Analytical tools for innovation and competitiveness in the low carbon transition

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> This report shows how different types of analytical tools lead to different policy insights and why, providing invaluable insight into why the choice of tool matters. By breaking down the pros and cons of dominant and emerging analytical approaches into simple language, and summarising the difficulty level for capacity-building, this report informs the process of weighing up a range of important trade-offs.
>
> **Hon. Matia Kasaija,** Minister of Finance Planning and Economic Development, Uganda

> What are the drivers of the low-carbon transition? How best to represent them and quantify their effects? How useful are such analytical tools to policymakers' daily decisions? These are a few of the questions addressed in a systematic way by this report. It brings critical insights into the essential capacities that ministries of finance need in order to be equipped for 21st century policymaking. Essential food for thought for the Coalition of Capacity for Climate Action (C3A).
>
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List of abbreviations

Acronym	Stands for
ABM	Agent-based model
BNEF	Bloomberg New Energy Finance
CBA	Cost–benefit analysis
CBAM	Carbon Border Adjustment Mechanism
C3A	Coalition for Capacity on Climate Action
CCICD	Climate Change and International Cooperation Division (Fiji)
CCDRs	Country Climate and Development Reports
CGE	Computable General Equilibrium
CFMCA	Coalition of Finance Ministers for Climate Action
CNDI	Brazil's National Industrial Development Council
CCUS	Carbon capture, use, and storage
EEIST	Economics of Energy Innovation and System Transition
EU	European Union
EV	Electric vehicle
FTT	Future Technology Transformations
GDP	Gross domestic product
IAMs	Integrated assessment model
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
MININFRA	Ministry of Infrastructure (Rwanda)
MINECOFIN	Ministry of Finance and Economic Planning (Rwanda)
MLP	Multi-level perspective
NDP	National Decarbonisation Plan
OECD	Organisation for Economic Cooperation and Development
PFR	Public Finance Review
PV	Photovoltaic
RCA	Revealed comparative advantage
RDM	Robust decision-making
R&D	Research & development
ROA	Risk–opportunity analysis
SDGs	Sustainable Development Goals
US	United States
ZEV	Zero emission vehicle

Executive Summary

In the context of the low carbon transition, innovation affects finance ministries' core interests. Estimates of the additional investment needed for the low carbon transition range as high as $3.5trn globally each year between now and 2050. At the same time, a transition to zero emissions energy use throughout the global economy by 2050 could save around $12trn compared to continued reliance on fossil fuels, as lower operating costs more than offset the additional investment. The success or failure of policies to promote clean technology innovation, particularly the cost-cutting innovation that occurs as clean technologies spread through markets, will strongly influence how much of that potential cost saving is realised, with important consequences for public finances.

National economic competitiveness is also a core concern of finance ministries, in the context of the transition. As global markets and supply chains are transformed by the shift from fossil fuels to clean technologies, there are emerging opportunities for job creation, development, and growth, but also risks of socio-economic decline in regions highly dependent on carbon-intensive industries. Changes in a country's competitive position are likely to affect its trade balance, employment, tax revenues, and spending on social support.

Finance ministries' decisions can strongly influence clean technology innovation, cost reduction, and competitiveness. Innovation does not only happen through research and development. Much of the innovation that reduces costs happens as new technologies are deployed, when industry invests in their improvement, and economies of scale are realised. Finance ministries influence this 'cost-cutting' innovation and deployment process through many avenues of their work, including when they design taxes, approve clean technology subsidies or investments in infrastructure, or contribute to setting regulatory policies that strengthen demand for clean technologies.

Finance ministries from many countries are interested in a similar set of questions, despite widely varying national circumstances and priorities. These include: which clean technologies have the greatest potential for further innovation and cost reduction? How can a country identify the sectors in which it has the best opportunity to be internationally competitive, in the context of the low carbon transition? Which policies will be most effective in driving innovation, cost reduction, and competitiveness? And how will these policies affect macroeconomic outcomes such as employment, growth, and the balance of trade?

The most commonly used conceptual frameworks and analytical tools are limited in their ability to address these questions. These tools are most appropriate for contexts of economic stability, where change is expected to be marginal, and where there is relatively high certainty about the outcomes of decisions. But the low carbon transition is a process of structural economic change, at a rapid pace, on a large scale; and decisions relating to innovation and competitiveness are characterised by a high degree of uncertainty.

A different set of tools exists that is more suited to the context of the low carbon transition. These are designed to address explicitly the dynamics of structural change, and deal constructively with uncertainty. The tools alone do not provide the answers to policy questions, but together with subject matter knowledge and judgement, they can contribute to well-informed decisions. In many cases, they would benefit from further development. The two sets of tools are not mutually exclusive, and insights can be gained from using them together.

Capabilities and limitations of analytical tools in relation to key policy questions

What is the rationale for policy? The market failure framework can be useful to distinguish between situations where policy intervention in the economy is necessary or unnecessary, when the aim is to ensure well-functioning markets. But it is limited as a guide when the aim or context is structural change, including the creation of new markets and industries. In such situations, the market-shaping framework can be used to check whether proposed policies tend to encourage or prevent change in a desired direction.

How can policy advance technology transitions? Technology transitions are not commonly the focus of government policymaking, but they are required to eliminate greenhouse gas emissions from power, transport, buildings, industry, and agriculture – including as developing countries rapidly build new infrastructure. The multi-level perspective on transitions is a conceptual framework that identifies the patterns in technology transitions of the past, and can be used to identify the types of policies likely to be effective at each stage of the low carbon transition in each sector.

How can policies build competitiveness? 'Horizontal' approaches to building competitiveness, such as investing in infrastructure or education, are familiar to governments and are close to being 'no regrets'. Conceptual frameworks for innovation-driven industrial strategy suggest approaches to building competitiveness by focusing on particular sectors or by addressing societal problems. These are higher risk, but may be relevant in the context of the low carbon transition, which will involve deep change in an identifiable set of sectors on a global scale.

Is a policy worth doing or not? Cost–benefit analysis is useful in situations of relatively high certainty and marginal change, but has limitations if applied outside this domain. Scenarios and robust decision-making can be used to assess options in contexts of uncertainty, and systems mapping can be used to assess the likely dynamic effects of a policy. These can be brought together in a general framework of risk–opportunity analysis, for use in situations of uncertainty, diverse interests, and structural change.

Which technologies should be invested in and deployed? Expert predictions of the future costs of clean technologies have often proven inaccurate, sometimes by large margins. Probabilistic learning curves, based on historical data relating cost to deployment, can be used to predict costs within a range of uncertainty, indicating which clean technologies are likely to become cheaper and more dominant in global markets.

Which policies are likely to be effective in driving innovation and cost reduction? Systems mapping with causal loop diagrams can be used to differentiate between policies that are self-amplifying and those that are self-limiting. Simulation models, which may be system dynamics or agent-based models, can be useful for exploring the effectiveness of different policies. These are complementary to cost-optimisation models, which suggest which technologies to aim for, but not which policies to use.

In which sectors or technologies should a country aim to build competitiveness and skills? Revealed comparative advantage indicates the products or sectors where a country has been competitive in the past, but if global markets change, this may not be a good guide to the future. Economic complexity analysis and gravity models can suggest areas in which a country may be able to develop new competitive strengths or increase exports, though many factors can distort their findings. All analytical techniques that aim to address this question are subject to a high level of uncertainty. Labour market models can address the related question of where skills gaps or unemployment are likely to arise as a result of different development and transition strategies.

What will be the macroeconomic effects of innovation and competitiveness policies? Equilibrium-based macroeconomic models, which are widely used within governments, primarily explore marginal reallocations of resources that arise from changes in relative price levels. Disequilibrium models can have greater scope for exploring the structural change that arises from the innovation and diffusion of new technologies, causing impacts on employment and growth. A wide variety of approaches to representing innovation exists in macroeconomic and integrated assessment models. For government analysts, it is important to understand a model's assumptions and how these influence its projections.

Priorities for knowledge sharing and capacity building

Finance ministries can enable better decision-making on innovation and competitiveness by building capacity for the use of conceptual frameworks and analytical tools designed for contexts of uncertainty and structural change. Table (i), below, relates the tools of this kind considered in this report to the key policy questions expressed by finance ministries in our consultations. Table (ii) gives a rough guide to the accessibility of each tool, in terms of its skills, data requirements, and availability – factors finance ministries can consider as they decide which capacities to build. A more detailed version of this table is included in the Conclusion chapter.

Given countries' differing levels of resources and governance capacities, there is an important role for international organisations in developing analytical tools that can be widely used. This particularly applies to economic models, which are resource intensive to develop. Dynamic models suitable for informing policy on innovation and competitiveness in the low carbon transition are not yet well developed or widely available, and may be insufficiently tailored to the interests of developing countries. There is a trade-off in model development between specificity and speed, making it useful to develop both country-specific models where needs are greatest and circumstances most unique, and generally applicable models that can be used by many countries to address the most common policy questions. There is great potential for countries to learn from each other as new tools are tested and put to use.

The structure of this report

The introduction describes the nature of the low carbon transition, finance ministries' interests and roles in the transition, the nature of decision-making, and the importance of analytical tools. In the 'Policy questions' chapter, we provide an initial assessment of finance ministries' policy questions on innovation and competitiveness in the low carbon transition, from which their analytical needs can be understood. We then briefly define the core concepts of innovation, structural change, and competitiveness for the purposes of this report, and explain why they may require a different set of analytical tools from those most commonly used.

The main part of the report considers each conceptual framework or analytical tool in turn, describing its capabilities and limitations in relation to questions of innovation and competitiveness. We focus particularly on the tools that are less widely used by finance ministries at present, but that are relevant to the policy questions of interest. Brief examples illustrate how these tools can be used, and in several cases we highlight how different tools provide contrasting assessments of policy options. Case studies show how such tools are already being used to inform finance ministries' decisions in Brazil, Georgia, South Africa, Czechia, Angola, and Denmark. We conclude with reflections on priorities for knowledge sharing and capacity building.

Table (i): Mapping of policy questions to analytical tools.

	Policy question	Relevant frameworks and tools
A	How can innovation and investment in low carbon technologies drive economic development and improve a country's economic prospects?	Industrial strategy frameworks (horizontal and innovation-driven) Macroeconomic models
B	Which technologies have the greatest potential for further innovation and cost reduction, in each of the sectors most affected by the low carbon transition?	Probabilistic learning curves
C	How can policies best contribute to accelerating clean technology innovation, cost reduction and diffusion?	Market shaping framework Multi-level perspective on transitions Risk opportunity analysis Robust decision-making Systems mapping with causal loop diagrams Sector-specific system dynamics models Sector-specific agent-based models
D	How much can clean technology costs be reduced by factors subject to domestic control and influence, and how much will they depend on international factors?	No tools specifically relevant to this question were identified
E	How can countries identify sectors or product categories relevant to the low carbon transition in which they could be internationally competitive?	Revealed comparative advantage Economic complexity analysis Gravity models Labour market models
F	Which policies are likely to be most effective in increasing a country's competitiveness in a technology or sector, in the context of the low carbon transition?	Market shaping framework Innovation-driven industrial strategy frameworks Risk opportunity analysis Robust decision-making Systems mapping with causal loop diagrams Sector specific agent-based models
G	How will the low carbon transition affect supply chains and jobs, globally and nationally?	Labour market models Macroeconomic models
H	What will be the macroeconomic effects – on employment, economic growth, and the trade balance – of sector-specific technology innovation and diffusion policies?	Macroeconomic models (particularly disequilibrium macro models) Labour market models
I	How should the transition be funded? How can policies best mobilize private investment into clean technologies?	Sector-specific agent-based models

Table (ii): Ease of use of conceptual frameworks, decision-making frameworks and analytical tools

Conceptual framework or analytical tool	Accessibility		
	Skills	Data	Availability
Multi-Level Perspective			
Horizontal industrial strategy			
Innovation-driven industrial strategy			
Cost-Benefit Analysis			
Risk-Opportunity Analysis			
Robust Decision-Making			
Scenario Analysis			
Cost optimisation models			
Probabilistic clean technology cost forecasts based on learning curves			
Systems mapping with causal loop diagrams			
Sector-specific system dynamics models			
Sector-specific agent based models			
Revealed comparative advantage			
Gravity models			
Economic complexity analysis			
Labour market models			
Computable general equilibrium models			
Integrated assessment models			
Disequilibrium macroeconomic models			

I. Introduction: why low carbon innovation matters to ministries of finance

The global transition to a low carbon economy is under way. Every day, the world invests two billion dollars in solar and wind power.[1] These technologies, once expensive and experimental, are now low cost and mass market – including in emerging and developing countries.[2] More than six million jobs have been created in their manufacture and deployment,[3] and many millions more are expected to be created while jobs in fossil fuel industries decline.[4] The shift to electric vehicles is revolutionising the automotive sector, where international trade is worth around $800bn each year.[5] Countries and regions – from China, the US, and EU to India, Indonesia, South Africa, and Vietnam – are competing to attract electric vehicle and battery manufacturing companies to their shores, as this will shape the competitiveness (or even survival) of their car industries.[6]

This is only the beginning. As the low carbon transition spreads across all sectors and countries, cost savings worldwide compared to continuing with a fossil fuel economy could be in the region of $12trn by 2050.[7] Countries in the Global South alone could save over $100bn annually on fuel imports solely through the transition to electric vehicles.[8] Oil and gas assets worth over $1trn could be stranded, as a result of current policy and technology trends.[9]

In this context, innovation and competitiveness in clean technologies are core concerns for finance ministries. Finance ministries might think that clean technology innovation is not their responsibility, and that competitiveness is not their concern: other government departments are usually in charge of these issues. But to neglect them would be a mistake. Finance ministries' decisions strongly influence clean technology innovation and competitiveness, and those factors, in turn, strongly affect finance ministries' core interests.

1 BNEF (2024). Energy Transition Investment Trends.

2 In 2023, more than 95% of new utility-scale solar photovoltaic (PV) installations and new onshore wind capacity had lower generation costs than new coal and natural gas plants. See IEA (2024) Strategies for Affordable and Fair Clean Energy Transitions); IRENA (2021), Renewable Power Generation Costs 2020; Sloss et al.(2021), The Energy Transition and the Global South.

3 IRENA (2023). Renewable energy and jobs: Annual review 2023.

4 IEA (2023a). World Energy Employment 2023.

5 Workman (2023). Car Exports by Country.

6 For example, see Alochet (2023). Comparison of the Chinese, European and American regulatory frameworks for the transition to a decarbonized road mobility; IEA (2024). Global EV Outlook 2024; Bond et al. (2023). X-Change: Cars.

7 Way et al. (2022). Empirically grounded technology forecasts and the energy transition. This estimate refers to the transition across power, transport, buildings, and industry, but not land use.

8 Carbon Tracker (2023). Driving Change: How Electric Vehicles can rise in the Global South.

9 Semieniuk et al. (2022). Stranded fossil-fuel assets translate to major losses for investors in advanced economies.

The nature of the transition

The low carbon transition is, fundamentally, a process of innovation and structural change.[10] In each of the major greenhouse gas- (GHG-) emitting sectors of the economy – power, transport, buildings, industry, and agriculture – zero emission technologies and solutions must first be developed, and then rapidly spread through markets and societies. Business models, market structures, skills, labour markets, and infrastructure must also change, to enable and to respond to the growth of new technologies and sectors. The growth of these new sectors, and the decline of old ones, also leads to structural change in the economy. In developing countries, where industrialisation is limited, this ongoing structural change in the global economy alters the available pathways for development.

When governments commit to achieving net zero emissions, as those of almost all countries have, they are committing to advancing this process of innovation and structural change. Even without any such commitment, now that the global low carbon transition is underway, it is creating a new economic context in which countries have no choice but to participate.

Innovation takes place continually, not only through research and development, but also as new technologies are deployed and spread through markets and society. Increasing deployment typically leads to increasing investment in the improvement of products and manufacturing processes, in turn driving cost reduction. In this report, we focus mainly on the cost-cutting, product-improving innovation that takes place during deployment and diffusion, because it is in these later stages that finance ministries' decisions are more likely to be guided by economic analysis. Given that an estimated 65% of the emissions reductions needed to reach net zero across power, transport, buildings, and industry sectors by 2050 can be achieved through the deployment of available technologies, this is a crucial area of policymaking.[11]

10 IPCC (2018). Summary for Policymakers, in Special Report on the Impacts of Global Warming of 1.5°C. Efficiency improvements, demand reduction, and behaviour change can also contribute to emissions reduction.

11 IEA (2023d). Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C in Reach.

12 More precisely, such transitions are referred to as socio-technical transitions, reflecting the importance of societal factors in processes of innovation and structural change.

13 See Victor, Geels & Sharpe (2019). Accelerating the Low Carbon Transition for more detail.

14 Perez, C. (2002). Technological Revolutions and Financial Capital. See also Bond et al. (2023). X-Change: Electricity.

Technology transitions evolve through different stages: emergence, diffusion and reconfiguration.[12] In the 'emergence' stage, new technologies are developed and demonstrated; in the 'diffusion' stage the new technologies are deployed and spread through markets, displacing incumbents; and in the 'reconfiguration' stage, economic and social structures are adapted to work with the new technologies. In each of these stages, different policy instruments are needed.

The transition in each sector is unique. Each sector is different in its technologies, political economy, and industrial and financial structures. The transition in cement will be unlike the transition in agriculture, which will be different from the transition in road transport. Each sector has its own stakeholder dynamics and solutions, each with different capital intensiveness and asset-replacement lifecycles.[13] Making a cost-effective transition to a net zero emissions economy requires policies that are carefully tailored to each sector.

Transitions occur both globally and locally. In any sector, the characteristics of the transition will vary across countries. For example, the agriculture transition will differ substantially across countries that produce different crops; and the need for transitions in heating or cooling will vary according to local climates. Globally, the diffusion of new technologies is typically led by countries with larger economies; this drives innovation and cost reduction, enabling diffusion in less developed countries.[14] But this is not the whole story, as adoption and use of imported technologies is an active process that requires less developed countries to also develop new capabilities (and organisational and institutional structures) to make good use of the new technologies, which may additionally require adjustments to make the imported technology more suitable to new contexts.

Finance ministries' interests: what is at stake?

Finance ministries have strong interests in understanding and navigating this process of change. This will affect:

- **Spending:** Around $3trn was expected to be invested globally in energy in 2024, with 60% of that directed towards clean technologies including solar and wind power, nuclear power, electric vehicles, electricity grids, energy storage, low emission fuels, energy efficiency improvements, and heat pumps.[15] Investment in the energy transition has risen steeply in recent years (see Figure 1), and is expected to rise further. The success or failure of policies aimed at driving innovation, cost reduction, and diffusion of low carbon technologies will strongly affect the level of investment needed, and the share of investment that is provided by the private sector, with important consequences for public finances.[16] (See below: Financing the transition.)
- **Jobs:** While up to 17 million clean energy jobs could be created globally by 2030, 2.5 million fossil fuel jobs are likely to be lost.[17] Skills gaps may undermine the transition, and lack of strategic reskilling risks chronic unemployment.[18] These changes will influence both tax revenues and social spending.
- **Productivity:** Innovation stimulated by the low carbon transition in some sectors is likely to increase productivity, as does greater energy efficiency (which lowers maintenance costs and increases production per unit of energy input).[19] Innovation is widely recognised as a driver of industrial growth, productivity and competitiveness.[20]
- **Competitiveness, trade, and growth:** As global markets in each of the emitting sectors are transformed by the transition to zero emission technologies and solutions, and as change cascades through supply chains, the competitive positions of many businesses – and of countries – are likely to be altered.[21] Countries that succeed in building competitiveness in these solutions can expect to benefit from more job creation, exports, and economic growth. Meanwhile, in regions highly dependent on carbon-intensive industries, there are risks of industrial and even socio-economic decline. These outcomes are likely to vary substantially between countries, and can be influenced by policies on innovation, skills, and economic diversification.[22]

15 IEA (2024). World Energy Investment 2024.

16 IRENA (2016). Renewable Energy Benefits: Measuring the Economics.

17 IEA (2023b). World Energy Employment 2023.

18 Berryman et al. (2023). Modelling Labour Market Transitions: The Case of Productivity Shifts in Brazil.

19 Zenghelis et al. (2024) Boosting growth and productivity in the United Kingdom through investments in the sustainable economy ; Geels et al. (2021) Productivity opportunities and risks in a transformative, low-carbon and digital age. IEA (ND). Multiple benefits of energy efficiency.

20 See, for example, Cirera et al. (2022). Bridging the Technological Divide: Technology Adoption by firms in Developing Countries; Cirera et al. (2020). A Practitioner's Guide to Innovation Policy; Cirera & Maloney (2017). The Innovation Paradox: Developing-Country Capabilities and the Unrealized Promise of Technological Catch-Up.

21 Fankhauser et al. (2013). Who will win the green race? In search of environmental competitiveness and innovation; Mealy, P. (2021). Navigating the green transition: insights for the G7; Krishnan et al. (2023). An affordable, reliable, competitive path to net zero; Bolton, P. and Kacperczyk, M. (2021). Global pricing of carbon-transition risk.

22 Lynch, C. et al. (2023). Hidden disparities on the road to net zero: identifying areas of opportunity and risk.

23 ECLAC (2023). Lithium extraction and industrialization: opportunities and challenges for Latin America and the Caribbean.

24 IEA (2024). Strategies for Affordable and Fair Clean Energy Transitions.

25 Schumpeter, J. (1942). Capitalism, Socialism, and Democracy.

26 Semieniuk et al. (2020). Low carbon transition risks for finance.

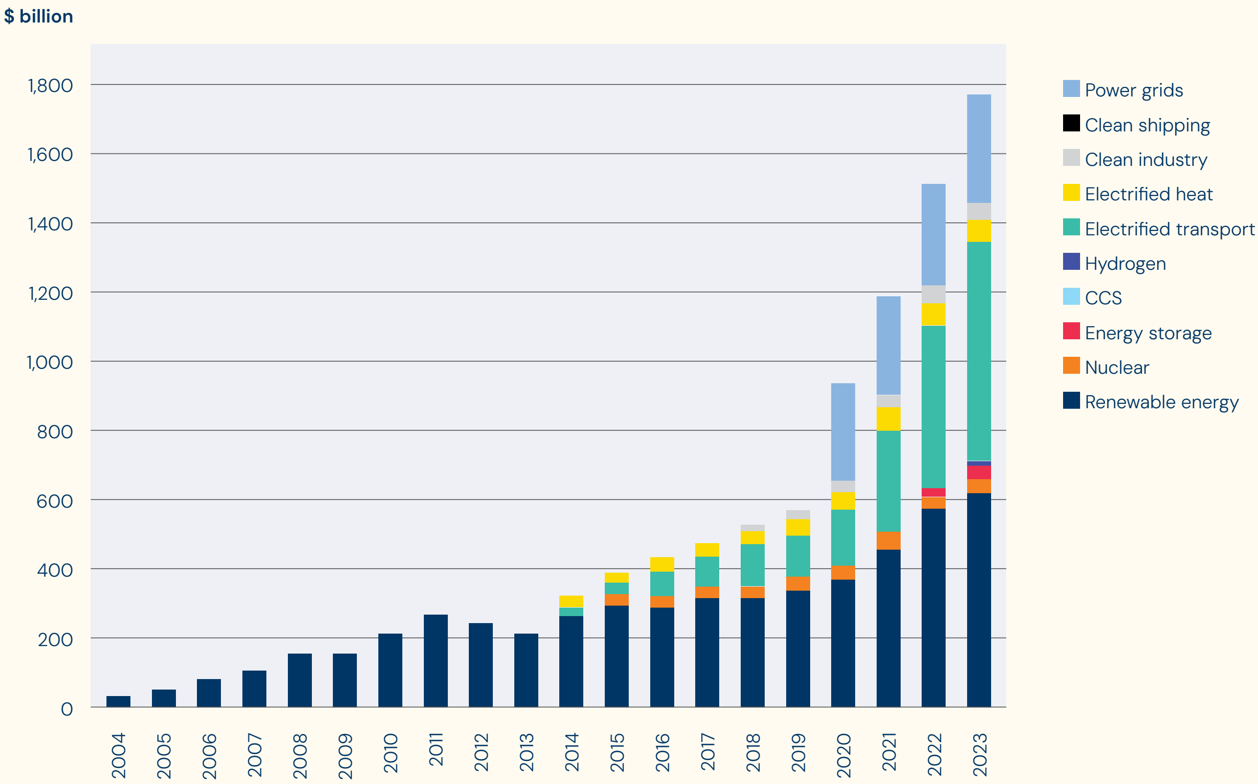
27 See forthcoming C3A report Financing the transition: how can ministries of finance build sustainable financial strategies?

28 Sharpe, S. (2023). Five times faster: rethinking the science, economics, and diplomacy of climate change.

- **Tax revenues and public balance sheets:** Tax revenues will be influenced by the growth or decline of industry, exports, and employment that result from changes in a country's competitive position. For example, revenues from fuel duties will largely decline – while opportunities for revenues from resources such as lithium are already increasing.[23] Changes in spending, including on social support for unemployed workers, and new infrastructure, will also affect fiscal balances.[24]
- **Financial stability:** The process of innovation has long been understood to involve 'creative destruction'.[25] In the low carbon transition, the destruction of value of fossil fuel assets, if it occurs more quickly than anticipated by financial markets, could present risks to financial value and even financial stability.[26] [27]

More broadly, finance ministries, and the governments they are part of, have a stake in the success of the low carbon transition. Avoiding dangerous climate change, which could itself undermine economic growth, requires decarbonisation of the global economy roughly five times faster this decade than has been achieved over the past two decades.[28] Failure to achieve this would put many social and economic objectives at risk. This means policies must be 'time effective' – able to achieve their goals quickly – as well as cost-effective.

Figure 1: Rapidly rising global investment in clean technologies



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The role of finance ministries

Finance ministries can, and do, strongly influence national policies and outcomes on low carbon innovation and competitiveness (see Figure 2). As a report for the Coalition of Finance Ministries for Climate Action, 'Strengthening the role of ministries of finance in driving climate action: a framework and guide for ministers and ministries of finance'[29] (hereafter referred to as 'the Guide'), has set out, these issues are relevant to finance ministries' core functions of fiscal policy, economic strategy, and budget management, as well as to their competencies in areas including public procurement, competition policy, trade policy, financial regulation, and inter-departmental coordination. Even when other departments of government are responsible for designing relevant policies, finance ministries often have the power to approve, reject, or alter them. Finance ministries are typically involved in policymaking in three ways:[30]

1. **Leading policy design:** Finance ministries often lead the design of tax policy. Together with other policies such as subsidies and regulations, taxes and tax deductions can alter the relative profitability of clean technologies and fossil fuels, influencing rates of investment and innovation. Finance ministries may also have responsibility for major infrastructure investment decisions that enable the diffusion of clean technologies, or for the design of public financing instruments aimed at mobilising greater private investment.

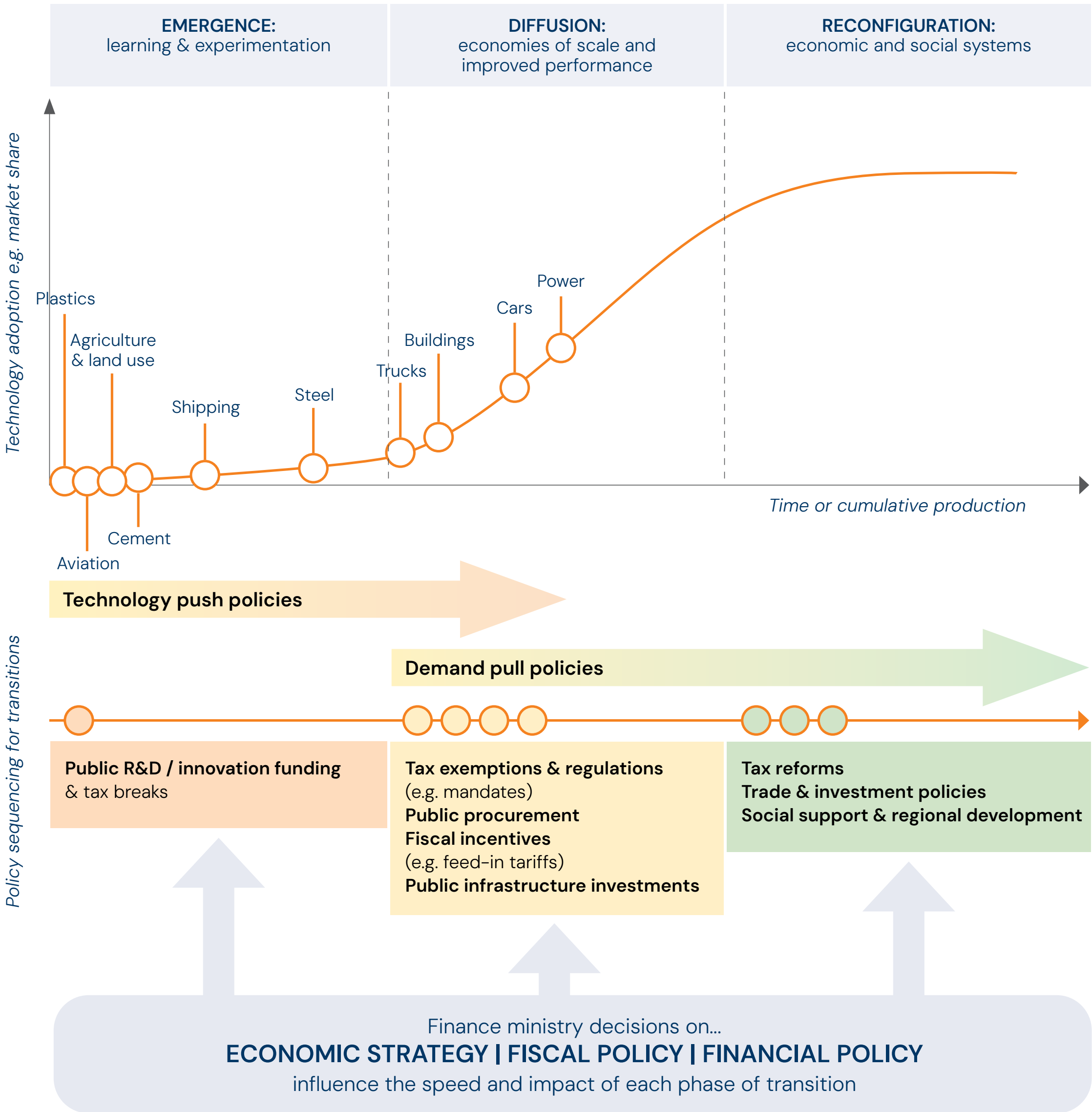
2. **Influencing, approving, or rejecting policies proposed by other departments:** Finance ministries often have the power to approve or reject policies proposed by other government departments, particularly those that involve public spending. This may apply to public procurement and subsidy policies, which can be instrumental in enabling the first deployment of clean technologies, and supporting their subsequent diffusion – crucial steps in the process of innovation and transition. It may also apply to manufacturing incentives designed to strengthen competitiveness in new technologies and industries.

