efforts to reduce the risks of private investment in clean technologies, including public finance acting as a lead investor, can reduce technology risk and financing costs and greatly increase rates of investment and deployment.

Rationale for the traditional principle

Meeting the international climate change goals requires a significant increase in investment, of the order of US$1 trillion per year between 2030 and 2050,[66] from diverse sources including venture capital, private equity, bank finance, state agencies and institutional investors.[67] There is an expectation that markets supporting this transformation with 'investment grade policy',[68] which ensures that externalities are costed and internalised, will drive this change. Financial markets can be useful mechanisms for more efficient capital allocation in response to various types of risks, including some types of technological and price risks. For example, more developed financial sectors (i.e., those that had bigger markets and more informative prices, less state ownership, and strong minority investor rights) are associated with improved capital allocation in terms of increasing investment in growing industries and decreased investment in declining industries when compared to 'undeveloped' financial sectors.[69] It is also well known that businesses and financial markets respond to prices (including energy prices) by increasing firm innovation.[70]

In some cases, public investment can crowd out private investment. For example, the creation of the UK Green Investment Bank (GIB) and clean technology investments by the German Development Bank (KfW) played an important role in mobilising private finance in many technology areas. By investing in higher-risk assets, these public investments created market track record and built trust such that private investment could then follow. However, in other areas, such as particular types of GIB investments in UK biomass developers, and investments into some mature markets by the German KfW, the public investments were seen to have partially substituted for private investment, as these public sector-backed organisations had lower return expectations and therefore offered cheaper capital than the private investors.[71] When public investment is used for renewable technologies, there is a real risk that without proper consideration of local circumstances they could hinder the involvement of private actors, potentially competing (crowding out) private sector lending or investment.[72]

---

66 Bertram, W., de Boer, H-S., Bosetti, V., Busch, S., Després, J., Drouet, L., Emmerling, J., Fay, M., Fricko, O., Fujimori, S., Gidden, M., Harmsen, M., Huppmann, D., Iyer, G., Krey, V., Kriegler, E., McCollum, D.L., Nicolas, C., Pachauri, S., Parkinson, S., Poblete-Cazenave, M., Rafaj, P., Rao, N., Riahi, K., Rozenberg, J., Schmitz, A., Schoepp, W., van Vuuren, D., Zhou, C. (2018). Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals," Nature Energy, 3. 589-599.

67 PEW Charitable Trust (2010). Who's Winning the Clean Energy Race? G-20 Investment Powering Forward.

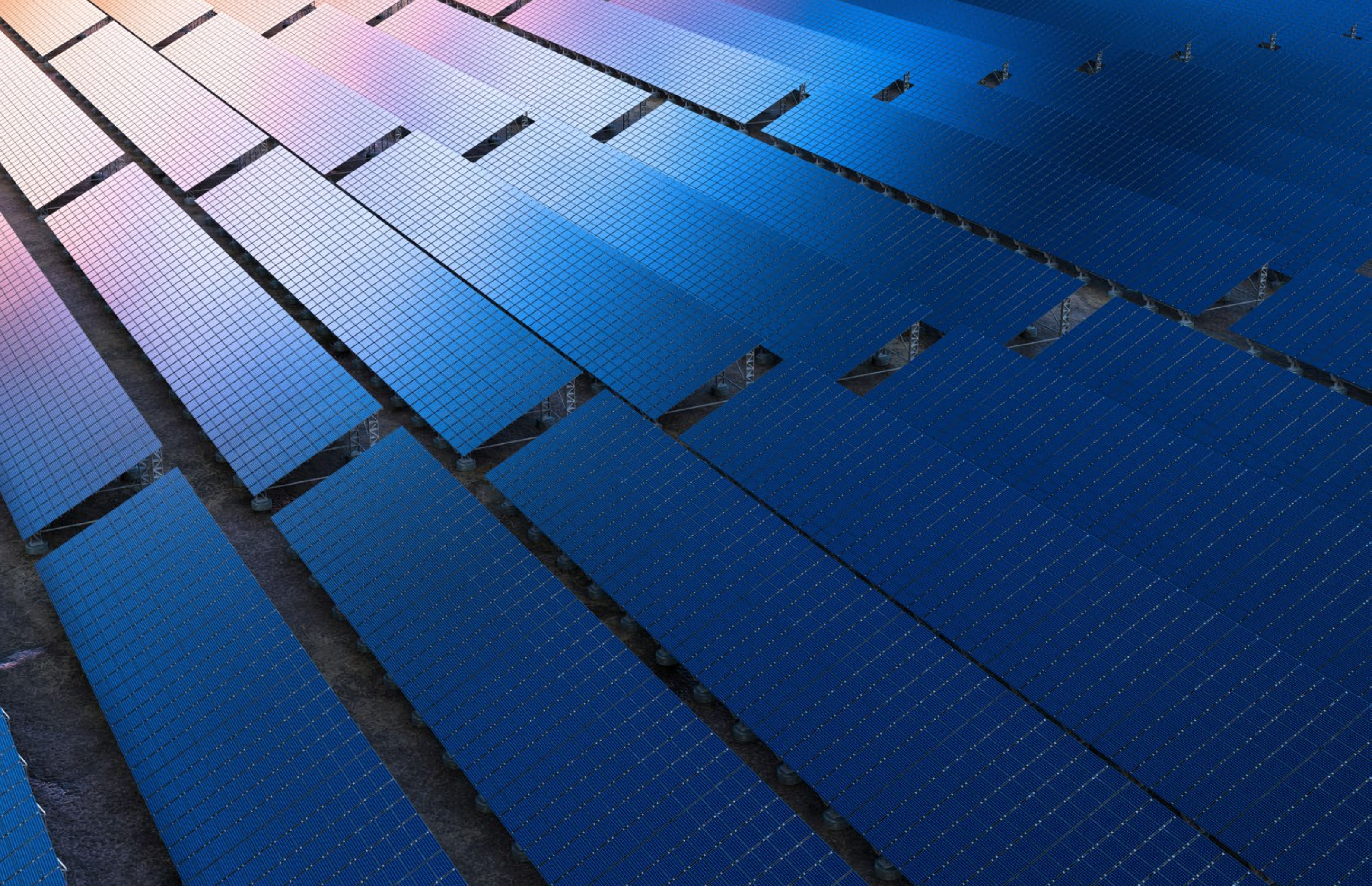
68 Hamilton, K. (2009). Unlocking Finance for Clean Energy: the Need for 'Investment Grade' Policy. Renewable Energy Finance Project, Chatham House.

69 Wurgler, J. (2000). Financial markets and the allocation of capital. Journal of Financial Economics. 58:187-214.

70 Popp, D. (2022). Induced innovation and energy prices. *American Economic Review* 92(1):160-180.

71 Geddes, A., Schmidt, T.S., Steffen, B. (2018) The multiple roles of state investment banks in low-carbon energy finance: an analysis of Australia, the UK and Germany, Energy Policy, 115, 158-170.

72 Boyd, R., Buchner, B., Hervé-Mignucci, M., Mazza, F., Micale, V., Stadelmann, M., Trabacchi, C., Wilkinson, J. (2013). Global Landscape of Climate Finance 2013. Climate Policy Initiative.



Limitations of the traditional principle

Tackling climate change is likely to rely on many disruptive technologies whose development and deployment are often characterised by great uncertainty. In such circumstances, markets can deal with *some* technology and market risks, but are not set up to manage *all* risks. A recent review by the OECD, for example, concluded that markets are not sufficiently pricing-in climate risks, including climate physical and transition risk.[73]

One reason why markets are not by themselves fully able to manage all transition risks in particular is the scope, complexity and timescales around the transition – and its unavoidable dependence on policy in multiple arenas, including politically charged areas of pricing. Public interventions can in some cases reduce some of the fundamental uncertainty associated with such a transformation in the economy in which non-marginal changes occur. Uncertainty adds a risk premium and raises the returns expectation on any investment, reducing the incentives for investment in technologies and businesses in the early stages of innovation, especially when their profitability relies on creating new markets.

Evolutionary dynamics dominate in these situations – meaning that changes in technologies and markets are constant, non-marginal and interdependent, and resources cannot be assumed to be optimally allocated. Public investment is needed to foster the transition, which cannot be guaranteed to happen otherwise. This is accepted even under a neoclassical economics framing, given that not all externalities can be managed or internalised.[74] Therefore, in some sectors relevant for the energy transition, rather than crowding out private investment, public finance can create a 'crowding-in' effect, in that it will mobilise private investment[75] by acting as a lead investor, thereby reducing the perception of technology, revenue and other risks. Public finance can, for instance, help reduce the cost of capital for private firms while maintaining many competitive pressures on technology performance and cost-reduction. This is most likely to be the case in circumstances in which public finance is expected to lead to societal benefits that are significant and would not otherwise materialise.

73 OECD. (2021). Financial Markets and Climate Transition: Opportunities, Challenges and Policy Implications, OECD Paris, www.oecd.org/finance/Financial-Markets-and-ClimateTransition-Opportunities-challenges-and-policy-implications.htm

74 Deleidi, M., Mazzucato, M., Semieniuk, G. (2020). Neither crowding in nor out: public direct investment mobilising private investment into renewable energy projects, *Energy Policy*. 140, 111195.

75 Deleidi, M., Mazzucato, M., Semieniuk, G. (2020). Neither crowding in nor out: public direct investment mobilising private investment into renewable energy projects, *Energy Policy*. 140, 111195.

The case for Principle 3

There are some important risks that governments are uniquely positioned and able to take. These go beyond (for instance) the well-accepted role of taking on early-stage discovery risk by financing R&D.

The first is technology risk along the innovation process, past R&D. This includes the so-called 'demonstration valley of death', a term used to describe the fact that, in some cases, the technology risk during the early scale-up and commercialisation of a technology is too high in terms of costs and/or performance for private investments to take on the risk by itself.[76]

A second risk is related to the non-technology risks associated with deploying new clean technologies for the first time without existing markets, regulations, business models or financing channels. Governments are uniquely able to take at least part of this risk to begin with because they hold the power of market design and can shape markets so that solutions they consider critical to low-carbon transitions have a greater chance of succeeding. No private investor can have such confidence. When governments take on or share early commercialisation risk (through grants, loan guarantees or innovation procurement, for instance), and demonstrate that the risk is lower than previously perceived, their actions can unlock a significant increase in private investment.

To state the obvious, governments should, of course, not try to take on all risks in all cases just because they can, for instance, lower finance costs. The question is, then, how to design public investments to incentivise the crowding-in of private funding. Or more generally: what is the appropriate role of public finance and intervention beyond the well-accepted notion that, when acting in markets, policy certainty is key?[77,78,79]

The most effective policies for incentivising deployment and investment in renewable energy technologies are those that address both the risk and return of investments.[80] For example, price-based support schemes are positively correlated with an increase in private investment,[81] and public investments through state investment banks "take a much broader role in catalysing private investments into low-carbon investments, including enabling financial sector learning, creating trust for projects and taking a first or early mover role to help projects gain a track record",[82] although a crowding-out effect is seen if investment continues as the market matures. The policy evaluation literature[83] indicates that the use of public investment as direct investment into technologies to create a 'track record' (e.g., regarding construction times, technology performance, maintenance costs, and returns), has been particularly valuable (see case 3 on incentivising renewables investment in Uganda).

Regarding the role of specific policy instruments, feed-in tariffs have been consistently effective at fostering private investment by reducing revenue risk in a targeted way. In contrast, the impact of emissions trading schemes on renewable deployment has historically been smaller,[84] something that can be at least partly attributed to the fact that future price uncertainty maintains perceived revenue risks.[85] Similarly, in the case of tradeable green certificates (TGCs, known as Renewable Obligation Certificates, ROCs in the UK), when certificate prices have been volatile they have been less effective in promoting innovation,[86] especially when measured by cost reductions for more immature technologies.[87,88]

76 ;Anadon, L.D., Bin-Nun, A., Chan, G., Goldstein, A.P., Narayanamurti, V. (2017) Six principles for energy innovation. Nature 552: 25-27 Doi:10.1038/d41586-017-07761-0; Kraus, M., Nemet, G., Zipperer, V. (2018). The valley of death, the technology pork barrel, and public support for large demonstration projects.' Energy Policy. 119:154-167.

77 Jones, A. (2015). Perceived barriers and policy solutions in clean energy infrastructure investment, Journal of Cleaner Production. 104, 297.

78 Egli, F., Polzin, F., Schmidt, T.S., Steffen, B. (2019). How do policies mobilize private finance for renewable energy? A systematic review with an investor perspective. Applied Energy. 236, 1249-1268.

79 Blinde, P., Blyth, W., Gilbert, A., Lam, L. (2014). Cap-setting, price uncertainty and investment decisions in emissions trading systems. Ecofys on behalf of UK Department of Energy and Climate Change, London. Microsoft Word - EU ETS cap-setting project_REPORT (publishing.service.gov.uk)

80 Egli, F., Polzin, F., Schmidt, T.S., Steffen, B. (2019). How do policies mobilize private finance for renewable energy? A systematic review with an investor perspective. Applied Energy. 236, 1249-1268.

81 Cárdenas Rodríguez, M., et al. (2014), Inducing Private Finance for Renewable Energy Projects: Evidence from Micro-Data, OECD Environment Working Papers, No. 67. doi.org/10.1787/5jxvg0k6thr1-en

82 Mazzucato, M., Semieniuk, G. (2018). Financing renewable energy: who is financing what and why it matters. Technology Forecasting and Social Change. 127, 8-22.

83 Geddes, A., Schmidt, T.S., Steffen, B., (2018). The multiple roles of state investment banks in low-carbon energy finance: an analysis of Australia, the UK and Germany, *Energy Policy*. 115, 158-170

84 Egli, F., Polzin, F., Schmidt, T.S., Steffen, B. (2019). How do policies mobilize private finance for renewable energy? A systematic review with an investor perspective. Applied Energy. 236, 1249-1268.

85 Cárdenas Rodríguez, M., et al. (2014), Inducing Private Finance for Renewable Energy Projects: Evidence from Micro-Data, OECD Environment Working Papers, No. 67. doi.org/10.1787/5jxvg0k6thr1-en

86 Anadon, L.D., Peñasco, C., Verdolini, E. (2021). 'Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments.' Nature Climate Change. 11, 257–265 doi.org/10.1038/s41558-020-00971-x

87 Finon, D.; Lamy, M-L., Menanteau, P. (2003). Prices versus quantities: choosing policies for promoting the development of renewable energy. *Energy Policy.* 31, 799–812.

88 Gautesen, K., Midttun, A. (2007). Feed in or certificates, competition or complementarity? Combining a static efficiency and a dynamic innovation perspective on the greening of the energy industry. *Energy Policy.* 35 (3), 1419-1422.

The design of policies to crowd-in private investment for technologies that have the potential to become cheaper and help meet energy goals must also take into account distributional aspects (see Principle 7). For instance, when introduced in 2002, the UK Renewable Obligation Certificates (the UK version of TGCs) were shown to favour large incumbents and existing low-cost technologies in detriment to small-scale investments in rural areas involving more innovative solutions.[89] Regardless of whether early deployment support policies take the form of taxes or subsidies (such as Feed-in-Tariffs, TGCs or Contracts for Difference), fiscal incentives need to be proactive and responsive (see Principle 6) to reduce risks in technology investment, the cost to government and excessive windfall profits. In other words, it is important to focus on the dynamic efficiency of policy and public finance[90] in providing transparency as well as risk-mitigation measures.

Given the changing nature of risk along the technology development process, as technologies are developed, deployed and mature, different policy instruments may be needed to support reducing the risk. Taking the US innovation ecosystem as an example, institutions like the Advanced Research Projects Agency – Energy (ARPA-E) can help quickly reduce technology risk in a targeted manner at early stages of development by awarding and managing high-risk/high-reward R&D projects in novel ways.[91] Mission-oriented military R&D, for instance, has crowded in private R&D.[92] Further along in the process, the Loan Programs Office (LPO) at the US Department of Energy was created with the mission of serving as a bridge to bankability for innovative and high-impact energy technologies, providing them with access to needed loans and loan guarantees when private lenders cannot or will not until a given technology has reached full market acceptance.[93]

It supported, among other efforts, the production engineering and assembly for Tesla's Model S. At later stages of the transition, state banks, different types of public-private partnerships[94,95,96] such as fund-of-funds or direct public investment, and other types of public investments (e.g., other subsidies or tax incentives) can help lower the cost of capital and crowd-in private investment in areas of national priority such as the energy transition.

89 IRENA. (2017). Renewable Energy Auctions: Analysing 2016. International Renewable Energy Agency, United Arab Emirates.

90 Scotchmer, S. (2011). Cap and Trade, Emissions Taxes, and Innovation. Innovation Policy and the Economy, 11 (1), 29-54.

91 Azoulay, P., Fuchs, E., Goldstein, A.P., Kearney, M. (2019). Funding Breakthrough Research: Promises and Challenges of the ARPA Model. Innovation Policy and the Economy, Vol 19. University of Chicago Press.

92 Pallante, G., Russo, E., Roventini, A. (2021). Does mission-oriented funding stimulate private R&D? Evidence from military R&D for US states. LEM Working Paper Series 2020/32. Institute of Economic, Scuola Superiore Sant'Anna, Pisa, Italy.

93 LPO. (2022). Loan Guarantee Program Office Mission. U.S. Department of Energy. Available at: www.energy.gov/lpo/mission

94 Brown, J., Jacobs, M. (2011). Leveraging Private Investment: the Role of Public Sector Climate Finance. Overseas Development Institute.

95 Nassiry, D., Wheeler, D. (2011). A Green Venture Fund to Finance Clean Technology for Developing Countries. Center for Global Development.

96 WEF (2011). Critical Mass Initiative Working Report: Scaling up Low-carbon Infrastructure Investment in Developing Countries. World Economic Forum.

CASE STUDY 3:

Feed-in tariffs and internationally funded top-ups for small hydropower in Uganda

[For a full analysis, see[97]]

In 2007, the Ugandan government launched its Renewable Energy Policy, setting a target of reaching a renewables (including large hydro) power capacity of 1,420 MW in 2017 – a doubling of total existing capacity, including thermal and renewables. In the same year, the government introduced a Feed-in Tariff (FiT) to incentivise investment from independent power producers (IPPs).

The initial level of the FiT (US$0.09/kWh in 2012) was too low given the risk profile of the country; by 2012 it had attracted some, but limited, interest from IPPs (leading to the deployment of only 28 MW in small-scale hydropower). The scale of investment in the country's power infrastructure was considered too small and it was expected that a business-as-usual scenario would lead to power supply constraints in 2015-2016.

To attract private-sector investment in renewable energy in Uganda, the government, the Ugandan Electricity Regulatory Authority (ERA) and the German Development Bank (KfW) jointly launched the Global Energy Transfer (GET) FiT programme in 2013, supported by a number of other donors. This involved improving existing regulatory frameworks but, most importantly, paying for the difference between the maximum price a utility was able to pay and the price of renewable power, which was determined through tariffs in the case of small-hydro.

The small-hydro GET FiT involved paying an additional US$0.01-2/kWh to project developers over the previous US$0.09/kWh tariff (around a 20% increase in revenue), thereby increasing project returns. It also reduced investment risk by providing developers with standardised power purchase agreements that were bankable documents. Between the three rounds (one per year between 2013 and 2015) 17 projects (14 of them small hydro) out of 39 applications received the GET FiT.

The analysis of detailed financial data over the years showed that the internal rate of return required for investors (IRR) of hydro-power projects went down significantly over the three rounds of the GET FiT program, which spanned between 2013 and 2015. While the IRR required in rounds one and two was around 15%, for round three it went down to 9% (see black discontinuous line in Figure 5). This indicated that investors were facing lower investment risks and therefore tolerating lower returns (Figure 5). This tended to lower the cost of capital for hydro projects, allowing them to generate power at lower cost.