3. **Co-leading, coordinating, or overseeing policies and strategies with other departments:** Finance ministries often contribute to shaping policies and strategies that fall mainly under the remit of other departments, through inter-departmental consultations or committees. For example, they may take an interest in regulatory policies as an opportunity to avoid the need for additional spending or taxation. Regulations such as energy efficiency standards and clean technology mandates can play an important role in reallocating industrial investment towards clean technologies, promoting innovation, and cost reduction. When governments develop industrial strategies, or long-term strategies for emissions reduction, finance ministries are often involved in assessing macroeconomic implications and ensuring priorities for public investment are carefully chosen. Some finance ministries are also ministries of economy or of planning, and have the development of such strategies as one of their core responsibilities.

29 Coalition of Finance Ministers. (2023). Strengthening the Role of Ministries of Finance in driving climate action: a framework and guide for Ministers and Ministries of Finance.

30 General functions are taken from the Guide; examples given here are specific to this report.

Figure 2: The role of finance ministries in the transition



Source: authors' own, adapted from Victor, Geels & Sharpe (2019).

Table 1: Examples of the role of finance ministries in the transition

Country and issue	Finance ministry role
Fiji Climate strategy	Fiji's Ministry of Finance, Strategic Planning, National Planning & Development created a Climate Change and International Cooperation Division (CCICD) to coordinate inter-ministerial work on climate change policy. The CCICD developed Fiji's long-term strategy for emissions reduction, setting out a net zero vision for 2050 and a list of priority actions. It also issued Fiji's first sovereign 'blue bond', which aims to advance low-emissions shipping and marine transportation, as well as enhance waste management value chains.
Rwanda Electric vehicle policy	Rwanda's Ministry of Finance and Economic Planning (MINECOFIN) supported the development of a policy package for the deployment of electric vehicles. This involved removing all taxes, import and excise duties and VAT on electric vehicles, their components, and charging stations; allowing companies to access and set up charging stations on government land rent-free; ensuring charging at industrial cost-price for consumers; and giving companies manufacturing and assembling EVs in Rwanda a preferential 15% Corporate income Tax rate and a tax holiday.[31]
United Kingdom Net zero strategy	The UK Treasury participated in the development of the UK Net Zero Strategy, which sets targets to reduce emissions for each sector, by assessing the fiscal implications, risks of the transition, social impacts, and investment needs. It also led a Net Zero Review which examined the implications of the transition for households, government finances, and the economy's competitiveness.
Uruguay Power sector decarbonization	Uruguay's Ministry of Economy and Finance supported the transformation of the power sector towards a system almost fully supplied by renewables (renewables supply 85%-100% of electricity generation, varying depending on the availability of hydropower),[32] by providing tax incentives for renewable energy development, deployment, and investment. The ministry also used a macroeconomic model to test effect of emissions reduction targets on macroeconomic variables, informing the Uruguay's Nationally Determined Contribution.
USA Clean technology industrial policy	The US Treasury played a central role in designing the Inflation Reduction Act, the legislation containing fiscal incentives for investment in clean energy technology manufacturing and deployment across a wide range of sectors.[33]

Adapted from LSE (2023) Strengthening the role of Ministries of Finance in driving climate action, with input from Nick Godfrey and Anika Heckwolf (LSE).

31 Government of Rwanda (n.d.). Supercharging Rwanda's E-mobility Transition; MININFRA (2021). Rwanda has awesome new incentives for electric vehicles.

32 International Trade Administration (2024). Uruguay – Country Commercial Guide.

33 US Department of the Treasury (2022). The Inflation Reduction Act Program Office.

Financing the transition

Significant additional investment is needed for the low carbon transition – and mobilising it requires the right policies, informed by good analytical tools. Even if the transition saves costs overall, additional investment will be needed in coming decades due to the high capital intensity of clean technologies and the need to install new infrastructure systems. The additional investment required for the energy transition in developing countries and emerging economies other than China has been estimated at $1.3 to $1.7trn per year by 2030[34] and estimates for the additional investment needed globally for the transitions in energy and land use systems range up to $3.5trn per year from the present to 2050,[35] though these numbers are subject to considerable uncertainty. Far larger amounts – in the range of $5trn to 7trn/year – are estimated to be needed to meet the Sustainable Development Goals.[36] This is a particular challenge in emerging and developing economies, where high financing costs present a major hurdle.[37]

In each sector, the financing needs are different at each stage of the transition. Public funding tends to be more important in early stages, while private finance – including loans, bonds, and equity – becomes increasingly important in later stages, due to the large financial resources required for deploying new technologies at scale. In between, venture capital and public support for demonstration and pilot projects can be important to help technologies cross the 'valley of death' between demonstration and first commercialisation.[38]

At every stage, well-designed policies can help to mobilise more private investment, reducing the cost of capital and the proportion of new investment that falls on the public balance sheet. Finance ministries may implement or oversee policies that provide public finance for the transition, such as grants, capital allowances, concessional lending from a national development bank, equity investments, and risk guarantees. These are more likely to mobilise high levels of private investment if there is high private sector confidence in the growth prospects of the new technologies. This depends in turn on market-shaping policies such as subsidies, taxes, and regulations, over which finance ministries have significant influence, as discussed below (see Figure 3). In developing countries, the cost of capital often also depends on global financial factors beyond their control.

34 Songwe, Stern, and Bhattacharya (2022). Finance for climate action: scaling up investment for climate and development.

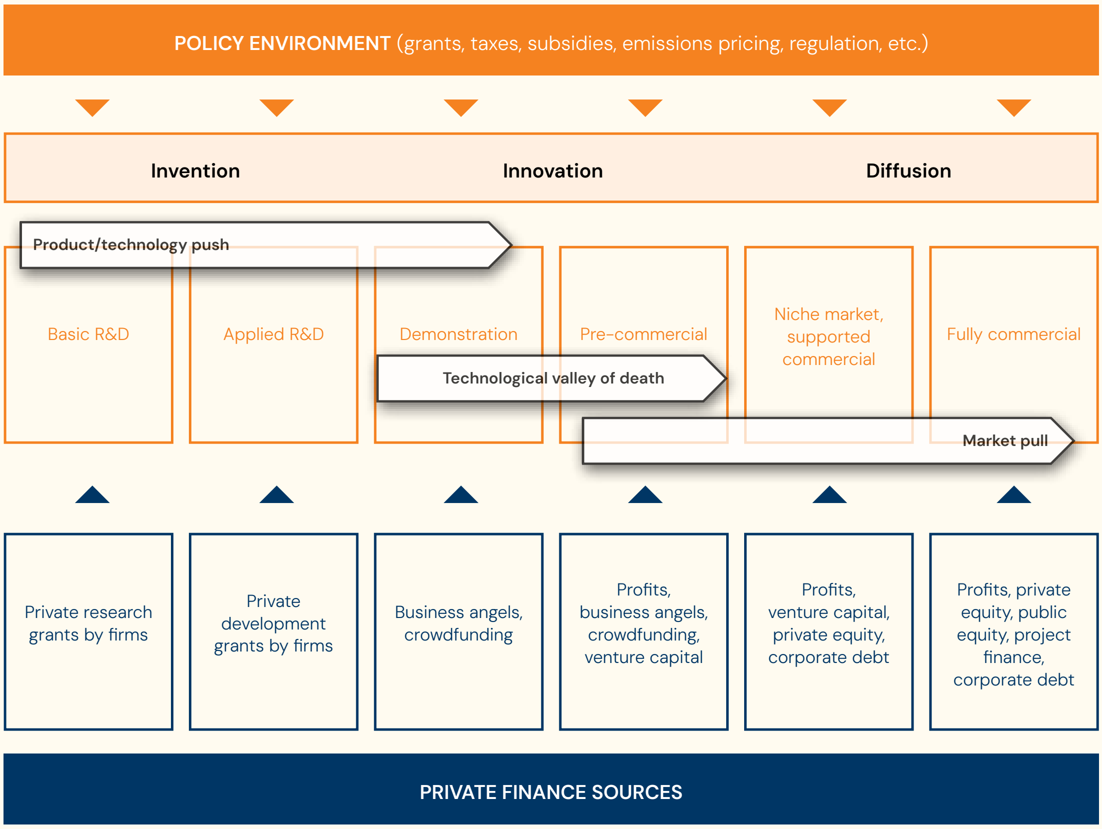
35 Krishnan et al. (2022). The net-zero transition; ETC (2023). Financing the Transition: how to make the money flow for a net-zero economy.

36 UNCTAD's World Investment Report 2014 estimated that in the range of $5–7trn per year was needed between 2015 and 2030 to achieve the SDGs globally. Its Trade and Development Report 2023 called for $4trn yearly in developing countries alone.

37 IEA. (2024). Strategies for Affordable and Fair Clean Energy Transitions.

38 Grubb (2013). Planetary Economics: Energy, Climate Change and the Three Domains of Sustainable Development.

Figure 3: Public and private sources of finance across the innovation chain



Adapted from Polzin (2017) Mobilizing private finance for low-carbon innovation – a systematic review of barriers and solutions, and Wurstenhagen and Menichetti (2012), Strategic choices for renewable energy investment: conceptual frameworks and opportunities for further research.

The nature of decision-making

Decision-making in the context of the low carbon transition, or low carbon growth, is not simple for several reasons: a) structural change (development or transition) is both an aim and the context; b) policy problems are dynamic, not static; c) the transition is characterised by uncertainty, and the future effects of policies generally cannot be predicted precisely; d) stakeholders, analysts, and experts can give conflicting advice (due to different interests, preferences, and assumptions); and e) what works well varies according to economic sector, place, and time. Judgement is therefore essential. Decision-making on the transition is concerned with the pace of change, as well as with its opportunities and risks. As with any area of public policy, it is characterised by trade-offs and constraints. For all countries, but most acutely for developing countries, limited fiscal space forces choices between objectives. Political challenges are considerable, since the structural change that is central to the transition strongly affects private sector interests, and can also affect living costs and livelihoods.

These characteristics, together with the interests at stake mentioned above, create the need for both quantitative and qualitative analysis. Faced with difficult decisions, governments need the best possible information and assessment of their options. This may include explicit acknowledgement of the different findings that can arise from different choices of assumptions, analytical frameworks, and tools. In this report, our discussion of analytical tools does not presume that decision-making is 'technocratic' and undertaken in the absence of politics. Analysis is an input to political decision-making, not a substitute for it. All policies need political capital to implement; good analysis can help ensure that political capital, as well as financial capital, is not wasted.

The importance of analytical tools

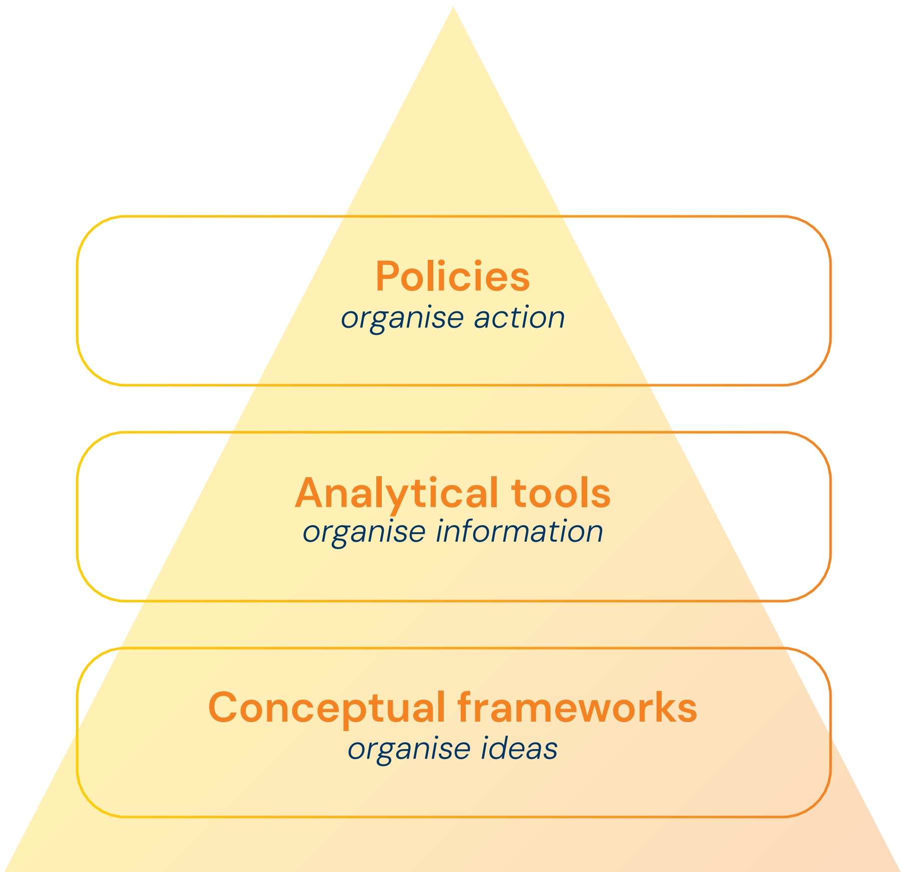
Good analysis helps finance ministries take policy decisions that realise and expand the economic opportunities of the low carbon transition, and limit the risks. Analysis can clarify the costs, benefits, opportunities, and risks of alternative policy options, enabling better decisions.

In this report our focus is on analytical tools – models and other forms of analysis that arrange and process information in ways that can help inform policies – and not on the policies themselves. We also consider conceptual frameworks – ways of understanding the context and role of policy – since these can be used both as a complement and as a substitute for analytical tools. As an example of this relationship:

i. The conceptual framework of welfare economics, and within that, the concept of 'market failure', provides a way of judging when a policy intervention may be justified.

ii. Having decided that there is a case for intervention, an economic model (an analytical tool) may be used to predict the costs and benefits of different policy options.

iii. Once a policy (such as a tax) is chosen and implemented, it will influence actions in the economy, such as the investment decisions of companies or the purchasing decisions of consumers.



It is always important to choose the right tools for the task – and there is reason to believe that the right analytical tools for the low carbon transition are not yet widely available. The extensive consultations with finance ministries that informed the Guide led to the conclusion that 'Ministries of Finance will need to place an ever-greater emphasis on upgrading existing tools and/or developing new tools to support decision-making' in relation to climate change and the low carbon transition. Innovation and industrial competitiveness were among the issues found to be particularly challenging to address, with the analytical approaches most commonly used by finance ministries at present. Similarly, researchers from the UK, China, India, and Brazil working together in the Economics of Energy Innovation and System Transition (EEIST) project have found that a different set of decision-making frameworks, principles for policymaking, and economic models may be needed to inform policy on the low carbon transition, compared to those that are appropriate in contexts where innovation and structural change are not central considerations.

The aim of this report is to help finance ministries identify the analytical tools and conceptual frameworks that will be most useful for informing their decisions in relation to innovation and competitiveness in the low carbon transition. Throughout this report we discuss concepts and tools that arise from two strands of economic research: one that is based on theories of equilibrium and marginal change, suitable for situations of stability and reliable information, which is already widely used within finance ministries; and the other that is based on theories of innovation and structural change, and approaches to dealing with uncertainty, which is less commonly used at present. (This distinction is discussed in Section IV). Since the former set of tools will already be familiar to our readers, we concentrate mainly on presenting the latter set, showing how it can address some of what would otherwise be analytical gaps. We note that in many cases different tools are complementary, and that in all cases such tools can only provide an incomplete picture, which must be complemented with other evidence, expertise, and judgement.

II. Policy questions

This assessment is informed by views expressed by finance ministries in a series of C3A programme workshops and meetings of the Coalition of Finance Ministers for Climate Action,[41] as well as by aforementioned work in the EEIST project,[42] and by the Guide, which itself was based on earlier consultations. This is a preliminary assessment, and we expect it to evolve in response to further exchanges with finance ministries through the C3A programme and other relevant initiatives.

Based on these discussions, we understand finance ministries to be interested in the following policy and analytical questions relevant to innovation and competitiveness in the low carbon transition. In this list we have roughly divided the questions into groups related to 'innovation' and 'competitiveness' for ease of reference, but in reality the two are closely related to each other.

41 These included C3A programme workshops in Paris (June 2023), Santiago (September 2023), Marrakech (October 2023), Almaty (May 2024), and Brasilia (June 2024), a workshop on green macroeconomic modelling co-hosted by the Coalition of Finance Ministers for Climate Action in Venice (November 2023), an online workshop to launch the C3A Innovation and Competitiveness hub (January 2024), the Sherpa meeting of the Coalition of Finance Ministers for Climate Action in The Hague (February 2024), and a forum on the macroeconomics of green and resilient transitions hosted by the governments of the USA and Denmark together with the Coalition of Finance Ministers and the Bezos Earth Fund (April 2024).

42 A collaborative research project to develop analytical tools appropriate for situations of innovation and structural change, and apply them to policy decisions relevant to the low carbon transition. Website: https://eeist.co.uk/

Innovation

Table 2: Policy questions on innovation and deployment

Label	Policy question	Relevance
A	**How can innovation and investment in low carbon technologies drive economic development and improve a country's economic prospects?**	An overarching strategic question which may be informed by the other questions below.
B	**Which technologies have the greatest potential for further innovation and cost reduction, in each of the sectors most affected by the low carbon transition?**	Relevant to finance ministries' interest in achieving a cost-effective low carbon transition, and to interests in economic strategy, national competitiveness, and emissions reduction.
C	**How can policies best contribute to accelerating clean technology innovation, cost reduction and diffusion?**	Relevant to understanding the effectiveness of market-shaping policies that influence consumer demand and industry investment in new technologies, including: carbon pricing and other taxes; public procurement; deployment subsidies and the progression towards 'subsidy-free' deployment of clean technologies while increasing private investment; and the use of regulation to achieve similar outcomes at lower public cost. Finance ministries are interested in which policies and market designs most cost-effectively support the diffusion of clean technologies, and how this affects the costs of goods and services.
D	**How much can clean technology costs be reduced by factors subject to domestic control and influence, and how much will they depend on international factors?**	Relevant to decisions about which technologies and policies to support, and the timing of those policies.

Competitiveness

Table 3: Policy questions on competitiveness

Label	Policy question	Relevance
E	**How can countries identify sectors or product categories relevant to the low carbon transition in which they could be internationally competitive?**	Relevant to identifying opportunities for economic diversification, and understanding where the transition may create risks to existing competitive positions. Opportunities and risks are relevant to judging the value of potential public investments and to understanding how the transition may affect tax revenues.
F	**Which policies are likely to be most effective in increasing a country's competitiveness in a technology or sector, in the context of the low carbon transition?**	Relevant to the increasing number of countries developing innovation and industrial policies with the aim of supporting the growth of new low carbon sectors (as noted in the Guide). Finance ministries are interested in understanding the effectiveness of policy options such as manufacturing subsidies, tax credits, domestic content requirements, trade tariffs, and carbon border adjustments, and how to respond to other countries' use of such policies. With respect to trade and the low carbon transition, finance ministries are interested in how best to balance the objectives of accessing low carbon technologies on international markets at low cost, enabling the growth of domestic industries, and improving trade balances, and in how to realise first-mover advantages while avoiding first-mover disadvantages.[43]
G	**How will the low carbon transition affect supply chains and jobs, globally and nationally?**	Understanding how global supply chains will change due to the transition is relevant to judgements about where countries may realistically be able to build competitiveness. Understanding how the transition will affect labour markets is relevant to budget management, as it has implications both for tax revenues and for expenditure – for example on social security.

Finance ministries also have strong interests in policy and analytical questions that relate these issues to those covered by other themes of the C3A programme. Most notably, these include understanding which policies and strategies for the low carbon transition will have the best macroeconomic outcomes (H); how policies can best mobilise private investment in clean technologies (I); and how policies for the low carbon transition will interact with interests in climate resilience and the preservation or regeneration of natural capital.

In the main part of this report, where we consider a range of conceptual frameworks and analytical tools, we use the letters A – I from the list above to indicate the policy questions to which each tool is relevant.[44]

While these questions summarise common interests expressed by a diverse set of countries, there is wide variation between countries in the specific responsibilities and policy interests of their finance ministries, and in their analytical needs and capabilities, resources, and national circumstances. For some, ensuring access to affordable goods and services may be a greater priority than promoting innovation and competitiveness. It will be important for countries' unique interests to be addressed as closely as possible in any in-depth knowledge exchange and capacity building initiatives.

43 Note that the World Bank report The Trade and Climate Change Nexus: The Urgency and Opportunities for Developing Countries (2018) provides a comprehensive overview of the ways in which trade and climate change intersect.

44 In many cases, we describe the policy questions a framework or tool can address in terms that do not exactly match the questions in this list. This reflects the unique capabilities and limitations of each framework and tool, which we attempt to describe as accurately as possible.

III. Defining innovation, diffusion, structural change, and competitiveness

In general terms, *innovation* is the process of development and improvement of technologies that takes place continually from research to diffusion. This process is often depicted as an 'innovation chain' in which the rate and direction of innovation is influenced by both 'technology-push' and 'demand-pull' policies.[45] Here, we make a distinction between innovation at different stages in this process, and subsequent stages of a technology transition, to help explain the focus of this report.

Governments can support innovation at each stage of the chain. In the earliest stages, governments can support research and development through direct funding in public institutions, or through tax incentives for private companies. In the later stages, governments can support cost-cutting innovation through policies that create and expand markets for the new technology.[46] In this report, our focus is on cost-cutting innovation, because policy decisions in this domain are likely to be informed by economic analysis, whereas decisions on research and development tend to be more heavily reliant on pure subject matter expertise.[47]

***Diffusion* is the process by which technologies are adopted and spread through markets and societies.** Rapid diffusion of low carbon technologies (towards widespread deployment by businesses and adoption by consumers) is essential to meet climate change policy objectives.

Diffusion and cost reduction are mutually reinforcing. Lower costs make a technology more attractive; and growing market share (which policies can promote) can drive increased investment, innovation, and cost reduction. This process benefits from several positive feedback effects:[48]

- i learning-by-using (increased deployment leads to improvements in user contexts);
- ii network externalities (expanding user networks enhances the technology's attractiveness, as for example with telephones);
- iii scale economies in production (allowing the price per unit to decrease);
- iv informational increasing returns (wider use improves visibility and awareness of other users); and
- v technological inter-relatedness (wider use stimulates the development of complementary innovations).

***Structural change* is the process by which the economy, through technological change, reinvents itself.** It involves the growth of new sectors, and the decline of old activities.[49] Each act of adoption of a new technology makes an incremental contribution towards structural change. For example, adoption of electric vehicles increases demand for batteries, and reduces demand for oil. Eventually, this process can be expected to lead to transformational change in markets for oil and its derivatives. The change is social as well as technological, in its drivers and in its outcomes. Political choices, reflected in regulations and investments, and social norms, reflected in consumer choices, influence the rate of uptake of new technologies. The occupations that people have change as a result of the transition. In this example, fewer oil engineers and more people with electrochemical knowledge will be needed.

***Competitiveness* refers to the ability of a country's products or services to compete successfully in international markets.** Innovation, at all stages of the chain, can be a strong driver of competitiveness, while factors including exchange rates, trade policies, marketing, and financing systems, and corporate strategies are also influential. Governments can influence competitiveness by acting on these variables as well as through policies designed to increase innovation.

45 Kline, S. J., & Rosenberg, N. (1986). An overview of innovation.

46 The innovation in the earliest stages can be classed as 'radical innovation', including research, invention and development of new technologies. 'Cost-cutting innovation' takes place from the demonstration of a new technology through its first deployment to its wider diffusion. Cost-cutting innovation can itself be divided into product innovation (the development of new technologies, manufacturing methods, and systems) and process innovation (the work of improving manufacturing processes, which lower production costs and improve product quality through continual problem solving and through the economies of scale that result from increasing production).

47 The International Energy Agency estimates that 65% of the emissions reductions needed to reach net zero emissions across energy and industrial sectors by 2050 can be achieved with technologies that are already available in markets. (IEA (2023d). Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C in Reach.) These low carbon technologies are new compared to the fossil fuel technologies they displace, suggesting that there is significant potential for their costs to fall as they are more widely deployed. (Way et al. (2022). Empirically grounded technology forecasts and the energy transition.)

48 Arthur, B. (1989). Competing Technologies, Increasing Returns, and Lock-In by Historical Events. The Economic Journal, 99(394), 116– 131.

49 Semieniuk, et al. (2020). Low-carbon transition risks for finance.

IV. Choosing the right tools for the task

Different analytical tools can lead to different policy conclusions. This is because models and other analytical tools are incomplete representations of reality, and because each analytical tool is based on a set of concepts and theories about how the economy works. For example, in a study for the European Commission, one model forecast that the low carbon transition would incur a net economic cost, while another forecast a net economic benefit.[50] The divergence came from different theoretical foundations: one model assumed financial resources in the economy were fixed and fully employed, so that low carbon investment would displace other more efficient investment, while the other model assumed that financial resources would be created by banks in response to demand. It is therefore useful for governments to be aware of the theoretical foundations of different analytical tools, and to choose the most appropriate tools for any given problem.

In the context of the low carbon transition, it is important to distinguish between problems of marginal change and those of structural change. In problems of marginal change, the environment within which economic actors take decisions, and the relationships between economic variables (such as prices and quantities) can be assumed to be stable. Within these relatively static contexts, when economic actors have enough information to be confident in the outcome of their decisions, they can calculate costs and benefits and pursue strategies of optimisation. A utility company making short-term decisions in a competitive electricity market may exhibit this behaviour. In problems of structural change, the economic environment is not fixed: changes in technology, infrastructure, and institutional systems transform the relationships between economic variables. Economic actors face significant uncertainties and must take decisions based on interpretation and judgement. An example is a government using policy to create a first market for a new technology such as solar power.[51]

In stable 'marginal change' contexts with clear and reliable information, static, equilibrium-based tools and theories are most applicable. The foundations for this set of tools are the theories of welfare economics, where economic actors are assumed to use cost–benefit calculations and perfect information to determine optimal actions.

In contexts of structural ('non-marginal') change, with significant uncertainties, dynamic, disequilibrium tools and theories are more appropriate. These include evolutionary, institutional, and complex systems economic theories, and tools designed to help actors make strategic decisions based on analysis of risks and opportunities.[52]

The dynamic, disequilibrium set of concepts and tools is particularly relevant to problems of innovation and competitiveness in the low carbon transition. This is because problems of innovation and competitiveness typically involve significant uncertainty, and the low carbon transition creates a context of structural change. Consequently, this set of concepts and tools is the main focus of this report. We also discuss concepts and tools from the static, equilibrium set, because these are most widely used at present in finance ministries (as well as in other departments of government). Table 4 indicates a rough division between the applicability of these two families of tools and theories.

50 Mercure, J.- F., et al. (2016). Policy-induced energy technological innovation and finance for low-carbon economic growth.

51 Grubb, et al. (2015). The Three Domains structure of energy-climate transitions. The 'Three Domains' framework refers to these different domains of decision-making as 'optimising' and 'transforming' respectively, and also describes a domain of 'satisficing' in which economic actors take decisions based on routines, heuristics and convenience.

52 Ibid.

Table 4: Summary of the key differences between the purpose and rationale for policy when marginal or non-marginal change is the objective or expectation, along with the appropriate assessment framework, theoretical underpinnings, and analytical models.

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

Source: Grubb et al (2021) The New Economics of innovation and transition: evaluating opportunities and risks.

There are advantages in using multiple concepts and tools. Governments can use models with different theoretical foundations for different purposes. For example, in Brazil, a model based on environmental economics theory was used to inform the Integrated Long-Term Infrastructure Plan, while a macroeconometric model based on post-Keynesian theory (where investment is driven by demand) was used to inform fiscal policy. Governments can derive useful insights from the differences as well as the similarities in findings from different analytical tools.

Are the analytical tools and frameworks discussed in this report equally relevant to developed and developing countries?

Many of the tools discussed in this report are equally relevant to countries that are developed or developing, large or small. A finance ministry in any country wants its policies to be cost-effective, and so has an interest in choosing the appropriate decision-making frameworks. Countries of all kinds are interested in how to identify the technologies likely to be successful in the low carbon transition, and how to anticipate the transition's likely macroeconomic effects.

There are areas where countries are likely to differ in analytical needs, and yet still find some overlap in the analytical tools and frameworks that may be used. These include:

- **Cost-cutting innovation:** Countries with larger, more developed economies have greater potential than countries with smaller economies to use deployment policies to drive cost-cutting innovation in clean technologies. However, many of the analytical tools relevant to considering this opportunity can also be used to identify policies for cost-effective diffusion of clean technologies, which matters equally in a market of any size.
- **Industrial competitiveness:** Larger and more developed countries have a wider range of options and greater potential for developing competitiveness in clean technologies; for some smaller or less developed countries this may be less of a priority or less feasible. Still, many developing countries are interested in how the low carbon transition will affect their opportunities for economic diversification and growth, and how changes in global value chains could alter their positions of comparative advantage.
- **Finance:** All countries are interested in how to mobilise private finance for the transition, but developing countries face greater difficulties in doing so, and higher costs of capital. This creates a greater need for analytical tools that explicitly consider financing options at both the sector and macroeconomic levels. Tools discussed in this report that can incorporate an explicit representation of finance include sector-specific system dynamics and agent-based models, and disequilibrium macroeconomic models.

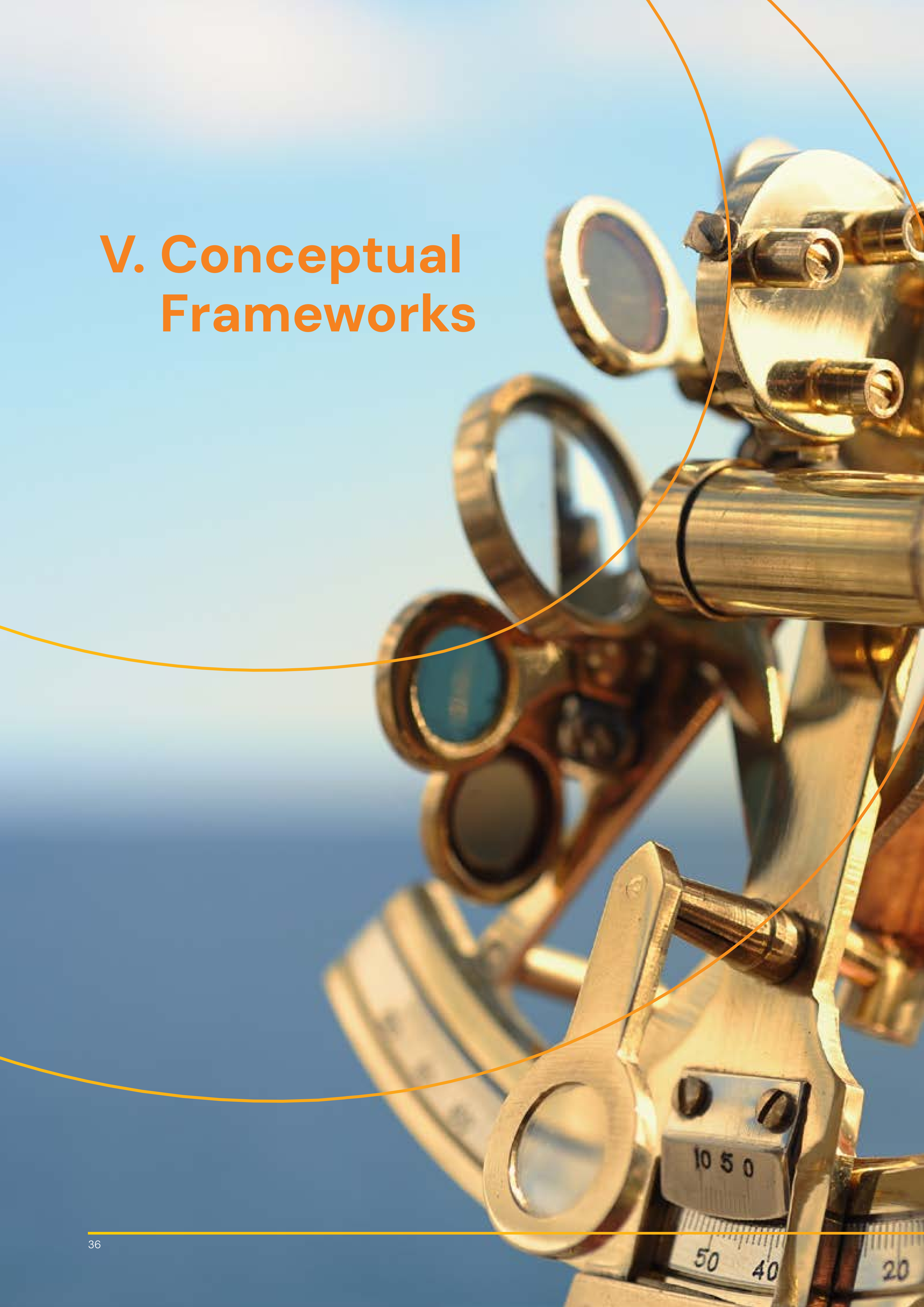
While many of the same analytical tools may be relevant in principle to developed and developing countries, in practice there may be important differences, particularly regarding economic models. For example, a technology diffusion model for road transport that only represents sales of new cars may be less useful to a country that relies on the second-hand market, and may have been designed to model policy interventions more likely to be used by some countries than others.[53] Labour market models may be less applicable if a large part of the labour market is informal and undocumented. Data availability limitations often mean that global models only represent larger countries in detail.

An additional consideration is capacity within government for the use of analytical tools, which may differ widely between countries. Developing countries may face more complex challenges in building national innovation ecosystems, at the same time as having weaker analytical and policymaking capabilities within government.[54] In the Conclusion chapter of this report, we include a table with a rough assessment of the relative ease of difficulty of adoption of each framework and tool.

53 Cirera & Maloney (2017) highlight that developing countries are likely to have more limited options for innovation policies compared with developed countries based on more limited capabilities – but many models have been designed first and foremost to model policy interventions delivered by the largest economies.

54 Cirera & Maloney (2017). The Innovation Paradox: Developing-Country Capabilities and the Unrealized Promise of Technological Catch-up.

V. Conceptual Frameworks



1. What is the rationale for policy?

Before considering specific policy options, governments often ask themselves more general questions: is there a need for policy at all? Why should there be? What is the role of policy in this situation? Here we outline two conceptual frameworks that can be used to respond to these questions: the market failure framework, and the market-shaping framework. (These are, respectively, grounded in the static and dynamic families of economic theories and tools described in the previous chapter).

Market failure

Market failure has been defined for policy purposes as a situation 'where the market alone cannot achieve economic efficiency', with economic efficiency being defined as an imagined state where nobody can be made better off without someone else being made worse off.[55] Its core assumptions are:

i. That a state of 'economic efficiency' (optimal allocation of economic resources) exists and is possible.

ii. That overall economic welfare is reduced when deviations from this state occur. Causes of these 'market failures' include asymmetries of information, misalignment of public and private interests and incentives, and coordination failures.

iii. That policy can improve economic outcomes when it addresses a market failure, and may worsen economic outcomes when it does not.

Governments often use the market failure framework to distinguish between situations where policy intervention in the economy is necessary, and situations where the private sector can be left to itself. If applied appropriately, this can help restrain overactive policymaking, and may be valued by finance ministries as a check against other government departments' spending proposals.

While the market failure framework can be useful, it also has limitations in relation to policy interests of innovation and competitiveness in the low carbon transition, for which its core assumptions are not usually valid. It has long been recognised that in the presence of one uncorrected market failure actions to correct other market failures will not necessarily improve overall economic efficiency.[56] Alternately stated, actions that introduce additional deviations from the theoretically optimal conditions may improve economic outcomes. This means that the concept can be unreliable as a guide to policymaking in situations where multiple market failures are present.[57] The low carbon transition is such a situation: the negative externality of GHGs is not the only market failure. Others include the disparity between public and private benefits from research and development, imperfections in capital markets, network effects and increasing returns to scale in technological change, coordination failures in relation to infrastructure systems and cross-sector decarbonisation opportunities, information asymmetries, and social benefits of emissions reduction that are not rewarded by markets.[58]

55 This notion of optimal allocation of economic resources follows here the concept of Pareto optimality, which says nothing about the fairness of the initial distribution. The optimal allocation is compatible with a state of extreme inequalities. UK Treasury, 2018. 'The Green Book: Central Government Guidance on Appraisal and Evaluation'.

56 Lipsey & Lancaster (1956). The General Theory of Second Best.

57 Government analysts may also consider the 'Tinbergen Rule', that to achieve a given number of policy objectives, at least the same number of policy instruments is required. This can be interpreted as implying that there should be one policy for each market failure. However, in the context of multiple interacting market failures, the effects of policies will also interact, and the relationship between combinations of policies and combinations of outcomes is likely to be more complex.

58 Stern et al. (2022). The Economics of Immense Risk, Urgent Action and Radical Change: Towards New Approaches to the Economics of Climate Change.

Table 5: The many market failures of climate change and the low carbon transition

Market failure	Explanation	Example policy response
GHG and air pollution negative externalities	Markets overproduce GHGs and air pollution because the 'social cost' is not reflected in market prices, meaning there is insufficient incentive to invest in reducing them	• Carbon/pollution tax • Emissions cap-and-trade scheme
R&D and innovation positive externalities	Markets underinvest in low carbon technology research and development because private benefits to the innovator are not as great as social benefits	• Public funding of research and development • Tax incentives for private R&D • Support for technology demonstration/first deployment
Imperfect information in capital markets	Markets underfinance low carbon projects given perceived high risks, long payback periods vs short-term incentives, underestimation of climate or transition risks of inaction, or the presumption that losses will be socialised	• Government concessional lending through green development banks, green bonds, or blended finance • Climate/transition risk disclosure and stress-testing requirements for financial institutions
Network effects and infrastructure coordination failure	Markets under-deploy low carbon technologies given lack of infrastructure to support them, and under-develop infrastructure for low carbon technologies given dominance of fossil fuel products	• Public investment in infrastructure to support diffusion of low carbon technologies • City planning
Information deficits and suboptimal choices	Consumers and firms do not purchase or produce low carbon technologies given inadequate information, or undervalue long-term benefits of low carbon investments	• Labelling and information requirements on products • Information campaigns to increase awareness of options
Other 'co-benefits' (positive externalities) of low carbon technologies	Markets undervalue the broader environmental, health, energy security, productivity, and other societal benefits of many low carbon technologies	• Policies valuing and protecting ecosystems and biodiversity • Streamlined permitting for low carbon projects
Negative macroeconomic externalities such as losses of productivity and competitiveness losses from climate change and transition impacts	Markets do not fully anticipate the macroeconomic effects of sector-level technology transitions	• Policies for adaptation • Social support and reskilling of workers in fossil fuel industries

Based on Stern & Stiglitz (2021). The social cost of carbon risk, distribution, market failures: an alternative approach, and Stern et al. (2022). The economics of immense risk, urgent action and radical change: towards new approaches to the economics of climate change.

More fundamentally, the market failure framework is concerned with making the best use of a fixed set of economic resources at a fixed point in time, but is less suitable when the aims of policy are to create *new* resources or structural change over the course of time (dynamic efficiency, rather than allocative efficiency).[59] Such contexts involve deep uncertainties, meaning no optimal outcomes can be calculated or reliably identified.[60] For example, the empirical evidence on solar power shows that strong policies have helped to drive innovation and make solar energy 'the cheapest source of electricity in history',[61] a beneficial economic outcome regardless of the GHG market failure (and similarly positive effects from policies on wind power and electric vehicles). In such contexts, while the market failure framework can be compatible with the use of a diverse range of policies, it becomes less reliable as a guide to whether a policy intervention is justified.

59 Kattel et al. (2018). The Economics of Change: Policy and Appraisal for Missions, Market Shaping and Public Purpose. Historical studies show that government actions that went well beyond correcting market failures have been instrumental in the creation of new technologies and new markets.

60 It may also be considered that in contexts of structural change, solving the utility optimisation problem changes the resources (e.g. technologies) present in the economy, which changes the boundaries of the optimisation problem itself, creating an infinite number of pathways forward, and no single solution to the problem.

61 IEA. (2020). World Energy Outlook 2020. Nemet, G. (2019). How Solar Energy Became Cheap.

Market shaping

Market shaping refers to the ability of governments to design, grow, or alter markets in ways that influence their functioning and outcomes. Whereas market failure is typically defined in relation to the allocation of economic resources, market shaping is concerned with the creation and change of economic resources and structures. Its core principles are:

- **i** In contexts of innovation and structural change, no optimal allocation of economic resources exists, because the possibilities are continually changing.[62]
- **ii** Innovation and growth in the economy can vary in their direction, as well as their rate.[63] Many different economic futures (including many different low carbon pathways) are possible.
- **iii** For many technologies and emerging sectors, markets do not yet exist and must be created along with the technologies.
- **iv** All markets are co-created by governments, private, and third sectors. They are shaped by many factors: institutions, infrastructure, regulations, taxes, industrial and financial structures, social norms, trade policies, and more. All these factors influence the functioning and outcomes of markets, and many of them can be changed by policy.
- **v** Policy can improve economic outcomes when it shapes markets to prepare for change that is likely, bring about change that is desirable, or avoid change that is undesirable.[64]

The market-shaping framework is relevant to many policy decisions on the low carbon transition. It can be used to consider whether policies are consistent with a desired direction: will they promote innovation and growth in ways aligned with the elimination of GHG emissions from the economy? [Policy question C] It can also be used to consider compatibility with likely change: if the global low carbon transition is likely to move a given sector from fossil fuels to clean technologies, which policies are consistent with preparing a country's economy to be competitive in that context? [F]

Example

Governments have used market-shaping policies to support the rapid development and deployment of solar power. Capital-intensive investments, through public procurement and deployment subsidies in the US, Japan, and Germany from the 1970s to the 2000s, created early markets for the technology, stimulating innovation and the development of industrial supply chains.[65] China's support for manufacturing and deployment expanded economies of scale, increasing investment, and accelerating cost reduction. Many countries are now enabling the diffusion of solar power through changes to infrastructure – expanding electricity grids – and by creating new financing structures, such as fixed-price contracts that help manage risks and lower the cost of capital. In the early stages, these policies did little to reduce emissions, since solar power was only a small fraction of electricity generation. They could be justified by the market-shaping framework, because they drove innovation and growth in the direction of low emission and low cost electricity.

Contrasting assessments	
	Market failure In the early decades of development of solar photovoltaics, policies such as public procurement and deployment subsidies were not typically seen as justified by the market failure framework, since there were much cheaper ways to reduce emissions at those moments in time (for example by using carbon pricing or efficiency regulations to make coal power plants more efficient).
	Market shaping Deployment subsidies and public procurement could be justified by the market-shaping framework, since they guided investment and innovation in a desired direction. The outcome of 'the cheapest electricity in history' may be seen as desirable, regardless of the existence of the market failure of GHG emissions.

62 Arthur (2013). Complexity economics: a different framework for economic thought.

63 Mazzucato (2016). From Market Fixing to Market-Creating: A new framework for innovation policy.

64 Kattel et al. (2018). The economics of change: Policy appraisal for missions, market shaping and public purpose.

65 Nemet (2019). How Solar Energy Became Cheap.

The market-shaping framework implies a different approach to policy appraisal compared with the market failure framework, reflecting the different nature of problems to which it is appropriately addressed (summarised in Table 6).

Table 6: Comparing the market failure and market-shaping conceptual frameworks. Adapted from Kattel, R. et al. (2018). The economics of change: policy and appraisal for missions, market shaping and public purpose.

	Market failure	Market shaping
Underlying principles	Equilibrium and utility maximisation	Disequilibrium and evolutionary
Rationale for policy	To address market failures, such as negative externalities, imperfect competition or information, or coordination failures	To ensure markets support public interests, by preparing for change that is likely, creating change that is desirable, or avoiding change that is undesirable
Nature of problems addressed	Low uncertainty	High uncertainty (such as results from radical innovation and structural change)
	Desired or expected change is marginal/ incremental	Desired or expected change is non-marginal/structural
	Cause-and-effect relationships are known, proportionate, linear	Cause-and-effect relationships are uncertain, disproportionate, non-linear
Principles applied to policy appraisal, evaluation, and monitoring	Value predictable, quantified future outcomes	Value likelihood and strength of alignment with desired direction of change
	Minimise uncertainty in analysis	Work constructively with irreducible uncertainty
	Focus on efficiency of operation; minimise distortion	Focus on efficiency of change; identify points of greatest leverage
	Assess deterministic effect of each action individually (micro level)	Assess emergent effects of all actions collectively
	Value evidence of optimality	Value evidence of adaptability and resilience to unexpected events

Adapted from Kattel, R. et al. (2018). The economics of change: policy and appraisal for missions, market shaping and public purpose.

Limitations

The market-shaping framework is less restrictive than the market failure framework regarding the role of policy. The market-shaping framework is less restrictive than the market failure framework regarding the role of policy. It allows for a wider range of purposes for which policy may be justified, and implies a more active and creative role for government. This greater flexibility carries associated risks: of misuse (for example justifying the allocation of public resources to politically favoured private sector actors); and of mistakes – not all market-shaping policies will be successful. It requires more judgement to be exercised in deciding whether there is a rationale for policy. In addition, a state proactively engaged in shaping markets requires the skills and capabilities to do so. These can be slow to build.

2. How can policy advance technology transitions?

For policymaking on the low carbon transition, it can be useful for governments to include in their analytical toolbox conceptual frameworks designed specifically to inform policy in contexts of uncertainty and structural change. Here and in the following section we present closely related conceptual frameworks of this kind, which can support policymaking on technology transitions and industrial strategy.

The multi-level perspective on transitions

The multi-level perspective (MLP) is a conceptual framework for understanding the processes involved in socio-technical transitions. A socio-technical transition involves transformational change in energy, food, industrial, or transport systems, from one set of technologies and their associated markets, practices, institutions, and cultures to another. To understand these changes, the MLP uses ideas from evolutionary economics, institutional theory, and social constructivism.[66] It thus resonates with the market-shaping and non-marginal change frameworks discussed above. The framework was developed, tested, and refined through analysis of dozens of historical case studies, including the transitions from horse-drawn transport to automobiles, from sailing to steam ships, and from traditional factories to mass production.[67] Since climate change goals require transitions of this kind in each of the GHG-emitting sectors of the economy, the MLP framework can be used by governments considering which strategies and policies are likely to be effective.[68]

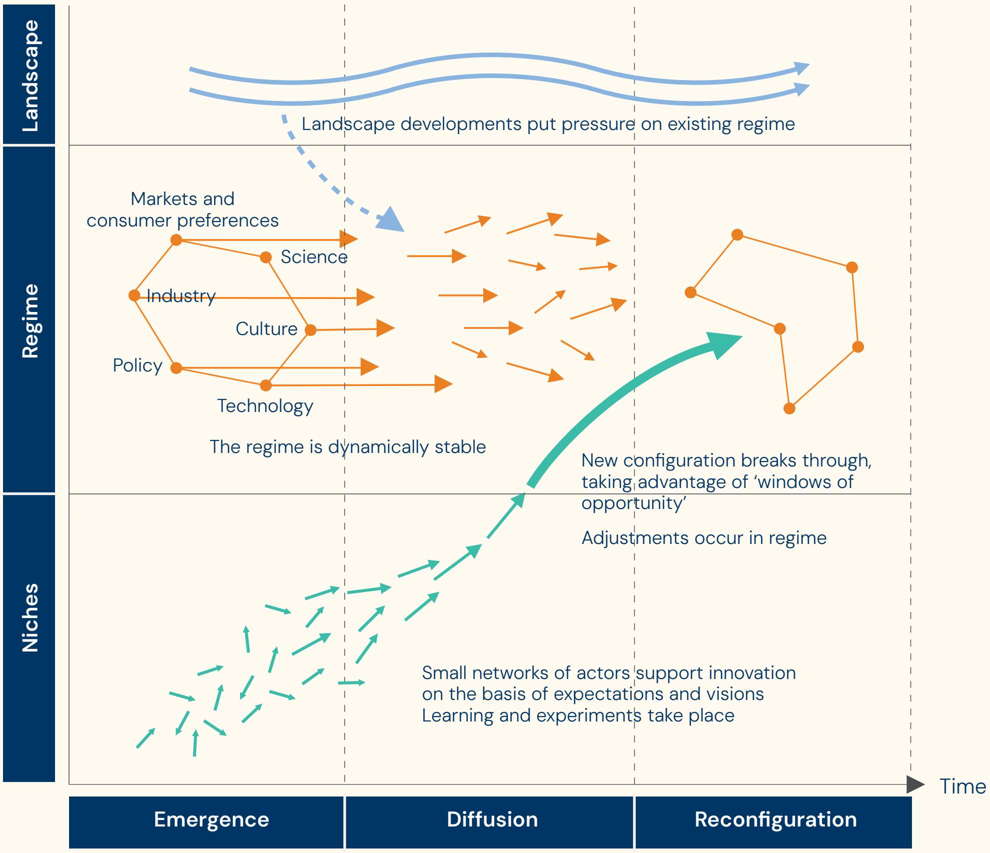
The MLP describes how transitions come about through the interplay of processes across three scales: the niche, regime, and landscape; and unfold in three main phases: emergence, diffusion, and reconfiguration (see Figure 4). Niches are protected spaces that nurture the emergence of radical innovations. The regime is the dominant cluster of technologies, businesses, infrastructures, government institutions, and consumer practices. The landscape is the wider economic and societal context that includes both gradual trends and shocks.

66 Geels (2020). Micro-foundations of the multi-level perspective on socio-technical transitions: developing a multi-dimensional model of agency through crossovers between social constructivism, evolutionary economics and neo-institutional theory.

67 Geels and Schot (2007). Typology of Sociotechnical Transition Pathways.

68 European Environment Agency. (2020). The European Environment – State and Outlook.

Figure 4: the Multi-Level Perspective on Transitions



Source: Victor, Geels and Sharpe (2019) Accelerating the Low Carbon Transition. adapted from Geels (2002) Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study.

The central challenge of transitions concerns how radical innovations first get a footing in small market niches, and then compete with and transform existing regimes. The MLP provides insights into how policy can support this process at each of the three phases of transition:

1. **Emergence:** Entrepreneurs and others pioneer radical innovations, using trial and error in a context of high uncertainty. Competition and learning eventually leads to stabilisation of a dominant design. Policymakers can accelerate these processes by supporting research, development, and demonstration projects, and by establishing niche markets for the first deployment of new technologies, using policies such as public procurement or targeted subsidies.

2. **Diffusion:** The new technology enters mainstream markets and competes head-on with the entrenched regime and vested interests that typically oppose major change. Government can accelerate the diffusion process with policies that give the new technologies an advantage over the old, through regulations, taxes, subsidies, or investments in infrastructure. These deployment policies help drive the positive feedbacks of increasing returns to adoption.

3. **Reconfiguration:** As the new technology becomes dominant and outcompetes the old regime, wider changes take place as systems reorganise around it. Governments can accelerate this process through measures such as supporting the emergence of complementary technologies (for example energy storage and smart grids, to complement renewable power technologies), market reforms, extension of new infrastructures and creation of new institutions, and skills policies that help the workforce adapt to the new industries.

Policy questions

For policymaking in the low carbon transition, the MLP framework is particularly relevant to the questions of:

- Which types of policies are likely to be most effective for advancing clean technology innovation and diffusion within a sector, at its current stage of transition? [C]
- Which types of policies should be planned for, in a given sector, given their likely need in the next stage of its transition? [C]

These questions will be of interest to finance ministries when they participate in developing long-term strategies for emissions reduction, and when they consider the cost-effectiveness of individual policies proposed by other government ministries.

Example

The low carbon transition in the light road transport sector has already passed through the emergence phase, where some governments supported its progress by investing in the research and development of electric vehicle drivetrain and battery technologies. Now that the transition is in the diffusion phase, governments are using policies such as electric vehicle purchase incentives, zero emission vehicle mandates, fuel taxes, and investment in charging infrastructure, to give electric vehicles an advantage compared to petrol or diesel cars. These policies are contributing to the reallocation of industrial capital towards the new technologies, which in turn is driving their continual improvement and cost reduction. In the countries that are furthest ahead in this transition, governments are already beginning to plan for the reconfiguration stage, for example by considering how to ensure universal access to electric vehicle charging infrastructure, and how to replace tax revenues from fuel sales. Understanding the progress of the transition in this way can help governments consider the types of policies most likely to be needed at present, and in the next stage. Insights from the MLP have been used to inform research in the European Commission[69] and the OECD,[70] and to inform policymaking in countries including the UK, Denmark, New Zealand,[71] the US,[72] and Kenya.[73]

Limitations

The MLP provides general 'big picture' insights into the processes of socio-technical transitions based on the patterns they frequently follow. To guide policy on any specific transition, it must be combined with knowledge of the relevant sector and its technologies, and of the relevant country and its social and economic structures. As an interpretive conceptual framework, the MLP indicates which types of policy are likely to be needed at each stage of a transition, but does not provide a means for comparing individual policy options. It necessarily provides a simplification of reality, and the boundaries between levels and stages of the transition are blurred rather than precise.[74]

The MLP has been found to be relevant to developing countries as well as developed economies, despite significant differences in national circumstances.[75] However, countries with larger economies are likely to have more opportunity to influence the global pace and direction of low carbon transitions, while the options available to smaller and less wealthy countries depend more strongly on the international context.

There are governance challenges associated with an active role in technology transitions: governments must use judgement to identify where supporting the development and diffusion of a new technology is in the public interest, while avoiding undue influence from private interests.

69 Directorate-General for Research and Innovation (European Commission), Science, Research and Innovation Performance of the EU 2022: Building a Sustainable Future in Uncertain Times.

70 United Nations Environment Programme. (2022). Emissions Gap Report 2022.

71 Hawley et al. (2020). Leveraging Transport Disruption to Influence Change.

72 Parkhurst et al. (2023). Agricultural Carbon Programs: From Chaos to Systems Change.

73 Dong & Mori (2017). Multi-Level Analysis of Sustainable Energy Transition in Kenya: Role of Exogenous Actors.

74 Geels (2011). The Multi-Level Perspective on Sustainability Transitions: Responses to Seven Criticisms.

75 Wieczorek (2018). Sustainability Transitions in Developing Countries: Major Insights and Their Implications for Research and Policy.

3. How can policies build competitiveness

The role of government in building economic competitiveness is disputed academically as much as it is politically. Our purpose here is not to endorse a particular approach. Instead, we aim to briefly introduce a set of conceptual frameworks – horizontal industrial strategy, and innovation-driven industrial strategy – that governments may choose to use, depending on the circumstances and their own view of their role in national economic strategies.[76]

76 A forthcoming World Bank ETICC Green Investment Climate Diagnostic (GICD) tool and report on policy guidance can be used to assess the quality and effectiveness of a country's regulatory environment to attract green investment and improve the environmental performance either at the economy-wide level or for a specific industry or sub-industry, such as wind turbine or solar PV manufacturing.

Horizontal industrial strategy

The most widely accepted policy approach towards improving national economic competitiveness focuses on creating the right framework conditions for economic activity.[77] To improve the business environment, horizontal industrial policies typically focus on: investing in education (from early learning to tertiary education) to improve skill levels; investing in research (through public investments in universities or providing R&D tax incentives for firms); streamlining and lowering corporate taxes; strengthening market rules and regulations that promote competition; trade policies, including export promotion; investing in infrastructure; and strengthening the rule of law.

The horizonal industrial strategy approach can also be referred to as a 'no industrial strategy' approach, in the sense that it aims to improve general economic conditions but not to make choices about the direction of development. Historically, support for this approach arose in response to problems with the vertical industrial policies of the post-war decades in which governments focused on strategic industries (such as coal, steel, electricity, and railways) and selectively supported national champions. It was also a response to wider political trends such as market liberalisation and the idea that market actors are best placed to make strategic decisions.

The horizontal industrial strategy approach has the advantage of being low risk, or even 'no regrets'. It can be applied in any circumstances, with a reasonable expectation of positive economic effects.

A corresponding limitation is that it does not provide a framework for considering more specific challenges, such as driving or responding to structural change in a particular part of the global economy.

Innovation-driven industrial strategy

Innovation-driven industrial strategies go beyond strengthening the fundamentals of the economy, and give policymakers stronger roles in shaping the competitiveness of national sectors or regions through supporting innovation, providing strategic direction, and creating markets. We briefly discuss three related conceptual frameworks that fall within this category: smart specialisation strategy, green industrial policy, and mission-oriented industrial strategy. To a varying extent, these conceptual frameworks start from the premises that:

- The economy is constantly changing, with new opportunities being created, as well as risks that could undermine current competitive strengths.
- Innovation and growth have a direction, as well as a rate. Depending on how efforts are directed, different technologies will be developed, influencing the future structure and characteristics of the economy.
- Governments can influence the direction and rate of innovation, and the development of competitiveness, not only by funding research and development, but also by supporting commercialisation of new technologies and by using a wide variety of market-creating and market-shaping policies to increase demand for new products.[78]

77 Tagliapietra, S., & Veugelers, R. (2023). Sparking Europe's New Industrial Revolution: A Policy for Net Zero, Growth and Resilience.
78 Kattel et al. (2018). The Economics of Change: Policy and Appraisal for Missions, Market Shaping

1 Smart specialisation strategy

The smart specialisation framework[79] suggests that countries (and regions) should focus their competitive strategy on sectors and technological domains where they have strong and distinctive capabilities and assets that could be further developed to enable them to compete in international markets. Identifying these priority sectors and technologies should be informed by strategic analysis of market demand and potential competitors, but is also very much seen as an 'entrepreneurial discovery process' that involves learning by doing and discussion with relevant stakeholders.[80]

There are several steps in this process: 1) analysis of sectoral or regional assets and capabilities to identify potential and opportunities; 2) dialogues between policymakers, firms, universities, research institutes, and other stakeholders to identify potential domains of specialisation as priority areas; 3) collaboratively making concrete action plans for investments in exploratory innovation projects and accompanying platforms (where actors can continuously discuss progress and bottlenecks of projects); and 4) policymakers and other stakeholders funding well-developed action plans and projects and further supporting those with promising outcomes.[81] These action plans may include policies to create markets for the new technologies and support their wider deployment.

2 Green industrial policy

The green industrial policy framework[82] suggests that policymakers should play stronger roles in driving innovation to address climate change and to compete successfully in global markets for clean technologies.[83] In this framework, the low carbon transition is recognised as an important global economic trend, creating particular competitiveness opportunities and risks to which countries may wish to respond. The key elements of this approach include:

- A portfolio approach to supporting clean technologies in the earliest stages of their development, reflecting the uncertainties around their potential performance and future market share. This involves policymakers, firms and other stakeholders identifying and prioritising a range of promising options, while using learning, experimentation, and market creation to allow the best pathways to emerge.
- The use of market-creating policies to support the deployment of clean technologies from first deployment through to wider diffusion, incentivising private investment. When uncertainties decrease and the initial variety gives rise to 'dominant designs',[84] an element of technology choice becomes unavoidable in many policy decisions. Building on the increased availability of information and knowledge, technology choices become, in fact, necessary to drive further diffusion and reap potential competitive advantage from rapid deployment or manufacturing.[85]
- A continual process of collaborative learning between business and the government, in which constraints and opportunities are identified, and policies are revised and adapted.[86] While ex ante analyses and strategic visions are important as initial guides, areas of competitiveness are gradually discovered as firms and policymakers build and extend technical capabilities and learn about market demand and competitors.

Depending on how this framework is interpreted, it can have more in common with the smart specialisation strategy framework (above), in which the focus is on sectors where a country has strong capabilities, or with the mission-oriented industrial strategy framework (below), where there is a greater focus on addressing societal problems that are linked to global market demand.