It is also noteworthy that many projects that were awarded GET FiT support in round one had IRRs with support that were below the IRR of projects that applied for support but were rejected and constructed anyway (on the basis that they were already commercially viable). This suggests that the GET FiT top-up worked by both increasing returns and lowering risks. As a result of the reduced investment risks, the programme, over time, reduced the value of the top-up.

GET FiT was launched with about US$104 million of development funding from KfW and other donors and it attracted around US$453 million in private-sector investment in total for 17 medium-sized renewable electricity projects totalling 157 MW, suggesting that its approach reduced risks and financing costs and attracted private-sector investment.

97 Anadon, L.D., Kontoleon, A., Probst, B., Westermann, L. (2021). Leveraging private investment to expand renewable power generation: Evidence on financial additionality and productivity gains from Uganda. *World Development*. doi.org/10.1016/j.worlddev.2020.105347

Figure 5. Internal Rate of Return of small hydropower plants in the GET FiT programme with counterfactual Internal Rate of Return (IRR) based on KfW data. The y-axis represents the project-level Internal Rate of Return in % and each of the bars in the x-axis represents individual projects awarded the Global Energy Transfer (GET) Feed-in Tariff (GET FiT) in the respective rounds. There were nine projects in Round 1 (in 2013) and Round 2 (in 2014) combined and five projects in Round 3 (in 2015). Between 2013 and 2015 the IRR required for investors went down, indicating that investment risks went down significantly. The counterfactual internal rate of return (IRR) was calculated using projects that did not get funding, but went ahead with the project even without GET FiT funding. This counterfactual data exists as firms needed to hand in detailed financial data to apply for KfW funding. In addition, these rejected firms were unlikely to change their construction design or other factors later in the process, as environmental and other permits were tied to a specific design. Source:[98]

98 Anadon, L.D., Kontoleon, A., Probst, B., Westermann, L. (2021). Leveraging private investment to expand renewable power generation: Evidence on financial additionality and productivity gains from Uganda. World Development. doi.org/10.1016/j.worlddev.2020.105347

PRINCIPLE 4:

Target tipping points

Traditional principle: Simply price carbon at a level that internalises the damages of climate change

Summary: Well-targeted interventions can activate tipping points in technology competitiveness, consumer preference, investor confidence, or social support for transitions, where a small input leads to a large change. This can inform the targeting and level of subsidies and taxes, as well as the stringency of regulations.

Rationale for the traditional principle

The standard approach to economic policymaking in the presence of 'externalities' – costs or benefits to actors that are unpriced – is for government to identify and to act to ensure they face an appropriate price ('internalising the externality').[99,100] In the case of climate change, the core externality in this framing is that emissions of greenhouse gases are not priced by free markets – for markets to be efficient, governments need to correct this through taxation or the allocation of 'emission allowances' which are then priced through trading.[101] Following this logic, the level of the carbon price should reflect the economic damage that is expected to arise from the emission of each tonne of carbon emitted, also known as the social cost of carbon, and/or the corresponding agreed emissions goal. As we note under Principles 1 and 8, however, this, by itself, will *not* necessarily minimise the costs of transition over the long term.

This standard approach also observes that innovation in new clean technologies will be required to substantially reduce emissions to avoid carbon costs, and that innovation spill-overs (the fact that the innovating company does not get all the benefits of their ideas) imply there is a second key externality that governments need to tackle.[102] This justifies public investment in research and development.

Carbon pricing in the form of carbon taxes and trading systems has spread in various parts around the world and, even with low average prices of US$10/t$CO_2$ and coverage of around just 22% of total emissions,[103] have delivered some useful emissions reductions.[104] Some carbon pricing is better than none, and higher levels are more likely to be effective than lower levels. Governments have also, on average, increased public energy R&D investments since around the decade of the 2000s[105,106] and evidence points to public energy R&D as a useful driver of innovation outcomes.[107]

Limitations of the traditional principle

There are several challenges with this traditional approach insofar as it is often claimed to be sufficient and/or better than others. Some we have partly already addressed in Principles 1, 2 and 3. Perhaps the most fundamental is the assumption of the economy as relatively close to some sort of equilibrium that is optimal, rather than as a highly dynamic, complex adaptive system. A related assumption is that achieving efficiency (in the form of least-cost abatement) in the short term should also deliver the least-cost abatement in the longer term, and indeed that efficiency (rather than, say, effectiveness or resilience) is the primary objective. A third assumption is that, where there are multiple 'market failures', it is possible to isolate each and deal with them individually, with one targeted policy

99 Pigou, A. C. (1920). The economics of Welfare. *McMillan and Co (3rd edition 1928)*

100 Coase, R. H. (1960). The Problem of Social Cost. *Journal of Law and Economics, 3, 1.*

101 Baumol, W. J., & Oates, W.E. (1988). *The theory of environmental policy*. Cambridge University Press.

102 Jaffe, A.B., Newell, R.G., Stavins, R. N. (2005). A tale of two market failures. *Ecological Economics* 54(2-3), 164-174

103 World Bank. (2022). State and Trends of Carbon Pricing 2022, openknowledge.worldbank.org/handle/10986/37455. Washington D.C. Accessed on July 2022.

104 Ellerman, use this instead: Skea, J., Shukla, P., & Kılkı. (2022). Climate Change 2022: Mitigation of Climate Change.*

* From the IPCC report: "The European Union Emissions Trading Scheme (EU ETS), the longest-standing regional climate policy instrument to date, has reduced emissions, though the estimates of the amount vary by study, by country, and by sector; ranging from 3 to 28% (McGuinness and Ellerman, 2008; Ellerman et al., 2010; Abrell et al., 2011; Anderson and Di Maria, 2011; Egenhofer et al., 2011; Petrick and Wagner, 2014; Arlinghaus, 2015; Martin et al., 2016). The EU ETS avoided emitting about 1.2 GtCO2 between 2008 and 2016 (3.8%), almost half of what EU governments promised to reduce under their Kyoto Protocol commitments (Bayer and Aklin, 2020)."

105 IEA Energy RD&D Database. (2022). Available at: https://www.iea.org/data-and-statistics/data-product/energy-technology-rd-and-d-budget-database-2

106 Anadon, L.D., Galeazzi, C., Meckling, J., Shears, E, Xu, T. (2022). Energy innovation funding and institutions in major economies. *Nature Energy*, accepted.

107 Penasco et al. (2021). Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments. Nature Climate Change.

instrument to correct that,[108] though this contrasts with a long-standing economic 'theory of the second best' (see also Principle 5). In the context of a low-carbon transition, all these assumptions are questionable.

A further challenge is that social cost of carbon estimates 'vary widely in the literature': between US$10/t$CO_2$ and US$1000/t$CO_2$, or even infinite if highly uncertain potentially catastrophic outcomes are not excluded. The 'challenge of comparability across methodologies' means that 'many estimates are not robust'[109] and there is still a wide range of possible values of carbon prices for policymakers to consider.

Practically speaking, there are three additional challenges to relying purely on the traditional principle. First, carbon prices coexist with continuing fossil fuel subsidies, the value of which often outweigh that of the carbon price.[110] Second, with some exceptions, it has been difficult to raise them to higher levels (US$50-100/t$CO_2$)[111] more consistent with the more-commonly accepted range of estimates of the social cost of carbon because of political economy reasons.[112] Third, in an uncertain and dynamic world, it is not necessarily sensible to rely on a very small set of policy instruments to deliver an important goal, requiring a portfolio (Principle 5) and adaptive (Principle 6) approaches.

All these considerations indicate that pricing carbon and supporting R&D, by themselves, will not deliver the pace and scale of the transformation required to meet the goals of the Paris Agreement and are not, by themselves, necessarily the most cost effective approach to decarbonisation.

Case for Principle 4

Complex adaptive systems can display surprising, chaotic, path-dependent, and non-linear behaviours – especially where we consider technology diffusion and transitions in human practice. In such systems, one approach that can be useful – within a broader range of approaches to accelerate transitions – is to seek to identify 'sensitive intervention points' (SIPs)[113] or 'social tipping points'[114], where the socio-technical system is at or near a state of criticality and a well-judged 'kick' could move it into a different (and preferable) state. At these points, a small policy input can lead to a disproportionately large outcome as a result of self-reinforcing feedbacks.

Tipping points can exist in situations where, within a given sector, competing technologies are close to each other in cost. In such cases, a carbon price that is just enough to tip the balance can put one technology on to a growth path, and the other on to a pathway of decline. Tipping points of this kind have played a role in the world's fastest decarbonisation of the power sector (in the UK – see case study 5), and in the world's fastest transition in road transport, in Norway.[115] In these cases, it was the *relative* value of carbon pricing (and of other taxes and subsidies) that determined its effectiveness in particular sectors, not the *absolute* value (which is the focus of social cost of carbon estimates). Moreover, carbon pricing could only activate tipping points in these two cases because other policies – including R&D, investment in clean technologies and regulatory market reforms – had first done the hard work of bringing the system towards what one could refer to as a state of criticality.

In other cases, a particular set of demonstration projects may help private firms decide where to make their bets, activating investor confidence tipping points. Another example may be when a regulation requiring a particular level of energy-efficiency or carbon intensity makes one technology more competitive or viable than another – as, for example, EU vehicle efficiency regulations at first only led manufacturers to produce more efficient internal combustion engine cars, but beyond a certain level of stringency have increasingly driven a shift towards the production of electric vehicles. This provides a helpful input to designing different types of policies at a sectoral level.

108 Tinbergen, J. (1952). On the Theory of Economic Policy. North-Holland Pub. Co.,.

109 IPCC, WGII. (2011). 6th Assessment Report. Cross working group box on 'Estimating Global Economic Impacts from Climate Change'. Chapter 16. Available at: report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_Chapter16.pdf; Accessed on July 5, 2022.

110 Indicator 4.2.3, 2021 Lancet Countdown: www.thelancet.com/journals/lancet/article/PIIS0140-6736(21)01787-6/fulltext#seccestitle570

111 Stern, N., Stiglitz, J. (2017). Report of the High-level Commission on Carbon Prices. Carbon Pricing Leadership Coalition. World Bank. Available at: www.carbonpricingleadership.org/report-of-the-highlevel-commission-on-carbon-prices. Accessed on July 5, 2022.

112 Cullenward, D., Victor, D. (2020). Making climate policy work. Polity Press, Cambridge, UK.

113 Farmer, J. D., Hale, T., Hepburn, C., Ives, M. C., Mealy, P., Rafaty, R., Srivastav, S., Way, R., Wetzer, T. (2019). Sensitive Intervention Points in the Post Carbon Transition. *Science*, 364 (6435).

114 Otto I. M., et al. (2020). Social tipping dynamics for stabilizing Earth's climate by 2050. *Proc. Natl. Acad. Sci.* U.S.A. 117, 2354-2365.

115 Lenton, T., Sharpe, S. (2021. Upward-scaling tipping cascades to meet climate goals: plausible grounds for hope. *Climate Policy*, 21(4), 421-433.

Similarly, taking a wider lens, rather than lament that "the political will is not there" for carbon pricing or other decarbonisation policies, or that "the public don't like it", one might think of public attitudes and preferences as part of the system – or endogenous[116] – that might be changed by identifying SIPs in the form of shifts in narratives, beliefs and cultures. Opening up the political space – or the Overton Window[117] – can then facilitate the design of a wider range of fiscal or regulatory interventions, including but not limited to carbon pricing. Multiple other interventions – delivering changes to central bank policies, corporate legal duties, shifts in financial norms and disclosures, shareholder expectations, consumer behaviours, clean technology costs and skills training – all help to rewire and reconfigure our economies towards meeting the goals of the Paris Agreement, and identifying possible tipping points can help both design policy instruments and prioritise policy action.

For many conventional policy questions, it can be very sensible to identify the externality and for government to use a single, well-specified instrument to internalise it. However, to deeply and rapidly rewire our complex adaptive economic systems to meet the goals of the Paris Agreement, we need to go (and indeed have gone) well beyond carbon prices and R&D support.

In summary, with a detailed understanding of the important elements of the system or sector that we are trying to change, in some cases we may be able to identify possible tipping points in consumer preference, investor confidence, or social support for the transition, where a small input can lead to a large change in the desired direction. We can use that knowledge to help design the specific levels of taxes, regulations and/or incentives to cost-effectively accelerate the transition in each of the different greenhouse gas-emitting sectors.

116 Hepburn, C., Mattauch, L., Spuler, F., Stern, N. (2022). The economics of climate change with endogenous preferences. *Resource and Energy Economics*, 101312.

117 The Lancet. (2021). Moving the Overton Window. *Lancet Planetary Health* 5 (11), E751. https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(21)00293-X/fulltext

CASE STUDY 4:
Triggering the electricity transition with Electricity Market Reform and a carbon price floor

The UK, once described as an 'island of coal in a sea of oil and gas', has undergone a remarkable transformation in its power sector, phasing out coal and more than halving CO_2 emissions – most of this achieved in just a few short years (Figure 6). The seeds of this lay in policies which had opened the electricity sector to competition in the 1990s, while also ratcheting up pollution controls on coal, directly supporting development of renewable energy (along with other countries) through subsidies, and programmes to enhance energy efficiency, through the following decade. Nevertheless, as of 2010, progress in phasing out coal and cutting CO_2 emissions remained limited. The dramatic changes that followed can be traced directly to policy that triggered a deeper transformation.

The two main policies involved were transformation of the approach to renewables, and a floor price on CO_2 emissions.

The context for the UK renewable energy revolution was laid by recognition of the need for technology differentiation beyond flat rate subsidies (Principle 1): in the 2000s in the UK these included FiTs for small-scale generation, and a move to accelerate offshore wind technology in particular through coordinated industrial support and 'banding' the renewables obligation subsidy to enhance investment (Principle 2). Together with the responsiveness of established fossil-fuel generation to price signals, this established the technological capacity, as well as political conditions, to trigger a 'tipping point' through Electricity Market Reform (combined with other developments to expand small-scale renewables, notably PV).

Specifically, the phase of learning in offshore wind energy meant that the major deterrent was no longer technological uncertainty, but the scale of investment required in the context of high uncertainty around revenues and the scale of the market. The solution to this was better management of market risks (Principle 3) – in the UK case, through introduction of Contracts-for-Difference, offering effectively a fixed price for generated electricity, with a mechanism for (and initial commitment to) extensive deployment. This led to the combination of major cost reductions along with rapid expansion of renewables output, visible in Figure 6.

The tipping point was reached with the second mechanism, a strategically effective carbon price. This was initially designed as a floor price, to reflect the government's estimation of the (rising) social cost of carbon emissions, though as the differential from the EU Emissions Trading Scheme (ETS) price grew, this was turned into a legislated 'carbon price support' - a fixed carbon tax on electricity generated (on top of the EU ETS), which rose from £9/tCO_2 (April 2013) to £18/tCO_2 (April 2015). For investors in renewables energy, this gave assurance of the value of renewables beyond the contract length of the CfDs, thus further reducing the cost of capital – all factors contributing to high-volume and low-cost private-sector financing.[118]

But the impact of the carbon price support was even more dramatic in pushing out coal. Beginning in late 2015, the combined effect of this carbon tax and the EU ETS carbon price made power from gas cheaper than power from coal. This small change in relative pricing had a large effect: it switched the places of coal and gas in the merit order, meaning that gas would be called on to generate first, and coal plants would generate for far fewer hours. The economics of coal power then flipped from being just profitable, to loss-making. Finally, the combination of rising renewables input and declining electricity demand meant that the fleet of coal plants were no longer needed to 'keep the lights on'. In the context of the prevailing trends in the UK power sector at that time – the growth of renewables, the tighter restrictions on pollution from coal and the clear policy commitment to decarbonisation – this created a strong incentive to close down coal plants, which was the major, irreversible tipping point towards a much lower-carbon trajectory.[119]

118 Bolton, R., Foxon, T. J., Hall S. (2017). Investing in low-carbon transitions: energy finance as an adaptive market. *Climate Policy*. 17(3), 280-298.

119 Lenton, T., Sharpe, S. (2021). Upward-scaling tipping cascades to meet climate goals: plausible grounds for hope. *Climate Policy*, 21(4), 421-433.

One point to note about this example is that the carbon price that ultimately activated the tipping point was not very high – many estimates of the social cost of carbon are higher. It was the relative value that mattered, not the absolute value. A second important point is that, as noted previously, the carbon price was only able to play this role because other policies had first brought the system to a state of criticality: enhanced efficiency combined with the growth of renewables left coal and gas power to compete over a diminishing share.

As a result of these policies, the share of coal in the UK's electricity generation dropped from around 40% in 2012 to less than 1% in 2020 (see Figure 6). This made a significant contribution to the UK achieving the fastest power sector decarbonisation in the world over the period 2010 to 2019, with an annual rate of reduction in carbon intensity around eight times the global average.[120]

Estimates suggest that, as a consequence of using 'cleaner but more expensive energy' and in the absence of 'compensating adjustments through increased imports', the carbon price floor raised the day-ahead price in Great Britain between 2015-2018 by around €10/MWh.[121] However, while it is always important to consider the distributional aspects of policies (see Principle 7), it is notable that the effect on UK consumer energy bills of the carbon price and renewable power subsidies was more than offset by energy-efficiency improvements over the period 2008 to 2016, meaning that the climate change policies overall were assessed to save consumers money.[122] More recently, of course, the substantial investment in renewables in the 2010s have also begun to pay off handsomely, with continued decline in renewables costs now far below the sharply increased cost of fossil fuels in the energy crisis.

UK Electricity Generation

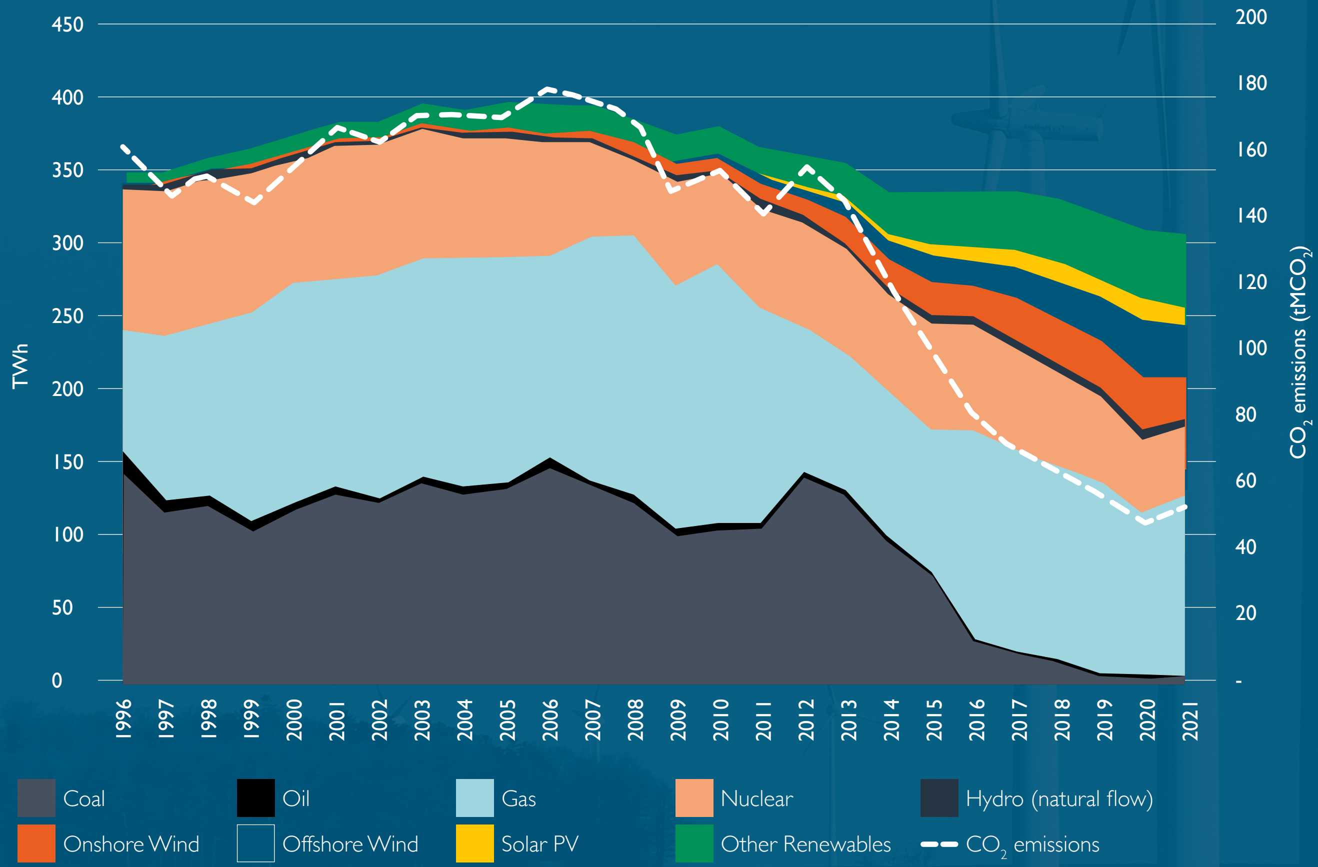


Figure 6. Composition of generation in the UK power sector between 1996 and 2021. Data from:[123] April 2013 marked the introduction of the carbon price floor.