79 Foray, D. (2017), The economic fundamentals of smart specialization strategies, in: Slavo Radosevic, S., Curaj, A., Gheorghiu, R., Andreescu, L.., Wade, I. (Eds.), Advances in the Theory and Practice of Smart Specialization; Foray, D. (2018). Smart specialization strategies as a case of mission-oriented policy—a case study on the emergence of new policy practices; Kopczynska, E., Ferreira, J. J. (2020). Smart specialization as a new strategic framework: Innovative and competitive capacity in European context.

80 See chapter V, section 3 for more discussion on this question.

81 Foray, D. (2018). Smart specialization strategies as a case of mission-oriented policy—a case study on the emergence of new policy practices.

82 Rodrik, D. (2014). Green industrial policy; Rodrik, D. (2023). Productivism and new industrial policies: Learning from the past, preparing for the future: in: Tagliapietra, S., & Veugelers, R. (Eds.), Sparking Europe's New Industrial Revolution: A Policy for Net Zero, Growth and Resilience; Aiginger, K., & Rodrik, D. (2020). Rebirth of industrial policy and an agenda for the twenty-first century; Veugelers, R., Tagliapietra, S., Trasi, C. (2024). Green industrial policy in Europe: Past, present, and prospects.

83 Aghion, P. (2023). An innovation-driven industrial policy for Europe, in: Tagliapietra, S., & Veugelers, R. (Eds.) Sparking Europe's New Industrial Revolution: A Policy for Net Zero, Growth and Resilience.

84 Murmann & Frenken (2006). Toward a systematic framework for research on dominant designs, technological innovations, and industrial change.

85 Diaz Anadon, L.,. et al. (2022). Ten principles for policymaking in the energy transition: lessons from experience.

86 Juhasz & Rodrik (2023). The New Economics of Industrial Policy.

3 Mission-oriented industrial strategy

The mission-oriented industrial strategy framework suggests that governments should build national competitiveness by driving innovation in a direction that addresses a significant societal problem.[87] Since climate change is a problem faced by many countries, this framework suggests that innovation to drive the low carbon transition could have a strong potential to build competitiveness in future global markets.

The key steps in this approach include:

- Identifying a large-scale problem that matters to society – a 'grand challenge'. A consultative process should be used for this step, and the next.[88]
- Identifying one or more specific 'missions' that can contribute to addressing the grand challenge. A mission is defined by its goal, which should be targeted, measurable, and time-bound. The mission itself is the process of different actors, across government and the private sector, working together to achieve this goal.[89]
- Developing a range of policies and projects to implement the mission. These should include policies to support innovation at each stage of a technology's development, including demand-pull measures (such as public procurement, subsidies, regulations, and taxes) as well as 'supply-push' measures (investment in research, development, and demonstration), and policies to cross the gap between research and commercialisation (such as public equity investment or concessional lending). These measures should cut across policy fields, economic sectors, and research disciplines, engaging whatever capabilities are relevant to achieving the mission's goal.
- Implementing the portfolio of projects and policies in a process of continuous experimentation and learning, adapting the approach as necessary while staying focused on the mission goal.

In the context of climate change being a grand challenge facing many countries, and the low carbon transition being a highly foreseeable global economic trend, missions could be framed around the elimination of emissions from certain parts of the economy.

Policy questions

Policy questions that can be addressed using any of the innovation-driven industrial strategy conceptual frameworks include:

- In which areas of economic activity should a country aim to build competitiveness? [E]
- Which policies could contribute to increasing a country's innovation and competitiveness, in the context of the low carbon transition? [F]

87 Mazzucato & Kattel (2023). Mission-Oriented Industrial Strategy.
88 Mazzucato & Gibb (2019). Missions: A Beginner's Guide.
89 Jonason (2023). Mission-oriented what? A brief guide to mission terminology.
90 Larrue (2021). The design and implementation of mission-oriented innovation policies: A new systemic policy approach to address societal challenges.
91 Zhang et al. (2023). A Tale of Two Cities: Mission-Oriented Innovation Policy in China's Green Industries; Altenburg and Assmann (2017). Green Industrial Policy.
92 Altenburg and Assmann (2017). Green Industrial Policy.
93 International Energy Agency (2023a). Trends in electric light-duty vehicles. Global EV Outlook.
94 Statista (2022). Number of passenger cars and commercial vehicles exported from China 2010–2021.

Examples

The OECD has documented examples of the application of innovation-driven industrial strategy to the low carbon transition in Japan, Germany, China, and South Africa.[90]

An outstanding example is China's industrial strategy in the automotive sector.[91] China's goals were to reduce urban air pollution and to enhance the competitiveness of its automotive industry.[92] The government identified a direction of innovation – towards electric vehicles – that was aligned with many countries' interest in addressing the problem of climate change. In the early stages, the strategy was experimental, supporting research and development, testing new technologies, and piloting demonstration projects at the city level. In later stages, the government set clear goals (such as that new energy vehicles should be 20% of new car sales by 2025), and used a wide range of market-creating policies, including purchase subsidies, public procurement, city-level policies, mandates requiring manufacturers to achieve a rising proportion of electric vehicles in their sales, and investment in charging infrastructure. The strategy has been highly successful. In 2022, the share of electric cars in total domestic car sales reached 29%, up from less than 6% from 2018 to 2020.[93] In 2015, foreign brands accounted for 60% of car sales in China, and China's car exports were approximately one third of what they are today.[94] Chinese brands now account for half of the electric vehicles sold.

Case Study 1: Brazil's Mission-Oriented Industrial Strategy

Nova Industria Brasil, the Brazilian government's industrial policy, takes a mission-oriented approach to building the country's productive capabilities in line with environmental and social ambitions. It has six missions addressing food security, healthcare resilience, infrastructure, digitalisation of industry, the energy transition, and national security.[95] These aim to convert challenges such as climate change into business and investment opportunities and generate a multiplier effect.[96] The mission-oriented approach is embodied by specific goals to address industrial challenges, and implementation through market-shaping policies alongside research and development. These policies include public financing, public procurement and incentives for deployment and manufacturing of low carbon technologies, and investments into relevant public sector capabilities.[97] NIB is being implemented through an interdepartmental approach, led by the National Council for Industrial Development (CNDI), a public-private body chaired by the Ministry of Development, Industry, Trade, and Services and which includes ministry of finance representatives alongside those from the national development bank BNDES, industrial entities, civil society and others.[98]

The finance ministry participated in the strategy's creation and is ensuring alignment with Brazil's Ecological Transformation Plan, an economy-wide strategy for the energy transition, bioeconomy and agrifood systems, sustainable finance, circular economy, technology density and new infrastructure for adaptation. Supporting policies include the Brazilian Emission Trade System, Sustainable Taxonomy, Sustainable Sovereign Bonds, EcoInvest Program, Tropical Forests Forever Facility, and Brazilian Investment Platform. There are also the Green Mobility and Innovation Program national content rules in public purchases; a combination of R&D, state and DFI-led financing, and a legal framework to accelerate low carbon hydrogen innovation and deployment.

To address analytical challenges associated with the industrial strategy and wider green transition, the finance ministry has five ongoing technical cooperations. These will assess the financial needs, macroeconomic implications, impacts on the labour market, and the value of specific policy tools including sustainable investments and targeted public procurement.

Produced with input from Cristina Reis (National Treasury of Brazil), Sarah Doyle (IIPP) and Julia Torraca (UFRJ).

95 Nova Industria Brazil 2024–2026.

96 Mazzucato, M. (2023). Innovation-driven inclusive and sustainable growth: challenges and opportunities for Brazil. UCL Institute for Innovation and Public Purpose, Policy Report 2023/06.

97 With funding from Open Society Foundations (OSF), Professor Mariana Mazzucato and a team from IIPP are working with Brazil's Ministry of Management and Innovation and Enap, Brazil's National School of Public Administration, to support the Government in building the capabilities, tools and institutions required to implement the industrial strategy.

98 Ministério do Desenvolvimento, Indústria, Comércio e Serviços. Conselho Nacional de Desenvolvimento Industrial (CNDI).

Limitations

Innovation-driven industrial strategy requires resources, strong governance and administrative capabilities, and sustained political commitment. Without these attributes, which are more available to some countries than to others, it may exist in name but not in substance, or be too ill-equipped or under-resourced to be effective.[99]

The conceptual frameworks of innovation-driven industrial strategy provide some guide as to the kind of strategies and policies that can be successful, but cannot provide definitive prescriptions.

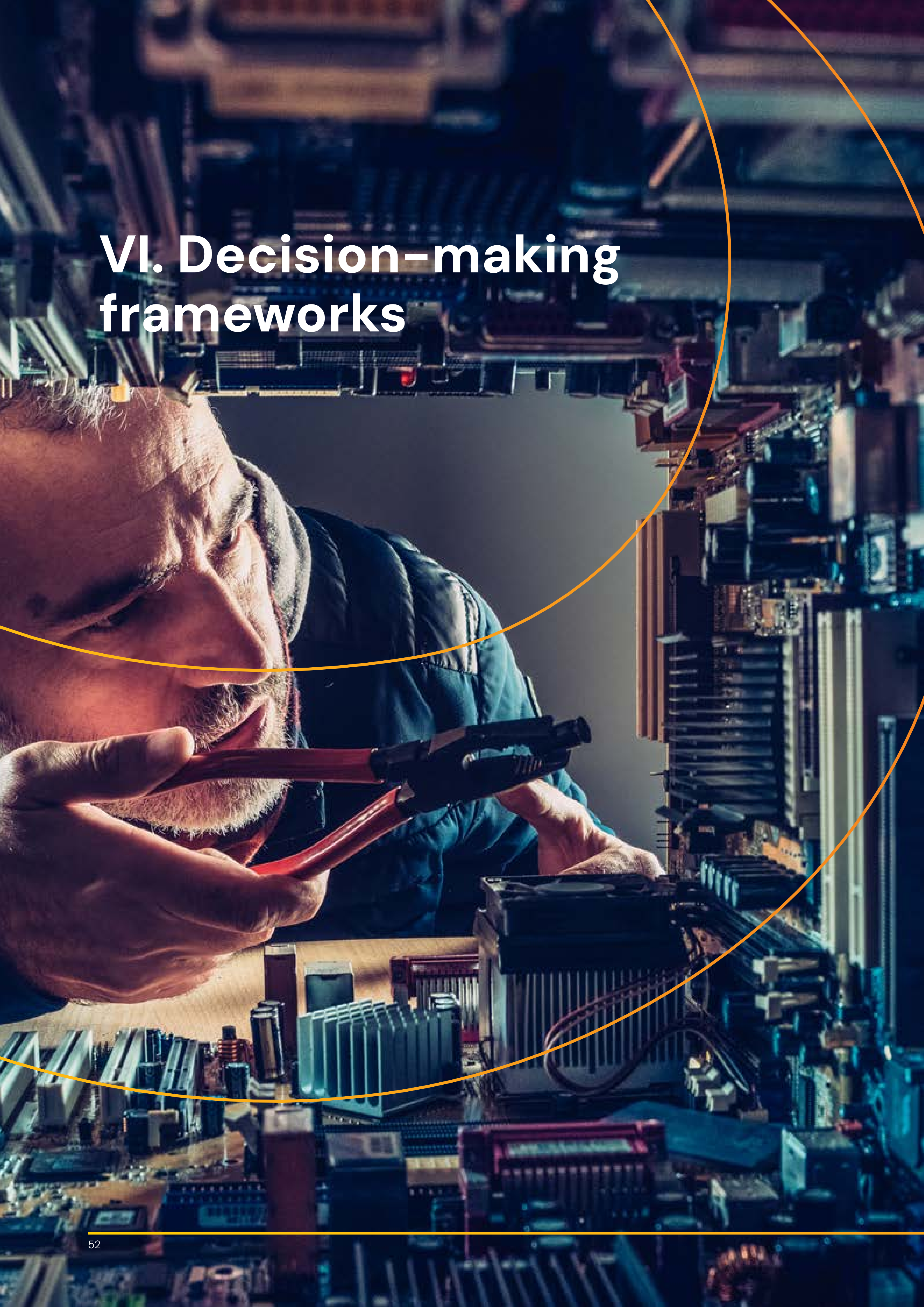
These approaches to industrial strategy may be considered relatively high risk. Since industrial strategy is by definition competitive, it is to be expected that for any approach other than the horizontal one, there will be failures as well as successes.[100] It can be difficult for countries to know which case studies of success could be relevant and replicable in their own circumstances, and which will not be. These frameworks do not explicitly provide an approach to considering the strategies of other countries and assessing the strength of the competition. Expert judgement, including perspectives from diverse stakeholders, is an essential input to all stages of the process.

Given the active role of government in innovation-driven industrial strategy, there is a risk that private sector actors use this as an opportunity to promote their own vested interests. However, this must be set against the risk that in the absence of strategy, the government may be overly vulnerable to pressure from vested interests that are served by maintaining the status quo.

99 Larrue, (2022). Do mission-oriented policies for net zero deliver on their many promises?; Tonurist, (2023). 13 reasons why missions fail; Branstetter and Guangwei (2024). The Challenges of Chinese Industrial Policy. Barteska (2023). Industrial Policy is back! But do countries have the capacity to successfully implement it?

100 See Alves (2024). The Cost of Missions: Lessons from Brazilian Shipbuilding.

VI. Decision-making frameworks



Having addressed the rationale for policy, and the types of strategies and policies that are likely to be successful in advancing and competing within low carbon transitions, here we turn to decision-making frameworks for considering individual policy options. We outline the approaches of: cost-benefit analysis, risk-opportunity analysis, robust decision-making, and scenarios. The first of these is appropriate for contexts of marginal change, while the others are appropriate for contexts of structural change and uncertainty.

Cost–benefit analysis

Cost-benefit analysis (CBA) is a general purpose tool for informing decisions on individual policies and investment projects. It enables the value for money of investments and policy options to be compared on a consistent, quantified basis. This tool works well for decisions in stable contexts with sufficient, reliable information. Since it is widely used and familiar to finance ministries, we do not describe its method here. It is, however, useful to consider the limitations of CBA that are relevant to the policy issues under discussion in this report. These limitations include:

Dynamic processes: CBA assesses the expected outcomes of a policy at a fixed moment, or moments, in time. It does not assess how a policy may affect processes of change in the economy, such as innovation, technology diffusion, growth, contraction, or the replacement of one set of technologies, assets, or market structures with another. Consequently, CBA is most appropriate where policies are not expected to result in any structural economic change, and least useful when the main aims of policy are to influence processes of change – such as accelerating innovation and building competitiveness in the context of the low carbon transition. When CBA is used in a context of structural change, its results can be misleading: for example, path dependence in technology development means that the least-cost way to reduce a tonne of carbon emissions at a moment in time may not be the least-cost way to achieve a transition to zero emissions over a period of time.[101]

Uncertainty: CBA is most appropriate when the expected outcomes relevant to policy interests can be confidently quantified. If important outcomes are fundamentally uncertain, it is more difficult for the analysis to be reliable. Using CBA in such contexts can create a bias toward inaction, since costs typically occur in the present and are quantifiable, whereas benefits occur in the future and are less confidently known. In the low carbon transition, for example, the costs of policies are relatively well known, but their benefits in terms of innovation and industrial competitiveness are potentially large but often highly uncertain and not quantifiable with confidence, so they tend to receive less emphasis in the analysis.

Diversity of interests: A strength of CBA is its simplicity, which includes expressing the value of a project or policy as a single number. The corresponding weakness is that it requires different kinds of policy outcomes to be converted into the single metric of monetary value (for example to value the benefits of an air pollution reduction policy, converting the expected reduction in respiratory illnesses into monetary terms). Many methods for this conversion are possible; the choice between them is unavoidably subjective and to some degree arbitrary, but this can strongly affect the outcome of the analysis. In policy decisions on the low carbon transition, finance ministries are often interested in diverse outcomes, such as impacts on costs, jobs, energy security, and emissions, and may find it more useful to consider outcomes in each of these areas explicitly, requiring a more multi-dimensional framework.

Cost-effectiveness analysis is an alternative to CBA that assesses policies in terms of their costs and desired effects, without assigning a monetary value to their desired effects. Multi-criteria decision analysis involves explicitly comparing policy outcomes in different dimensions of interest. Each of these approaches provides some additional scope for working with uncertainty and diversity of interests compared to CBA, but shares the limitations of CBA in respect of not providing an explicit method to assess the effects of policies on processes of change in the economy. We do not discuss these approaches further here since they are general purpose analytical tools, already familiar to finance ministries, and not specific to the analytical questions of the low carbon transition.

101 Grubb et al. (2021). The New Economics of Innovation and Transition: Evaluating Opportunities and Risks.

Risk–opportunity analysis

Risk opportunity analysis (ROA) is a generalisation of cost benefit analysis, appropriate for use in contexts where change is structural, important outcomes are uncertain, and diverse interests are affected.[102] These conditions apply to many policy decisions concerning innovation and competitiveness in the low carbontransition.

ROA has three main differences from CBA, which respond to the limitations of CBA discussed above:

(i) **Dynamic processes:** ROA assesses the likely effects of policies on processes of change in the economy, instead of primarily assessing expected outcomes at fixed points in time. This is appropriate where the context or aim is structural change not marginal change. This can be done using systems mapping with causal loop diagrams (see chapter VI, section 2 below).

(ii) **Uncertainty:** ROA assesses opportunities and risks that cannot be confidently quantified, as well as quantifiable costs and benefits, in a structured way and on an equal basis, instead of limiting the analysis to the latter. Qualitative assessments of uncertain outcomes are made using the best available evidence and expert judgement. 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.

(iii) **Diversity of interests:** ROA presents outcomes in multiple dimensions, instead of converting all outcomes into one metric. This means that the relative value of outcomes in different dimensions can be considered explicitly instead of assumed implicitly. This is appropriate when policies are likely to significantly affect diverse interests, for example costs, jobs, energy security, competitive advantage, the distribution of income, and environmental damage. (In this respect ROA is similar to multi-criteria decision analysis, but without applying scores and weightings to outcomes in different dimensions).

Policy questions

Policy questions that can be informed using this approach include any that fit the general criteria described above. They include, for example:

- Which clean technology deployment policy is most likely to be successful, taking into account policy interests such as reducing costs, cutting emissions, and creating jobs? [C]
- Which policies are likely to succeed in building industrial competitiveness in a low carbon technology or sector? [F]
- Should a given policy be implemented or not? (Do its benefits and opportunities outweigh its costs and risks?)

Where innovation and competitiveness are policy goals, there will always be uncertainty, and dynamic processes are likely to be important. In significant policy decisions relevant to the low carbon transition, a diverse range of interests are often affected.

102 Mercure, J.- F., et al. (2021). Risk-opportunity analysis for transformative policy design and appraisal.

Examples

Policies that were central to some of the most outstanding early successes in the low carbon transition were adopted despite generally not being supported by cost benefit analysis. These included policies using targeted investment (such as subsidy, public procurement, and concessional finance) to support the deployment of solar power in Europe and China, onshore wind in Brazil, offshore wind in the UK, and efficient lighting technology in India.[103] CBA tended not to favour these policies because the clean technologies were expensive at first, and there were cheaper ways to cut a tonne of carbon emissions.

The same policies can be considered differently using ROA.[104] The reinforcing feedbacks of technology development and diffusion (such as learning by doing and economies of scale) are well known, and the learning curves for clean technologies such as solar and wind are well documented, suggesting a strong prospect for targeted investment policies to drive innovation and cost reduction. The outcomes important to policy were not solely emissions reduction; they also included cost reduction, industrial development and competitiveness, job creation, energy security, and air quality. The fact that outcomes in some of these dimensions were not confidently quantifiable did not make them less important. Expert judgement could reasonably predict the direction of change in these variables that would result from policies, if not the precise outcomes at fixed points in time.

Contrasting assessments	
	Cost Benefit Analysis Subsidies for the first deployment of offshore wind in the UK were not strongly supported by cost-benefit analysis. Offshore wind generated electricity at around four times the market price. It was criticised as being 'among the most expensive ways of marginally reducing carbon emissions known to man.'[105] At that time, burning biomass was a cheaper way to reduce emissions.
	Risk Opportunity Analysis Risk opportunity analysis supported the case for investing in offshore wind rather than biomass. The data for onshore wind suggested a good potential for cost reduction through learning by doing and economies of scale. Market analysis suggested offshore wind had better opportunities for job creation than biomass, while lifecycle assessments showed biomass had significant environmental risks.[106] Within a decade, the UK's targeted subsidies drove the cost of offshore wind power down to below the market price of electricity. The sector now supports 32,000 jobs in the UK,[107] and its long-term contracts for electricity generation are increasingly subsidy-negative.

Limitations

ROA cannot, by definition, express the economic value of a policy option in a single number. Although this can present a challenge for communication to decision-makers used to receiving numerical estimates, it is intended for use in contexts where to do so would be inappropriate and misleading. It cannot point to one policy option as objectively and unarguably 'the best' when it is applied in contexts where diverse interests are important. In such cases, 'which policy is best' is not solely an analytical question; it is also a political and strategic question, requiring interpretation and strategic judgement.

As a general purpose decision-making tool, ROA is only as good as the quality of its input information and the strategic capabilities of the decision-maker.

103 Grubb et al. (2021). The new economics of innovation and transition: evaluating opportunities and risks.

104 ROA has been developed recently as a decision-making framework, outlined in a policy brief, paper, and report. It is not yet widely applied, and the examples given here are retrospective. Detailed implementation guidance is available in draft at www.scurveeconomics.org; many other publications address each of its component parts.

105 The Economist, 2014. Rueing the waves.

106 Carbon Trust and University College London (2020). Policy, innovation and cost reduction in UK offshore wind.

107 The Crown Estate (2024). Offshore wind industry unveils Industrial Growth Plan to create jobs, triple supply chain manufacturing and boost UK economy by £25 billion.

Robust decision-making

Robust Decision-Making (RDM) is an approach to making decisions in contexts of high uncertainty. It can be useful when there is uncertainty not only over the outcome of a possible course of action, but also over the probabilities of different outcomes. In such contexts, no 'optimal' policy can be calculated. Instead, a 'robust' policy or strategy can be identified. A robust strategy is one that performs well across a wide range of possible futures, preferences, and worldviews.[108] Characteristics that can make a strategy robust include being reversible, flexible, 'no-regret', and incorporating safety margins.[109] The opposite is a 'brittle' strategy: one that performs poorly when the future diverges from expectations.[110]

RDM typically involves four stages of analytical work:[111]

1. A stakeholder process to collect a) the range of strategies or policy options to be considered; b) performance metrics to use for evaluating options; and c) the range of uncertainties to consider.
2. Modelling to create a large database of simulation runs, examining the performance of the many suggested strategies or policy options over a wide range of alternative future states.
3. Algorithmically determining clusters of scenarios where strategies demonstrate particular strength or vulnerability.
4. Identifying options for reducing vulnerabilities in potential strategies, and associated trade-offs.

This is an iterative process: lessons which emerge from step 4 are sent back to step 1, so that revised strategies can be put through another round of analysis. This is repeated until vulnerabilities are assessed to be below acceptable levels. The results can reveal strategies that are high or low performing against the various success criteria, across the range of possible future scenarios.

While RDM normally involves quantitative modelling, the underlying logic and sequence of analytical steps can be applied in a qualitative, principles-based way.[112] This is less resource intensive, and may be appropriate if the available modelling capabilities do not match the range of uncertain factors that are relevant to the strategy's success.

108 Casey et al. (2014). Agreeing on robust decisions: new processes for decision making under deep uncertainty.
109 Hallegatte et al. (2012). Investment Decision-making under deep uncertainty – application to climate change.
110 Casey et al. (2014). Agreeing on robust decisions: new processes for decision making under deep uncertainty.
111 Hallegatte et al. (2012). Investment Decision-making under deep uncertainty – application to climate change.

Policy questions

Policy questions that can be informed using RDM include any that involve deep uncertainty or divergent views among stakeholders about likely or aspirational futures.[113] RDM has often been applied to inform decisions on adaptation to climate change, which take place in a context of uncertainty regarding the impacts of climate change. It can also be used for decisions relevant to innovation and competitiveness in the low carbon transition, since deep uncertainties can exist in relation to the future emergence of new technologies, the responses of consumers, businesses, and investors to government policies, and the policies of other countries, which shape global markets.

RDM can help decision-makers consider questions such as:[114]

- Which of our possible strategies (or policy combinations or sequences) are most 'robust' to the range of relevant plausible uncertainties (for example range of technology cost declines)? [C, F]
- Are the conditions under which our strategy performs poorly sufficiently likely that we should choose a different strategy? (For example, if the strategy involves investing in a particular low carbon technology, how likely is it that global markets in that sector will favour a different technology?)
- What trade-offs do we wish to make between robustness and cost, and/or between different measures of success? (For example, larger investments in electricity generation capacity could be more robust to the uncertainty of future increases in demand but also be more costly).
- Which options leave us with the most flexibility to respond to changes in the future?

RDM can be especially useful when policymaking can be planned as a series of decisions over time, allowing each decision to benefit from learning and new information acquired since the last[115]

Examples

RDM has been used to evaluate Costa Rica's National Decarbonization Plan (NDP).[116] The plan includes a wide range of policies and institutional reforms aimed at achieving net zero emissions by 2050. An integrated model was developed to explore costs and benefits associated with implementing the NDP across all major economic sectors. This was designed based on consultations with government, industry, and civil society stakeholders, and was used to explore over 3,000 plausible future scenarios, each with different assumptions about technologies, policy effectiveness, and underlying socio-economic conditions. The analysis showed the NDP would have net economic benefits in almost all future scenarios. It also identified areas of policy that were most critical to the NDP's success, and key conditions necessary to achieve close to net zero emissions at a larger economic benefit.

The same RDM approach is being used to evaluate national decarbonisation strategies in Chile, Peru, and Colombia. The World Bank is piloting projects using RDM methodologies in several countries and regions: these include water supply in Lima, flood risk management in Ho Chi Minh City and Colombo, hydropower investment in Nepal, and road network resilience in Peru and across Africa.

Limitations

The quantitative modelling approach to RDM can be costly, due to high data and resource requirements.[117] Sometimes it is difficult to obtain data with the necessary resolution. However, increasing experience with the method suggests that lighter-touch approaches can be used, relying more on expert judgement and less on quantitative data analysis.

RDM is likely to be less useful outside its intended scope: if there is no fundamental uncertainty, or if there are in practice few policy options to consider.

113 Marchau et al.(2019). Decision Making under Deep Uncertainty.

114 Casey et al. (2014). Agreeing on robust decisions: new processes for decision making under deep uncertainty.

115 Hallegatte et al. (2012). Investment Decision-making under deep uncertainty – application to climate change.

116 Groves et al. (2020). The benefits and costs of decarbonizing Costa Rica's economy – informing the implementation of Costa Rica's decarbonisation plan under uncertainty. [IDB, RAND Corporation, DCC and UCR].

117 Haas et al.(2023). Deep uncertainty and the transition to a low-carbon economy.

Scenarios

Scenario analysis is a tool to support decision-making in contexts of high uncertainty, where important contextual factors are outside the control or direct influence of the decision-maker. It is a structured approach to imagining and considering different possible futures, in ways that are relevant to the decision-maker's objectives. It is a more general approach to working with uncertainty than robust decision-making, since robustness is only one possible objective. It is often a qualitative exercise, and so can be used in contexts of even deeper uncertainty.

Scenarios can be used to test strategies, to understand how they might fare in different possible futures. Done well, they can turn confusion into well-structured uncertainty. A large part of the value is in the process of creating scenarios, rather than the results. The process can help people consider alternative futures, design strategies that better account for uncertainties, and be better able afterwards to identify indicators of change that signify a direction of travel consistent with one scenario or another.

Steps in the process typically include:

1. Determine scope: what strategy is being considered, for what purpose, in what context?
2. Identify critical uncertainties. Start with many, then group them into clusters representing two or three main categories of uncertainty. These two or three axes correspond to four or eight potential scenarios.
3. From this set, choose three or four scenarios that are the most relevant and challenging from the point of view of policy objectives, as well as being plausible. (The aim is *not* to identify the most likely).
4. Develop each of the chosen scenarios into narratives about the path from the present to the future. These should include known predetermined factors, as well as the uncertain factors that are the main focus. Quantitative analysis can be included if it is available; this should be driven by the narrative (which can deal with greater uncertainty) and should not determine the narrative.
5. Build a scenario impact matrix by plotting the implications of each scenario for strategy in relation to each policy objective (i.e. in each scenario, what should be done to increase the chances of success of each policy objective?).
6. Draw conclusions. Strategies can be developed with the aim of being robust (good under all outcomes); contingent (making the most of one particular scenario happening – placing a bet on this outcome); or resilient (having a high adaptability, able to respond to what happens).

Examples

Decision-making on innovation and competitiveness in the low carbon transition often takes place in a context of high uncertainty and limited direct control. For example, the pace of the transition in any sector, and the technology preferences of global markets, may be determined largely by the actions of other countries. Scenarios can be used to consider technology choices, deployment policy choices, and industrial strategies in the context of these uncertainties.

More broadly, scenarios are widely used within academia, governments, and the private sector to consider possible futures in relation to global emissions;[118] increases in global temperature and sea levels; physical climate risks; transition risks;[119] and global socio-economic development.[120]

Limitations

Creating good-quality scenarios requires a high level of investment of time and effort. The participation of experts in the subject matter being discussed is essential, including those who can present plausible views of how the future may differ radically from expectations.

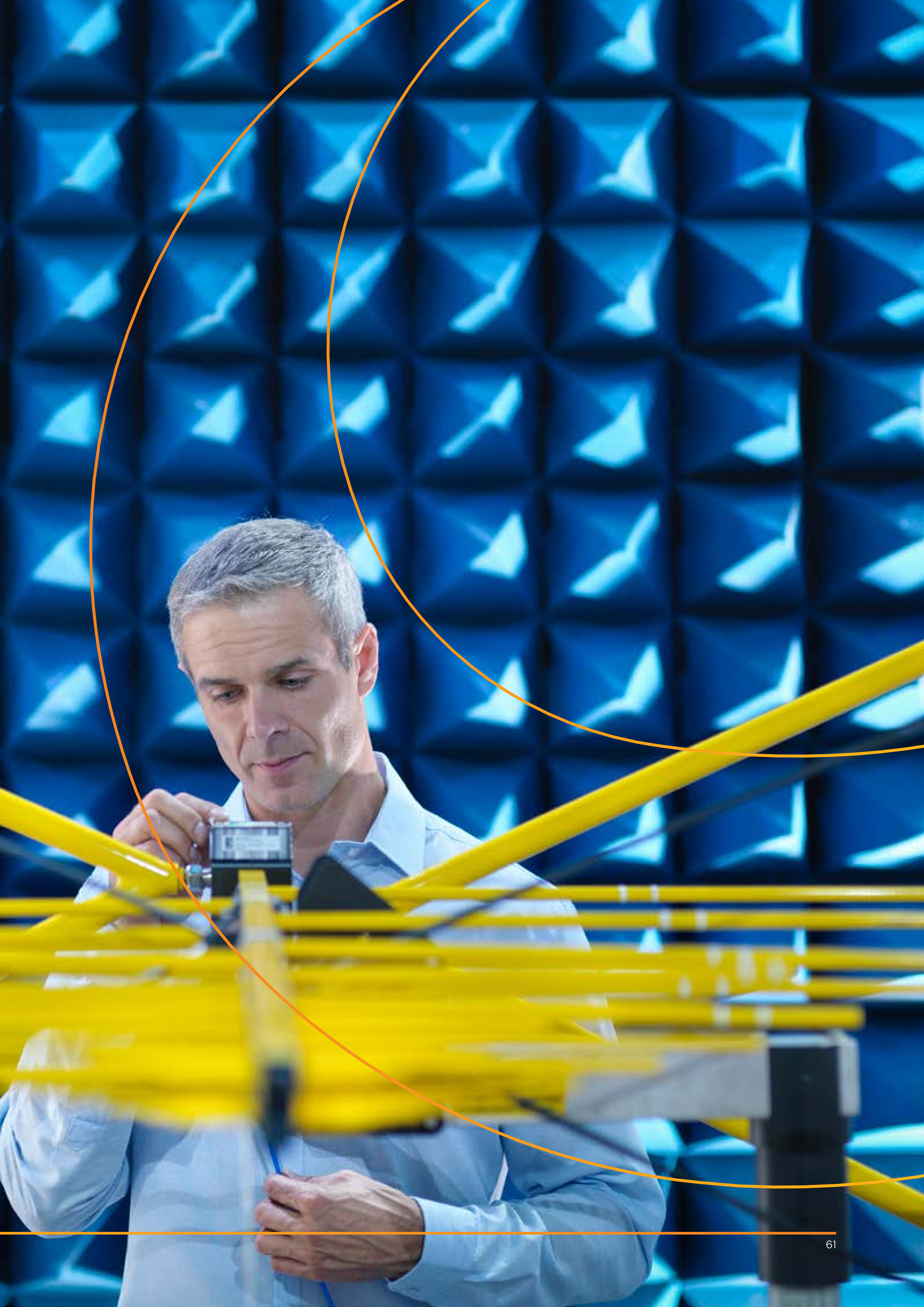
The value of the exercise is usually greater for those who participate in it than for those who are simply presented with its findings. Consequently, the involvement of senior leadership can be important for the findings to be acted upon.

Where uncertainty is high and the ability to influence change is also high, a 'pathways' approach may be more appropriate. An example is the 'three horizons' framework for considering transformative innovation, which involves distinguishing between innovations that improve the currently dominant system, and innovations that bring a new and fundamentally different system into being.[121]

118 See for example the emissions scenarios used by the Intergovernmental Panel on Climate Change.

119 See for example the scenarios of the Network for Greening the Financial System and the recommendations of the Task Force on Climate-Related Financial Disclosures on how organisations should use scenarios to assess the implications for their strategies of physical climate risks and transition risks.

121 Sharpe, B. et al. (2016). Three Horizons: A Pathways Practice for Transformation.



VII. Analytical tools

In this chapter we review a range of analytical tools that policymakers can use to compare options and inform decisions. They include sector-specific and macroeconomic models, qualitative techniques such as systems mapping with causal loop diagrams, and quantitative methods for analysing technology costs and industrial competitiveness. These are grouped in relation to the questions they address: i) Which technologies should be invested in and deployed? ii) Which policies are likely to be effective in driving innovation and cost reduction? iii) In which sectors or technologies should a country aim to build competitiveness and skills? iv) What will be the macroeconomic effects of innovation and competitiveness policies?

1. Which technologies should be invested in and deployed?

Governments often aim to apply a principle that policy should be 'technology neutral'.[122] In the right circumstances this can be a useful principle, creating competition between technologies to discover which emerges as the most successful. However, technology neutrality can be difficult or impossible in practice, especially in the context of a technology transition. Investments in research and development unavoidably support some technologies and not others. Market-shaping policies, even those intended to be technology neutral, will have different effects on different technologies. For example, a carbon pricing policy designed to incentivise the uptake of the least costly opportunities for short-term emissions reduction tends to encourage the deployment of clean technologies that are relatively mature.[123] Pursuing 'neutrality', therefore, in reality tends to support the status quo, rather than supporting the low carbon transition.

In the low carbon transition, technology choices affect not only costs, but also factors such as air quality, energy security, employment, and economic growth. Consequently, where technology choices are inevitable, finance ministries have an interest in ensuring that good choices are made. Here we outline two approaches: cost-optimisation models, and probabilistic clean technology cost forecasts based on learning curves. We also use a case study to illustrate a multi-dimensional approach.

Cost-optimisation models

Cost-optimisation models of the energy system are designed to inform choices between technologies, within the constraints of policy goals and available resources. These are widely used by governments in the context of the low carbon transition to generate least-cost technology pathways, indicating which technologies should be used, in which proportions, at different points in time (to meet assumed levels of demand for energy and energy-consuming products or services). They can also be used to determine the implications of some technologies not being available, or to look for trade-offs between choices in different sectors. They can be highly detailed, reflecting a country's natural resources, existing infrastructure, and policy commitments such as emissions targets. Sometimes they are used together with models of the wider economy, and linked to these within integrated assessment models (see sections below).

One important limitation of cost-optimisation models is that they are only as good as the technology cost forecasts that they contain. Often these are based on expert elicitation or on forward extrapolation of past technology cost trends, sometimes containing 'floor costs' – levels below which costs are assumed not to fall, or even sometimes the costs are not assumed to fall at all with deployment. Historically, the ability of experts to predict clean technology costs has been variable. A review of 25 expert elicitation studies conducted between 2007 and 2016 found that for five out of six key clean energy technologies, their predictions of costs in 2019 were overestimates when compared to actual observed costs (with nuclear being the exception).[124] Despite the relatively short forecasting period, the median expert forecast in 2010 overestimated the cost of solar PV modules in 2019 by an order of magnitude. As data on the global cost trends of the more established clean technologies becomes increasingly available, it may be possible for more reliable forecasts to be incorporated into national cost-optimisation models. Even then, it will be difficult for such models to incorporate fluctuations in costs due to fossil fuel price spikes or renewable technology supply chain constraints, which are difficult to predict, and the models will not reflect the way that costs may vary between different national deployment scenarios.

122 This is informed by awareness of the risk that choosing technologies can lead to government capture by industry. Theories of market-shaping and experimentalist governance propose ways to establish a 'symbiotic' relationship between the public and private sector to mitigate this risk and accelerate low carbon solutions. See Mazzucato (2013). The Entrepreneurial State, and Victor & Sabel (2020). Fixing the Climate: Strategies for an Uncertain World.

123 This paragraph summarises content from Díaz Anadon et al. (2022). Ten Principles for policymaking in the energy transition (p. 7).

124 Meng et al.(2021). Comparing expert elicitation and model-based probabilistic technology cost forecasts for the energy transition.

A more fundamental limitation is that while cost-optimisation models can set the technological agenda, indicating what may be a desirable mix of technologies, they do not inform detailed policy decisions on 'how to get there'. Since they generally are not designed to simulate the effects of policies on consumers or industry evolution, they cannot normally be used to compare the effectiveness of different policies for deploying a given technology. This means cost-optimisation models are of limited relevance to the questions of innovation in the low carbon transition that are outlined above, despite playing an important role in informing technology choice. Neither are they intended to inform questions of competitiveness. (Often there may be a trade-off between cost minimisation, which may be achieved through importing the lowest cost technologies, and the development of domestic supply chains.)

Probabilistic clean technology cost forecasts based on learning curves

Technology learning curves, also referred to as experience curves, can be used to measure and predict rates of technological improvement.[125] The technique has been extensively used by analysts over recent decades. As low carbon technologies are increasingly deployed, more data is becoming available to support assessments of the rates at which their costs are falling. Government analysts can use academic studies using this method to inform their technology choices, or they can apply it themselves if they have access to appropriate data.

Analysis of historical data shows that rates of cost reduction vary widely between technologies, but that the rate of cost reduction for a given technology tends to be relatively consistent over long periods of time.[126] Recent research has shown that the cost trends for technologies central to the low carbon transition are consistent with Wright's Law (costs falling by a constant fraction with each doubling of cumulative global deployment).[127]

Rather than simply projecting a historical trend forward to produce a single prediction of future costs, uncertainty can be introduced in the analysis to produce probabilistic forecasts. Methods for doing this include introducing random variation (based on historical fluctuations) around a stable long-term cost reduction trend, and creating a probability distribution based on the frequency with which different short-term learning rates appear in past data.[128] One study, which compared forecasting methods, found that forecasts based on these probabilistic learning curve techniques were more successful than expert elicitations in predicting the costs of six energy technologies over three to ten-year periods leading up to 2019.[129]

Policy questions

Policy questions that can be informed using this analytical tool include:

- Which technologies should be used to decarbonise a given sector of the economy? [B] (For example, analysis predicting continued rapid cost decreases in batteries, and no similar cost decreases in biofuels, could inform the choice of technologies for policy to support in the decarbonisation of road transport.)
- How quickly should a country move from fossils to clean technologies in a given sector, if the aim is to minimise costs?
- To what extent can switching from fossil fuel imports to domestic renewable energy production improve energy security and reduce energy price volatility for a given country, and on what time scale?

Understanding the innovation and cost-reduction potential of different technologies is relevant to governments' interest in competitiveness as well as to least-cost decarbonisation, since it can indicate which technologies are most likely to dominate global markets in future.

125 See the Systematic Review on induced innovation (Grubb et al., 2021) conducted for input to the IPCC Sixth Assessment, covering hundreds of papers and methodologies including an Annex summarising findings from more than 70 papers estimating learning curves.

126 Way et al. (2022) Empirically Grounded Technology Forecasts and the Energy Transition.

127 Way et al. (2022) Empirically Grounded Technology Forecasts and the Energy Transition.

128 Meng et al. (2021). Comparing expert elicitation and model-based probabilistic technology cost forecasts for the energy transition.

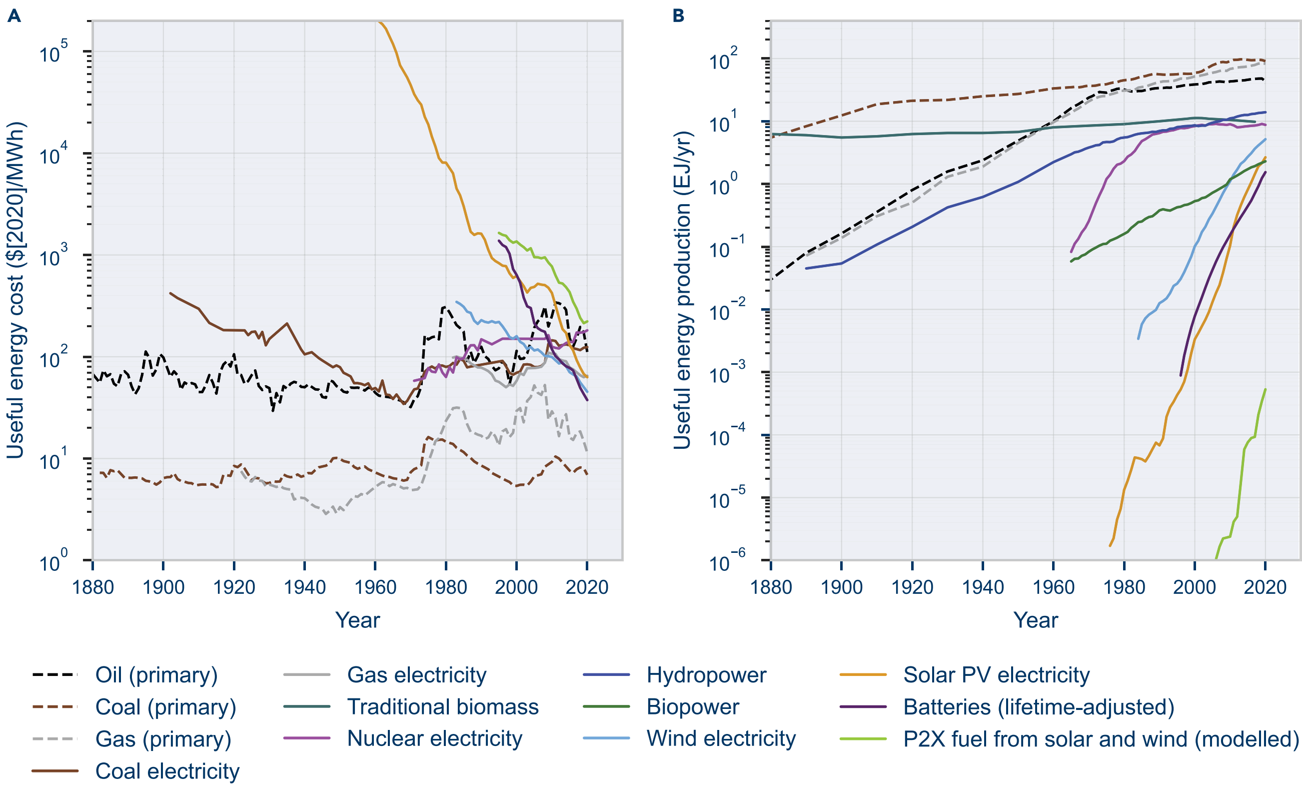
129 Meng et al. (2021). Comparing expert elicitation and model-based probabilistic technology cost forecasts for the energy transition.

130 Way et al. (2022) Empirically Grounded Technology Forecasts and the Energy Transition.

Example

Analysis of historical cost data shows that solar photovoltaics, wind power, and battery technologies have experienced exponential cost reduction consistently over recent decades. In contrast, there has been no demonstrated trend of cost reduction in nuclear or bioenergy technologies, and the costs of coal, oil, and gas have fluctuated but shown no overall cost trend over the past century (see Figure 5).[130]

Figure 5: Historical costs and production of key energy supply technologies. In A, note the difference in historical costs between coal/gas, and renewables such as solar, wind, and hydropower. In B, deployment shows the exponential rise in the production of oil and natural gas over a century, the rise and plateauing of nuclear energy, and the more dramatic exponential rise in the deployment of solar PV, wind, batteries, and electrolysers in recent decades.



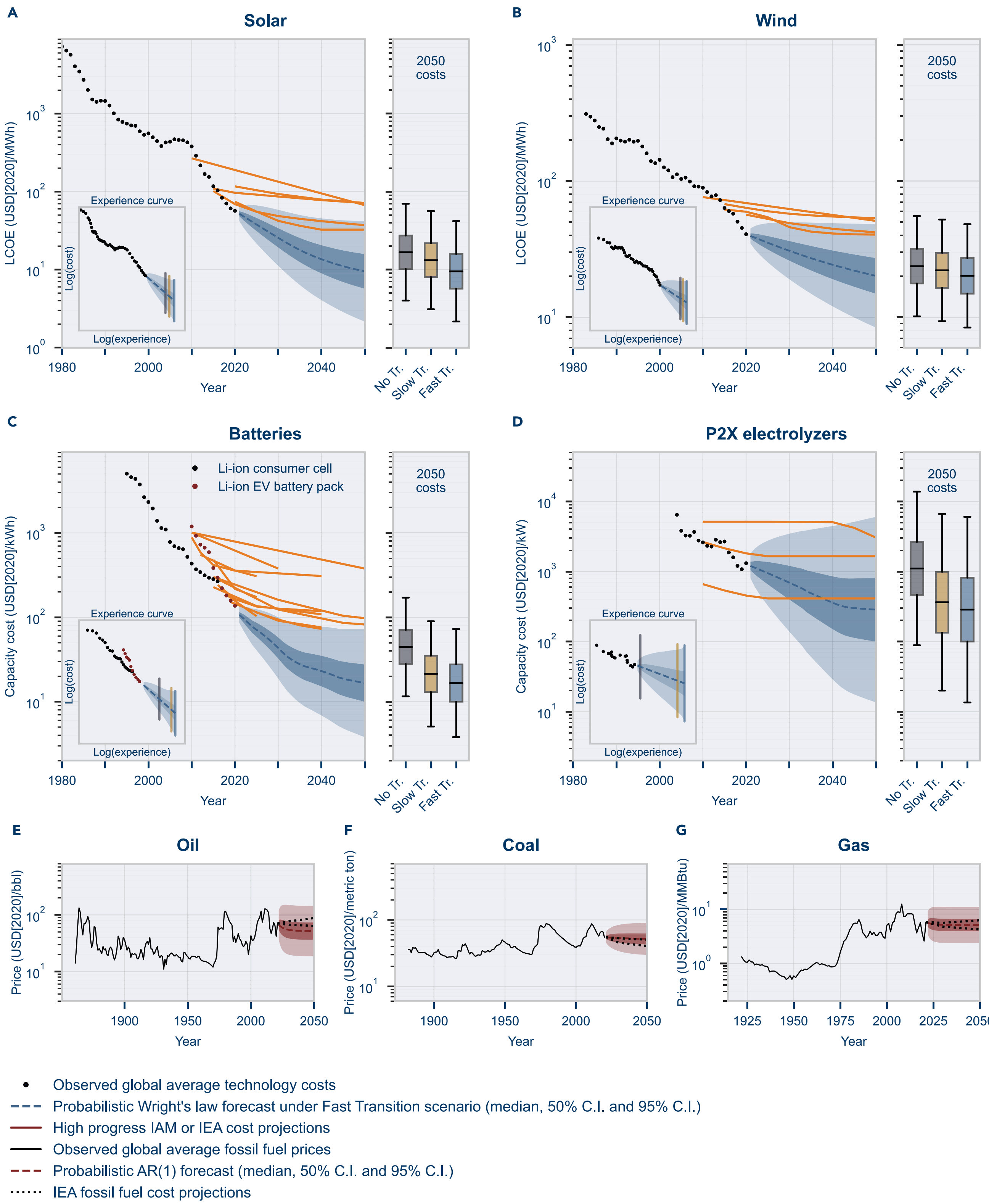
Source: Way et al. (2022). Empirically grounded technology forecasts and the energy transition.

Forecasts made using the probabilistic learning curve method suggest that the costs of solar, wind, batteries, and electrolysers are likely to be substantially lower than is typically assumed in even the most optimistic scenarios used by integrated assessment models (see Figure 6). This suggests that the combination of solar, wind, and batteries in producing clean electric power will become cheaper than coal or gas power earlier than is commonly anticipated.[131] Governments can take this knowledge into account when considering whether to invest in new coal or gas plants, or when considering the timing of electricity market reforms to support the integration of larger volumes of renewable power.

131 Nijsse, F. et al. Is a solar future inevitable?

Figure 6: Technology cost forecasts for key energy technologies

Note the difference between the dark and light blue forecasts (representing 50% and 95% confidence respectively), compared with the 'optimistic' mitigation scenarios made by IAMs and IEA cost projections. The implication is that technology costs will decrease faster than widely predicted, according to historical trends.



Source: Way et al (2022) Empirically grounded technology forecasts and the energy transition.

Contrasting assessments	
	Cost-optimisation models as input into integrated assessment models The integrated assessment models whose clean technology cost projections are shown in Figure 6 have been used to generate technology scenarios estimated to be consistent with cost-effective decarbonisation. Historically, the underestimation of technological progress has biased these scenarios against solar and wind power, and towards alternatives such as nuclear, biofuels, and fossil fuels with carbon capture and storage.
	Probabilistic clean technology forecasts The deeper cost declines predicted for solar, wind, batteries, and electrolysers by the probabilistic learning curve method suggest a greater role for these technologies in a cost-effective transition.

Limitations

Technology cost forecasts are likely to be most reliable when they are made at the global level, such as those shown in the figures above. In practice, the costs of many technologies are significantly affected by local factors (including the cost of capital, which tends to be higher in developing countries); incorporating these factors into projections for any individual country is likely to require other forms of analysis.[132] Nevertheless, global cost forecasts can be a useful input into policy decisions.

The probabilistic learning curve method is difficult to apply to new technologies for which little if any historical data is available. It may be possible to make estimates based on similarities to existing technologies (for example floating offshore wind power may follow a similar cost curve to fixed offshore wind) or based on the 'family' to which a technology belongs (for example semiconductor technologies), but in these cases forecasts will be made with less confidence. An alternative or complementary approach is to judge the potential for rapid cost-cutting innovation based on technology characteristics, with some research suggesting this potential is higher for technologies that are relatively simple and standardised (for example solar PV modules), and lower for those that are complex and customised (for example nuclear power plants).[133]

Even for established clean technologies, while this method can provide estimates of the likelihood and scale of fluctuations around the cost trend, it does not provide information on their exact timing. Cost fluctuations within a decade can be significant, and may be important to policy. It is also difficult to predict the point at which the global market for a given technology will become saturated, so that slower deployment rates lead to slower cost reduction.

While this approach can be used to predict rates of improvement for different technologies, it does not provide specific guidance as to how that innovation can best be enabled and accelerated. Similarly, while it can indicate the technologies likely to succeed in global markets, it does not contribute to the understanding of the feasibility of a particular country becoming competitive in those technologies.

132 The forecasting method described here is currently statistically validated only for global technology cost forecasts. At the national level, it may be used as a benchmarking tool to sense-check independently generated country-specific forecasts. It can also be used to form expectations about how the rates of cost reduction of different technologies are likely to compare to each other, and how likely different technologies are to become dominant in a particular sector.

133 Malhotra and Schmidt (2020). Accelerating low-carbon innovation.

Case Study 2: Denmark's approach to accelerating development and implementation of new clean technologies

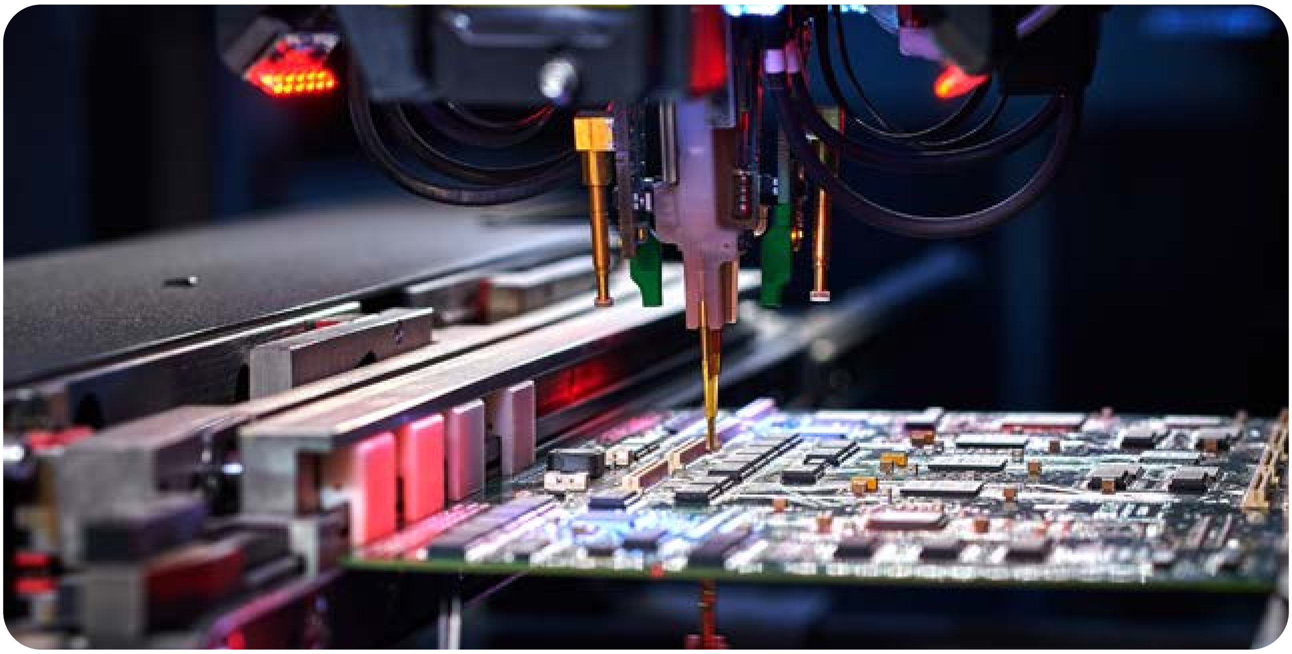
Technology development and implementation involves factors other than costs, and multidimensional assessments can be useful. The Danish Government[134] is using a recently developed risk screening tool to iteratively implement and refine sectoral decarbonisation policy, informing both technology choice and policy choice, starting with the agricultural sector. As part of a new Danish political agreement on climate and environment measures in agriculture, Danish farmers face an incoming GHG tax on livestock emissions, making the availability of affordable emissions reduction solutions increasingly important. The tool supports the use of proceeds from this tax towards enabling climate mitigation technology uptake by most impacted farms.

The excel-based tool screens for possible barriers to the development and implementation of new technologies. It identifies barriers across six dimensions: technology functional maturity, market conditions, cost-effectiveness, scaling, regulation, and GHG accounting. With technology-specific data input across these dimensions, the tool identifies barriers to uptake for that given technology. This informs choices between technologies and enables policymakers to target efforts to reduce those barriers.

In the first trial run of the screening tool, 16 technologies for the agricultural sector were examined, ranging from methane-reducing cattle feed supplements to different innovative manure management systems. The findings guided the design of the Danish Government's green research strategy in October 2024. They were used to target 500 million DKK towards identified funding priorities in a political agreement with broad majority of the parties in the Danish parliament on Denmark's yearly Research Reserve for 2024. This included funding for relevant testing and demonstration facilities and targeted documentation efforts for key technologies.

Use of the tool has generated practical findings and informed policy solutions. The majority of the screened climate technologies were found to need further financial incentives to drive adaptation at the farm level. Efforts to subsidize the uptake of the most developed technologies were then incorporated in the final initiatives. Second, regulatory hurdles and inefficiencies, notably processing time at the domestic and EU level, appeared frequently in the screening. As part of this, the Danish government has initiated cross-government initiatives aiming to adjust EU regulations to account for new climate technologies.

Produced with input from Mads Libergren, Ministry of Finance, Denmark.



134 The tool was developed through a cross-government cooperation involving the Ministry of Finance, Ministry for Climate, Energy and Utilities, Ministry of Food, Agriculture and Fisheries, Ministry of Environment, Ministry of Industry, Business and Financial Affairs and Ministry of Higher Education and Science.

Biochar on Agricultural Soils

Functionality

RISK ASSESSMENT: **LOW**

TRL-level
- Several maturity assessments (TRL)
- Overall assessment equal to or greater than level

Data on maturity
- Technology demonstrated in Denmark
- Agreement between TRL assessment and datapoint

Test facilities
- Test facilities identified in Denmark
- Facilities of relevant maturity level identified

Scalability

RISK ASSESSMENT: **LOW**

Complexity
- Appropriate for mass production/distribution
- No construction with budget slips required

Input
- No labour shortage for relevant jobs identified
- No heavy import of goods from outside the EU identified

Mitigation potential
- Other technologies overlapping mitigation potential
- Supporting energy infrastructure not required

Market conditions

RISK ASSESSMENT: **HIGH**

Market for climate effects
- Risk of reductions accruing to other countries
- Risk of regarding displacement of effect between agents
- Positive/neutral side effects in deployment

Technology users
- Relevant users identified
- Restrictions on technology purchase identified

Local support
- Local support in municipalities identified
- Local resistance in media identified

Regulation

RISK ASSESSMENT: **HIGH**

Before use
- Procedure for permits and approvals under 3 months
- Pending product approvals
- Unclear or lacking legislation

During use
- No mandatory certification for personnel etc. identified
- Need for mandatory fee-funded public oversights identified
- Unclear or lacking legislation

After use
- Procedure for permits and approvals under 3 months.
- Unclear or lacking legislation

Cost

RISK ASSESSMENT: **HIGH**

User costs
- Lacking incentive weighed against cost of externality

Access to capital
- Possible support for demonstration and testing
- Support for construction or production available

Cost drivers
- Identified monopoly in production of technology
- No carbon tax relevant for emissions sources

Inventory documentation

RISK ASSESSMENT: **HIGH**

Emission factors
- Appropriate estimation for relevant emissions sources
- Relevant emission factors not identified
- Relevant emission factors not documented

Activity data
- Possible data delivery from existing data supplier
- Lack of agreement on data delivery

Research capacity
- Low capacity on relevant research field(s)
- Negative trend for relevant research field(s)

2. Which policies are likely to be effective in driving innovation and cost reduction?

In any sector, a wide range of policy options can be used to promote clean technology innovation, diffusion, and cost reduction. Policies can be implemented with different stringencies, and in different combinations. Here we consider three analytical tools that can be used to compare the effectiveness of different policies: systems mapping with causal loop diagrams; sector-specific system dynamics models; and sector-specific agent-based models. These all provide ways to assess policies' dynamic effectiveness: the extent to which goals for non-marginal economic change are likely to be achieved, how quickly, and with what costs, benefits, opportunities, or risks.

Systems mapping with causal loop diagrams

Causal loop diagrams are a form of systems mapping – one of a family of methods for understanding systems by describing them in diagrams and models.[135] They are constructed by mapping relationships between variables in the system of interest, and identifying how some of these relationships together create feedback loops. There are two kinds of feedback loop: reinforcing feedbacks, in which an increase in one variable leads to a further increase in the same variable, tending to amplify impact or accelerate change; and balancing feedbacks, in which an increase in one variable leads to a decrease in the same variable, tending to limit change or preserve stability. Identifying the feedback loops in a system, and the interactions between them, can help to explain the system's behaviour.[136]

While this is a general method for analysing the behaviour of any system, it is relevant to finance ministries' interests in innovation and competitiveness in the low carbon transition. The process of development and diffusion of new technologies can involve reinforcing feedbacks such as learning by doing (the more something is made, the more it improves), economies of scale (the more it is made, the cheaper it gets), the emergence of complementary technologies (the more it is used, the more other technologies emerge that make it more useful), and the feedback between investment, innovation, and demand.[137] There can also be balancing feedbacks, including incumbent industries' opposition to change, that can prevent or delay a transition to new technologies. Within complex market or industrial structures, there can be many feedbacks operating at once.