120 The carbon intensity of the UK power sector decreased by 8.9% per year between 2010 and 2019 (Drax, 2020., Electric insights quarterly, July-Sep 2020, Available at: www.drax.com/wp-content/uploads/2020/11/201126_Drax_20Q3_005.pdf), while the global average power sector carbon intensity fell by 1.1% per year over the same period (International Energy Agency: Tracking Power 2021, Available at: www.iea.org/reports/tracking-power-2021).

121 Castagneto Gissey, G., Dodds, P., Ekins, P., Grubb, M., Guo, B., Lipman, G., Montoya, L. Newbery, D. (2019). The value of international electricity trading. Commissioned by Ofgem. Available at: www.ofgem.gov.uk/sites/default/files/docs/2019/10/value_of_international_electricity_trading.pdf; Accessed on July 5, 2022.

122 Committee on Climate Change (2017). Energy Prices and Bills – Impacts of Meeting Carbon Budgets. Available at: www.theccc.org.uk/wp-content/uploads/2017/03/Energy-Prices-and-Bills-Committee-on-Climate-Change-March-2017.pdf

123 Data from Digest of United Kingdom Energy Statistics (DUKES), UK Department for Business, Energy & Industrial Strategy. Available at: www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes. Accessed on 28 July, 2022.

PRINCIPLE 5:

Combine policies for better outcomes

Traditional principle: Consider policies individually based upon distinct 'market failures'

Summary: A combination of policies will be needed to drive each low-carbon transition. Since the effect of each policy depends on its interactions with others, assessing policies individually can be misleading. Assessing policies as a package can identify those that are mutually reinforcing, generating outcomes 'greater than the sum of the parts'.

Rationale for the traditional principle

The classical economic policy prescription is that each policy measure – 'intervention' relative to a market – should be identified in relation to a specific policy goal or market failure, and hence in principle, is separable from others.[124] The theoretical justification for this is that in a largely static context of 'optimal resource allocation', traditionally with reference to price-based market equilibrium, the focus is upon individual market failures which justify corresponding 'correction'. Hence, for example, an economics literature on 'twin market failures' of innovation 'spillovers' and the climate externality, justifying public R&D and carbon/GHG pricing.

In practice, most policymakers are well aware that complex problems such as low-carbon transitions need to be addressed with the application of more than one policy. Nevertheless, policies are often considered individually when their costs and benefits are assessed, and there can be a tendency to rank individual policies in terms of their expected net present value, or projected tons per dollar of emissions saved, when deciding how to use a limited budget. Such practices implicitly assume that the effects of individual policies can meaningfully be separated from each other.

Limitations of the traditional principle

A key limitation is that there can be many overlapping 'market failures', distortions and interacting policy goals. Most economies have a complex web of interacting policies around market structures, regulation and tax policies.

The classic theory of 'second best' demonstrated that, in the presence of multiple distortions (compared to a theoretical optimum), there is no guarantee that a policy to address one market failure will necessarily lead to an economic improvement. Classical economics itself thus challenges the theoretical underpinnings for the traditional policy presumption, and suggests a need to pragmatically consider policy interactions.[125]

In the area of climate change, most countries are at least as interested in economic development and increased opportunity as in decarbonisation, if not more so. Interests can include the development of urban or transport infrastructure, air quality and public health, job creation and industrial competitiveness, energy security and food security, and the affordability of essential goods and services. This makes consideration of how decarbonisation policies interact with wider policies and priorities essential, and unavoidable.[126]

Also, the 'system transitions' required by decarbonisation are complex, involving necessary changes in technology, market structures, infrastructure, etc. It is not generally feasible for a single policy to achieve all of these things, and when multiple policies are in place, interactions between them are inevitable. The failure to sufficiently consider policy interactions in practice can be damaging, as illustrated by the experience of setting emissions caps for the EU ETS, which did not account for the impact of energy efficiency or renewable energy policies to the necessary extent, contributing to carbon price collapses.[127]

124 Tinbergen, J. (1952). On the theory of economic policy. North-Holland.

125 Lancaster, K., Lipsey, R. G. (1956). The General Theory of Second Best. *The Review of Economic Studies*, vol. 24, no. 1., 11–32. *JSTOR*, doi.org/10.2307/2296233.; Lipsey, R. G. (2007). Reflections on the general theory of second best at its golden jubilee. *Int Tax Public Finance* 14, 349-364. doi.org/10.1007/s10797-007-9036-x

126 See for example analysis in the IPCC Mitigation Report (2022). Particularly relating to 'shifting development pathways towards sustainability' (Chapter 4) and the role of governance and enabling conditions (Chapter 13) as well as the literature on innovation systems (Chapter 16).

127 Jevnaker, T., Wettestad, J. (2016). *Rescuing EU Emissions Trading: The Climate Policy Flagship*. Palgrave Macmillan.

The case for Principle 5

When the focus shifts to a dynamic perspective and longer-term goals, and particularly the major transitions implied by meeting the goals of the Paris Agreement, the need to assess packages of policies becomes inescapable. A growing literature provides multiple lines of both theory and empirics to the fact that transitions – in particular, giving direction to processes of transition, such as decarbonisation – necessarily involve a mix of different policy instruments.[128] One useful high-level categorisation identifies three complementary 'pillars of policy'[129,130]:

- **Strategic investment** across a broad spectrum of interrelated technologies and infrastructure, designed to shape evolution of technologies, economic structures and regulatory regimes in low-carbon directions.
- **Markets and pricing** to ensure that the structure of markets and taxation does not, at a minimum, impede emergent low-carbon technologies, including removal of fossil fuel subsidies and the use of carbon pricing to align as far as possible private-sector decision-making with established public decarbonisation goals (or equivalent estimation of the social cost of GHG emissions).
- **Standards and engagement** to help overcome numerous barriers to consumer adoption of new and better technologies. Such 'barriers' are both structural (e.g. tenant/landlord divide and other 'contractual failures'), and social/behavioural norms. The aim is to accelerate diffusion and foster confidence and new norms around cleaner technologies and practices emerging from the other two pillars.

The need for policy mixes is already well-established in innovation studies, and research now highlights the need to integrate this with similar growing trend in distinct literatures on policy studies.[131]

The role of complementary policy packages has been documented across multiple sectors, including energy,[132] industry,[133] transport[134] and agri-food.[135] Orienting transitions also requires clear direction, with shared visions, and coordination of actors across different policy fields (such as climate and industrial policy), as well as governance levels.[136,137]

These literatures point to multiple reasons why policy mixes are required to foster dynamic transitions in particular directions. One way of explaining and categorising the different instruments for low-carbon transitions is the 'Three Domains' or 'Policy Pillars', which emphasises the complementarity across policies shaping trade-offs using markets and relative prices; policies which address behaviours and choices;[138,139,140] and policies to shape the evolution of the technology frontier in low-carbon directions[141]. These 'three pillars' (see Figure 7) rest on such a broadened economic framework to bring insights from behavioural and evolutionary economics along with classical 'equilibrium/resource allocation'.

In detail, there can be multiple instruments within each category – that is, different mechanisms and applications of strategic investment, from R&D to technology-specific demand-pull, as well as policies to enhance consumer engagement and accelerate adoption. When used together, policies in these categories can be mutually reinforcing.

128 Reichardt, K., Rogge, K. S. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy*. Elsevier B.V., 45(8), 1620-1635. doi: 10.1016/j.respol.2016.04.004.

129 Grubb, M., Hourcade, J-C., Neuhoff, K. (2014). Planetary economics : energy, climate change and the three domains of sustainable development. Routledge. Available at: books.google.co.uk/books/about/Planetary_Economics.html?id=b2nOygAACAAJ&redir_esc=y (Accessed: 31 August 2019).

130 Grubb, M., Hourcade, J-C., Neuhoff, K. (2015). The Three Domains structure of energy-climate transitions. *Technological Forecasting and Social Change*, 98. doi: 10.1016/j.techfore.2015.05.009

131 Howlett, M., Kern, F., Rogge, K. S. (2019). Policy mixes for sustainability transitions: New approaches and insights through bridging innovation and policy studies. *Research Policy*. Elsevier B.V., 48(10), p. 103832. doi: 10.1016/j.respol.2019.103832.

132 Howlett, M., Kern, F., Rogge, K. S. (2017). Conceptual and empirical advances in analysing policy mixes for energy transitions. *Energy Research & Social Science,* 33, 1-10. doi: 10.1016/j.erss.2017.09.025.

133 Scordato, L., et al. (2018). Policy mixes for the sustainability transition of the pulp and paper industry in Sweden. *Journal of Cleaner Production*, 183, 1216-1227. doi: 10.1016/j.jclepro.2018.02.212.

134 Givoni, M., et al. (2013). From Policy Measures to Policy Packages. *Transport Reviews*. 33(1), 1-20. doi: 10.1080/01441647.2012.744779.

135 Kalfagianni, A., Kuik, O. (2017). Seeking optimality in climate change agri-food policies: stakeholder perspectives from Western Europe. *Climate Policy* 17, S72–S92. doi: 10.1080/14693062.2016.1244508.

136 Harding, A., Shapira, P., Uyarra, E., (2016). Low carbon innovation and enterprise growth in the UK: Challenges of a place-blind policy mix. *Technological Forecasting and Social Change*, 103, 264–272. doi: 10.1016/j.techfore.2015.10.008

137 Nemet, G. F., et al. (2017). Addressing policy credibility problems for low-carbon investment. *Global Environmental Change,* 42, 47-57. doi: 10.1016/j.gloenvcha.2016.12.004.

138 Kahneman, D., Knetsch, J. L., Thaler, R. H. (1991). Anomalies: The Endowment Effect, Loss Aversion, and Status Quo Bias. *Journal of Economic Perspectives*, 5(1), 193-206. doi: 10.1257/JEP.5.1.193.

139 Kahneman, D., Tversky, A. (2017). Rational choice and the framing of decisions. Decision Science. doi: 10.1086/296365.

140 Anadon, L. D., Surana, K. (2015). Public Policy and Financial Resource Mobilization in Developing Countries: a Comparison of Approaches and Outcomes in China and India. *Global Environmental Change*. 34:340-359. doi:10.1016/j.gloenvcha.2015.10.001.

141 Nemet, G. F. (2009). Demand-pull, technology-push, and government-led incentives for non-incremental technical change. *Research Policy*, 38(5), 700-709. doi: doi.org/10.1016/j.respol.2009.01.004.

For example, carbon pricing can shift incentives away from carbon-intensive investments and enhance the case to pursue transitions to cleaner alternatives. Combined with strategic investment and market-creation policies, this can increase the overall 'demand-pull' for clean technology innovation while R&D also amplifies the 'supply-push'. The resulting innovation is faster than it would be with either policy alone. Similarly, regulatory standards can increase the supply of clean technologies to the market, at the same time as 'nudge' or other behaviour-oriented policies increase demand; together, they accelerate diffusion more than either policy would alone, enhancing the prospect and pace of reaching a tipping point (Principle 4). Additionally, investments in enabling infrastructure can remove obstacles to both supply and demand.

Figure 7 summarises some high-level supportive interactions between these three broad 'pillars of policy'.

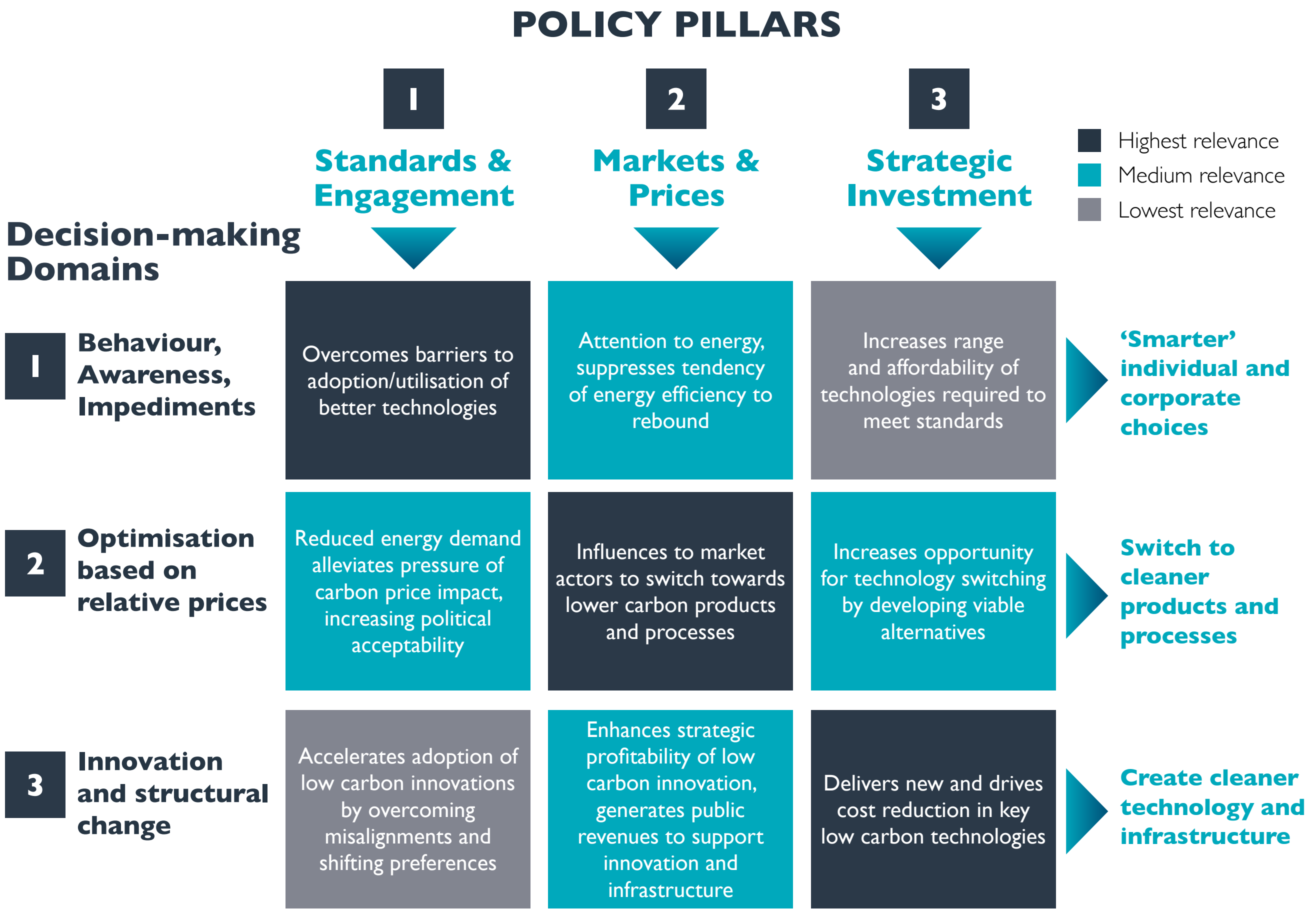


Figure 7. Complementary types of policies can work synergistically to advance change and innovation in different sectors. This schematic highlights the need to make progress through different types of policies, particularly given the timescales of innovation and urgency of climate change. A policy package should combine the strengths of policy instruments that are effective in each domain of decision-making. The diagonal elements show the direct impact of policies in influencing individual and corporate choices, incentivising consumers and companies to switch to cleaner products and processes; and fostering the development of new technologies and complementary infrastructure. Other elements in the matrix indicate important indirect ways in which policies targeted primarily at one decision-making domain may support others. Source[142]

142 Drummond, P., Grubb, M., Poncia, A. (2022). 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, Stockholm.

In this context, it makes little sense to attempt to consider the effect of each policy individually. The effect of a policy is determined by the package of policies of which it is a part. Moreover, policy packages can better tap into different sources of finance, again supporting the growth of low-carbon industries. This growth drives knowledge and confidence, reducing the perceived risks and, in turn, the cost of finance.[143,144] Calculating the 'net present value' of each policy individually as a means of prioritisation may miss the point and can be misleading. Instead, the effectiveness of *policy packages* (sometimes referred to as policy mixes[145]) should be considered and compared, with interactions between policies explicitly assessed.

The relative importance and balance of these different types of policy instruments vary according to type of technology, as well as the national and sectoral context.

The relative importance of different types of instrument may also vary with the phase of the transition process, as outlined further in our first report, '*The New Economics of Innovation and Systems Transition*'. The underlying point remains that, not only are all instrument types may be required to effectively drive a major transition, but also that they can be mutually reinforcing.

Finally, packages of specific policy instruments that can be classified and interrelated in this way need to combine climate, economic and development goals, and should be set in the context of broader 'enabling conditions', which the IPCC 2022[146] identifies as including governance and institutions, as well as financial capacity (e.g., sufficient capital markets or international financial support) – along with the availability of, and capacity to utilise, emergent technologies required for low-carbon transitions.[147]

143 Bolton, R., Foxon, T. J., Hall S. (2017). Investing in low-carbon transitions: energy finance as an adaptive market. Climate Policy. 17(3), 280–98. doi: 10.1080/14693062.2015.1094731.

144 Geels, F.W., Schot, J. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. 20(5), 537-554. doi: 10.1080/09537320802292651.

145 Reichardt, K., Rogge, K. S. (2016). Policy mixes for sustainability transitions: An extended concept and framework for analysis. *Research Policy,* 45(8), 1620-1635.

146 IPCC. (2022). Intergovernmental Panel on Climate Change 6th Assessment Report, Working Group III on Mitigating Climate Change. Chapter 4.

147 IPCC. (2022). Intergovernmental Panel on Climate Change 6th Assessment Report, Working Group III on Mitigating Climate Change. Chapters 4 and 13.

CASE STUDY 5:

Policies supporting China's electric vehicle development

In 2006, China named new energy vehicles (NEVs, including electric vehicles and highly efficient hybrid petrol vehicles) as one of the priorities in its National Long-term Plan on Science and Technology Development[148] for the country's vehicle manufacturing industry, with a view to China's dependence on imported petroleum and problems of urban air pollution. The report noted gaps in technological capability on internal combustion engine vehicles (ICEVs) between China and developed countries, and electric vehicles (EV) were seen as an opportunity for the country to lead in a new industry.

To achieve this goal, the government implemented a strong package of mutually reinforcing policies, starting with the 2006 plan, which included strategic investment, efforts on markets and prices and actions on standards and engagement seeking to change behaviour. In 2009, the '10 City' and '1000 EVs' programmes represented the beginning of the promotion of EVs in the public transport system through strategic investment.

The next phase of policies aimed to scale-up demand. In 2010, the government issued the first subsidy policy for private EVs. This effort was followed in 2011 by some provinces, which issued their own subsidies. As EV sales expanded it became important to also scale up complementary infrastructure, so in 2012 the EV purchase subsidy was expanded to include support for charging stations. In 2013, with additional subsidy from sub-national jurisdictions, the highest purchasing subsidy reached CNY120,000 (around US$18,500) per car.[149] As electric vehicle costs decreased, the subsidy was reduced at a national level. In 2015, the Chinese government announced plans to cut subsidies by 20% in 2017-2018, and by 40% in 2019, compared to the 2016 level. In 2020, the government announced further plans to cut subsidies by 10%, 20% and 30% year-over-year in 2020 to 2022.[150] By 2021, 15.5% of new light-duty vehicles sold were NEVs, and full phase-out was announced, on a schedule under negotiation.

Together with these economic incentives to increase demand for EVs, several major cities including Beijing and Shanghai fast-tracked registration numbers for new EVs (overall numbers being limited). These policies, which introduced a License Plate Lottery policy that favours EVs over ICEVs,[151] sent a strong behavioural signal on preference for EVs and risks around fossil-fuelled cars (the standards and engagement pillar). Other cities provide free licence plates to new consumers of EVs and Fuel Cell vehicles.

Another set of policies simultaneously acted to increase the supply of electric vehicles. In 2011, the government established the Corporate Average Fuel Consumption (CAFC) scheme, which sets fleet average fuel consumption targets.[152] Linked to this, in April 2018 the government created a dual-credit policy, which assigns credits for the production of NEVs. Manufacturers can meet the targets through a combination of ensuring high energy efficiency in their conventional cars, and ensuring EVs are a high proportion of their sales. This policy has been increasingly important in boosting the NEV market, after subsidies for NEVs were reduced.[153] This dual-credit policy is expected to be crucial in meeting China's target of 20% NEV sales by 2025.[154]

At the same time as supporting both supply and demand for EVs, China has invested in the enabling infrastructure. Many cities throughout the country have offered capital and operational subsidies for EV charging infrastructure and China has the largest charging network in the world, with more than 1.1 million public charging points across the country in 2021,[155] compared to 141,200 in 2016 (see Figure 8). Private chargers, installed along with EV purchases, have risen from 62,000 in 2016 to 47 million in 2021.[156]

148 State Council (2006) National Long-term Plan on Science and Technology Development, State Council, Beijing

149 Beijing Government (2013) Beijing's New Energy Vehicle Supporting Policies and Subsidy, Beijing Municipal Government, Beijing

150 Ministry of Finance (2020). Notice on optimizing fiscal subsidies for promoting new energy vehicles. /jjs.mof.gov.cn/zhengcefagui/202004/t20200423_3502975.htm?from=timeline&isappinstalled=0

151 Bai, X., Zhang, X., Zhong, H. (2018). Electric vehicle adoption in license plate-controlled big cities: Evidence from Beijing. *Journal of Cleaner Production*, 202, 191-196.

152 IEA. (2021). *Fuel economy in China*. IEA, Paris. www.iea.org/articles/fuel-economy-in-china

153 Li, H., Li, Y., Liu, B., Tang, Y., Zhang, Q. (2019). The impact of dual-credit scheme on the development of the new energy vehicle industry. *Energy Procedia*, 158, 4311-4317.

154 He, H., Chen, Z. (2022). How will the dual-credit policy help China boost new energy vehicle growth? Available at: ccci.berkeley.edu/sites/default/files/China_Dual_Credit_Policy_Brief_Feb2022.pdf (2022/03/31)

155 IEA. (2022). Global EV Outlook 2022. IEA, Paris www.iea.org/reports/global-ev-outlook-2022

By 2015, China already had the most EV sales of any country in the world. The effect of this package of policies working across all three policymaking areas has been a fast growth of EV sales in China, from just 6,023 in 2010 to over 3 million in 2021 (see Figure 8). Growth continues to exceed expectations: forecasts of 2.2 million EV sales in 2020 were exceeded by more than 50%, aided also by the ongoing energy crisis and the fact that China does not subsidise gasoline. The most recent data indicates NEV sales of 2.6 million in the first half of 2022 – more than double the same period in 2021 – accounting for over 20% of total sales of new cars.[157] According to forecasts from the China Automotive Technology and Research Center (CATARC) NEV sales will achieve 40% of the total new car sales by 2030 and more than 50% by 2035. Given the data from 2021/2022, these targets may even be reached sooner.

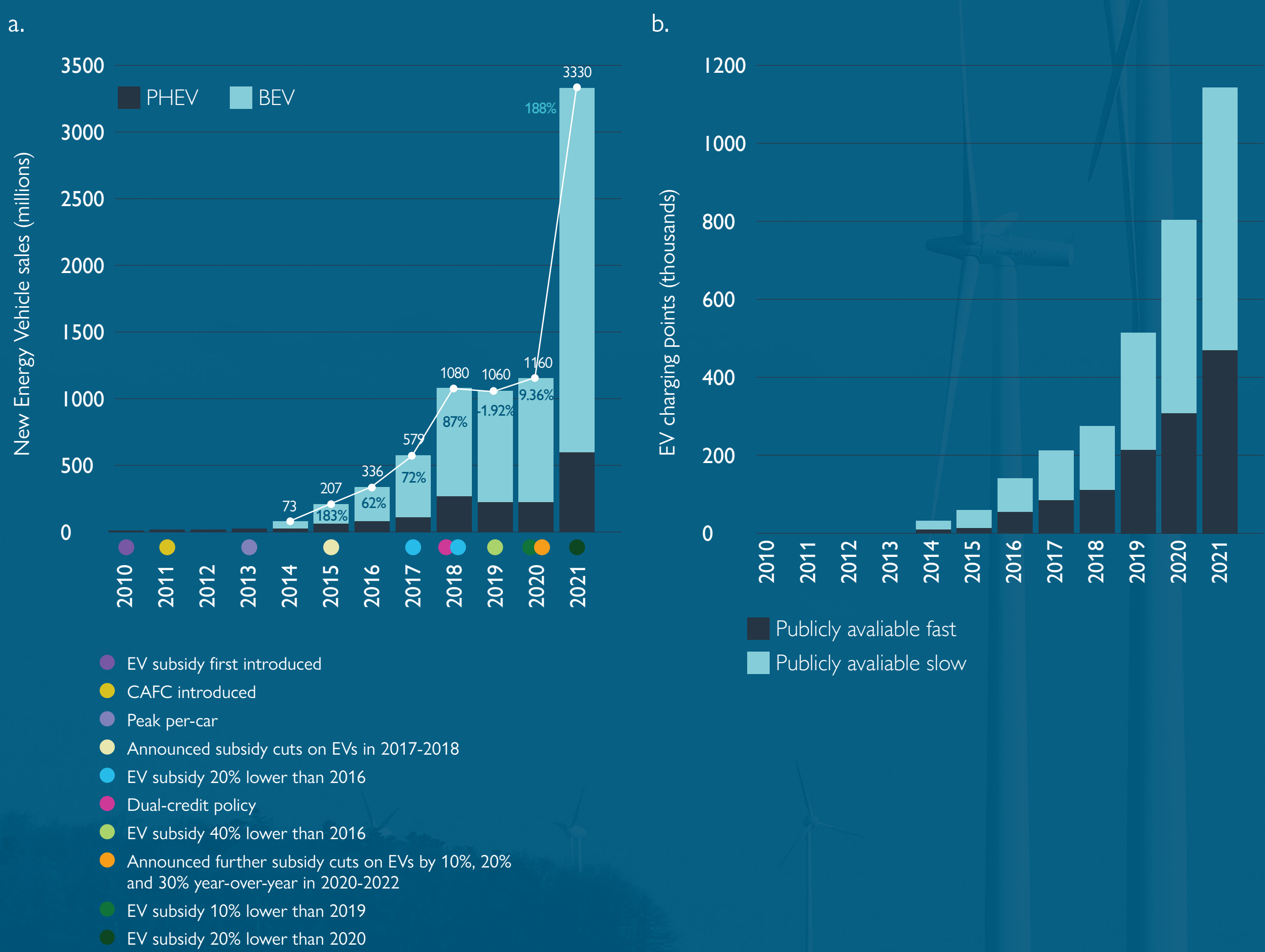


Figure 8. a) EV sales, and b) public charging points (bottom panel) in China between 2010 and 2021. Fast and slow refers to the charging speed of the charging points. Data source: Global EV Data Explorer[158]

156 All data except that from IEA is from China Electrical Vehicle Charging Infrastructure Alliance (EVCIPA, www.evcipa.org.cn)

157 Ministry of Industry and Information Technology of the People's Republic of China. (2022). Economic operation of the automobile industry in June 2022. Available at: www.miit.gov.cn/gxsj/tjfx/zbgy/qc/art/2022/art_236f9381746c4f56a9c2bdd0e8748b31.html. Accessed on July 2022.

158 IEA. (2022). Global EV Data Explorer. IEA, Paris. www.iea.org/articles/global-ev-data-explorer

PART 2

PRINCIPLES FOR POLICY APPRAISAL

Cost-benefit analysis is often equated with identifying policies that maximise economic efficiency in terms of aggregate money or GDP. This in itself is a gross simplification of the underlying formal theory of cost-benefit analysis*. This section charts ways to enhance policy appraisal through attention in particular to four fundamental challenges: deep uncertainty; distribution within countries; cooperation and complementarity between countries; and dynamics over time, including through integrating evaluation frameworks that address risks and opportunities.

* see '*The New Economics of Innovation and Transition: Evaluating Opportunities and Risks*', EEIST Report to COP26, www.eeist.co.uk/reports, Box 1.

PRINCIPLE 6:

Policy should be adaptive

Traditional principle: Policy should be optimal

Summary: There are many paths along which economies can develop over time. It is often impossible in practice to identify which is 'best' in terms of public goals, or even 'least cost' economically, which implies there may be no single 'optimal' policy. Given also the potential to learn from experience, policy should be designed to be adaptive, so that it can more easily respond to unforeseen changes, exploit opportunities and manage risks.

Rationale for the traditional principle

Economic policy analysts are commonly concerned with maximising economic efficiency, seeking 'optimal' policy to deliver a desired outcome at lowest cost. This is grounded in welfare economic theory, which suggests it is possible to identify and engineer a situation in which nobody can be made better off without someone else being made worse off. This is then considered an 'optimal' allocation of economic resources. Following this logic, in situations where market failures lead to a sub-optimal allocation of resources, policy can (and should) seek to establish a state of optimal allocation.

Limitations of the traditional principle

The simple theory, aside from making very strong assumptions about distribution (see Principle 7), is a static one: it concerns the allocation of existing resources, at a given point in time. The challenge of a low-carbon transition is different: it concerns innovation – the creation of new economic resources and techniques – and structural change (the transformation of the economy) over time. In this context, it is hard (if not impossible) to identify the 'optimal' choice *ex ante* – there is an effectively unlimited range of different pathways that economic development could take, many of which may be considered better or worse in relation to multiple possible policy interests.

Considering this, identifying an 'optimal' pathway for an economy, including its optimal response to climate change, is theoretically impossible (due to the sheer number of possibilities) – and in practice, the multiplicity of interactions and uncertainties surrounding the energy transition makes choosing a pathway and policy design that is 'better' and not 'worse' in relation to multiple policy aims, extremely difficult.

In this context, searching for policy 'optimality' is likely to be a distraction from a more realistic and thorough consideration of effectiveness and robustness, including opportunities and risks, on the basis of available knowledge and existing uncertainties.

The case for Principle 6

Policies aimed at making the transition to decarbonised economies must inevitably be implemented in a context of high uncertainty. Over the next three decades changes of all kinds are likely to be pervasive. It is inevitable that some things will not turn out as we expect. In the context of structural transformation policy, if a policy cannot expect to be optimal, it can at least aim to be adaptive – preserving the ability to change, taking advantage of opportunities that arise from changes in its environment, and reducing the risks and costs of being overly committed to a particular path too early on. This suggests that rather than seek optimality, policy choice should value the generation of flexibility and options (opportunities) while minimising risks (Principle 9).

Principles 1-5 outline the foundations of policy design to stimulate deep transitions. The intrinsic uncertainties of such dynamic processes – which contrast sharply with the idea of knowable and stable equilibria and the reference points for marginal changes – require adaptability. To remain effective and durable, policy – including both individual instruments and wider policy mixes (see Principle 5)[159] – must be able to adapt to relevant macroeconomic, demographic, social and geopolitical trends and developments, along with changing dynamics in technology, infrastructures, markets, preferences and politics. This includes being adaptive to dynamics shaped by policy itself. If not, policy may become ineffective and weak, or become brittle and break, forcing abrupt changes with damaging and costly consequences. To borrow the business terminology, given the impossibility of an enduring *optimal*, the aim should be *continuous improvement*.

159 A 'policy mix' incorporates both individual instruments and policy strategy, and the objectives, goals and design features of each, alongside the processes of policymaking and implementation and the overarching characteristics of the mix as a whole (including consistency, coherence, credibility and comprehensiveness).

Some effects and feedbacks, and their ability to generate virtuous or vicious cycles along decarbonisation processes, can be reasonably well forecast. For example, the characteristics of different technologies may help indicate the broad extent to which cost reductions may be expected, and how fast (see Principle 1, and our previous report, *The New Economics of Innovation and Transition*, section 3.5). The effect of any subsidy support over time can then be approximated, although with wide uncertainty ranges, including the time window when one may expect a new technology to become competitive with the incumbent. However, other outcomes may not be possible to forecast with confidence. The ways in which inherently uncertain R&D, learning-by-doing and economies of scale processes interact with the wider dynamics in the system, including the effects of ever-changing macroeconomic and geopolitical conditions (and their effects on, for example, international energy and other commodity prices), are the source of considerable uncertainty. Experience tells us that surprises happen – and happen often.

The concept of adaptive policy has been used since the 1920s, when American philosopher and educator John Dewey argued that policies should be treated as experiments that need to be adapted over time as new information derived from experience becomes available and as the context changes[160]. Adaptive policymaking represents a learning approach[161,162,163] in which initial plans are monitored and reassessed as additional information is acquired. In the context of the low-carbon transition the application of this principle is critical.[164,165,166,167,168,169,170] Figure 9 shows the different dimensions that should be considered when designing a policy with the aim of making it adaptive and the importance of engaging different types of stakeholders through the process of policy design and implementation.

160 Dewey, J., Rogers, M. L. (2012). The public and its problems: An essay in political inquiry. Penn State Press.

161 Busch, J., Foxon, T. J., Taylor, P. G. (2018). Designing industrial strategy for a low carbon transformation. Environmental Innovation and Societal Transitions, 29, 114-125.

162 Haasnoot, M., Kwakkel, J. H., Ter Maat, J., Walker, W. E. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global Environmental Change, 23(2), 485-498.

163 Cave, J., Rahman, S. A., Walker, W. E. (2001). Adaptive policies, policy analysis, and policy-making. European Journal of Operational Research, 128(2), 282-289.

164 Busch, J., Foxon, T. J., & Taylor, P. G. (2018). Designing industrial strategy for a low carbon transformation. Environmental Innovation and Societal Transitions, 29, 114-125.

165 Campos, I. S., Jeuken, A. B., Lorencová, E. K., Penha-Lopes, G., van der Brugge, R., Vizinho, A., Zandvoort, M. (2017). Adaptation pathways in planning for uncertain climate change: Applications in Portugal, the Czech Republic and the Netherlands. Environmental Science & Policy, 78, 18-26.

166 Flamos, A., Michas, S., Papadelis, S., Stavrakas, V. (2020). A transdisciplinary modeling framework for the participatory design of dynamic adaptive policy pathways. Energy Policy, 139, 111350.

167 Polzin, F. (2017). Mobilizing private finance for low-carbon innovation: A systematic review of barriers and solutions. Renewable and Sustainable Energy Reviews, 77, 525-535.

168 Geels, F. W., Schwanen, T., Sorrell, S., Sovacool, B. K. (2017). The socio-technical dynamics of low-carbon transitions. Joule, 1(3), 463-479.

169 Gambhir, A., Green, F. (2020). Transitional assistance policies for just, equitable and smooth low-carbon transitions: who, what and how?. Climate Policy, 20(8), 902-921.

170 Bizikova, L., Roy, D., Swanson, D., Tyler, S., Venema, H. D. (2018). Policy adaptability in practice: Lessons learned in the application of the Adaptive Design and Assessment Policy Tool (ADAPTool) to examine public policies in Canada in the context of climate change. Policy Design and Practice, 1(1), 47-62.