Systems mapping with causal loop diagrams can clarify the nature of these relationships, helping to explain the behaviour of the relevant part of the economy. It can show where policy interventions to strengthen or weaken existing feedbacks, or to create new feedbacks, could be most effective in changing the system in a desired direction.

Policy questions

Policy questions that can be addressed with this analytical tool include:

- Which policies to promote innovation and diffusion of clean technologies in a given sector are most likely to be effective? [C]
- How can policies for promoting low carbon innovation and competitiveness be designed to be self-amplifying and not self-limiting? [F]
- How can packages of policies be designed so that they are mutually reinforcing and likely to achieve more than the sum of their parts?

135 Barbrook-Johnson and Penn, Systems Mapping: How to Build and Use Causal Models of Systems.

136 Donella Meadows, Thinking in Systems: A Primer.

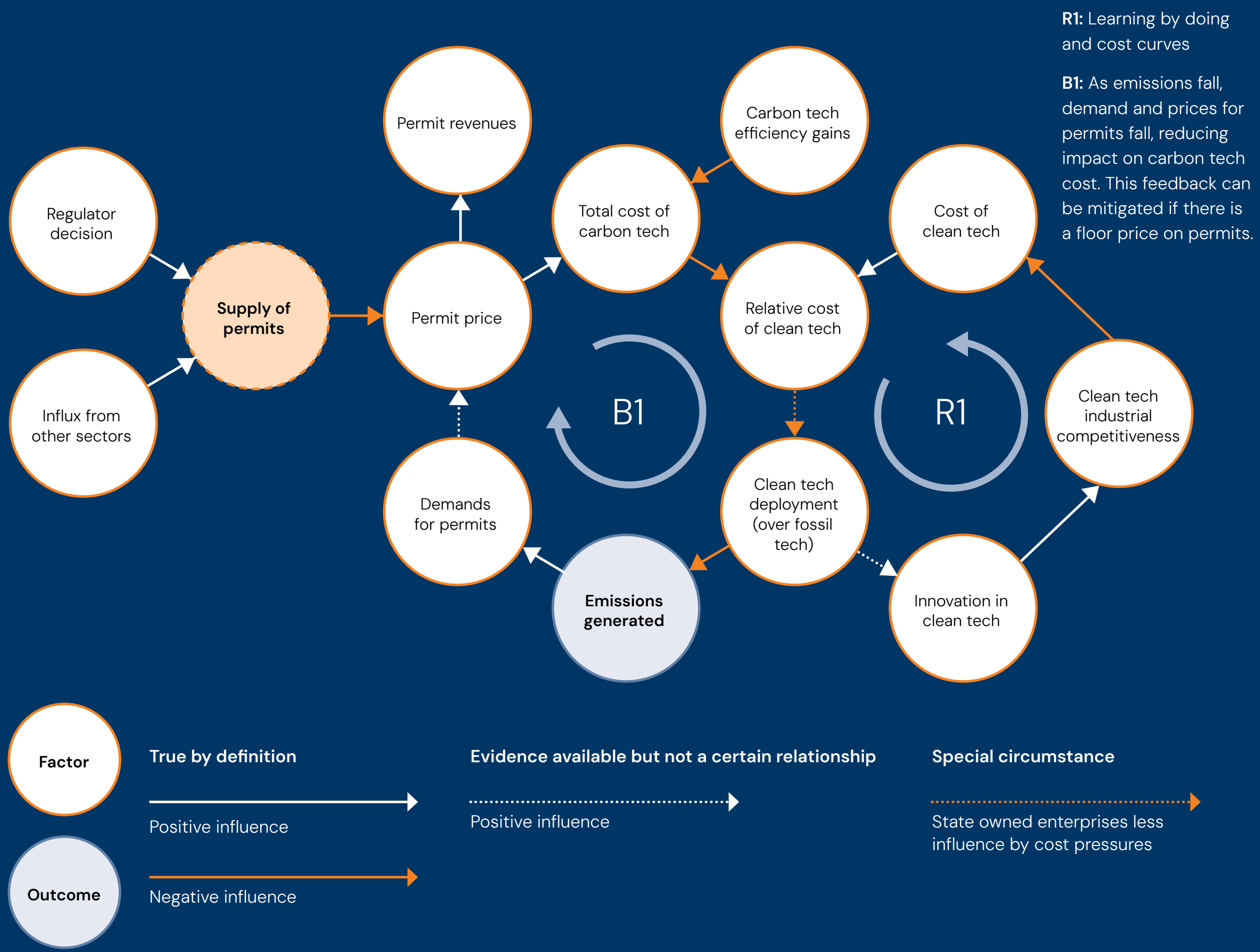
137 Arthur (1989). Competing Technologies, Increasing Returns, and Lock-In by Historical Events.

Example

Systems mapping with causal loop diagrams has been used to compare two approaches to carbon pricing.[138] A simple analysis finds that a cap-and-trade scheme creates a balancing feedback (see Figure 7): the more one company in the market reduces its emissions, the less other companies are incentivised to reduce theirs. In contrast, a fixed carbon tax creates no new feedbacks. This fundamental difference in the dynamics of the two policies suggests that all else being equal, a fixed tax is likely to be more effective. In practice, which option is more effective will depend on many factors including policy design, policy stringency, market context, political preferences, and institutional arrangements.

This is a simple example, but larger and more complex system maps can also be created. The UK Government used systems mapping to identify interactions to consider in the deployment of electric vehicles, including two key reinforcing feedback loops that were relevant to policy effectiveness.[139]

Figure 7: System map of an emissions trading scheme, illustrating the reinforcing feedback of clean technology deployment and cost reduction, and the balancing feedback created by the policy



Source: Sharpe et al in Barbrook-Johnson et al (2023) New Economic Models of Energy Innovation and Transition: Addressing New Questions and Providing Better Answers.

138 Sharpe et al., in Barbrook-Johnson et al. (2023) What Is the Most Cost-Effective Form of Carbon Pricing? Modelling Emissions Trading and a Carbon Tax in General and in China, in New Economic Models of Energy Innovation and Transition: Addressing New Questions and Providing Better Answers.

139 UK Government. (2022). The Journey to Net Zero Policy Paper.

Contrasting assessments	
	Equilibrium theory Equilibrium theory implies that a carbon tax and a cap-and-trade scheme are equally efficient, with any difference depending on the details of their implementation, since both policies are expected to incentivise companies to reduce emissions until the point at which their marginal abatement costs are equal to the carbon price.[140]
	Systems mapping Systems mapping with causal loop diagrams suggests the two policies are fundamentally different in their dynamics, since a cap-and-trade scheme creates a balancing (self-limiting) feedback, whereas a fixed carbon tax does not.

Limitations

Causal loop diagrams can be used to map a system as it currently is, and to consider changes that could be made to the system's structure that would alter its behaviour, but the approach cannot predict entirely different system structures that could emerge in future.

It can be difficult to predict the behaviour of a system in which many feedbacks are present, alongside other influences and constraints. In such cases, especially if quantitative outputs are desired, it can be useful to go beyond causal loop diagrams and construct a quantified model (such as a system dynamics model or agent-based model – see relevant sections).

As with other analytical tools, causal loop diagrams are likely to be useful only if applied in combination with expert knowledge of the subject matter of interest.

Sector-specific system dynamics models

System dynamics models are based on feedback loops – closed paths that start and end with the same variable. As described above, these include reinforcing feedbacks, where a certain form of change is amplified through the system, leading to non-linear growth or decline in particular variables, and balancing feedbacks, where change is offset through system interactions, leading to stability in relevant variables. The difference compared to causal loop diagrams is that in system dynamics models these relationships are quantified, enabling the system's behaviour over time to be simulated.

The low carbon transition can be understood as a set of 'system transitions' – shifts from old to new technologies and associated industrial, financial, physical, and social structures – in each of the GHG-emitting sectors of the economy.[141] A system dynamics model focused on one of the emitting sectors can be used to represent this process of change. Depending on the scope of the model, it is possible to represent the interactions between variables such as policies, industry investment, innovation, costs of technologies and related products, consumer demand, deployment and market share of old and new technologies, and emissions.

An important difference compared to cost-optimisation models is that system dynamics models simulate change over the course of time, rather than calculating optimal outcomes according to input criteria. This means that they aim to show what is *likely,* rather than what is *desirable*, and can be used to test the effects of policies whose outcomes are uncertain. These models can also be used to test the effects of combinations of policies, which may have outcomes that are different from the sum of their parts.

Policy questions

Policy questions that can be addressed with this analytical tool include:

- Which policies can best accelerate clean technology innovation and cost reduction, within a sector of interest? [C]
- Which policies can most cost-effectively support the diffusion of clean technologies, within a given sector? [C]

System dynamics models of different sectors can be linked together to provide insights on cross-sectoral interactions of policies and technological change. They can also be linked to models of the wider economy, to identify the likely macroeconomic effects of low carbon transition policies.

140 Stavins, R. The Future of U.S. Carbon-Pricing Policy. M-RCBG Faculty Working Paper Series, 2019, No. 2019-02, Mossavar-Rahmani Center for Business & Government, Harvard Kennedy School, Cambridge MA, USA, Available online: https://www.hks.harvard.edu/centers/mrcbg/publications/fwp/2019-02

141 International Panel on Climate Change (2021). Global Warming of 1.5°C. SR1.5.

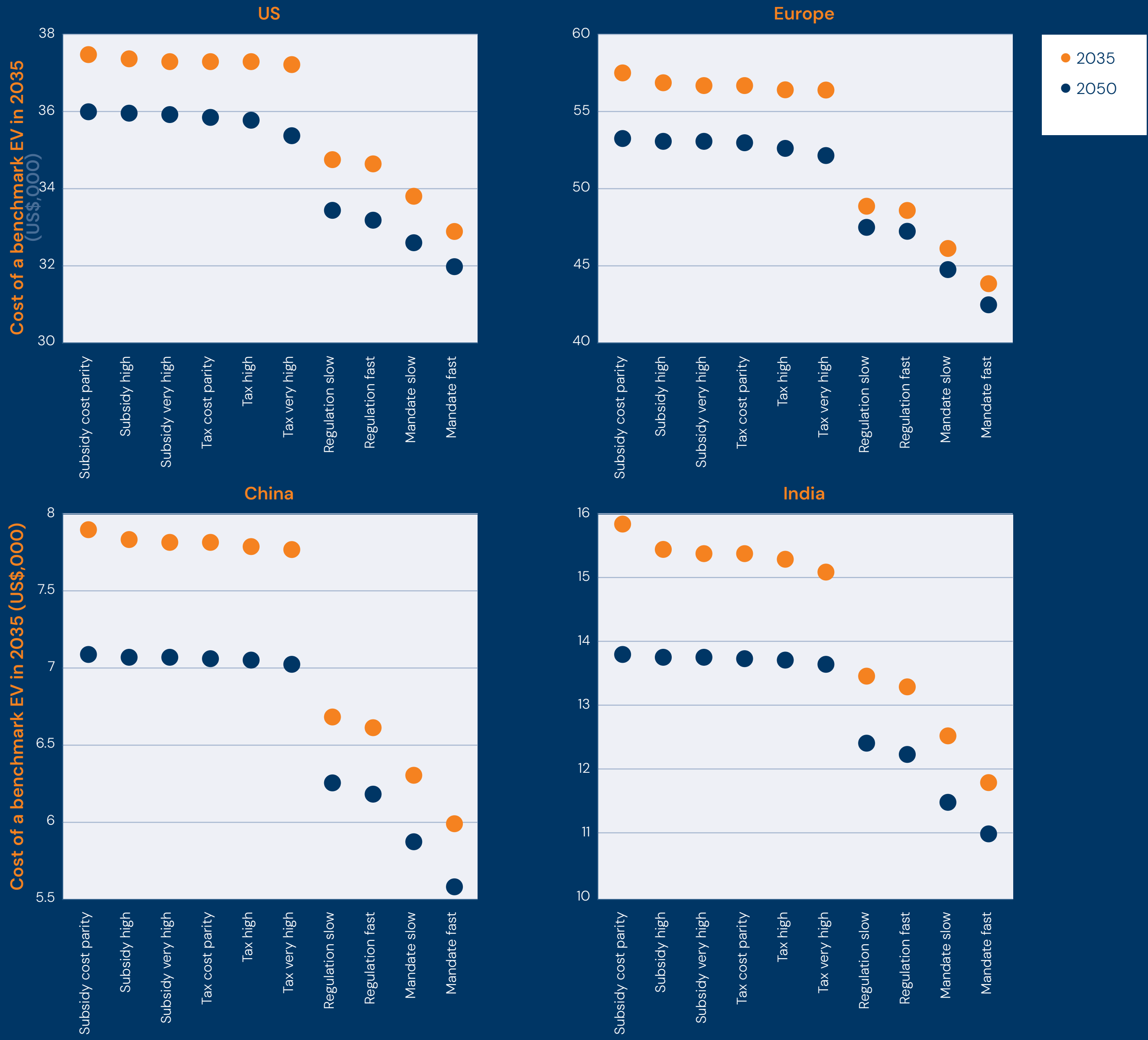
Example

The (FTT) suite of models includes system dynamics models for each of the power, steel, heating, and road transport sectors. The models represent competition between technologies in markets where industry actors are aiming to maximise profits or minimise costs, and consumers have diverse preferences. The models are centred on the reinforcing feedback of the technology learning curve, in which deployment leads to cost reduction, and lower costs increase demand, which leads in turn to further deployment.

In a study of policy options for the road transport transition, the FTT model showed that efficiency regulations and zero emission vehicle mandates were likely to be more cost-effective than subsidies and taxes in accelerating the diffusion and cost reduction of zero emission vehicles, in Europe, the USA, China, and India (see results in Figure 8).[142] The analysis also showed that combining a zero emission vehicle mandate with an efficiency regulation or a tax on fossil-fuelled vehicles could achieve more than the sum of the effects of these policies when used individually, whereas the combination of an efficiency regulation and a tax was likely to achieve less than the sum of its parts.

Figure 8: Cost of benchmark electric vehicle (EV) under different policy assumptions

The chart shows how each individual policy could influence the cost of EVs by 2035 and 2050, including in China. Focusing on China, the 'fast' ZEV mandate achieves the greatest cost reduction because, by ensuring the largest deployment of EVs during the time period, it pushes the technology furthest down the learning curve.



Source: Lam et al (2023) Policies to Pass the Tipping Point in the Transition to Zero-Emission Vehicles.

142 Lam et al. (2023). Policies to Pass the Tipping Point in the Transition to Zero-Emission Vehicles.

Contrasting assessments	**Equilibrium theory** Equilibrium theory is often interpreted as implying that carbon pricing is the most cost-effective policy for decarbonisation.
	Sector-specific system dynamics models Simulation with the FTT model suggests that zero emission vehicle mandates can be significantly more cost-effective than taxes in the road transport transition.

Limitations

The reliability of a system dynamics model depends on the robustness of the evidence used to define the relationship between its variables, as well as on the quality of the data with which it is calibrated. (Data requirements for system dynamics models are comparable with those of optimisation models). A choice must be made in model design about which variables and feedbacks are relevant to include, given the model's purpose. There is always a risk that some important factors have been omitted.[143] Conversely, the more feedbacks that are included, the more difficult it can be to validate model outputs in a way that provides confidence in the model's ability to predict system behaviour.

While sector-specific system dynamics models can be used to explore the dynamics of the low carbon transition within an individual sector of interest, they need to be combined with other models to explore cross-sectoral or macroeconomic consequences of the transition.

143 FTT-Transport, for example, does not explicitly cover second hand car sales, making it potentially less suitable for countries in which imported second hand vehicles account for a large share of the market and there are fewer new car sales.

Case Study 3: On the use of the FTT model in Georgia's Public Finance Review – is a modest carbon tax enough to decarbonise passenger road transport?

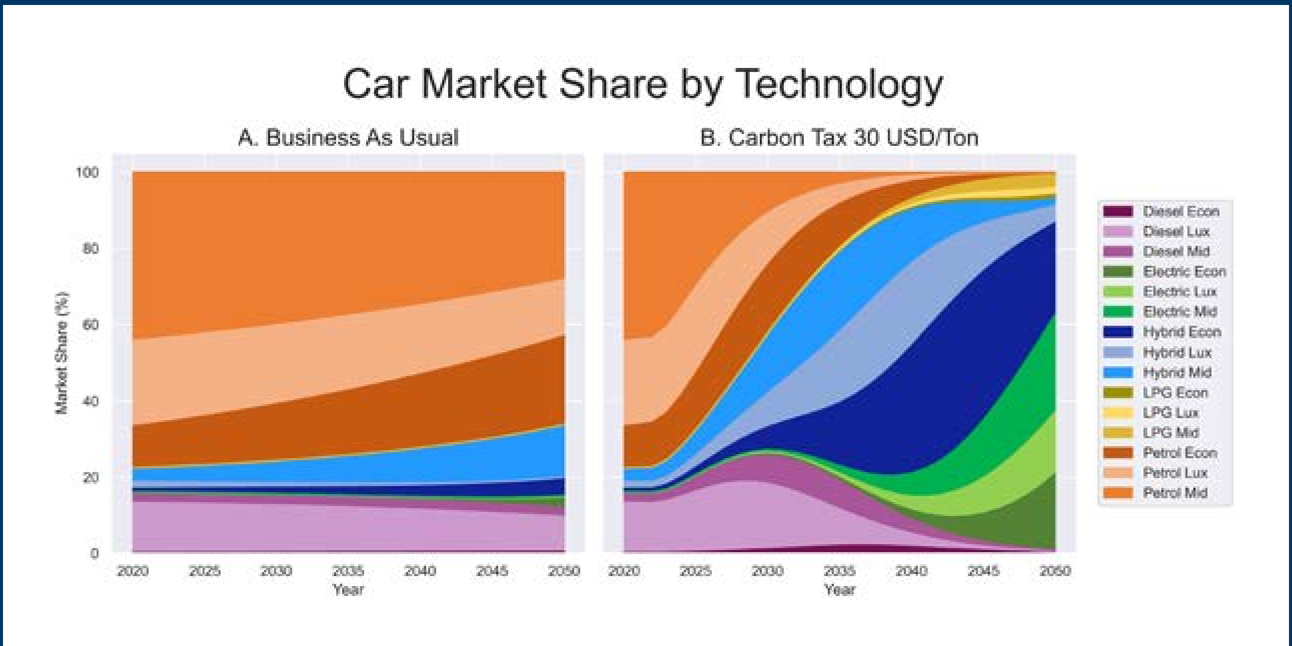
The World Bank has begun to pilot the use of the FTT, starting with its application to Georgia's transport sector as an input to the country's Public Finance Review (PFR). PFRs constitute the core product of the World Bank's Fiscal Policy and Sustainable Growth Unit, and are part of the World Bank's advisory service and analytics, meaning they have the potential to inform lending operations.

Georgia's road transport sector accounts for about 14% of the country's emissions.[144] The government plans to increase the share of electric and hybrid vehicles to 5% and 20% of total registered vehicles respectively by 2030.[145] While hybrid car adoption is on track, electric vehicle adoption lagged behind in 2022. Tax incentives already exist for both. The FTT model was used to evaluate the impact of a modest carbon tax on the market share of hybrid and electric vehicles.

Results indicate that a carbon price alone primarily encourages the adoption of hybrid vehicles, which, in turn, hinders the diffusion of electric vehicles. Modelling showed that introducing a modest carbon tax (rising from $5 to $30USD/tonne CO2e between 2023 and 2030, before levelling off), would accelerate the growth of the hybrid car market share, but with little positive impact on electric vehicle sales in the medium term, with these significantly missing the 5% target. The analysis suggests that other policies are needed. Other studies with FTT have indicated that zero emission vehicle mandates, energy efficiency regulations, and purchase incentives can all be cost-effective policies for advancing the transition to electric vehicles, with their relative cost-effectiveness varying across countries at different stages of the transition.[146]

Figure 9: Georgia: Changes in Car Market Share by Technology

Percent change in car market share by technology with vs. without carbon tax



Source: WB staff estimates based on FTT-Transport.

144 Ministry of Environmental Protection and Agriculture of Georgia (2021). Georgia's 2030 Climate Change Strategy – Mitigation.
145 Ministry of Environmental Protection and Agriculture of Georgia (2021). Georgia's 2030 Climate Change Strategy – Mitigation.
146 Lam et al. (2023). Policies to pass the tipping point in the transition to zero-emission vehicles. EEIST.

Sector-specific agent-based models

Agent-based models (ABMs) are built on assumptions about the behaviour of individual agents in the economy, such as consumers, businesses, or investors. These models represent how agents act in response to the conditions they encounter, and how they interact with each other and with their environment. Unlike other model types, ABMs make few assumptions about the structure of the system of interest. Instead, the system's structure, as well as its behaviour, emerges from the agents' interactions, and is observed as an output of the model.

ABMs can be highly conceptual, or strongly grounded in empirical data. Conceptual ABMs provide a more abstract representation of a system of interest, and can be used to explore the system's behaviour in a qualitative way, generating outputs that can be understood as contingent on the input assumptions. Data-based ABMs can be designed to closely represent an actual system, and can be validated by testing on out-of-sample data, enabling confidence in the quantitative outputs that they generate.

Like system dynamics models, ABMs are simulating models, and so can be used to test the effects of policies in situations of uncertainty. This can include testing policy options relevant to innovation and competitiveness in the low carbon transition. The main strength of ABMs compared to system dynamics models is their ability to show outcomes that arise from the interactions between economic agents. This can be helpful in exploring aspects of the low carbon transition such as the spread of new technologies among consumers, the adoption of new practices among producers, the changing expectations among investors, the effects of policies that influence competition between businesses within a country (such as emissions trading schemes), and the effects of deployment and trade policies implemented by different countries in hard-to-decarbonise sectors.

Policy questions

Policy questions that can be addressed with sector-specific ABMs include:

- Which policies can best accelerate clean technology innovation, diffusion, and cost reduction, within a given sector? [C]
- How can policies be designed to stimulate competition in a way that accelerates clean technology innovation and investment, within a given country and sector? [I]
- Which international policies (such as trade policies, and international coordination on deployment policies or standards) are likely to support a country's competitiveness in a given sector in the context of the global low carbon transition? [F]

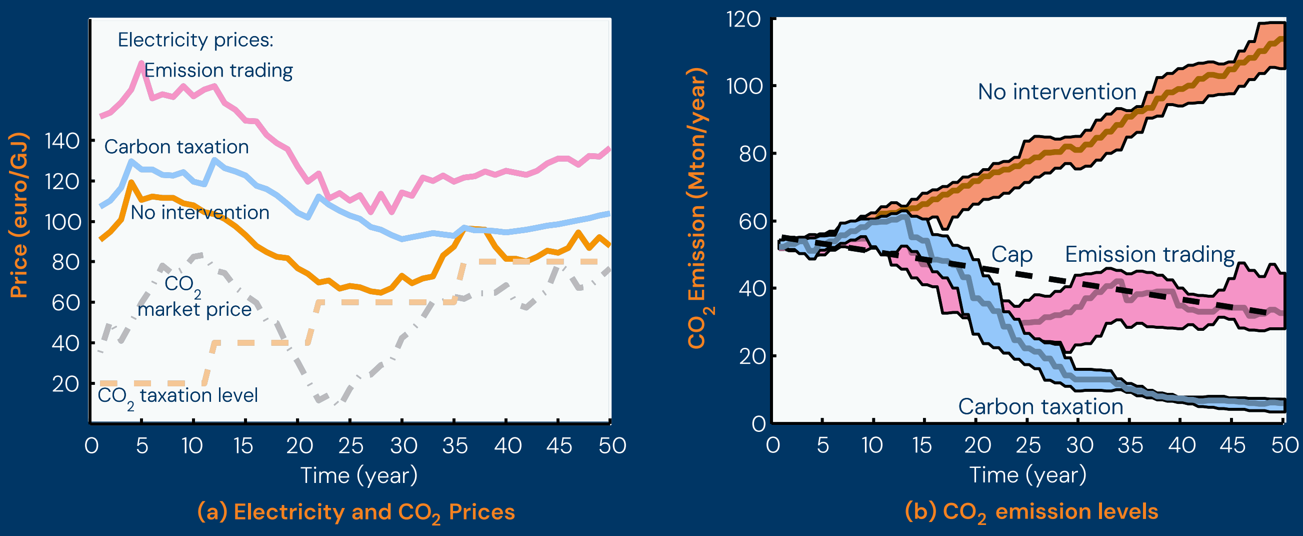
ABMs can also be designed to represent the macroeconomy, or particular markets such as financial markets or labour markets (see sections below).

Example

An agent-based model of the power sector has been used to compare the effect of different forms of carbon pricing policy.[147] The agents represented in the model were electricity producer companies, whose decisions included which power generation technologies to invest in. They interacted through markets for technologies and fuels, electricity, and emissions permits. The model simulation found that for the same average carbon price over a fixed period of time, a carbon tax reduced emissions more quickly than an emissions trading scheme, and at the same time resulted in a lower price of electricity (see Figure 10).

147 Chappin (2011). Simulating Energy Transitions.

Figure 10: Emissions and electricity price impacts of a carbon tax compared with an emissions trading scheme



Source: Chappin (2011). Simulating Energy Transitions.

Contrasting assessments	
	Equilibrium theory As noted in chapter V, equilibrium theory implies that a carbon tax and a cap-and-trade scheme are equally efficient, with any difference depending on the details of their implementation.
	Agent Based Models (aBms) The agent-based modelling study cited above finds that for the same average carbon price, a tax achieves faster emissions reduction than a cap-and-trade scheme, along with lower electricity prices and a larger shift to new technologies. This can be understood as arising due to the cap-and-trade scheme incorporating a balancing feedback,[148] which tends to have a self-limiting effect, whereas the tax has no such self-limiting dynamic. (Note: which policy is preferable in reality will depend on factors including context, stringency, enforceability, and political economy.)

Limitations

ABMs depend strongly on assumptions about the behaviour of individual economic agents. While these assumptions can be based on well-established evidence, such as behavioural science research, they may be difficult to calibrate when the model aims to represent a new situation for which historical data cannot provide an exact precedent. Another important challenge with ABMs is that their results can be too complex to understand and explain, particularly when modellers include too many interactions.

ABMs have about the same data requirements as other models (for example disequilibrium macroeconomic models). However, they can quickly become very slow to run when many agents are included, which means available computing power can be a limiting factor in their use.

148 If one actor in the market reduces emissions, demand for emissions permits falls; with supply of permits being fixed by the cap, this tends to reduce the price of permits (the carbon price), decreasing the incentive for other actors in the market to reduce their emissions.

3. In which sectors or technologies should a country aim to build competitiveness and skills?

As noted in section 2, governments can strengthen national economic competitiveness through cross-cutting interventions, and may also aim to develop stronger competitiveness in particular sectors or technologies, as part of a national development strategy or industrial strategy.

The low carbon transition will affect many sectors of the global economy, and the competitive positions of countries are likely to change as markets shift from fossil fuels to clean technologies. Many governments are interested in the question of where, across this broad landscape of economic change, they should aim to build up their countries' competitiveness. Here we outline three analytical tools that are relevant to this question: revealed comparative advantage (RCA), economic complexity analysis, and labour market models.

Revealed comparative advantage

The analytical approach of revealed comparative advantage (RCA) belongs to the family of equilibrium theories and analytical tools. It is based on the idea that patterns of international trade are governed by relative differences in productivity, with countries specialising in goods they can produce with greater relative productivity (more cheaply) compared to trading partners.[149] RCA is defined as the proportion of a country's exports that are of a given product, divided by the proportion of global exports that are of that product. A country is considered a competitive producer and exporter of a product when the RCA is greater than one.

A high RCA value for a given product may be understood to reflect some national strengths relevant to its production, such as natural resources, skills, or technological capabilities.[150] RCA analysis can be used to inform trade policies or industrial strategies where governments aim to exploit and further develop these existing national competitive strengths. It can also be used to evaluate the effects of past or prospective trade barrier policies such as tariffs and export subsidies.[151]

Limitations

RCA analysis has limitations that are important in relation to policy interests of innovation and competitiveness in the low carbon transition. It is essentially backward-looking and static: it shows what a country has done competitively in the past, but not what it could become competitive at in future. This can be an important limitation in two respects.

Firstly, **the world could change.** If global markets in the areas of economic activity being considered are likely to change significantly over the timescale of interest, comparative advantage revealed to have existed in the past may be a poor guide to competitiveness in future. In sectors affected by the low carbon transition – not only the emitting sectors, but also their value chains – deep technological and structural change in global markets is to be expected.

Secondly, **the country could change**. A country's own capabilities can be developed over time. Whereas RCA can imply that a country that successfully exports primary commodities should continue to focus on this as its competitive strength, a greater increase in national productivity and wealth may be achievable through developing the capabilities needed to move up value chains, industrialise, and move towards a more technologically sophisticated economy.

Given these limitations, countries that wish either to maintain their competitiveness in sectors affected by the low carbon transition, or to take advantage of the transition to industrialise through building comparative advantage in new elements of global supply chains, will need to look beyond RCA.

149 Krugman et al. (2018). International Economics: Theory and Policy.
150 Schumacher (2013). Deconstructing the Theory of Comparative Advantage.
151 French (2017). Revealed Comparative Advantage: What Is It Good For?