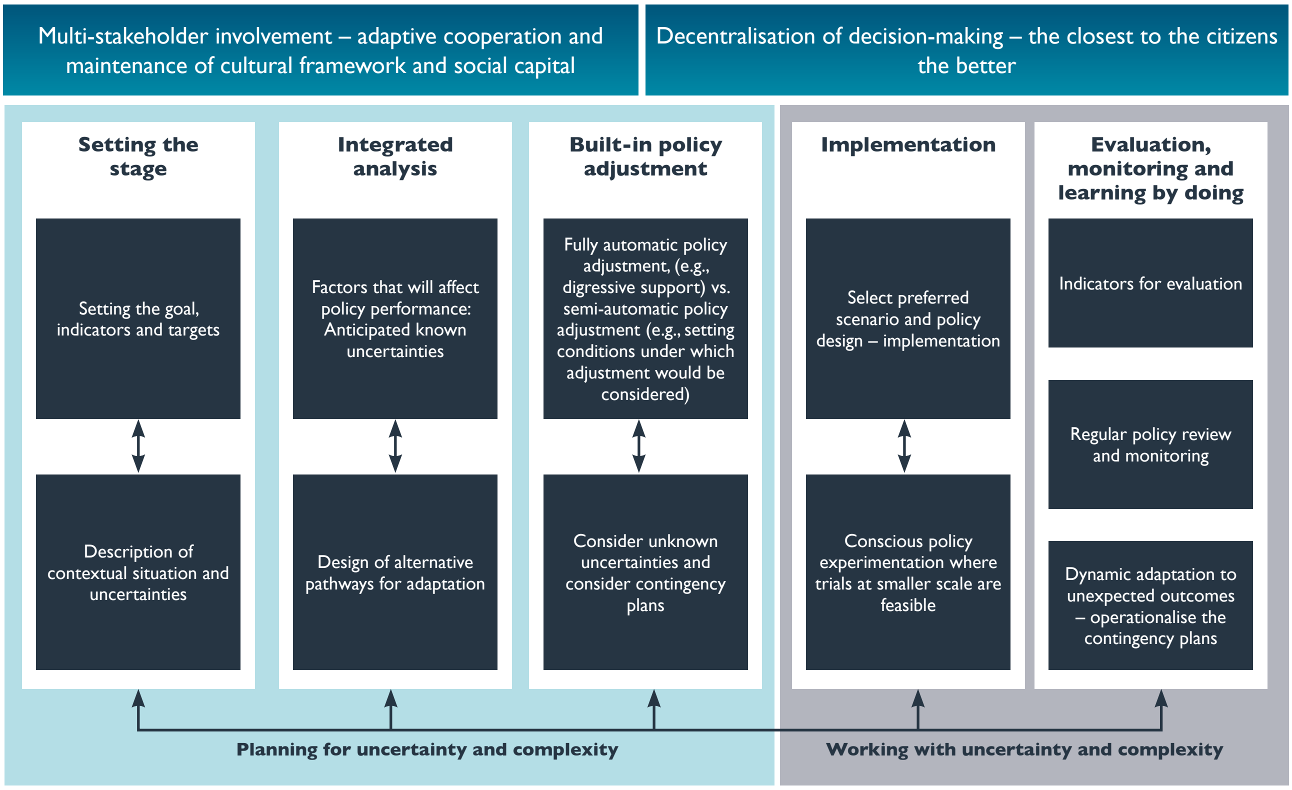


Figure 9. Schematic framework for the development and implementation of adaptive policies to function more effectively in complex, dynamic and uncertain conditions.[171] The top row indicates the importance of engaging in different types of stakeholders and experts during the policy design, implementation and evaluation process. Source: own elaboration based on[172,173,174]

To be adaptable, policies for the low-carbon transition need to be able to change when markets change and as more information becomes available.[175] This flexibility can be created at the policy programme level (for example, by putting in place clear dynamic targets for what the programme is aiming to achieve at different points in time and managing expectations about the changes that may be considered based on outcomes and other developments), or at the policy instrument level (for example by incorporating pre-defined review periods, or automatic adjustments in stringency or subsidy levels in response to evolution in technology characteristics). Such built-in flexibility mechanisms can allow for adjustment, replacement or cancellation of policy elements, retaining space for anything from minor policy design alterations to changes in strategic direction, if required, in an ordered and reasonably predictable way. Such alterations may be made automatically using pre-determined criteria, or through active choice by decision-makers.[176]

To be effective, flexibility mechanisms must be underpinned by robust systems for monitoring and reporting on key indicators, in turn supported by sufficient institutional apparatus and capacity (see the last column on Figure 9 on Evaluation and Monitoring). Monitoring and evaluation needs to be an intrinsic part of policy design from the start.[177] By providing clear and common information on the effects of the policy and context in which it is operating, the nature of policy feedbacks may themselves be influenced. To maintain trust, an independent agency may be most appropriately positioned to perform a monitoring role, and provide advice on policy adjustments. This approach is considered to have been generally successful with independent central banks in the realm of monetary policy, and similarly in the realm of climate policy with, for example, the UK's Climate Change Committee.

171 Bhadwal, S., Barg, S., Drexhage, J., Swanson, D., Tomar, S., Tyler, S., Venema, H. (2010). Seven tools for creating adaptive policies. *Technological Forecasting and Social Change*, 77(6), 924-939.

172 Bhadwal, S., Swanson, D. (Eds.). (2009). Creating adaptive policies: A guide for policymaking in an uncertain world. IDRC.

173 Haasnoot, M., Kwakkel, J. H., Ter Maat, J., Walker, W. E. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, 23(2), 485-498.

174 Cave, J., Rahman, S. A., Walker, W. E. (2001). Adaptive policies, policy analysis, and policy-making. *European Journal of Operational Research*, 128(2), 282-289.

175 Konidari, P., Mavrakis, D. (2007). A multi-criteria evaluation method for climate change mitigation policy instruments. *Energy Policy*, 35(12), 6235-6257.

176 Konidari, P., Mavrakis, D. (2007). A multi-criteria evaluation method for climate change mitigation policy instruments. *Energy Policy*, 35(12), 6235-6257.

177 Anadon, L.D., Bin-Nun, A., Chan, G., Goldstein, A. P., Narayanamurti, V. (2017). Six principles for energy innovation. *Nature* (2017) 552: 25-27. Doi:10.1038/d41586-017-07761-0.

CASE STUDY 6:

The expansion of solar PV in Brazil

Brazil is much sunnier than Europe, yet solar energy represented only 1.7% of the country's power supply in 2021[178]. This is much lower than in countries like Germany (9%), France (3%) and Spain (6%) which have heavily invested in the deployment of solar PV generation.[179] This disparity has been partly due to a somewhat late adoption of policy instruments in Brazil.

The country's first large photovoltaic plant was installed only in 2011, in Tauá, Ceará. However, since then, the number of photovoltaic systems installed in the Brazilian territory has been growing rapidly (Figures 10 and 11) thanks to policy changes that have been instrumental in driving solar deployment and cost reductions.

The expansion gained force after a change in the Brazilian regulation, in 2012, allowing small suppliers to access the country's power grid at zero or low costs.[180] While the initial regulation in 2012[181] was a policy change, the adjustments that followed in the next few years, including the introduction of a new regulation in 2015,[182] represented a planned adaptation of that policy. Importantly, in 2015, the regulation was adapted to extend compensation deadlines for distributed systems using net metering – i.e., the surplus of energy produced by the consumer is introduced into the network and they can use that surplus as a reward in the form of energy credits for up to 60 months – and also increase the limits of the installed capacity that was eligible, among other modifications.[183] These changes were possible due to flexibilities in the law that allowed experience from the ground regarding the demand from different users to be incorporated.

Centralised power generation gained force in 2014 when solar power plants were included in public auctions (with demand guarantees) at favourable prices for producers.[184] Auctions were established as a policy instrument in 2004 during a restructuring of the regulatory framework for electricity designed as a response to a power shortage experienced by the country between 2001 and 2002.[185] During this regulatory framework restructuring, the system was designed to hold both technology neutral energy tenders and reserves, and technology-specific auctions. This flexibility of design allowed policymakers to reallocate support between different technologies without having to pass new legislation or undertake new market reforms. Over time, they were able to respond to the rapid global progress in solar but relatively low deployment in Brazil by increasingly including solar (as well as wind) in the technology-specific 'reserve' auctions. Coinciding with the change in regulation mentioned above, solar-only auctions also started in 2015. Figures 10 and 11 show particularly fast deployment and cost reductions after 2015. The progress made in terms of cost reductions, the development of business models and growing consumer confidence resulted in additional developments in 2017, when a growing number of households and firms started investing in solar power to both reduce their electric bills and sell their surplus output to the public grid, giving a boost to solar PV energy in the country.

Beyond adapting timeframes and eligibility for compensation and creating technology-specific auctions, another feature of the adaptive policy design was that auction volumes in Brazil, except for reserve auctions, are tied to demand forecasts.[186] In other words, if forecast demand increases, so does the volume of clean power contracts to be auctioned. This enables policy to be constantly adjusted to more closely match the pace of market growth, instead of allowing disparities to develop that require larger corrections. Further opportunities to make the policy more adaptive have, however, been identified. For example, the lack of predictability in the auction calendar is a feature that is usually cited as a barrier for greater investment.[187]

Overall, Brazilian efforts in the adaptive design of solar PV policy created incentives for adoption of clean and sustainable technologies following a slow start. As shown in Figure 10, between 2017 and 2022 the country has experienced an exponential increase in the installed capacity of solar technologies and, for 2022, expects to add 3.7 GW of solar PV generation already under construction plus an additional 28.6 GW that has already been authorised.[191]

178 Ministerio de Minas e Energia. (2022). Boletin Mensal de Energia Novembro 2021. Available at: www.gov.br/mme/pt-br/assuntos/secretarias/spe/publicacoes/boletins-mensais-de-energia/2021/ingles/11-boletim-mensal-de-energia-novembro-2021/view

179 IEA. (2021). Electricity Information. www.iea.org/data-and-statistics/data-product/electricity-information. The percentage of solar PV energy over the country's electricity generation for Germany, France and Spain is from 2020.

180 Esposito, A., Fuchs, P. (2013). Desenvolvimento tecnológico e inserção da energia solar no Brasil. web.bndes.gov.br/bib/jspui/handle/1408/1421

181 Regulation ANEEL RN 482/2012, see: www.legisweb.com.br/legislacao/?id=342518

182 Regulation ANEEL's RN 687/2015, see: microinversor.com.br/resolucao-normativa-687-aneel/?v=19d3326f3137

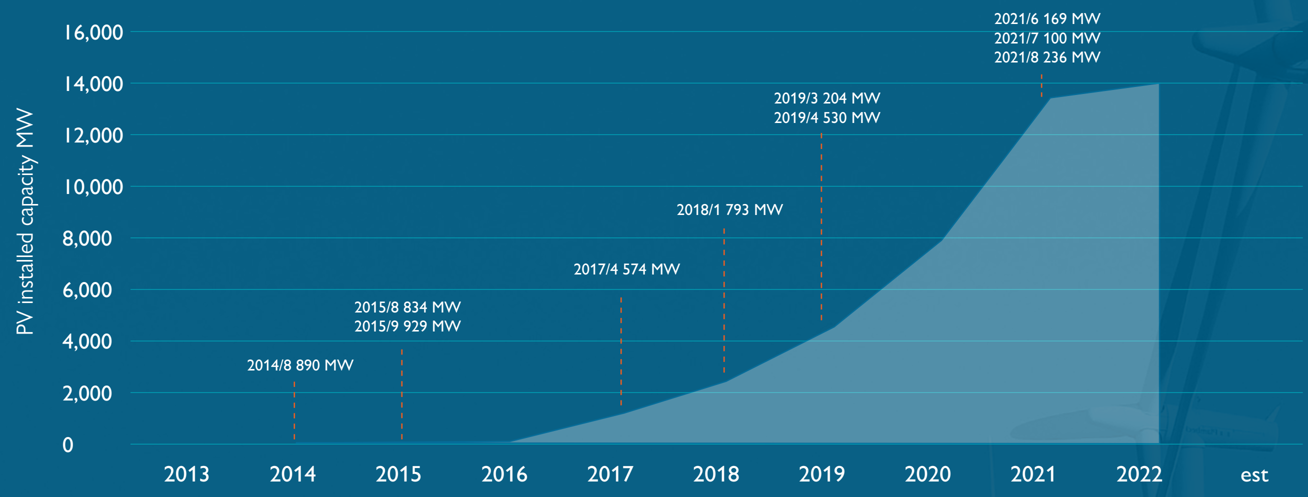


Figure 10. Installed capacity of solar PV in MW in Brazil (including both centralised capacity and distributed capacity).
Source: Own elaboration with data from Absolar.[188] Also showing the introduction of the Solar PV Generation Expansion Auctions (year/auction month number) and power capacity awarded per auction in MW (for example, 2014/8 890MW is a power auction in August (month 8) in 2014 with 890MW of solar).[189]

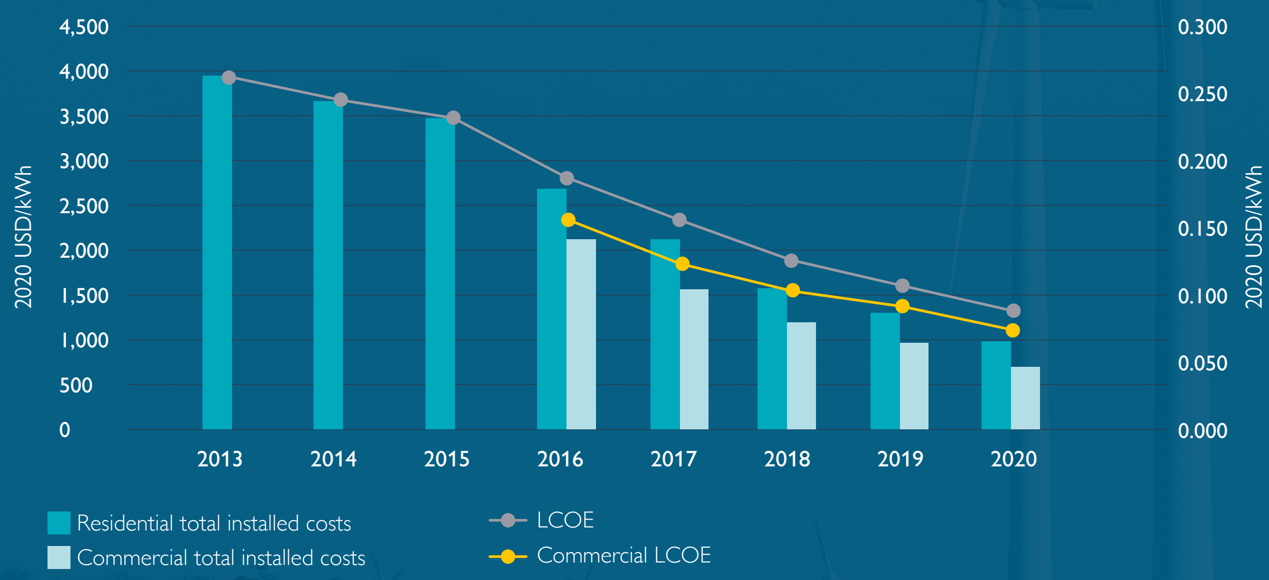


Figure 11. Total installed costs (left y-axis) and levelised costs of electricity (right y-axis) of solar PV in Brazil
Source: Own elaboration with data from IRENA 2021[190]

183 Barbosa, J. P., Saraiva, J. D., & Seixas, J. (2020). Solar energy policy to boost Brazilian power sector. International Journal of Climate Change Strategies and Management, 12(3), 349-367.

184 Pereira, N. (2019). Desafios e perspectivas da energia solar fotovoltaica no Brasil: geração distribuída vs geração centralizada. UNESP

185 Barbosa, J. P., Saraiva, J. D., & Seixas, J. (2020). Solar energy policy to boost Brazilian power sector. *International Journal of Climate Change Strategies and Management*, 12(3), 349-367.

186 Fraundorfer, M., Rabitz, F. (2020). The Brazilian renewable energy policy framework: Instrument design and coherence. *Climate Policy,* 20(5), 652-660.

187 Claro, J., Diógenes, J. R. F., Rodrigues, J. C. (2019) Barriers to Onshore Wind Farm Implementation in Brazil. *Energy Policy* 128: 253-266.

188 www.absolar.org.br/mercado/infografico

189 ANEEL. (2022). Resultados dos leilões de expansão da geração. Relatório interativo. Dados por Empreendimento. Accessible at: app.powerbi.com/view?r=eyJrIjoiYmMzN2Y0N-GMtYjEyNy00OTNlLWI1YzctZjI0ZTUwMDg5ODE3IiwidCI6IjQwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9. Last accessed July 2022.

190 IRENA. (2021). Renewable Power Generation Costs in 2020. International Renewable Energy Agency, Abu Dhabi.

191 www.statista.com/statistics/685667/brazil-power-generation-capacitiy-additions-by-source

PRINCIPLE 7:

Put distributional issues at the centre

Traditional principle: Act as long as total benefits outweigh the costs

Summary: Low-carbon transitions inevitably involve transfers of economic resources. Distributional issues should be central to policy analysis, since they are important for environmental, economic, and social goals, and are likely to have a strong bearing on social support for the transition.

Rationale for the traditional principle

Much economic analysis looks at aggregate efficiency outcomes. Cost-Benefit Analysis (CBA), is generally concerned with aggregate costs and benefits (and not how they are distributed), and governments using CBA are guided by the general principle of acting if the benefits of a policy exceed the costs, all measured in monetary terms,[192] although decisions usually take into account wider strategic considerations as well. In practice, CBA is rarely applied in accordance with the full theory of welfare maximisation (see[193], Box 2, "Fundamentals of Cost-Benefit Appraisal") – but instead benefits and costs are typically calculated as aggregate monetary values and decisions seek to maximise GDP (or minimise aggregate costs).

This is due to the practical difficulty of defining an appropriate social welfare function,[194] and justified by reference to the idea that 'increasing the size of the economic pie' can benefit all: if pressed, this rests on the idea that 'Pareto efficiency' (e.g., improving welfare of someone without reducing any others) could be achieved if the 'winners' from a policy use some of their gains to compensate the 'losers'. Alternatively, some analysts argue addressing inequality through redistributive policies would come at the expense of growth.[195] The assumption of 'compensation', to reconcile aggregate measures with the idea of Pareto improvements and distributional concerns, can more loosely be interpreted as the idea that policy towards markets (and decarbonisation) can reasonably focus on maximising GDP (or minimising aggregate costs), while governments should deal with distributional concerns using mechanisms including direct government expenditure (e.g., on public services) and through the structure of taxation.

Although limitations of CBA are widely recognised (e.g. concerning uncertainty, Principle 6, and Principle 9)[196], it has traditionally been seen by economic analysts as an objective tool that can provide safeguards against decisions based on political pressures, aspirations, feelings or power.[197] It can be useful for imposing a structure on decision-making, in place of what could otherwise be arbitrary, unstructured or overly politicised choices. The rigour of CBA is considered to be one of the strengths of the methodology for the appraisal of public projects and investments.[198]

Limitations of the traditional principle

As noted, the argument that economic analysis should focus on aggregate benefits implicitly assumes that benefits will be distributed fairly or equitably – something that cannot be assumed. Moreover, in our previous report, we argued that CBA can bias decisions towards the status quo. In addition, empirical evidence indicates that high levels of inequality can impede or constrain growth.[199] There are also questions in many jurisdictions regarding the extent to which policies are successful at dealing with distributional concerns.[200]

192 Sunstein, C.R. (2005) Cost-benefit analysis and the environment. *Ethics*, 115 (2), 351-385.

193 Anadon, L.D., Barbrook-Johnson, P., Clark, A., Drummond, P., Ferraz, J.C., Gao, J., Grubb, M., Hepburn, C., Ives, M., Jones, A., Kelkar, U., Kolesnikov, S., Lam, A., Mathur, R., Mercure, J-F., Pasqualino, R., Penasco, C., Pollitt, H., Ramos, L., Roventini, A., Salas, P., Sharpe, S., Waghray, K., Xiliang, Z., Zhu, S. (2021) The New Economics of Innovation and Transition: Evaluating Opportunities and Risks, EEIST Report to COP26, www.eeist.co.uk/reports; UK Department for Business, Energy & Industrial Strategy.

194 Adler, M. (2012). Well-being and fair distribution: beyond cost-benefit analysis. Oxford University Press.

195 Okun, A. (2015). Equality and Efficiency: The big trade-off. Brookings Institution Press. Washington D.C.

196 Adler, M. (2012). Well-being and fair distribution: beyond cost-benefit analysis (2012). Oxford University Press.

197 Sunstein, C. (2021). Some benefits and Costs of Cost-Benefit Analysis. Daedalus. Available at SSRN: ssrn.com/abstract=3825061

198 HM Treasury. (2022). The Green Book. London. UK Government.

199 Berg. A., Loungani, P., Ostry, J. D. (2019). Confronting Inequality: How Societies Can Choose Inclusive Growth. Columbia University Press, New York, USA. See also: Boushey, H. (2019). Unbound: How Inequality Constricts Our Economy and What We Can Do about It. Harvard University Press. Cambridge, MA, USA.

200 E.g., Piketty, T. (2017) Capital in the Twenty First Century. Harvard University Press, Cambridge MA, USA.

A particular concern in traditional policy appraisal is thus that the distributional consequences of a policy, including its perceived fairness, the allocation of resulting cost and benefits, and other welfare effects are not captured adequately.[201] Consideration of who 'gains' or 'loses' becomes less visible[202] in this process of aggregation. While these may be considered 'political' issues to be subsumed in general government distributional policy around regional funding and progressive (or regressive) taxation, the reality is that many specific energy-transition policies will have distributional consequences. This makes it logically essential for governments and policymakers to consider distributional issues explicitly.

A growing literature recognises that the tools used by governments to decide policy pathways for the low-carbon transition may not adequately signal or consider the distributional and welfare impacts of policy implementation in different groups. For example, some may neglect adverse impacts on poorer households[203] and, while some appraisal processes do include carefully chosen weights for different income groups, these may not always be capable of fully balancing both distributional and welfare impacts together.

Understanding if a specific policy instrument design, or a policy mix, is likely to generate – or aggravate – negative distributional impacts (even if aggregate benefits outweigh the costs) is likely to be essential for decarbonisation efforts going forward.[204] If policies are perceived as having unfair impacts (for example, leading to job losses in particular communities such as coal-based economies and regions), they may struggle to secure public support. This could slow down the transition, which current science suggests we cannot afford.[205] When negative distributional impacts are expected, addressing or reducing them is a crucial dimension of decarbonisation policy. Indeed, new approaches to CBA increasingly include some consideration of the incidence of costs and benefits.[206]

The case for Principle 7

The distributional impacts of decarbonisation policies need to be at the centre of any policy decision-making. A successful and just transition to net-zero carbon economies involves the distribution of costs and benefits in a fair way.[207]

Avoiding some negative distributional consequences is difficult because low-carbon transitions necessarily involve large-scale economic change. Unavoidably, there will be transfers of economic resources – across sectors, across technologies and producers within sectors, across geographical regions and across social groups.[208] We will be able to anticipate some of these changes, but not others. In Principle 1 we argued that, since no policy can be truly 'technology neutral', in some cases it is better to choose deliberately rather than accidentally. Here we argue that, since any set of low-carbon transition policies will have distributional consequences, it is better to be clear about what these are likely to be, so they can be appropriately considered and, if necessary, addressed. In addition, experience suggests that not sufficiently considering the distributional impacts of particular policies can inflame public opposition (see case study 7 on carbon fuel taxes and the '*Gilets Jaunes*' in France), leading to retreat and maybe jeopardising other decarbonisation polices in the future.

A growing number of studies have found instances of negative short or medium-term distributional impacts of various decarbonisation policies.[209] In many cases, these costs have been paid by energy consumers.[210,211,212] This has been particularly true for those policy instruments used to support the deployment of renewable energy – e.g., feed-in tariffs, Renewable Portfolio Standards (RPS), Tradable Green Certificates (TGC) and/or energy tenders.

201 Mouter, N., Shortall, R. (2021). Social and distributional impacts in transport project appraisals. Advances in Transport Policy and Planning, 8, 243-271.

202 Bos, F., Romijn, G., Van der Pol, T. (2017). Distributionally weighted cost-benefit analysis: From theory to practice. CPD Discussion Paper N 364.

203 Ruiz-Huerta, J. (2022). Libro Blanco sobre la reforma tributaria. Madrid, Government of Spain. www.ief.es/docs/investigacion/comiteexpertos/LibroBlancoReformaTributaria_2022.pdf

204 Combet, E., Edenhofer, O., Hepburn, C., Klenert, D., Mattauch, L., Rafaty, R., Stern, N. (2018). Making carbon pricing work for citizens. Nature Climate Change, 8(8), 669-677.

205 IPCC. (2022). Mitigation of Climate Change. Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf

206 Hammitt, J. K., Robinson, L. A. (2018). Assessing the Distribution of Impacts in Global Benefit Cost Analysis. Guidelines for Benefit Cost Analysis Project Working Paper No. 3. Also available at SSRN: ssrn.com/abstract=4014003. Available at: https://cdn2.sph.harvard.edu/wp-content/uploads/sites/94/2017/01/Robinson-Hammitt-Adler-Distribution-2018.03.07.pdf ; Accessed: July 2022.

207 McInnes, G. (2017). Understanding the distributional and household effects of the low-carbon transition in G20 countries. OECD report. February. Available at: www.oecd.org/env/cc/g20-climate/collapsecontents/McInnes-distributional-and-household-effects-low-carbon-transition.pdf; Accessed on: July 19, 2022.

208 Anger-Kraavi, A., Markkanen, S. (2019). Social impacts of climate change mitigation policies and their implications for inequality. *Climate Policy*, 19 (7), 827-844.

209 Anadón, L. D., Peñasco, C., Verdolini, E. (2021). Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments. *Nature Climate Change*, 11(3), 257-265.

210 Del Río, P., Gual, M. A. (2007). An integrated assessment of the feed-in tariff system in Spain. *Energy Policy* 35, 994-1012.

211 Bean, P., Blazquez, J., Nezamuddin, N. (2017). Assessing the cost of renewable energy policy options – A Spanish wind case study. *Renewable Energy* 103, 180-186.

212 Finon, D., Lamy, M-L., Menanteau, P. (2003). Prices versus quantities: choosing policies for promoting the development of renewable energy. *Energy Policy* 31, 799–812.

While these have often accelerated innovation, they have also often added to energy prices for consumers (at least in the short term) which, in turn, put a relatively higher burden on poorer households as opposed to richer ones[213] – in economic terms, increases in energy prices are generally regressive.[214,215,216]

Negative distributional effects are also well documented at the firm level, and they often depend on the size of the firms. Independent renewable energy developers, for instance, have in some cases been at a disadvantage when compared to large companies.[217,218,219] These negative effects have also been widely documented for particular designs of carbon taxes in that, without recycling and/or compensatory mechanisms, carbon taxes have disproportionately impacted poorer households[220] and households in rural areas.[221]

Some such issues and trade-offs can be managed by careful policy design.[222] For example, renewable energy support policies can be designed to be stable, predictable, dynamic and adjustable over time and, in coordination with complementary policies, can prevent the generation of windfall profits for producers and limit the potential for negative distributional impacts on energy consumers.[223,224,225,226] Carbon taxes can be accompanied by recycling mechanisms – such as lump-sum redistribution or by shifting the tax burden through a deeper environmental tax reform that recycles environmental taxes through a reduction in payroll taxes – to give rise to a double (even triple) dividend; namely they simultaneously contribute positively to environmental objectives and social equity.[227,228]

Policy also needs to address fundamental potential tensions around the costs associated with innovation-related investments both within and across countries. These investments generally involve greater costs in the short term, but can yield benefits in the longer term and are essential to tackling the great inequities that arise from climate impacts and that are at the core of differences between high-income countries and low and middle-income countries. Practical and financial support with the adoption of new technologies will be needed to foster a faster and more just transition (see Principle 8).[229]

213 Costa-Campi, M.T., Trujillo-Baute, E. (2015). Retail price effects of feed-in tariff regulation. Energy Economics, 51, 157-165.

214 Some economists claim that this is not the case in low and middle-income economies and carbon pricing can be progressive in those contexts in certain circumstances (see Ohlendorf et al. 2021; Steckel et al., 2021)

215 Jakob, M., Minx, J. C., Ohlendorf, N., Schröder, C., Steckel, J. C. (2021). Distributional impacts of carbon pricing: A meta-analysis. Environmental and Resource Economics, 78 (1), 1-42.

216 Dorband, I.I., Montrone, L., Steckel, J.C., et al. (2021) Distributional impacts of carbon pricing in developing Asia. Nature Sustainability 4, 1005-1014. https://doi.org/10.1038/s41893-021-00758-8

217 Astrand, K., Ericsson, K., Khan, J., Nilsson, L.J., Uyterlinde, M.A., Van der Linden, N.H., Vrolijk, C., Wiser, R. (2005). Review of international experience with renewable energy obligation support mechanisms. ECN, ECN-C-05-025.

218 Bergek, A., Finon, D., lauber, V., Jacobsson, S., Mitchell, C., Toke, D., Verbruggen, A. (2009). EU renewable energy support policy: faith of facts? Energy Policy, 37 (6): 2143-2146.

219 Farooquee, A.A., Konda, C., Shrimali, G. (2016). Designing renewable energy auctions for India: Managing risks to maximize deployment and cost-effectiveness. Renewable Energy, 97, 656–670.

220 McInnes, G. (2017). Understanding the distributional and household effects of the low-carbon transition in G20 countries. OECD, Paris.

221 Callan, T., Lyons, S., Scott, S., Tol, R.S.J., Verde, S. (2009). The distributional implications of a carbon tax in Ireland. *Energy Policy,* 37, 407-412.

222 Anadon, L.D., Peñasco, C., Verdolini, E. (2021). 'Systematic review of the outcomes and trade-offs of ten types of decarbonization policy instruments.' Nature Climate Change. 11, 257-265. doi.org/10.1038/s41558-020-00971-x

223 Ang, G., Burli, P., Röttgers, D. (2017). The empirics of enabling investment and innovation in renewable energy. OECD Environment Working Papers, 123, OECD Publishing, Paris.

224 Butler, L., Neuhoff, K. (2008). Comparison of feed-in tariff, quota and auction mechanisms to support wind power development. *Renewable Energy*, 33(8), 1854-1867.

225 Schallenberg-Rodriguez, J. (2017). Renewable electricity support systems: Are feed-in systems taking the lead?. *Renewable and Sustainable Energy Reviews*, 76, 1422-1439.

226 Barquín, J., Fagiani, R., Hakvoort, R. (2013). Risk-based assessment of the cost-efficiency and the effectivity of renewable energy support schemes: Certificate markets versus feed-in tariffs. *Energy policy*, 55, 648-661.

227 Dimitropoulos, A., Oueslati, W., , Rousseliere, D., Zipperer, V. (2017). Energy taxes, reforms and income inequality: An empirical cross-country analysis. *International Economics*, 150, 80-95.

228 Vona, F. (2021). Managing the distributional effects of environmental and climate policies: The narrow path for a triple dividend. OECD, Paris

229 Guivarch, C., Méjean, A., Taconet, N. (2020). Influence of climate change impacts and mitigation costs on inequality between countries. *Climatic Change*, 160 (1), 15-34.

CASE STUDY 7:

Carbon road fuel taxes and the 'Gilets Jaunes' movement in France

A well-known example of a carbon pricing instrument that lacked a thorough consideration of distributional impacts was the tax on road transport that the French government imposed in 2018, which it said was intended to reduce greenhouse gas (GHG) emissions in the sector. As part of its commitments after COP21 in Paris, environmental taxation, and in particular energy taxation for products for transport purposes, rose as one of the main instruments in the French strategy towards a low-carbon transition and the reduction of GHG emissions in the transport sector. Specifically, one of the planned measures involved increasing gasoline and diesel taxes by nearly 5 and 8 cents per litre (excluding VAT), respectively, representing an average increase of 3-5% of the price paid in petrol stations. While the measure was accompanied by a flat subsidy for the purchase of electric vehicles and an energy rebate, the fuel taxes as initially designed disproportionally affected the poor.

From a welfare economics perspective, there were reasons to oppose the government's original policy package, since it did not sufficiently consider the distributional impacts of the taxes.[230]

The perceived unjust nature of the policy[231] led to the creation in November 2018 of the 'Gilets Jaunes' (yellow vests) movement, with a broad objective to block the tax. While very heterogeneous as a group, 48% of the participants in the movement were aged over 50, 75% were using a motor vehicle every day and 65% were below the standard living national monthly average income.[232,233] Around a month later, the government responded by instead proposing a more gradual increase in fuel taxes and doubling the amount of subsidy provided for the purchase of EVs for lower-income groups.

Both of these policy changes were the result of considering, in a more central manner, the balance between climate mitigation and socio-economic justice.[234,235] This case illustrates the importance of incorporating welfare and distribution aspects in the assessment of policies before implementation.

230 Salies, E. (2019). Gilets Jaunes: Is the energy transition possible while still reducing inequality? OFCE –le Blog. SciencesPo publishing. Paris. www.ofce.sciences-po.fr/blog/gilets-jaunes-is-the-energy-transition-possible-while-still-reducing-inequality

231 Teixidó, J. J., Verde, S. F. (2017). Is the gasoline tax regressive in the twenty-first century? Taking wealth into account. Ecological economics, 138, 109-125.

232 Les 'Gilets Jaunes': La Partie Emergée de la Crise Sociale Française? (2019). Institut Montaigne. www.institutmontaigne.org/blog/les-gilets-jaunes-la-partie-emergee-de-la-crise-sociale-francaise

233 Islar, M., Martin, M. (2021). The 'end of the world' vs. the 'end of the month': understanding social resistance to sustainability transition agendas, a lesson from the Yellow Vests in France. Sustainability Science, 16(2), 601-614.

234 Islar, M., Martin, M. (2021). The 'end of the world'vs. the 'end of the month': understanding social resistance to sustainability transition agendas, a lesson from the Yellow Vests in France. Sustainability Science, 16(2), 601-614.

235 Salies, E. (2019). Gilets Jaunes: Is the energy transition possible while still reducing inequality? OFCE –le Blog. SciencesPo publishing. Paris. www.ofce.sciences-po.fr/blog/gilets-jaunes-is-the-energy-transition-possible-while-still-reducing-inequality

PRINCIPLE 8:

Coordinate internationally to grow clean technology markets

Traditional principle: Link carbon markets to minimise current costs

Summary: Countries should coordinate internationally to grow clean technology markets in each of the emitting sectors of the global economy. This can lead to faster innovation and larger economies of scale, accelerating the cost reduction of clean technologies, with benefits for all countries.

Rationale for the traditional principle

Economists and economic institutions have traditionally advised countries to work together to grow international carbon markets, as an efficient way to reduce global emissions.[236] The logic for this is that a carbon market can find the least-cost opportunities to reduce emissions at any given moment in time, and the larger the market, the more low-cost emissions-reduction opportunities may be discovered.[237] In practice, international carbon-emission markets have made some contributions to emissions reduction. For example, as we noted in our earlier report '*The New Economics of Innovation and Transition*', the Kyoto Protocol's Clean Development Mechanism (CDM) provided important support to the early phase of India's transition to efficient lighting.[238] It also provided finance to support the initial adoption of a range of other clean technologies in developing countries, although in many cases it was found not to have been additional to other types of finance.[239]

Limitations of the traditional principle

A dynamic understanding of the economy makes clear the limitations of this approach. Least-cost emissions reductions at a moment in time do not necessarily lead to least-cost emissions reduction over the course of time. The dramatic technological progress that has made solar power 'the cheapest electricity in history'[240] was brought about by targeted policies focused on what was initially a very expensive way of reducing emissions. As discussed under Principle 1, these policies activated the feedbacks of learning, improvement and cost reduction.

As previously mentioned in Principle 4, some carbon price is better than no carbon price, and a carbon market is better than no policy at all. But to the extent that carbon markets encourage a search for least-cost emissions reductions, they could end up diverting resources from, or delaying investments in, such high-cost, but ultimately high-benefit, opportunities. Logically, the larger the carbon market, the more low-cost short-term emission reductions can be found[241] and the easier it is for firms to meet regulatory requirements without investing in zero-emission technologies that are initially more expensive.[242]

236 See icapcarbonaction.com/system/files/document/icap_linking-input-paper.pdf and www.oecd.org/economy/growth/towards-global-carbon-pricing-direct-and-indirect-linking-of-carbon-markets.pdf and openknowledge.worldbank.org/bitstream/handle/10986/26430/WP-PUBLIC-RegulatoryFrameworkWeb.pdf?sequence=1&isAllowed=y
Note: such advice has been caveated with the need to carefully consider risks to effectiveness that might arise from different levels of stringency in different markets and from other practical aspects of linkage. The limitation in terms of dynamic effectiveness that we discuss here is distinct from those issues.

237 icapcarbonaction.com/system/files/document/icap_linking-input-paper.pdf [p4: *Flachsland et al. (2008) and IETA (2006), among others, emphasise three main potential economic benefits to larger linked markets: increased efficiency through the cost effective allocation of abatement among a larger number of abatement options, increased market liquidity, and a reduction in competitiveness distortions. Together, these benefits serve as the underlying motivation to link domestic systems.*]

238 Grubb et al (2021) The New Economics of Innovation and Transition: Evaluating Opportunities and Risks, 19 and India case study, www.eeist.co.uk.

239 ec.europa.eu/clima/system/files/2017-04/clean_dev_mechanism_en.pdf

240 IEA. (2020) World Energy Outlook 2020

241 icapcarbonaction.com/system/files/document/icap_linking-input-paper.pdf

242 Hallegatte, S., Meunier, G., Vogt-Schlib, A. (2018). When starting with the most expensive option makes sense: Optimal timing, cost and sectoral allocation of abatement investment. Journal of Environmental Economics and Management, 88, 210-233.

As explained in Principle 5, effective innovation in practice requires a mix of policy instruments to drive transitions, of which some other elements (notably, strategic investments) may initially be more expensive. Consequently, where national carbon markets already exist, linking them to create international carbon markets could in some cases delay the processes of transition, particularly in countries that are key drivers of technological change, and in the absence of other effective national or international action.[243]

Case for Principle 8

The progress made so far in low-carbon transitions highlights the value of *coordinating internationally to grow clean technology markets*. This derives from the empirically observed learning curves (or increasing returns) that typically arise when scaling up new clean technologies. As discussed under Principle 1, the costs of solar panels, wind turbines, EV batteries and hydrogen electrolysers have each been found to fall by a largely constant fraction with each doubling of cumulative global deployment, albeit with significant volatility around it.[244] The faster that these technologies grow their share of global markets, the faster their costs fall, benefiting all countries. There are several important ways in which countries can work together to grow markets for clean technologies:

i) **Coordination on early development and testing of clean technologies.** In the early stages of a transition, alignment of research and development efforts internationally, combined with the sharing of learning, can accelerate the identification of viable solutions. Testing new technologies in a variety of contexts can help to increase understanding of their potential and their limitations. Although countries have a strong interest in competing for industrial leadership in new technologies, the ongoing sharing of insights through the long-standing International Energy Agency's Technology Collaboration Programs[245], the US China Clean Energy Center[246], or the increased funding for clean energy RD&D in major economies after the launch of Mission Innovation[247], for example, suggests that some pre-competitive collaboration on technology development is possible, and can be valuable.

ii) **Coordination on policies to expand deployment.** While early in the transition there can be advantages to experimentation with a diverse range of solutions, later there can be benefits from greater alignment in scaling up those solutions that have proven most viable. Each country will want to choose the technologies most appropriate to its national circumstances; at the same time, the more countries support the deployment of the same clean technologies, the faster those technologies will progress down the learning curve. In the power sector, the aligned actions of the five countries that together created 70% of the global market for each of solar and wind power[249] have played a decisive role in making renewable power cheaper than power from coal or gas in the vast majority of the countries of the world. Similarly, coordinated international action to grow markets for green hydrogen would result in a faster fall in the costs of electrolysers.[250] If countries coordinate policy or regulatory trajectories with a rapid pace of deployment, this can incentivise a faster reallocation of industrial investment towards zero-emission technologies, the emergence of dominant designs, and of harmonised market rules and capital allocation mechanisms. The road transport sector provides an example of this opportunity (see case study 8).

iii) **Coordination to establish level playing fields where they are needed.** Measures to establish a level playing field can be important in sectors such as energy-intensive industries, shipping and aviation, where clean technologies are more expensive than fossil-fuelled alternatives and early adopters of clean technologies risk being undercut in international trade. Coordination on standards (for example, regulating the carbon intensity of a traded product or requiring zero-emission fuels on transport routes) can ensure that competition is an accelerator of the growth of clean technologies' share of global markets and not a brake.[251] Coordination on carbon pricing could also be used for this purpose, and this could take the form either of coordination on the level of carbon pricing within a particular sector, or of linking countries within a sector-specific carbon market. The latter option may not be the most effective depending on the situation, for the reasons discussed above.