Economic complexity analysis

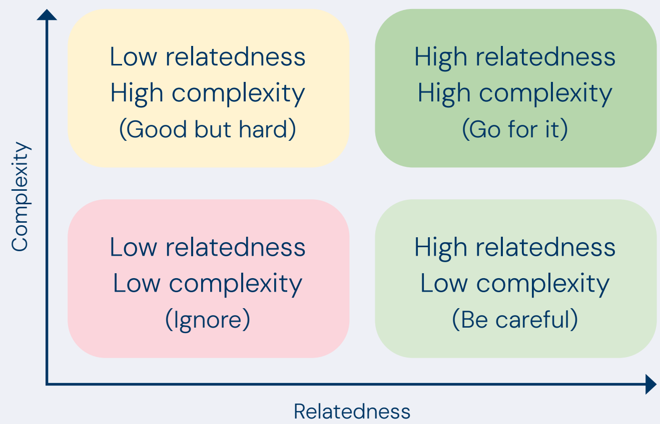
Economic complexity analysis uses network science to explain and predict changes in economic structures. It includes analysis of RCA, but also goes further, becoming at least partly forward-looking. While its reliability as a guide to policy remains debated (see 'Limitations' below), it has been used in development economics to help countries identify sectors and activities in which they have potential to industrialise and become competitive.[152]

The key premises of economic complexity analysis are that:

- i Growth can be driven by diversification, particularly by producing and exporting more 'complex'[153] products.[154]
- ii Industrial structures are path dependent, meaning that the options available at any time depend on choices made previously. Knowledge and capabilities are difficult to rapidly acquire, so it is easier for a country to diversify into products that are similar ('related') to those that it already produces.[155]

The implication is that a diversified, 'complex' economy is desirable, and can be achieved over time by pursuing products that are similar to or related to those that the country already produces (see Figure 11). This may help countries escape the so-called 'middle-income trap', which is often experienced by countries with relatively high income but low complexity economies.[156]

Figure 11. The (simplified) implication of economic complexity is that a diversified, 'complex' economy is desirable, and can be achieved by pursuing related products. This graphic highlights the following: (i) that pursuing high-complexity products with low relatedness may help a country industrialise into more complex products, but will be difficult; (ii) that pursuing high-relatedness products with low complexity will be easier, but may not help industrialisation; and (iii) that the 'sweet spot' is to pursue highly related products that are also higher complexity, compared with what an economy already produces. Adapted from Hidalgo (2023). The policy implications of economic complexity.



Economic complexity analysis has been applied to low carbon industries and supply chains to help inform policymakers' strategies for low carbon economic growth.[157] It uses trade data to identify products in which a country is already competitive (where RCA >1) and to map the relatedness of different products in the global economy. It combines measures of current competitive advantage, product relatedness, and product complexity to identify low carbon products in which a country has the potential to gain competitiveness. This can be useful for identifying and prioritising opportunities for economic diversification and growth.

152 Hidalgo (2023) The policy implications of economic complexity.

153 The definition of complex is products that few other places are able to make competitively (low ubiquity). This is often because the product is technologically sophisticated, but can be because of market structure or other dynamics. Note that diversification and complexity are different. Complexity is a measure of sophistication or knowledge intensity, and economies can specialise in a few complex products. Many of the most complex economies according to ECI (Japan, Switzerland, Finland, Taiwan) are not very diverse compared to relatively less complex economies (e.g. Spain, Italy).

154 Hidalgo and Hausmann (2009). The Building Blocks of Economic Complexity; Balland et al. (2022) Reprint of The New Paradigm of Economic Complexity.

155 Hidalgo et al. (2007). The Product Space Conditions the Development of Nations; Andres et al. (2023). Stranded Nations? Transition Risks and Opportunities towards a Clean Economy.

156 Hidalgo (2023). The Policy Implications of Economic Complexity.

157 Mealy and Teytelboym (2022).

Figure 12: The UK has existing strengths and future opportunities in complex green products. This figure plots the product complexity index (product complexity) and proximity measures (relatedness) to identify strengths and opportunities.

Source: Curran et al. (2022) Growing clean: Identifying and investing in sustainable growth opportunities across the UK.

As a counterpart to this approach, 'brown' complexity analysis can be used to quantify the extent to which a country's productive capability is tied up in declining sectors, and to identify viable transition pathways from brown (fossil fuel-related and declining) to 'green' (low carbon and growing) products and sectors.[158 159]

Policy questions

Policy questions that can be addressed with this analytical tool include:

- In which low carbon products or sectors does a country (or region) have potential to gain international competitiveness? [E]
- Which regions within a country would be most suitable for the development of a specific new industrial capability?[160]
- What sequencing of development of new industrial capabilities can lead towards the production of higher-value (more complex) products?
- What are viable economic diversification opportunities for regions and workforces that are currently highly dependent on declining fossil fuel industries?

158 Andres et al. (2023). Stranded Nations? Transition risks and opportunities towards a clean economy.

159 It has also been found that higher complexity activities require less energy and emissions to produce a unit of GDP – for example, producing $1 of GDP by extracting coal is more energy and emissions intense than producing $1 GDP through financial services, implying that there may be potential to decouple economic growth from per capita GHG emissions through increasing product complexity, although this ultimately depends on structural change in the greenhouse gas emitting sectors of the economy. João P. Romero and Camila Gramkow, Economic Complexity and Greenhouse Gas Emissions, World Development 139 (1 March 2021): 105317, https://doi.org/10.1016/j.worlddev.2020.105317.

160 See Economic Complexity for competitiveness and innovation: a novel bottom-up strategy for linking global and regional capacities.

Examples

A study of the UK showed that the country was relatively competitive in offshore wind, tidal energy, nuclear energy, and carbon capture use and storage (CCUS) technologies.[161] It found that there were opportunities for the UK to develop competitiveness in floating offshore wind, and to strengthen competitiveness in CCUS given its expertise in related technologies including environmental monitoring equipment, chemical separation, liquefaction, and solidification (see Figure 12).

Economic complexity analysis has been used in reports for countries including China, Mexico, Russia, Brazil, Turkey, Uruguay, Canada, Italy, South Africa, the UK, France, Ethiopia, and for the EU. The World Bank has recently begun using this technique in some of its Country Climate and Development Reports (including in Brazil and Argentina).

Limitations

While economic complexity analysis can suggest areas in which a country has a greater likelihood of developing competitiveness, it cannot provide certainty. Its findings should not be interpreted too simplistically: sometimes there may be better strategies than aiming for the most related and/or high-complexity products. It can be useful to consider more than one step ahead, though there is need for more research on path-breaking diversification strategies.

In some cases, the technique may give misleading guidance. The extent to which the measure of relatedness used in economic complexity (derived from trade data) can inform the transferability of capabilities across products is, in general, subject to some uncertainty. A country that exports petrol-powered cars competitively may not have a comparative advantage in electric vehicles, given the different technologies involved. In addition, a countries' pattern of exports can reflect aspects of its political economy (such as the political influence of a particular industry), not just its relative competitiveness across sectors and products. The extent to which the technique is generally reliable or unreliable as a guide remains a matter of debate among researchers and practitioners.

Economic complexity analysis is often highly specific, identifying product segments that are individually very small, and is limited to products that already exist, rather than new products that may emerge. To identify product clusters, industries, and sectors as strategic growth opportunities, as well as to provide more rounded analysis, it can be helpful to complement this with other forms of analysis including qualitative expert knowledge, patent data analysis, and stakeholder consultation. Focusing on relatedness can be quite limiting, especially if there are no closely related, high-complexity products identified for a country, and there is a lack of evidence on path-breaking diversification.

While economic complexity analysis can indicate products or sectors in which a country may have a good chance of building competitiveness, it does not indicate which policies are likely to be effective in achieving that goal.

161 Curran et al. (2022). Identifying and Investing in Sustainable Growth Opportunities across the UK, 2030.

Case Study 4: South Africa's use of economic complexity analysis to identify green growth opportunities

Economic complexity analysis was used in South Africa to identify opportunities for competitiveness in emerging supply chains critical to the global low carbon transition.[162] The analysis compared the closeness of value chains for a range of clean technologies, as well as products throughout each of those value chains, with South Africa's areas of current and potential comparative advantage.[163] It was complemented with stakeholder consultations and qualitative research.

The analysis revealed strong low carbon growth opportunities for South Africa. Opportunities to become competitive in products such as batteries, electric vehicles, and green hydrogen were considered to be grounded not only in plentiful natural resources of solar, wind, and minerals, but also in existing industrial capabilities in metals, electronics, machinery, and chemicals. While for batteries, South Africa had existing comparative advantage in products across the supply chain, for green hydrogen South Africa was competitive in some parts of the value chain but would need to invest significantly to become competitive in others – a more challenging 'strategic bet'.[164] South Africa's Industrial Development Corporation[165] used the analysis to inform its policy positions on the transition to electric vehicles, and its engagement with the automotive sector.

South Africa's National Treasury is now using this analytical approach to review and evaluate sector-specific industrial plans and policies, and to inform the next iteration of green growth strategy development. It is considering complementing this with strategic Foresight studies to generate insights into emerging and likely trends.[166] Recognised challenges include: the method's focus on economic growth but not job creation and inequality reduction; the need for other tools to address constraints such as high costs of capital; and the need for more coordinated policies across government departments to build competitive value chains.

Written with contributions from Ketan Ahuja and Tim O'Brien (Harvard Growth Lab); Georgina Ryan (National Treasury of South Africa); and Rian Coetzee, Phiwe Marumo, Pamela Mondliwa, and Khethollo Morolong (Industrial Development Corporation of South Africa Ltd).

Gravity models

The gravity model of international trade can predict trade flows between countries based on the size of the countries' economies and the distance between them. Comparing a predicted trade flow to an actual trade flow can indicate, to a first approximation, whether there is potential for trade to be increased. This analysis can be done at the product or sector level, by aggregating exports of specific products or product categories.[167] This can provide some indication of the sectors in which a country may have the opportunity to increase its exports, and of which countries could be viable as destination markets.

Models can be developed to include representation of factors that influence trade flows – such as transport costs, tariffs and non-tariff barriers, regional integration agreements, currency unions, time delays at export or import and trade facilitation, governance, corruption, and contract enforcement – and then used to test the effectiveness of policies or trade agreements that change any of those factors.[168]

Policy questions

Policy questions that can in principle be informed through this analysis include:

- In which sectors or product categories does a country have potential to increase its exports, by how much, and to which countries? [E]
- To what extent could trade be increased by trade agreements or other relevant policies?

In the context of the low carbon transition, this could be applied to considering trade in products in each of the emitting sectors of the economy, or in the value chains of those sectors.

162 Undertaken with support from the Harvard Growth Lab.
163 This differs from other approaches for economic complexity, which identify comparative advantage in individual green products, but not value chains. E.g. See Economic Complexity and the green economy.
164 Hausmann et al. (2023). Chapter 4: Green Growth, part of the two year project Growth through Inclusion in South Africa.
165 A national development finance institution owned by the SA Government and the key implementing agency of the country's industrial policy.
166 See NACI Foresight reports.
167 World Bank (2024) Uzbekistan's Green Export Potential (Preliminary Results) – forthcoming.
168 World Bank (2024) Uzbekistan's Green Export Potential (Preliminary Results) – forthcoming.

Example

Gravity modelling has been used by researchers in combination with economic complexity analysis to evaluate Mozambique's industrial strategy.[169] This enabled a consideration of both supply- and demand-side factors. Economic complexity analysis was used to identify a set of products with high complexity and relatedness to Mozambique's existing productive capabilities. Gravity modelling was used to predict which export markets and products would be more feasible for Mozambique, given product-specific constraints on trade and geographically dispersed demand. The analysis found that demand conditions for target products were particularly favourable in agriculture and agro-industry, metals and minerals; and that there was very high export potential in machinery and electronics, and vehicles and transport equipment. By combining the supply side-focused complexity analysis with a demand-side analysis based on gravity models, this approach provided indications of the products, sectors, and destinations that held the highest potential for Mozambique to generate additional export revenues.

Limitations

Gravity models often assume countries are similar to each other, overlooking variations in economic structures, industrial compositions, and technological capabilities. The quality of the analysis is highly dependent on the degree to which such variations are controlled for or integrated.[170] It is particularly difficult to model the influence of non-economic factors such as cultural ties, historical relationships, political alliances, and institutional quality. In addition, gravity models typically assume static relationships between countries over time, overlooking changes in comparative advantage, technologies, and global supply chains.

Complementary approaches

Due to the high uncertainty and complexity inherent in the question of how to build competitiveness in a changing economic context, each of the analytical tools discussed in this section risks being misleading if used in isolation. The best approach is likely to involve a combination of analytical tools, together with the maximum possible input of qualitative, place-based and industry-specific knowledge and expertise.

To identify sectors where a country has current strengths, it can be useful to compare the productivity of different sectors in the domestic economy, as well as measuring RCA (defined in terms of exports).

To identify sectors where a country has future opportunities to build competitiveness, in addition to measuring the relatedness of sectors or products to those in which the country already has a comparative advantage (as in economic complexity analysis) it can also be useful to consider the country's share of the global market in each sector (a measure of its absolute advantage), and the rate of growth of the global market (an indicator of future opportunity).

To determine where within supply chains there is a need to build industrial capabilities, input–output analysis may be helpful. This can indicate how changes in demand in one sector (such as may be caused by the low carbon transition) are likely to translate into changes in demand in other sectors, potentially informing policy decisions on investment, infrastructure, or skills.

To assess the chances of success in any competitive strategy, it is also important to consider the strategies of competitors. These may not yet be visible in past or present market data, but are often stated publicly in political speeches and government documents.

169 Bo et al. (2020). Economic complexity and structural transformation: the case of Mozambique.
170 Aguiar & Cossu (2020). The Gravity Model for Trade Theory.

Labour market models

Macroeconomic models of various kinds (including Computable General Equilibrium (CGE), input–output, system dynamics, and others as referred to elsewhere in this report) can be used to project changes in labour demand in different sectors of the economy as a result of the low carbon transition. Often, these models assume that labour demand is met by labour supply – in other words, whatever jobs are created are filled by appropriate people.[171]

Models that explicitly represent the labour market can explore the interactions between labour supply and demand and other factors such as wages, skills, and geography. They can show how these factors may lead to unfilled positions, or unemployed people.

These findings can be relevant to governments' interests in innovation and competitiveness in the low carbon transition.[172]

Individuals are more likely to move into new jobs that involve activities similar to those they have undertaken in the past. Consequently, network analysis of occupations and activities within labour markets can provide insights into the transitions between occupations that are more and less likely to occur (see Figure 13).[173] This analytical approach can also show how occupations in some parts of the economy have fewer job transition opportunities than others, and how this affects unemployment.[174]

Figure 13: Occupational mobility network. Nodes represent occupations, links represent transitions of workers between occupations, and node size is proportional to the logarithm of number of employees in each occupation. Nodes are coloured by broad category of occupation. The links show how likely it is that a worker in one occupation moves to another occupation and therefore that some transitions are more likely than others.

Source: del Rio-Chanona et al. (2021). Occupational mobility and automation: a data-driven network model

171 García-García et al. (2020). Just Energy Transitions to Low Carbon Economies: A Review of the Concept and Its Effects on Labour and Income.

172 Mealy et al. (2018). What You Do at Work Matters: New Lenses on Labour; Saraji and Streimikiene (2023). Challenges to the Low Carbon Energy Transition: A Systematic Literature Review and Research Agenda.

172 Mealy et al. (2018). What You Do at Work Matters: New Lenses on Labour; Saraji and Streimikiene (2023). Challenges to the Low Carbon Energy Transition: A Systematic Literature Review and Research Agenda.

173 Mealy et al. (2018). What You Do at Work Matters: New Lenses on Labor.

174 Del Rio-Chanona et al. (2021). Occupational mobility and automation : a data-driven network model.

Agent-based modelling can be used together with network analysis to simulate the response of a labour market to changes such as the low carbon transition.[175] This approach takes changes in labour demand (projected by a macroeconomic model) as an input, models the decisions of individual workers based on factors such as their incomes, skills, and location and options, and simulates the labour market outcomes that arise from the interactions of all workers' decisions.

Policy questions

Policy questions that can be addressed using these analytical tools include:

- In which sectors and occupations are skills shortages likely to act as a constraint on a country's ability to grow and increase its competitiveness in low carbon industries? [E]
- In which occupations are workers most vulnerable to unemployment as a result of the low carbon transition? [G]
- What skills policies could best help workers move from occupations where jobs are declining to occupations where jobs are being created?
- (When used together with macroeconomic models): How are different low carbon transition strategies (for example different pace of the transition or different technology choices) likely to affect employment and the distribution of income levels within a country? [G, H]

Example

An agent-based model combined with network analysis has been developed and used to study how changes in labour demand could affect labour markets in the USA and Brazil.[176] An 'occupational mobility network' was created by mapping the proximity of each occupation to other occupations, with the probability of a worker moving from one occupation to another being based on a historical dataset. This created a constraint that was used in the agent-based model: workers could only apply for jobs in neighbouring occupations within the network.

In the USA, the analysis found that some 'brown' (fossil fuel-related) occupations were relatively close in the network to 'green' alternatives, implying greater potential for labour mobility than previously expected.[177] In Brazil, the study compared different growth paths for the economy and found that the number of occupations facing higher unemployment due to limited labour mobility is lower in a manufacturing-driven growth path than in an agriculture-driven growth path.[178]

While agent-based labour market modelling has provided valuable insights into the functioning of labour markets and the consequences of policies,[179] there are very few examples so far of this technique being used to model the impact on labour markets of the low carbon transition.

Limitations

Models that explicitly represent the labour market require detailed and good-quality data. This is more available in some countries than in others. It is particularly difficult for models to represent informal labour markets, where data is usually scarce.

Like any models, labour market models are only as good as their inputs and assumptions (and on the contextual knowledge and interpretative capabilities of the decision-maker). Labour market models require assumptions to be made on issues such as how individuals make decisions about changing occupations, how they are constrained by skills and other factors, and how policies affect labour productivity.[180] Importantly, if a labour market model uses a macroeconomic model to provide projected changes in labour demand as an input, then it inherits any of the limitations of the macroeconomic model.

Just as technology models cannot represent technologies that do not yet exist, labour market models cannot represent jobs that do not yet exist. Models that focus on skills and tasks rather than on jobs and occupations are an alternative to partially address this limitation,[181] but these are also subject to economic change.

There are likely to be other relevant factors that are also excluded. Labour market models are likely to be most useful when they are complemented by other knowledge and analysis of the industries, communities, and places of interest.

175 Berryman et al. (2023). Modelling Labour Market Transitions: The Case of Productivity Shifts in Brazil.
176 Berryman et al. (2023). Modelling Labour Market Transitions: The Case of Productivity Shifts in Brazil.
177 Mealy, del Rio-Chanona, & Farmer (2018). What You Do at Work Matters.
178 Berryman et al. (2023). Modelling Labour Market Transitions: The Case of Productivity Shifts in Brazil.
179 Neugart & Richiardi (2012). Agent-based models of the labor market. Centre of Employment Studies; Hynes et al. (2020). Systemic Thinking for Policymaking: The potential of systems analysis for addressing global policy challenges in the 21st century.
180 Laubinger et al. (2020). Labour market consequences of a transition to a circular economy: a review paper.
181 See the World Bank (2022) Argentina CCDR.

4. What will be the macroeconomic effects of innovation and competitiveness policies?

Finance ministries have strong interests in understanding the macroeconomic effects of the low carbon transition and relevant policies, for reasons discussed in our introduction. Here we briefly outline three categories of economic model that can be used for this purpose: CGE models, integrated assessment models, and disequilibrium macroeconomic models. The first of these is based on equilibrium theories and assumptions; the third is consistent with evolutionary theories; and the integrated assessment models can be derived from either, though in most cases belong to the equilibrium set. These models are applicable to a wide range of policy questions, many of which are beyond the scope of this report. Here we outline their capabilities and limitations specifically in relation to questions of innovation and competitiveness in the low carbon transition.

Given the diversity in modelling approaches, analysts in finance ministries and other parts of government should make careful choices in selecting the models most appropriate for their purposes. A model's capability to represent policy-driven innovation and its macroeconomic effects depends on many aspects of model design. Some of the most important factors are shown in Table 7 below.

Table 7: Drivers of model capabilities

Model's ability to represent...	Depends on extent of...
Effect of policy on technology deployment	• Ability to represent a range of different policies • Detail in representation of individual countries and sectors • Representation of heterogenous agents (consumers or businesses with different expectations and preferences)
Effect of deployment on technology cost reduction	• Representation of policy-induced innovation within the model • Reliability of assumptions on technology learning rates
Effect of technology cost reduction and diffusion on macroeconomic variables	• Realism of assumptions about behaviour of the macroeconomy

Source: authors.

Computable general equilibrium models

CGE models are often used by governments to form expectations about the impact of policies on resource allocation in the macroeconomy. They are used together with energy system models to create idealised scenarios of the economic effects of the low carbon transition.

The structure of CGE models is defined by the assumption that the economy is in a state of general equilibrium, where demand and supply are balanced in all parts of the economy, achieved through economy-wide collective utility maximisation, and where a predetermined amount of economic resources is allocated between uses. The models incorporate changes to the economy as input data, and recalculate changes to the levels of prices and other economic variables that result from these input changes, which is consistent with equilibrium at either fixed points in time or intertemporally (across time). Typically, this approach involves the assumption that economic actors such as firms and households have perfect information about the present and future, act rationally, and have no constraints on exchanging goods and services with each other, so that all resources in the economy are optimally allocated. 'Myopic' model versions relax the assumption of knowledge of the future. Variants of the CGE approach include partial equilibrium models, in which equilibrium conditions are imposed within particular economic sectors, and Dynamic Stochastic General Equilibrium (DSGE) models, which introduce randomness into some economic variables to produce a wider range of possible outputs.[182]

A limitation of this family of models is that the assumption of equilibrium prevents the exploration of important classes of possible dynamic states of the economy – such as instability, including financial crises, and path-dependent structural change, including technology transitions that lead to a transformation of the nature of economic activity. In practice, equilibrium models primarily explore marginal resource reallocations that result from marginal changes in relative price levels and do not explore transformative change that could alter the amount of resources that can be allocated. The assumption that economic actors have perfect information limits the scope to test how businesses may respond to policy in the conditions of uncertainty that exist in situations of innovation and technological change. The use of system-level optimisation to represent the behaviour of all consumers limits the potential to test how policy will drive the diffusion of new technologies across markets containing consumers with diverse preferences and income levels.[183] The assumption that all resources are optimally allocated in the economy limits the scope for exploring ways in which policy could create resources by stimulating innovation, strengthening industrial competitiveness, and achieving positive outcomes for overall investment, job creation, and growth, and how some resources could be destroyed by economic transformation processes (stranded assets are not possible in CGE models).[184]

Other forms of analysis such as expert judgement, game theory, and Bayesian statistics are often used alongside CGE models to compensate for some of these limitations. Nevertheless, the models' core assumption of equilibrium creates a risk that they provide misleading advice when applied to situations of innovation and structural change.

A more general criticism is that a lack of systematic comparison of CGE models' projections and the actual behaviour of the economy calls into question the reliability of the models' outputs. This is a criticism that can also be applied to other forms of models (see box on alternative model types, and 'limitations' in the section on disequilibrium macroeconomic models).

Integrated assessment models

Integrated assessment models (IAMs) combine models of different human and natural systems, including energy, land use, the economy, and the climate. By bringing these different elements together within an integrated modelling structure, they aim to inform high-level consideration of climate goals and strategy, such as the emissions targets consistent with a given global temperature goal, the technology choices consistent with a given emissions target, or the least-cost pathways for reducing emissions across different economic sectors.[185]

The range of modelling approaches being used in IAMs is becoming increasingly diverse (see later section on disequilibrium macroeconomic models). However, the use of equilibrium assumptions and optimisation structures has been common to the IAMs used by the Intergovernmental Panel on Climate Change, and by some governments, since the 1990s. Even within this traditional framework, IAMs vary widely in their scope, design, and degree of complexity.[186] Consequently, any general statement about their capabilities and limitations risks over-generalising. The brief description we present here should be read with that caveat in mind.

IAMs can be described in terms of two categories of differing complexity: cost–benefit IAMs, which broadly aggregate the economy in a small number of variables, aiming to compare the economic costs and benefits of emissions reduction at an economy-wide level; and process-oriented IAMs, which represent the economy in more detail.[187] While the former may be valued for their simplicity, the latter can include a wider range of specific emissions reduction opportunities.

182 One example of a DSGE model applied to climate change is a study of the macroeconomic returns of investment in resilience to natural disasters. Corugedo et al. (2023). The Macroeconomic Returns of Investment in Resilience to Natural Disasters under Climate Change: A DSGE approach, an IMF working paper.

183 Mercure et al. (2016). Modelling complex systems of heterogeneous agents to better design sustainability transitions policy.

184 Mercure et al. (2016). Modelling complex systems of heterogeneous agents to better design sustainability transitions policy.

185 An example of a simple IAM is the World Bank's Climate Policy Assessment Tool (CPAT), which is designed to quantify the impacts of carbon pricing on energy demand, prices, emissions, government revenues, welfare, GDP, air pollution, and other indicators.

186 An accessible overview of IAMs is provided by Carbon Brief (2018) at How integrated assessment models are used to study climate change.

187 Kotchen, et al. (2023). The costs of 'costless' climate mitigation.

The main advantage of IAMs is that their broad scope creates the potential to consider trade-offs between choices about the energy system, the economy more broadly, and the environment. General criticisms of IAMs are that they tend to be limited in their treatment of uncertainty, heterogeneity of consumers, and technological change, understating both the opportunities and the risks for economic development in the context of the low carbon transition.[188 189]

As with any kind of model, the outputs of IAMs are only as reliable as their input assumptions. The economy components of IAMs are usually equilibrium models (CGE, partial equilibrium, or DSGE), making them subject to the limitations described above in relation to their ability to represent processes of change in the economy. The energy system components of IAMs are usually cost-optimisation models, with the limitations described above relevant to innovation, competitiveness, and policy choices; although, as mentioned above, this is subject to considerable variation. When both energy system and economy components are optimising (solving equations to maximise welfare, or minimise costs, in each time period or across time), not simulating (mimicking patterns of cause and effect), the models have limited ability to test and compare policies, such as those designed to advance innovation and competitiveness, whose outcomes are uncertain. Lastly, the use of equilibrium models in IAMs leads to excessive focus on prices as policy levers, and to disregarding other types of policy levers such as regulation and investment.

Innovation is treated by some models as an external factor. For example, an assumed trajectory for the changing cost of a technology over time may be used as an input to the model. In this case, the model cannot show how any policy might influence the rate of cost reduction. When innovation is included within models, it can be represented as resulting from i) research and development, increasing productivity in relevant sectors; ii) the learning and experience that arise from deployment of relevant products (learning by doing); or iii) innovation that takes place in response to a change in relative prices.[190] The approaches taken to representing innovation in 28 different IAMs have been compared in detail in an academic study;[191] an illustrative sample of these are presented in the table below.

Table 8. The diversity of approaches to representing innovation in integrated assessment models

Model	Treatment of induced innovation
DICE (Nordhaus, 1992, 2017)	None
ENTICE (Popp, 2004)	R&D builds up knowledge stock, with diminishing returns to scale, and crowding out of growth-enhancing R&D
PAGE (Hope, 2012)	Learning by doing expands knowledge stock, decreasing abatement cost
IMACLIM-R (Crassous et al., 2006)	Learning by doing for energy; price-induced change and international knowledge spillovers in the productive sector
MESSAGE (Gritsevskyi & Nakicenovic, 2000)	Induced technological change does not take place within the model, but can be incorporated by offline iteration using learning curves to project technology costs
REMIND (Kriegler et al., 2017)	Induced innovation represented by learning curves for solar, wind, and electric vehicles
WITCH (Bosetti et al., 2006)	Induced technological change for advanced, non-commercial technologies. Experience depends on cumulative deployment; innovation depends on R&D investments; also incorporates international knowledge spillovers

Source: abridged from Grubb, Wieners, and Yang, (2021). Modeling myths: On DICE and dynamic realism in integrated assessment models of climate change mitigation.

188 Farmer et al. (2015). A Third Wave in the Economics of Climate Change; Stern et al.(2022). The Economics of Immense Risk, Urgent Action and Radical Change: Towards New Approaches to the Economics of Climate Change.

189 Note: IAMs have also been criticised for understating the risks of climate change. That is beyond the scope of this report.

190 Gillingham et al. (2008). Modeling Endogenous Technological Change for Climate Policy Analysis.

191 Grubb, M, Wieners, C., & Yang, P. (2021). Modeling myths: On DICE and dynamic realism in integrated assessment models of climate change mitigation.

A practical consideration is that while the main advantage of IAMs derives from their broad scope, a corresponding weakness is that it is difficult to keep all parts of the models up to date, and to represent specific countries and sectors in as much detail as may be needed to inform more specific policy choices.

Disequilibrium macroeconomic models

Disequilibrium macroeconomic models can, in principle, provide insights into the macroeconomic effects of the low carbon transition with fewer of the constraints that affect equilibrium models, as described above. Without the constraint of equilibrium, the models can explore imbalances and instability in the economy. Without assumptions of optimal allocation of resources, the models can show how policies designed to promote innovation and diffusion of low carbon technologies may lead to better or worse outcomes for variables such as employment and economic growth.

These models can take different forms, depending on the core assumptions on which their structure is based. They include system dynamics, macroeconometric, and ABMs. A highly generalised overview of advantages and criticisms of these model forms, together with those of the widely used equilibrium-based models discussed above, is shown in Table 9 below. In practice, models are often hybrids of these approaches. Here we present them in a deliberately oversimplified way to make the distinctions visible.

Table 9: An illustrative comparison of different structural forms of macroeconomic model

Focus of core assumptions	Basis for assumptions	Advantages	Criticisms	Model types
Behaviour of the economy as a whole	Theory of an idealised economy in a state of equilibrium	Widely available, relatively easy to use	Unrealistic assumptions lead to unrealistic outputs	CGE models DSGE models
Relationships between economic variables	Empirical evidence for individual relationships	Can generate complex economic behaviour from relatively simple models	Outcomes may be affected by relationships that have not been included	System dynamics models
	Statistical analysis of historical data	Can represent wide range of economic outcomes in high level of detail	Past data may be unreliable guide to the future	Econometric models
Behaviour of individual economic agents	Empirical evidence for agent behaviour	Can represent complex system behaviour with relatively high confidence	Resource intensive to construct	Data-driven ABMs
	Theory of the economy in states of change	Can explore a wide range of possible economic system behaviours	Lack of empirical basis gives lower confidence in outputs	Conceptual ABMs

Source: authors

Since innovation and competitiveness are often important in relation to specific technologies, products, or sectors, and since most low carbon transition policies are sector-specific, macroeconomic models are generally limited in their ability to address policy questions on these issues unless they either incorporate, or are linked to, detailed sector-specific models.