243 Cullenward, D., Victor, D.G. (2020). Making climate policy work. John Wiley & Sons, 1-242.
244 Way et al. (2021). Empirically grounded technology forecasts and the energy transition (2021) www.inet.ox.ac.uk/files/energy_transition_paper-INET-working-paper.pdf
245 IEA. (2022). *International Energy Agency Technology Collaboration Programme*. https://www.iea.org/programmes/technology-collaboration-programme ; Accessed on August 8, 2022.
246 Lewis, J. (2014). Managing intellectual property rights in cross-border clean energy collaboration: The case of the US-China Clean Energy Research Center. *Energy Policy* 69, 546-554.
247 Anadon, L.D., Galeazzi, C., Meckling, J., Shears, E, Xu, T. (2022). Energy innovation funding and institutions in major economies. *Nature Energy*, accepted.
248 For solar: China, USA, Japan, Germany, and India; for wind: China, USA, Germany, India and Spain www.irena.org/publications/2021/March/Renewable-Capacity-Statistics-2021
249 IRENA www.irena.org/newsroom/pressreleases/2021/Jun/Majority-of-New-Renewables-Undercut-Cheapest-Fossil-Fuel-on-Cost
250 www.energy-transitions.org/publications/making-clean-hydrogen-possible
251 www.energy-transitions.org/publications/mission-possible

iv) Practical assistance and shared learning. In the power sector, international assistance for electricity market reforms has helped many countries access the benefits of cheap and clean power.[252] This includes, for example, assistance with the design of renewable power auctions, the creation of capacity markets, or other regulatory changes that help to mobilise investment in clean power. When these measures are successful, they add further growth to the global market for solar and wind technologies, and further reductions in their costs. Similar international assistance can be provided in each of the emitting sectors building on experience.

v) Coordinated infrastructure investments. In international shipping, aviation and road freight, coordinated investments in refuelling or charging infrastructure will be essential to allow the deployment of zero-emission technologies or fuels on international routes. Physical links between countries can also support the faster growth of markets for clean technologies: interconnectors can facilitate countries' transitions to clean power,[253] and international hydrogen pipelines can support the growth of the hydrogen economy.[254]

Limiting global temperature rise to below 2 or 1.5°C requires a dramatic acceleration of decarbonisation in all emitting sectors. International coordination to grow markets for clean technologies in each emitting sector can make this more achievable. This was recognised by the countries representing over 70% of global GDP that launched the Breakthrough Agenda at COP26, committing to work together to make clean technologies and sustainable solutions the most affordable, accessible and attractive option in each emitting sector by the end of this decade. The forms of cooperation described above can create stronger incentives for investment, and can stimulate faster innovation and cost reduction. A targeted approach to each sector is essential, since each sector differs in its technologies and market structures.[255]

Companies and countries will always compete for leadership in new technologies, and for the benefits in jobs and growth that come from taking a large share of global markets. With the right coordination to agree the rules of the game, such competition can be a powerful accelerator of low-carbon transitions, and need not be a brake.

252 See Climate Investment Funds: Ten years on www.climateinvestmentfunds.org/news/cif-ten-years

253 www.sciencedirect.com/science/article/abs/pii/S1364032119301364

254 www.energy-transitions.org/publications/making-clean-hydrogen-possible

255 Geels, F.W., Sharpe, S., Victor, D. G. (2019) Accelerating the low carbon transition: the case for stronger, more targeted and coordinated international action. www.energy-transitions.org/publications/accelerating-the-low-carbon-transition

CASE STUDY 8:

International cooperation on zero-emission vehicles

In road transport, each doubling in the cumulative global deployment of EV batteries has brought a cost reduction of around 20%.[256] From early 2020, governments of most of the world's largest car markets began discussing the necessary pace of the transition, first bilaterally and later as a group at the Zero Emission Vehicle Transition Council.[257]

A growing consensus was reflected in the commitments of California (September 2020), the UK (November 2020) and Canada (June 2021), and the proposals of the European Commission (July 2021), followed by many more countries at COP26 in November 2021, to require all new car sales to be zero-emission by 2035.

Modelling suggests that if the three largest car markets (China, the EU and the US) were to implement policies in line with this trajectory, then due to larger economies of scale and faster innovation, the achievement of cost-parity between electric and fossil-fuelled vehicles could be brought forward by up to four years (see Figure 12).[258] Progress down the learning curve will be faster if countries coordinate on technology choice, backing only those technologies that are consistent with the zero-emissions goal – predominantly, meaning battery electric and fuel-cell electric vehicles.[259] In addition, international assistance can help developing countries benefit from this transition by mobilising investment in charging infrastructure.[260]

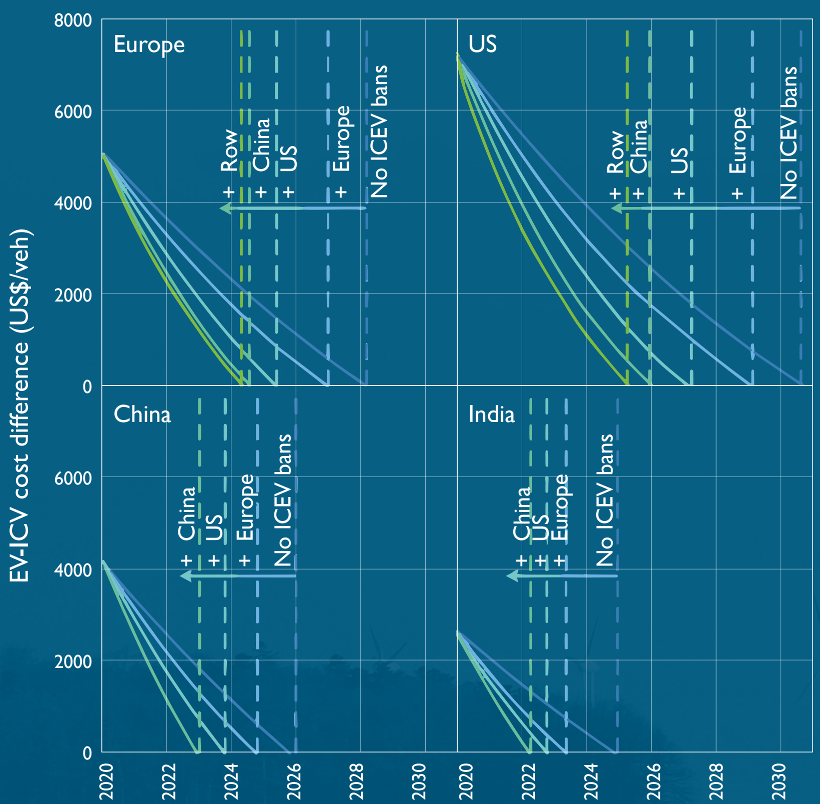


Figure 12. Faster cost reductions and cost parity between electric vehicles (EVs) and internal combustion engine vehicles (ICEVs) as a result of international coordination to grow the global market for electric vehicles. Each square refers to a different vehicle market. The impact of adding Rest of the World (RoW) is only visible for Europe and the US, where cost parity is reached later. The impact of adding India is not shown as induced differences are small, the market remaining small relative to others shown. Source: [261]

256 Trancik, J.E., Ziegler, M.S. (2021). Re-examining rates of lithium-ion battery technology improvement and cost decline. *Energy & Environmental Science* 4. https://doi.org/10.1039/D0EE02681F

257 Joint Statement of the Zero Emission Vehicle Transition Council (2020) www.gov.uk/government/news/joint-statement-of-the-zero-emission-vehicle-transition-council

258 Lam, A., Mercure, J-F. (2022) Evidence for a Global Electric Vehicle Tipping Point, forthcoming. University of Exeter, Global Systems Institute. Working Paper Series 2022/01. Available at: ore.exeter.ac.uk/repository/handle/10871/129774; Accessed on: July 2022. Note: cost parity refers to total cost of ownership.

259 theicct.org/sites/default/files/Global-LCA-passenger-cars-FS-EN-jul2021.pdf

260 World Bank, Global Facility to Decarbonise Transport concept note. thedocs.worldbank.org/en/doc/e14c76f49f8907a58fbfe039fc51d8d3-0190072021/original/GFDT-Concept-Note.pdf

261 Lam, A., Mercure, J-F. (2022). Evidence for a global electric vehicle tipping point. University of Exeter, Global Systems Institute. Working Paper Series 2022/01. Available at: ore.exeter.ac.uk/repository/handle/10871/129774; Accessed on: July 2022.

PRINCIPLE 9:

Assess opportunities and risks

Traditional principle: Assess aggregate costs and benefits

Summary: Policy appraisal should consider risks and opportunities, not just costs and benefits, when unquantifiable or very uncertain factors are likely to be important. Where the aim is transformational change, appraisal should consider the effects of policies on processes of change in the economy, alongside their expected outcomes.

Rationale for the traditional principle

As noted (e.g., Principle 6, Principle 7), the appraisal of proposed public policies is in many countries done on the basis of comparing aggregate costs and benefits, as well as strategic political and legal implications and constraints. In some countries, such as the UK and US, this is formalised under cost-benefit analysis (CBA) frameworks. At the European Commission, multi-criteria analyses are used. In other countries including Germany and India, no formal guidelines exist, and instead more tailored approaches are taken to informing policy choices with relevant evidence.

CBA can be a valuable tool in its domain of applicability (see Rationale for traditional Principle 7). It encourages a methodical approach to comparing alternative options, which can have advantages compared to more ad-hoc or overly politicised approaches to policy appraisal.

Limitations of the traditional principle

However, it is important to understand the boundaries the applicability of CBA, which is less appropriate when any of the following conditions are present.[262]

a) **Uncertainty:** The use of CBA involves the implicit assumption that probabilities for all possible events and outcomes are quantifiable, and that uncertainties are limited.[263] In reality, some of the outcomes of policy will always be uncertain – that is, their probability or magnitude cannot be confidently quantified. If some of the *most important* intended or possible outcomes of policy are of this nature, then analysis that compares options primarily in terms of their quantifiable costs and benefits risks being misleading. Since near-term specific costs tend to be better known than the subsequent wider benefits of action, this can create a systematic bias towards inaction which maintains the status quo. This can apply, for example, when innovation is one of the intended or resulting policy outcomes. This is illustrated by scenarios in the Sixth UN Global Environmental Outlook (GEO-6) which explores the implications of both current trends, and the transformation to a low-carbon, resource efficient economy: No conventional cost–benefit analysis for either scenario is possible. This is because the final cost of meeting various decarbonisation and resource-management pathways depends on decisions made today in changing behaviour and generating innovation. The inadequacies of conventional modelling approaches generally lead to understating the risks from unmitigated climate change and overstating the costs of a low-carbon transition, by missing out the cumulative gains from path-dependent innovation.[264]

b) **Diversity of interests:** CBA converts all policy outcomes into a single metric: money. There are different methods by which this conversion, or monetisation, can be done, and while a method may be applied consistently, the choice of which method to use is unavoidably arbitrary (see Principle 7). This can be a drawback not only in relation to equity implications, but in situations where the policymaker is interested in possible outcomes in a diverse range of dimensions. By implicitly assigning weightings to different interests or outcomes, it makes important choices less easily visible.

262 Drummond, P., Ives, M., Grubb, M., Knobloch, F., Lam, A., Mercure, J.F., Nijsse, F.J., Pollitt, H., Sharpe, S., Vinuales, J.E. (2021). Risk-opportunity analysis for transformative policy design and appraisal. *Global Environmental Change*, 70, 102359.

263 HM Treasury. (2020). The Green Book - Central Government Guidance on Appraisal and Evaluation.

264 Ekins, P., Zenghelis, D. (2021). The costs and benefits of environmental sustainability. *Sustainability Science*, 16, 949-965. doi.org/10.1007/s11625-021-00910-5

c) **Structural change:** CBA considers the expected outcomes of policy at a fixed moment, or moments, in time. This means it has limited ability to assess how effective a policy will be at bringing about change *over time*. Consequently, it is appropriate for use in situations of 'marginal change': where the structure of the economy (including the price or existence of technologies and the structure of markets) is not expected or intended to change; but is not appropriate for use where the aim of policy, or the context in which it is expected to operate is one of structural, or transformational, change.

Moreover, CBA is generally conducted at a project or national level, based purely on national criteria, and neglects the kind of international dimensions and potential collective gains considered in Principle 8.

These limitations can be critically important for policies with transformational aims in which innovation takes a central role,[265] where fundamental uncertainty is present, and where many different policy interests (and many different stakeholders) are affected. Many of the policies necessary for the zero-carbon transition are in this category.

An additional limitation relates to resilience. In many systems, there is a trade-off between performance and resilience.[266,267] The more we tune systems (e.g., institutions, engines or ecosystems) to maximise performance, the higher the likelihood of their failure becomes. Similarly, policies that maximise the cost-benefit ratio may turn out to possess low resilience to unforeseen circumstances. For example, operating hospitals with bed numbers tailored to everyday demand is least expensive, but it offers little resilience to pandemics. A similar trade-off may exist in that the more we seek to maximise outcomes that can be known with high certainty, the lower our ability becomes to capture unforeseen innovation opportunities.

The case for Principle 9

Risk-opportunity analysis can be seen as a generalisation of cost-benefit analysis. If CBA is appropriate in the special cases where there is high certainty, very few outcome dimensions of interest and only marginal change, then risk-opportunity analysis is appropriate to the broader range of situations that do not meet those conditions.

The main aspects involved in risk-opportunity analysis, and their advantages, are:

a) **Uncertainty.** Possible outcomes that are important to the policymaker's interests but that cannot be quantified (risks and opportunities) are considered alongside those that can be quantified (costs and benefits), in a structured way and on an equal basis. The value of a policy option is not described by a summing-up of only the factors that are quantifiable. This encourages proper consideration of all important factors, and avoids presenting a misleading conclusion.

b) **Diversity of interests.** Different outcomes of policy are assessed in their own appropriate metrics (for example, jobs, costs, emissions, competitiveness, public health benefits, distributional consequences), without monetisation. This multi-criteria approach avoids a default of monetary value being the only metric of trade-offs, and thus makes more explicit and transparent the judgements about the relative importance of different interests and impacts: ultimately it aims to inform decision-makers so that choices can be made using explicit information and judgement.

c) **Structural change.** The likely effect of policies on *processes of change* in the economy are considered, alongside their expected outcome. Processes of change include technology innovation and diffusion, changes in investor expectations and consumer preferences, the growth and decline of business strategies and sectors, and changes in financial, industrial and market structures. Consideration of the dynamics of these processes – the feedbacks between variables – can help to distinguish between policies whose effects will be self-amplifying, and those whose effects will be self-limiting.

265 Following the UK's Green Book guidance on policy appraisal, 2020 update (HMT 2020), marginal change refers to projects or policies that pose little impact to the economy as a whole, while transformational change refers to actions that leave the economy or society irreversibly qualitatively transformed.

266 Carlson, J. M., Doyle, J. (2002). Complexity and robustness. *Proc. Natl. Acad. Sci.* 99 (Supplement 1), 2538–2545.

267 Carlson, J. M., Doyle, J. (2000). Power laws, highly optimized tolerance, and generalized source coding. *Physical Review Letters*. APS 84 (24), 5656.

Risk-opportunity analysis (see our previous report, *The New Economics of Innovation and Transition*, section 4) can be helpful as governments increasingly seek to achieve not just marginal decarbonisation at minimal cost, but to maximise the benefits from the transformational change required to meet the goals of the Paris Agreement. As the IPCC notes, combined with attention to minimise trade-offs and maximise synergies, it can help policymakers identify net 'co-benefits' to deep decarbonisation, particularly in the context of pursuing wider sustainable development.[268]

In business and innovation management, deliberately positioning a company to take advantage of a situation of uncertainty is a bet that often pays off. Evidence from more than 35,000 enterprises across the EU shows that good management of uncertainty in innovation strategies largely underpins high levels of European business performance and resilience.[269] Equally, a lack of innovation in a context of change is not a safe strategy: it may lead to business failure. Similar considerations are likely to be relevant to governments' interests in positioning their countries for success in the global low-carbon transition.

Finally, risk-opportunity analysis can support a careful consideration of the appropriate balance between the objectives of performance, resilience, and opportunity creation. This can help to coordinate some of the different functions of policymaking: strategy-making (e.g., executive decisions), regulation (maintaining rates of system failure within regulatory limits) and accounting (managing expenditure). It can also help avoid the risks that arise from these functions being exercised without co-ordination: where strategies that maximise performance can create problems for regulators, ultimately at greater unforeseen costs to accountants.[270]

268 IPCC. (2022). Summary for Policymakers. Notably sections 1.8 and 13.6.

269 Klingebiel, R., Rammer, C. (2014). Resource allocation strategy for innovation portfolio management. *Strategic Management Journal*, 35(2), 246-268.

270 Cont, R., Moussa, A., Santos, E. B. (2010). Network structure and systemic risk in banking systems. SSRN. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1733528

CASE STUDY 9:

India's transformation of LED demand aggregation through procurement

[Source largely from[271]]

During the last decade and a half, a series of Indian government policies to increase the efficiency of household lighting had remarkable success. The primary motivation of the government to launch these schemes was effective electricity demand management at the macro level and a reduction in carbon emissions for the economy. The spin-off was household savings, which was then used as a powerful marketing strategy.

A forerunner to the national policies was the Domestic Efficient Lighting Program, launched in 2014 in the city of Pondicherry to promote the adoption of more efficient residential lighting and address the large cost burden of lighting for low-income households. This involved a joint venture between state-run power companies, Energy Efficiency Services Ltd (EESL), which bulk-procured highly energy-efficient LED lightbulbs and distributed them to consumers at minimal cost, with utilities benefiting from the reduced demand for power. The scheme was successful: nearly half of the households in Pondicherry switched to LED lighting, and annual energy savings reached 14 GWh.

This inspired a similar policy at the national level: the Unnat Jyoti by Affordable LED for All (UJALA) scheme, launched in 2015 with a target to replace 770 million inefficient bulbs by 2019. Again, the scheme was based on bulk procurement of LEDs by EESL, which were sold to vendors at a minimal cost, with the remaining purchase price recovered through instalments on electricity bills. This was accompanied by various public awareness campaigns. The scheme was designed to address the obstacles to adoption of LEDs, especially their high upfront costs, initially low availability, and a lack of awareness of their long-term benefits compared to incandescent bulbs.

The adoption of the UJALA policy, and its design, were informed by consideration of a variety of opportunities and risks. The most important set of opportunities was to improve energy access, living conditions and the economic prospects of low-income households. Further opportunities included reducing peak load on the power system (increasing its resilience), helping electricity distribution companies manage demand more efficiently, and enabling more productive uses for electricity. Risks included negative health and environmental impacts from the disposal of compact fluorescent lamps.[272] Some of the most important of these potential outcomes of the policy were not quantifiable with confidence. A major uncertainty was the level of adoption of LEDs that would result from the policy. How the immediate cost saving would translate into improved economic prospects for low-income households – perhaps the most important consideration – was even more uncertain.

In addition, the adoption of the policy was strongly informed, evidently, by distributional considerations. The share of total household electricity demand taken up by lighting in India varies strongly across income groups. While the national average is around 20-27%, the share is only 14% for wealthy households but reaches around 60% for poor households.[273]

Finally, the policy was influenced by considerations of structural change. There was a reasonable expectation that bulk procurement of LEDs could lead to reductions in their cost, given their availability on the global market and initially low penetration in India. The government also hoped to increase manufacturing of LEDs in India, and required LEDs procured for the UJALA scheme to have an Indian value-added component.

271 Grubb et al. (2021). The new economics of innovation and transition: evaluating opportunities and risks. EEIST report to COP26. eeist.co.uk/eeist-reports. Transforming Lighting Efficiency in India Annex.

272 Chunekar, A., Kelkar, M., Mulay S. (2017). Understanding the impacts of India's LED bulb programme, 'UJALA'. Accessed on shaktifoundation.in/wp-content/uploads/2014/02/02-PEG-Report-on-impacts-of-UJALA.pdf

273 TERI-NFA. (2020). Behavioural Dimensions in the Indian Power Sector (13), presented at 'Behavioural Dimensions in Indian Power sector', September 2020.

All these considerations – unquantifiable risks and opportunities, distributional issues and the potential for structural (or non-marginal) economic change – provided a stronger rationale for action and a more transparent presentation of interests and trade-offs than could have been provided by cost-benefit analysis.

The policy was successful on several measures. It transformed the efficiency of lighting in Indian households, with around 90% of electrified households meeting their lighting demand using LEDs by 2019. Although the number of LEDs deployed directly through the scheme was less than its highly ambitious target – managing 368 million by July 2022, compared to a target of 770 million by 2019 – it brought about a dramatic 85% drop in the price of LEDs between 2014 and 2016[274] (see Figure 13), and spurred the growth of a wider market. Annual sales of LED bulbs in India increased from 3 million in 2012 to 670 million in 2018, becoming the lighting technology with the largest market share (see Figure 14).[275]

The scheme itself is estimated to have saved around 50 TWh of energy and avoided up to 10 GW of peak power demand. It is also estimated to have achieved annual emissions savings of 40 MtCO2 and cost savings of US$2.4 billion. The local value-add requirement of the policy prompted a shift from importing LED bulbs to importing LED components, and the establishment of a domestic industry in downstream LED manufacturing with a present market value of more than US$1 billion.

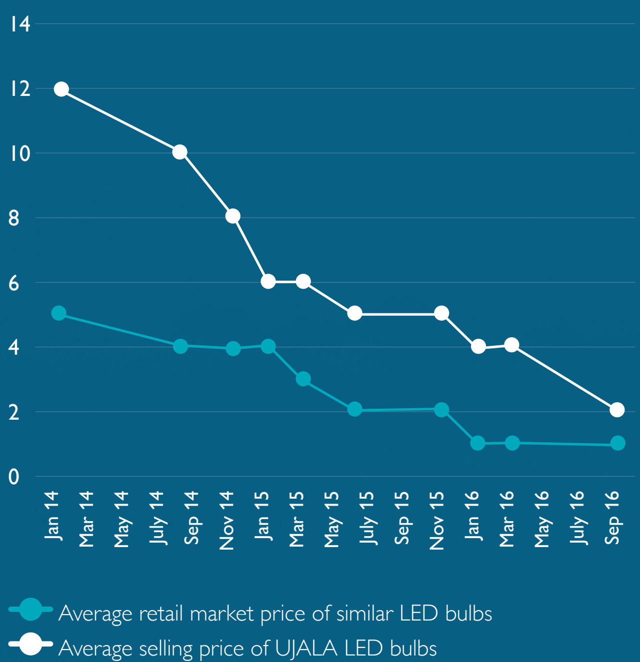


Figure 13. LED price trends in India 2014-2016 (USD) Source: [276]

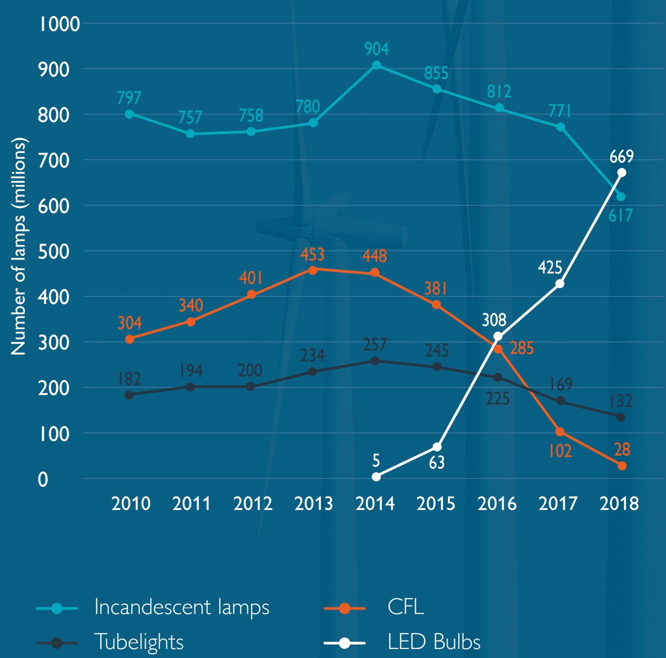


Figure 14. Lighting market trends in India indicating the number of sales of different types of lamps over time (2010-2018). Source: [277]

274 IEA (2020) LED price trends in India, January 2014 to September 2016, for 9 watt LED bulb. IEA, Paris. www.iea.org/data-and-statistics/charts/led-price-trends-in-india-january-2014-to-september-2016-for-9-watt-led-bulb

275 Kamat, A. S., et al. (2020) Illuminating homes with LEDs in India: Rapid market creation towards low-carbon technology transition in a developing country. *Energy Research & Social Science.* doi:10.1016/j.erss.2020.101488

276 IEA (2020) LED price trends in India, January 2014 to September 2016, for 9 watt LED bulb. IEA, Paris. www.iea.org/data-and-statistics/charts/led-price-trends-in-india-january-2014-to-september-2016-for-9-watt-led-bulb

277 Kamat, A. S., et al. (2020) Illuminating homes with LEDs in India: Rapid market creation towards low-carbon technology transition in a developing country, Energy Research & Social Science, doi:10.1016/j.erss.2020.101488

PRINCIPLE 10:

Know your biases

Traditional principle: Policy models and assessment are neutral

Summary: The construction of economic models unavoidably involves many choices that will influence their outputs, in which there are no 'correct' answers. We should be aware of our biases, make model choices transparently and, where possible, use a range of models instead of a single one.

Rationale for the traditional principle

Policy appraisal processes have been designed to provide a systematic way of evaluating evidence associated with alternative policy options. The tools used within policy appraisal in the energy space include Integrated Assessment Models such as those used in the Intergovernmental Panel on Climate Change (IPCC) and Energy Economic Models, alongside cost-benefit analysis or multi-criteria analysis (see Principle 9).

The case for using formal models and processes for assessing policies is that they can help provide a consistent and comparable decision-making framework. They can also be helpful to make assumptions transparent and explicit. All of these economic modelling tools are regularly updated[278] to account for new requirements in policy development, and as new data becomes available. Most governments have official policy guidelines that require or recommend the use of appropriate policy appraisal methods which have taken into account the context in which they will be applied.

Limitations of the traditional principle

However, in policy appraisal, it is important to recognise that the choice, design and subsequent outputs of these processes and models are never neutral, but always political in terms of what questions are asked, how the findings are presented and how the results are interpreted and by whom, among other topics.[279] This is, of course, particularly true where models and their input assumptions are driven by vested interests (such as dominant or incumbent advocacy coalitions, or lobby groups). For example, the scaling up of energy efficiency[280] or technology diffusion has on occasion been slowed because their true costs or benefits have not been adequately identified and objectively evaluated as part of a standard policy appraisal processes in which the choice of models plays an important role.

Models and their parameters used in policy advice are constructed and negotiated during the policymaking process. How this is done and what information is made available could lead to the evidence from such models being seen as politically influenced.[281,282] Indeed, at the extreme, models can be used for policy-based evidence-making, instead of the evidence-based policy making that scientists and policymakers alike claim to strive for.[283]

Models can be considered as 'boundary objects'[284] between knowledge-making and knowledge-using communities (modeller and policymaker), which requires 'Interpretative Flexibility'[285] to provide relative freedom for actors to follow their own interpretations.[286,87] Where these two communities interact, at these boundary objects, will necessarily involve political and ideological choices.

278 See for example Atkinson, G., Mourato, S., Pearce, D. (2006). Cost-benefit analysis and the environment: recent developments. OECD, Paris. ISBN 9264010041

279 Foulds, C., Jones, A., Pasqualino, R., Royston, S. (2022). Masters of the machinery: The politics of economic modelling within European energy policy. Energy Policy (submitted).

280 Dupont, C. (2020). Defusing contested authority: EU energy efficiency policymaking. Journal of European Integration, 42, 95-110. doi.org/10.1080/07036337.2019.1708346

281 Pielke Jr., R.A. (2007). The Honest Broker: Making sense of science in policy and politics. Cambridge University Press.

282 Foulds, C., Royston, S. (2021). The making of energy evidence: How exclusions of Social Sciences and Humanities are reproduced (and what researchers can do about it). Energy Research & Social Science, 77, 102084. doi.org/10.1016/j.erss.2021.102084

283 Ellenbeck, S., Lilliestam, J. (2019). How modelers construct energy costs: Discursive elements in Energy System and Integrated Assessment Models. Energy Research & Social Science, 47, 69-77.

284 Griesemer, J. R., Star, S. L. (1989). Institutional Ecology, "Translations" and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology. Social Studies of Science, 19, 387-420.

285 Bijker, W.E., Pinch, T. J. (1984). The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology might Benefit Each Other. Social Studies of Science, 14, 399-441. doi.org/10.1177/030631284014003004

286 Lovell, H., Pullinger, M., Webb, J. (2017). How do meters mediate? Energy meters, boundary objects and household transitions in Australia and the United Kingdom. Energy Research & Social Science, 34, 252–259. doi.org/10.1016/j.erss.2017.07.001

287 Foulds, C., Silvast, A. (2022). Sociology of Interdisciplinarity: Dynamics of energy research. Palgrave Macmillan, Cham.

The case for Principle 10

Model design and policy appraisal inevitably involves choices. In all of these choices, there is no 'correct' answer. All involve the use of judgement, and all can be contested. These choices strongly influence what the model will say about different policy choices – which ones it will suggest are good value, and which ones less so. Consequently they are of great interest to stakeholders affected by the policy, and likely to be the subject of lobbying. To avoid policy being overly subject to vested interests, or stuck in the consideration of an artificially constrained range of options, it can be helpful for a) these choices to be made transparently; b) these choices to be regularly reviewed; and c) a range of different models to be used, rather than relying on a single one.

In an analysis of in-depth interviews with 24 European modellers and policy-workers, we identified some of these dynamics of contestation and differentiated influence that reflect and reproduce underlying power relations between those entities that commission modelling exercises and the modellers. Table 1 shows the five main areas identified from the interviews that are relevant to assessing the level of neutrality in the policy-modelling process.

Table 1. Dimensions for assessing neutrality in the policy-modelling process. Adapted from[288]

The politics of...	Scope
Framing problems and questions	What questions are (not) asked; construction of ***problems*** and the agendas underlying these.
Framing solutions and scenarios	Which scenarios are (not) considered; construction of ***solutions*** and the agendas underlying these.
Designing models' structural assumptions	Structural aspects of models' design and mechanisms (as opposed to variable inputs).
Defining quantitative inputs	Numerical values assigned to variable inputs (as opposed to structural aspects).
Access and exclusion	Issues of ownership, transparency and capacity that permeate the design and use of models.

The fact that models and outputs are influenced by policy and political processes means that it is important to understand the following: the political nature of model testing; how policymakers influence models and modellers, data and assumptions, study scopes and acceptable questions to explore; and how results are used.[289] Within these contested areas, there can be a mismatch in expectations as well as interest-driven conflicts between actors over the definition of scenarios, the specific values assigned to input variables, and more fundamental issues of transparency, access and exclusion, whereby an emphasis on model-based policy can exclude certain voices from debates.[290,291]

In addition, modelling exercises often require choices about what policy options to consider and how to model them. These choices may depend on who is commissioning the work, the preferences or perspectives of the modellers, and on interactions between analysts and external stakeholders that may or may not be public.

Established models generally have an advantage over new models because over time they become more familiar and trusted by policymakers and they tend to develop a wider and more politically salient set of analysis capabilities.[292] Because of this, some energy economic models, such as NEMS[293] (an energy and economic model used by the

288 Foulds, C., Jones, A., Pasqualino, R., Royston, S. (2022). Masters of the machinery: The politics of economic modelling within European energy policy. Energy Policy (submitted).

289 Ceglarz, A., Gaschnig, H., Flamos, A., Giannakidis, G., Lilliestam, J., Stavrakas, V., Süsser, D. (2021). Model-based policymaking or policy-based modelling? How energy models and energy policy interact. Energy Research & Social Science, 75, 101984. doi.org/10.1016/j.erss.2021.101984

290 Baumgartner, T., Midttun, A. (1986). Negotiating energy futures: The politics of energy forecasting, *Energy Policy*, 14 (3), 219-241.

291 Foulds, C., Robison, R. (2017). The SHAPE ENERGY Lexicon - interpreting energy-related social sciences and humanities terminology. SHAPE ENERGY, Cambridge.

292 Daly, H., Fais, B., Strachan, N. (2016). Reinventing the energy modelling–policy interface. *Nature Energy* 1, 16012.

293 US Energy Information Administration (2015). Analysis of the Impacts of the Clean Power Plan, US Energy Information Administration, US Department of Energy, Washington DC.

United States created by the US Energy Information Administration), PRIMES[294] (an applied energy system model used by the European Union, for instance) or E3ME[295] have been used for decades. This also leads to the specific discourse, values and choices contained within those models becoming dominant within specific government policy development and appraisal processes and, as such, models have been referred to as 'meaning-making machines'.[296]

Therefore, it is useful to maintain transparency and reflexivity alongside a pluralistic approach to the use of models, especially when appraising policy that seeks non-marginal change[297] and involves uncertainty, innovation, long-time horizons, a diversity of actors[298] and considerations of finance[299]. There is a need to actively reflect on, and account for, the biases present in policy appraisal and modelling processes, which in turn demands greater transparency on model assumptions, structures and functioning.

294 E3Mlab (2017). PRIMES Model Version 6 (2016-2017) - Detailed model description. National Technical University of Athens.

295 Cambridge Econometrics. (2022). E3ME Model. www.e3me.com

296 Ellenbeck, S., Lilliestam, J. (2019). How modelers construct energy costs: Discursive elements in Energy System and Integrated Assessment Models. Energy Research & Social Science, 47, 69-77.

297 Drummond, P., Ives, M., Grubb, M., Knobloch, F., Lam, A., Mercure, J.F., Nijsse, F.J., Pollitt, H., Sharpe, S., Vinuales, J.E. (2021). Risk-opportunity analysis for transformative policy design and appraisal. Global Environmental Change, 70, 102359.

298 Foulds, C., Jones, A., Pasqualino, R., Royston, S. (2022) Confronting difference in the policymaking-modelling system: comparing energy modeller and policyworker views on uncertainty, innovation, long-time horizons and diversity of actors. *Journal of Cleaner Production* (submitted).

299 Knobloch, F., Lewney, R., Mercure, J. F., Paroussos, L., Pollitt, H., Scrieciu, S.S. (2019). Modelling innovation and the macroeconomics of low-carbon transitions: theory, perspectives and practical use. *Climate Policy*, 19 (8), 1019-1037.

CASE STUDY 10:
European 2030 renewable energy targets

We can see from past examples that models have had a strong influence in supporting initial policy positions, as well as supporting a criticism of that initial position, and subsequently a role in confirming a revision and change.

To give one such example, between 2012 and 2018 the European Union developed and adopted a target for renewable energy as a share of total energy consumption. This target was supported, in part, by various model outputs. In October 2014, the European Council initially proposed a 27% by 2030 target and in 2016 the European Commission published the 'Clean Energy for all Europeans' (CE4ALL) package. This package was supported by policy analysis performed by the Directorate-General for Energy using the PRIMES modelling suite[300], coupled with GEM-E3 and subsequent analysis using E3ME, that confirmed this target. Subsequent discussion of the analysis by the European Parliament and experts highlighted that, at the time, the input assumptions used by PRIMES were relatively conservative. In particular, according to some analysis[301] the use of PRIMES in this case may have resulted in the (a) overestimation of the costs of renewables (through reductions over time through innovation, capacity factors assumed to be lower than actual, and the capital costs of investment differences between nation states); (b) overestimation of the price of carbon (through assuming perfect foresight for investors the model exaggerates the potential role of markets); and (c) downplaying the role of sectoral policies and frameworks.

The specific application of the PRIMES model for that analysis initially showed very little difference between the costs to achieve a 27% or 30% share of renewable energy by 2030 across the European Union. However, it showed an increased cost to achieve a 35% target. Following the feedback regarding the input assumptions, updates to the modelling were done and higher renewable shares were then supported. However, the initial target of 27% was seen as political by the experts interviewed and the modelling results were being seen as a way to confirm that political choice. The European Parliament then proposed setting higher targets and commissioned their own modelling work to support these higher targets. This exercise led to the parliament proposing a 35% renewable energy target, relying on analysis by the International Renewable Energy Agency (IRENA). Subsequently, the European Commission confirmed a 32% renewable energy target and proposed a review of the target by 2023 (an example of adaptive policy, Principle 6).

None of the models involved in this case should be considered to be 'correct' or incorrect, though some may have been closer to reality than others in their assumptions and projections in particular occasions. The important point is that, rather than taking the output of any model at face value, it is useful for policymakers to critically examine model assumptions, compare the projections of different models and use the broader information gained through that process to support their policy choice.

300 Ceglarz, A., Flamos, A., Gaschnig, H., Giannakidis, G., Lilliestam, J., Stavrakas, V., Süsser, D. (2021). Model-based policymaking or policy-based modelling? How energy models and energy policy interact. Energy Research & Social Science, 75, 101984. doi.org/10.1016/j.erss.2021.101984

301 Buck, M., Graf, A. (2017). The cost of renewable energy: A critical assessment of the Impact Assessments underlying the Clean Energy for all Europeans-Package, Agora Energiewende, Berlin.

Conclusion

The Ten Principles for Policymaking in the Energy Transition outlined in this report are built on a wealth of empirical evidence gathered over the last three decades and represent a first (and necessarily incomplete) step. The knowledge generated by exploring the different ways in which policy has induced rapid innovation and growth in clean energy technologies can be used to enhance traditional approaches to policy appraisal and development. We suggest that, within a complex system, a structural change requires transformational policy, underpinned by appropriate policy processes, and informed by a clear set of organising principles.

We have contrasted each of these Ten Principles with a 'traditional principle', which are stylised versions of advice or guidance that has often been assumed, advocated, or implemented. While we have acknowledged the usefulness of those traditional principles in their appropriate domains, we have also pointed out some of their limitations and the need to complement them with the Ten Principles. A fundamental distinction is that most, if not all, of the traditional principles are based on analytic frameworks which place economies in relation to an identifiable 'default' equilibrium, typically assumed as optimum, "a situation in which nobody has any immediate reason to change their actions, so that the status quo can continue, at least temporarily",[302] whereas low-carbon transitions inherently involve processes of substantial innovation and structural change in particular directions. Where the traditional principles aim to achieve an efficient allocation of existing economic resources, our principles aim to guide the processes of economic change in an effective and fair way. This can be useful for governments that wish to achieve low-carbon transitions fast enough to avoid dangerous climate change, while also minimising costs and social dislocation, and maximising opportunities for economic development.

We will learn more as we make further progress in low-carbon transition. The lessons from practical experience should continually be reflected upon, and the principles to guide policy updated, to inform those policies that take on the enormous challenge of transforming our economies over the next three decades.

302 Oxford Dictionary of Economics.

EEIST

Economics of Energy Innovation and System Transition

The Economics of Energy Innovation and System Transition (EEIST) project develops cutting-edge energy innovation analysis to support government decision making around low-carbon innovation and technological change. By engaging with policymakers and stakeholders in Brazil, China, India, the UK and the EU, the project aims to contribute to the economic development of emerging nations and support sustainable development globally.

Find out more at:
eeist.co.uk

All documents can be found online here: eeist.co.uk/downloads

2022IIB035