Policy questions

Policy questions that can be addressed by disequilibrium macroeconomic models in combination with sector-specific simulation models include:

- Which technology choices and low carbon transition policies have the most positive effect on economic growth? [H]
- How will low carbon transition policies affect the number of jobs in different sectors of the economy? [H]
- Which policies and strategies are likely to improve a country's trade balance, in the context of the global low carbon transition? [H]

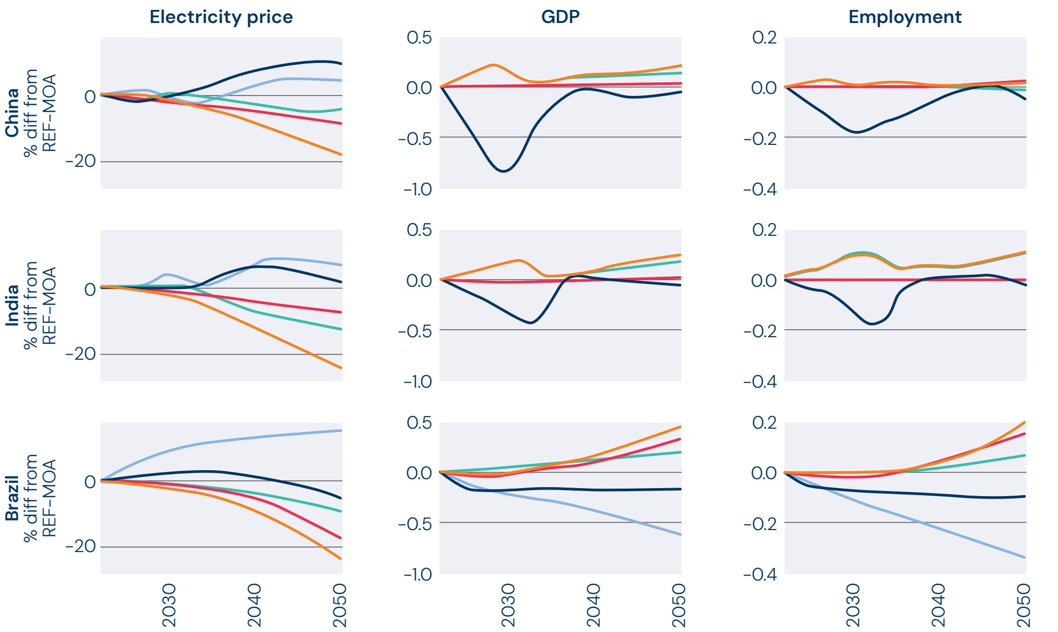
Many other policy questions can be addressed, depending on model scope and design.

Example

The E3ME model is a disequilibrium macroeconometric model based on input–output databases covering 71 countries and 43 sectors, and macroeconomic time series data. It uses historical data to define the relationships between economic variables, and uses these relationships to simulate changes in the economy that could occur in future. Its simulations are path dependent: options at any moment in time depend on choices and actions taken at earlier times – a characteristic observed in the real economy.

Energy innovation is represented in E3ME by investments in research and development, which increase energy efficiency and reduce energy demand. To simulate innovation and diffusion in low carbon technologies, the model is linked to the FTT sector-specific system dynamics models (see above). These models were used together to test the macroeconomic effects of different technology choices and market designs in the power sector, in China, India, and Brazil.[192] The findings suggested that a larger near-term shift from coal and gas power to solar and wind power would have positive impacts on jobs and GDP, and that these positive impacts would be greater if electricity markets were designed to form prices based on weighted average levelised cost of generation than if prices were formed based on the marginal unit of supply (see Figure 14).

Figure 14: Comparison of electricity prices, total employment, and GDP of various scenarios in percentage difference to the reference scenarios in China, India, and Brazil.[193]



Source: Vercoulen et al. in Barbrook-Johnson et al. (2023). New Economic models of energy innovation and transition: addressing new questions and providing better answers.

192 Vercoulen et al. in Barbrook-Johnson et al. (2023) New Economic models of energy innovation and transition: addressing new questions and providing better answers.

193 Scenario names and assumptions: REF-MOA = Diffusion of technologies follows current trajectory (with merit order approach, MOA, to market design). HighFF-MOA = Greater barriers to VRE uptake, expressed as reduced diffusion rates for VRE technologies (MOA market design). HighVRE-MOA = Fewer barriers to VRE uptake, expressed by a maximum capacity cap on FF technologies (MOA market design). REF-WALC = Diffusion of technologies follows its current trajectory (with Weighted Average of Levelized Costs, WALC, market design). HighFF-WALC = greater barriers to VRE uptake, expressed as reduced diffusion rates for VRE technologies (WALC market design). High VRE-WALC = Fewer barriers to VRE uptake, expressed by a maximum capacity cap on FF technologies (WALC market design).

Contrasting assessments	
	Computable general equilibrium (CGE) models In a study for the European Commission,[194] a CGE model forecast that the low carbon transition would incur a net economic cost. This finding followed from the assumption that financial resources in the economy were fixed and fully employed, so that low carbon investment would displace other more efficient investment.
	Disequilibrium macroeconomic models In the same study, the (disequilibrium) E3ME model forecast that the transition would have a net economic benefit. This finding followed from the assumption that financial resources would be created by banks in response to demand.

Case Study 5: The use of E3ME-FTT with the Czech Ministry of Environment and Ministry of Finance

The E3ME-FTT macroeconomic model was used in Czechia to assess the economic and social impacts of different elements of the European Green Deal, and in particular the 'Fit for 55' package, (policies aiming to reduce EU emissions by 55% by 2030, compared to 1990) including the impacts of the EU Emissions Trading Scheme, revised EU directives on renewable energy sources, energy efficiency and energy taxation, the Carbon Border Adjustment Mechanism, removal of environmentally harmful subsidies, reforms to payment structures in agriculture, and a range of other policies.[195] The work enabled the Czech Government to better understand how different policy designs and stringencies could affect the Czech economy at the macro level (in terms of GDP and employment), as well as in more detail at the sectoral level, and to design domestic policies to reinforce the positive impacts of European policies.

The modelling found that overall welfare gains could be increased by combining the EU's policies on energy efficiency, renewable power, clean heating, and electric vehicles, with a recycling of revenues from carbon pricing into social policies (modelled as lump sum payments to the bottom two income deciles). However, GDP impacts were higher when social policies were not included in the implemented policy package.

The modelling showed that the combination of the EU's Fit for 55 policy package with a more ambitious national policy programme (including subsidies for wind power) created complementary effects with the redistribution of the revenues from the emissions trading system, and was the most effective way to eliminate fossil fuels from electricity generation. The path dependency and non-linearities of the E3ME-FTT model were important in showing that a modest extra subsidy from the government could push the use of wind power beyond a tipping point, where a virtuous circle of deployment and learning by doing drove down costs and made wind one of the most attractive options for power sector investors, leading to the generation of cheap electricity in large quantities.

Provided by Jon Stenning, Cambridge Econometrics.

194 Mercure, J.- F., et al. (2016). Policy-induced energy technological innovation and finance for low-carbon economic growth.

195 **This was undertaken as part of a long-term partnership between Cambridge Econometrics and Charles University.** The work was steered principally by the Czech Ministry of Environment, with analysis and findings shared with the Czech Ministry of Finance, the Governmental Office and the National Budgetary Council.

Limitations

The outputs of any model are only as reliable as its input assumptions. Within each of the model categories described above, models vary widely in the extent to which their structural assumptions are grounded in evidence and realistically represent the economy. In addition, most macroeconomic models have not been subject to rigorous testing of their predictive capabilities.

Together with the criticisms of model types listed in the table above, these limitations mean that governments can have, at best, moderate levels of confidence in the outputs of macroeconomic models in relation to innovation and competitiveness in the low carbon transition.

Case Study 6: System dynamics modelling with Angola

The Integrated Sustainable Development Goals Model (iSDG) was used in Angola to develop quantitative scenarios to inform the preparation of the National Development Plan, and later to analyse strategic options for achieving the Sustainable Development Goals (SDGs).[196] As part of the latter exercise, the model was used to evaluate 17 different policy (budgetary and non-budgetary) interventions[197] across various domains such as health, education, environmental action, agriculture, industry, infrastructure, energy, water, and sanitation. The impacts of those interventions were analysed under three scenarios reflecting different assumptions about oil prices and governance quality.

The analysis revealed that: environmental and climate action investments offered the highest return on investment, positively impacting multiple SDGs. Infrastructure and energy investments positively affected several SDG targets, while investments in human capital (health, education, water, and sanitation) produced strong synergetic impacts, highlighting the importance of their integrated implementation. Investments in environment and climate action, health, and water and sanitation yielded positive impacts in the medium term, while the benefits from education investments became significant in the longer term.

The analysis informed the preparation of Angola's SDG report, and the National Development Plan. Officials from the Ministry of Finance, Ministry of Economy and Planning, and National Statistics Institute have trained in the use of the model, and the model is gradually being integrated into the national planning process.

Provided by Matteo Pedercini, Millennium Institute.

196 The iSDG Angola model is a dynamic, integrated tool designed for the analysis of medium- to long-term impacts of policy interventions on a broad set of socio-economic and environmental indicators, including an extensive set of Sustainable Development Goals indicators. The model was implemented through a collaboration between the Millennium Institute and the Angolan Ministry of Economy and Planning, Ministry of Finance, and National Statistics Institute.

197 Budgetary includes public and PPP investment of various nature, from supporting specific public services, to providing subsidies in various sectors, taxing others, etc. Non-budgetary includes changes in legislation/regulation which do not involve a significant budget, including introducing specific standards for vehicles. Modelled interventions were selected through a series of participatory workshops.

VIII. Priorities for knowledge sharing and capacity building

As the low carbon transition progresses, the analytical needs of governments are becoming more complex.[198] The reality of technological change unfolding globally in each of the GHG-emitting sectors is now part of the context within which policy objectives such as energy security, cost reduction, job creation, and economic growth are pursued. The analytical challenge is to compare policy and strategy options, and inform decisions, in this context of change and uncertainty.

198 Barbrook-Johnson et al. (2024). Energy modelling fit for the demands of energy decision-makers.

To improve the analysis that informs policy decisions on innovation and competitiveness in the low carbon transition there is a need to further develop dynamic analytical tools, and to enable their wider use. At present there is an imbalance between policy needs and analytical capabilities. In part IV of this report we made a distinction between static, equilibrium-based analytical frameworks and tools that are most appropriate in contexts of marginal change, and dynamic, disequilibrium tools that are more likely to be appropriate where the aim or expectation is structural change. Tools in the former category (static) are already in widespread use in governments, and in many of the academic institutes that governments often rely on for advice, but are inadequate to address many of the policy questions on innovation and competitiveness in the low carbon transition. Tools in the latter category (dynamic) are particularly relevant to these policy questions, but are less widely used both in government and in academia. Redressing this imbalance does not mean replacing all the analytical tools and methods that are widely used at present; rather, it means complementing them, increasing the diversity of tools that are at policymakers' disposal.

The role of finance ministries in building analytical capacity

Finance ministries have an opportunity to be at the forefront of enhancing analytical capabilities within governments. This is consistent with their interests in good use of public funds and prudent budget management, and with their role in scrutinising spending proposals put forward by other government departments. Finance ministries can advance this agenda through:

- **Applying conceptual frameworks consistent with aims and contexts of structural change**, such as the market-shaping rationale for policy, the MLP on transitions, or innovation-driven industrial strategy, as appropriate, in their consideration of low carbon development strategies, emissions reduction strategies, and policy proposals integral to those strategies.
- **Providing guidance and training to officials on approaches to decision-making in contexts of uncertainty and non-marginal change,** such as systems mapping, scenarios, or risk-opportunity analysis.
- **Signalling their needs for new modelling capabilities (see below) to the community of academic researchers and international organisations;** and (those with sufficient resources) funding the development of new models.

Determining priorities for capacity building nationally

Table 11 in the Appendix presents an overview of the conceptual frameworks and analytical tools most relevant to each of the policy questions listed in chapter III of this report. Finance ministries could determine priorities for building analytical capabilities by matching these to the policy questions in which they have the greatest interest.

Table 10 in the Conclusion chapter below provides an approximate guide to the relative accessibility of each tool, in terms of its skills, data requirements, and availability. This can inform finance ministries' decisions on whether a new analytical capability should be promoted widely among officials, developed by a small number of expert staff, or temporarily brought in by external consultants or researchers.

Priorities for model development, internationally

Models are only a subset of the analytical tools described in this report, but since they are the most resource intensive to develop, their availability to countries depends on priorities chosen internationally as well as nationally. The policy questions outlined in chapter III of this report imply three areas where further development of economic models would be particularly useful:

- **Sector transitions:** Many of the critical policy decisions on innovation and competitiveness will be specific to individual sectors; to inform these, governments would benefit from access to sector-specific simulation models that realistically represent policy options, technologies, and markets, including conditions or constraints that are important in their own countries.
- **Macroeconomics:** To fully assess the possible macroeconomic implications of policies aimed at driving clean technology innovation, diffusion, and competitiveness, governments need access to macroeconomic models that simulate the behaviour of the economy in states of instability and change (disequilibrium), complementing the equilibrium models that they already have.
- **Labour markets:** To explore the consequences of the transition for employment, informing policies on skills or economic diversification, governments would benefit from access to models that realistically represent their countries' labour markets.

There is a trade-off in model development between specificity and speed. Ideally, every government would have access to economic models highly tailored to its national conditions, developed by local experts, to inform low carbon transition policy in each sector and at the economy-wide level. In practice, this is constrained not only by resources, but also by time. Policymaking on the low carbon transition needs to proceed at a rapid pace, not only because of the urgency of climate change but also because of the rapid development of clean technologies that is already reshaping global markets and transforming policy options. Model development that takes longer than the policy decisions it seeks to inform is of limited use.

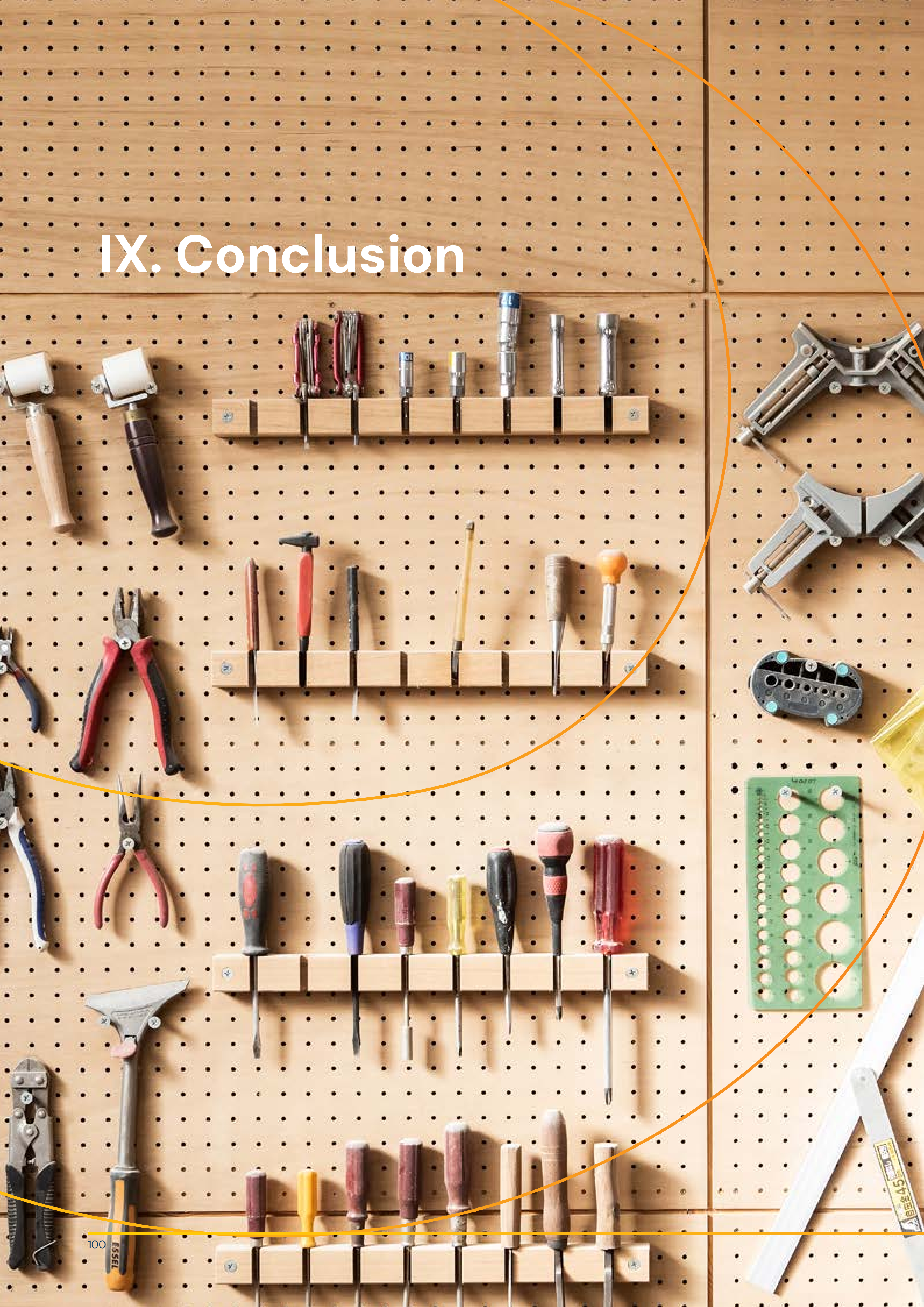
Consequently, a twin track approach is likely to be appropriate: Governments, together with academic and institutional partners, should invest in the development of new country-specific models in the areas where the policy and analytical needs are greatest, and the national circumstances most unique. International organisations, such as multilateral development banks, should develop generally applicable models of the kinds described above that can be used by many countries to address the most common policy questions. Those that already exist should be tested, improved, and made more widely available. No single model can ever present the full picture. Just as there is value for governments in having access to a wider set of models, an accelerated effort by the academic community to compare findings from structurally diverse models could generate useful new insights.

Priorities for knowledge sharing

Finance ministries in different countries can help each other by sharing learning from their application of conceptual frameworks and analytical tools that explicitly address innovation, competitiveness, and structural change in the economy. This sharing of knowledge will support a stronger understanding of each tool's capabilities and limitations, enabling governments to make better choices between them and to use them more effectively. It will also contribute to the further improvement and development of new frameworks and tools.

Finance ministries could benefit greatly from sharing knowledge on policies that are proving effective in advancing clean technology innovation and building competitiveness in the context of the low carbon transition. The focus of this report has been on analytical tools, which often play an important role in the process of decision-making within governments. However, when rapid decision-making is required, governments are also keen to know which policies have worked well in other countries, and why. We noted in our introduction that finance ministries have not typically seen innovation and competitiveness as central to their responsibilities, but that the low carbon transition provides reasons to change this perspective. The increasing interest of finance ministries in this field, and the rapid pace of policymaking across many countries, suggest there is great scope for productive sharing of knowledge.

IX. Conclusion



In the context of the low carbon transition, innovation and competitiveness matter to finance ministries. The success or failure of policies to promote innovation and diffusion of clean technologies will strongly influence the level of public spending required to shift from fossil fuels to clean technologies, and as global markets and supply chains are transformed by the transition, the development of a country's competitive position will affect its prospects for economic growth.

The analytical tools with which governments are most familiar are not well suited to address these policy challenges. The familiar tools are most appropriate for use in contexts of economic stability, where there is relatively high certainty regarding the outcomes of decisions. But the low carbon transition is a context of structural change, at a rapid pace, on a large scale; and decisions relating to innovation and competitiveness are characterised by a high degree of uncertainty.

A different set of tools exists that is more suited to informing the policy questions that finance ministries are facing. It includes conceptual frameworks that define the rationale for policy in a changing economic context, and decision-making frameworks that deal with uncertainty and differentiate between self-amplifying and self-limiting dynamics. It includes analytical tools for comparing technologies and identifying where competitive advantage may be developed, and models for simulating the diffusion of clean technologies, the effects of policies, and the imbalances in the macroeconomy that could result from the transition. A rough mapping of these tools against the policy questions set out in chapter III is outlined in the Appendix: Mapping of policy questions to analytical tools.

Finance ministries can enable better decision-making on innovation and competitiveness by building capacity in the use of these analytical tools designed for contexts of uncertainty and change. Not all of them are difficult to adopt, and their use can be spread through guidance documents and training for officials. At the same time, policymakers should keep in mind their limitations, and the principle that any analytical tool is only as useful as the contextual knowledge and judgement with which it is applied.

Given countries' differing levels of resources and governance capacities, there is an important role for international organisations in developing analytical tools that can be widely used. This particularly applies to economic models, which are resource intensive to develop; dynamic models suitable for informing policy on innovation and competitiveness in the low carbon transition are not yet well developed or widely available.

There is also great potential for countries to learn from each other, as new tools are tested and put to use. However much countries may compete for leadership in clean technologies, effective policymaking to confront the threat of climate change is, after all, a common interest.

Table 10: Accessibility of conceptual frameworks, decision-making frameworks and analytical tools

Conceptual framework or analytical tool	Accessibility			Other	Explanation
	Skills	Data	Availability		
Multi-Level Perspective					The multi-level perspective on transitions is an easy-to-use conceptual framework which does not require deep quantitative data, technical skills or extensive time and resource to use. It does require specific (qualitative) knowledge of the sector, country, technologies, actors, social and economic structures being examined. Open-source resources include this Forum for the Future's Facilitators Pack.
Horizontal industrial strategy					Horizontal industrial strategy generally requires fewer technical or specialist capabilities than innovation-driven industrial strategy to apply as a conceptual framework, although implementing it successfully can be difficult for many reasons. It does require specific (qualitative) knowledge of the country's economy, particularly cross-cutting areas like education, infrastructure and finance.
Innovation-driven industrial strategy				High institutional capabilities & inter-ministerial coordination	Innovation-driven industrial strategies (like smart specialisation, green industrial policy, and mission-oriented strategies) may require more specialist knowledge and analytical skills and capabilities than horizontal industrial strategy. To assess potential relative competitiveness, they require more in-depth knowledge of the country's industrial capabilities and resources (natural, knowledge, financial) as well as of relevant global trends and international competitors. These strategies also require policymakers to have governance capabilities such as abilities to convene and elicit views from experts and wider stakeholder groups and engage in collaborative learning processes that feed into (later) strategic economic bets ('backing winners'). These strategies may also require strong institutional capacity to coordinate policies across different (sectoral) departments and crowd-in private sector finance. Implementing these strategies also requires the resources to back winners, drive diffusion, and upskill mission teams with the tools to implement new portfolio strategies, procurement and budgeting practices. The OECD and IIPP both have starter resources.
Cost-Benefit Analysis					CBA requires skills including economic analysis, environmental economics, statistical analysis for data interpretation and policy analysis to evaluate implications of different options. Teams delivering CBA typically draw on results from other tools such as economic models as inputs to the analysis, meaning teams may also require this technical expertise. The quality of cost-benefit analysis also depends strongly on differentiated, up-to-date and rigorous datasets, which often require dedicated (and sometimes challenging) information gathering and processing. An example of MoF guidance on CBA is the UK Treasury's Green Book.
Risk-Opportunity Analysis				Higher analytical capabilities	Risk-Opportunity Analysis requires in-depth knowledge of the specific sector, technologies, social and economic structures being considered. ROA requires analytical capabilities in techniques such as systems mapping with causal loop diagrams (to identify the impacts of policy options on processes of change) and scenarios (to deal with uncertainty). Because ROA and its underlying methodologies are less widely used than CBA, practitioners will need to communicate the rationale and results of ROA to ministers effectively. EEIST provides an overview of the approach. Detailed draft implementation guidance can be found on the S Curve Economics CIC website.

Conceptual framework or analytical tool	Accessibility			Other	Explanation
	Skills	Data	Availability		
Robust decision-making				High computing power or cloud servers	RDM can be time, cost, and data intensive, given extensive stakeholder engagement requirements and the delivery of quantitative modelling across many different scenarios. However, the underlying logic and sequence of analytical steps can alternatively be applied in a qualitative, principles-based way as a less-resource-intensive starting point. More information can be found on RAND's website.
Scenario analysis					Scenario analysis is usually done in a qualitative, principles-based way, and so does not necessarily have a high data requirement. Because the usefulness of scenario analyses depends strongly on iterative discussions and multi-stakeholder learning processes, the deployment of this tool does require skills in facilitation and other process-oriented governance capabilities.
Cost-optimisation models					Cost-optimisation models require technical modelling skills to build and use, are data intensive, and the more complex ones require powerful, high-performance computing resources as well as storage for large datasets and model outputs. Many cost-optimisation models are available.
Probabilistic clean technology cost forecasts based on learning curves					Research studies of clean energy technology learning curves are publicly available in the academic literature, as are descriptions of methods used to make probabilistic cost forecasts. There is scope to apply this method to more technologies relevant to the low carbon transition. Currently this forecasting method has been statistically validated only for global technology forecasts, but there is potential to use it with complementary analysis to produce technology cost forecasts specific to individual countries. Subject to future empirical validation, the same method could be used to produce national forecasts; this would require historical cost data and production data. The method itself requires relatively straightforward statistics concepts, modelling techniques, and programming skills.
Systems mapping with causal loop diagrams					Systems mapping with causal loop diagrams requires the knowledge and skills to build a 'map' of the system that accurately reflects the directions of causal relationships between its components. As with all analytical tools, applying it successfully requires subject matter knowledge, but the technique is not difficult to learn. It can be applied through a participatory process involving stakeholder engagement, or by an individual analyst with access to relevant information. Resources include the book Systems Mapping: how to build and use causal models of systems (Pete Barbrook-Johnson and Alexandra Penn), the articles System Archetypes by Daniel Kim and Leverage Points: Places to intervene in a system by Donella Meadows.

Conceptual framework or analytical tool	Accessibility			Other	Explanation
	Skills	Data	Availability		
Sector-specific system dynamics models				High computing power or cloud servers	Sector-specific system dynamics models typically have more significant data requirements than cost-optimisation models. Data requirements can include technology cost data (including capex, opex, assumed standard deviations of costs), technology market shares in the past and present, learning rates, historical cumulative deployment levels, a demand driver (such as demand for vehicles or for heating) and energy efficiency numbers.[199] Learning how to build, contextualise and use such models to compare policy options is not inherently more difficult than cost-optimisation modelling.[200] Not many sector-specific system dynamics models are widely available to inform policy on the low carbon transition. The FTT model used by the World Bank is one example.
Sector-specific ABMs				High computing power or cloud servers	Simple, conceptual ABMs can be built in contexts of low data availability, using the best available information. However, ABMs capable of informing policy on the low carbon transition will often need to be more complex. These require detailed data on the technologies, products, actors, and markets of the relevant sector. The more detailed the model, the more skills and resources are needed to build it. For larger ABMs, more advanced (software engineering) skills may be required than are needed for CGE modelling. Model calibration and validation, which can – if done well – enable ABMs to represent reality more accurately than alternative models, take up significant resources. Few sector-specific ABMs are widely available to inform policy on the low carbon transition at present.
Revealed comparative advantage					RCA relies on detailed trade data, which is typically widely available for most countries. It can be calculated with basic data analysis skills. The structural approach to comparative advantage, which also considers the country's share of the global market, product space density, and the rate of growth of the global market, requires more data manipulation and analysis capabilities. The qualitative knowledge needed to usefully interpret the policy implications of analysis of this kind is likely to be more of a challenge than the quantitative analysis itself. UNCTAD has an open-source tool to identify any country's RCA (not specific to the green transition); the Green Transition Navigator tool identifies the RCAs of categorised green products.
Gravity models					Gravity modelling requires more extensive data and a more advanced understanding of econometric techniques and modelling compared with RCA and economic complexity analysis. Data requirements involve not only trade data but also data on factors influencing trade, such as GDP, distance, and trade policies. A User Guide for gravity modelling (not specifically in relation to the low carbon transition) has been produced by Ben Shepherd.

199 Data is typically more difficult to obtain for harder-to-abate sectors, and for countries outside the OECD.

200 For FTT specifically, building new elements of a model may take around three to six months by a proficient coder; contextualising may take up to three months, and learning how to run it may take as little as two to three weeks with some follow-up support.

Conceptual framework or analytical tool	Accessibility			Other	Explanation
	Skills	Data	Availability		
Economic complexity analysis				High computing power or cloud servers	Economic complexity analysis has similar data requirements to RCA (detailed trade data, typically widely available for most countries), and is less data intensive than gravity modelling. It requires more complex metrics and network analysis techniques than RCA, and can benefit from a deeper understanding of network theory and statistical methods, but can typically be learnt by an economist proficient at coding and with a solid grasp of the policy area under question. The Green Transition Navigator tool or Greenplexity Dashboard can be used without needing to reproduce the underlying analysis.[201] However, applying this tool to inform policy requires extensive contextual knowledge, and ideally should be accompanied by complementary forms of analysis.
Labour market models					Labour market models typically require large, complex datasets with wide-ranging information, which can be challenging for many countries, especially those with significant informal labour markets. Developing such models can require a high level of technical skill in statistical and econometric analysis.
Computable general equilibrium models				High computing power or cloud servers	CGE modelling requires significant data and modelling expertise (typically more than system dynamics models, but less than disequilibrium macroeconomic models). Data requirements often include sectoral data, input–output tables and industry linkages, household and survey data, trade flows, government accounts, environmental data on emissions and resource use, and labour market data. Skills requirements range from economic theory on micro and macroeconomics to quantitative analysis, and modelling and programming capabilities.
Integrated assessment models				High computing power or cloud servers	IAMs often require comprehensive data and high levels of technical expertise due to their broader scope and multidisciplinary nature. For example, they typically require detailed environmental, energy, land use, and technological data, in addition to economic data. IAMs also demand a broad range of expertise, encompassing economic theory, climate science, energy systems, and dynamic modelling techniques, which requires collaboration among diverse experts.
Disequilibrium macroeconomic models				High computing power or cloud servers	Data requirements are typically larger for disequilibrium than for CGE models, though may be less than for IAMs if they are narrower in scope. Disequilibrium macroeconomic models may be more difficult to develop and use than CGE models, since they are structurally more complex. Few disequilibrium macroeconomic models have been developed in a level of detail that can support policy analysis relevant to innovation and competitiveness in the low carbon transition. E3ME (a proprietary model[202]) and the DSK model developed at Sant'Anna School of Advanced Studies are two examples.

201 Other online tools, such as the Observatory of Economic Complexity and the Atlas of Economic Complexity can be used to explore how a country's trade flows have changed over time, and to identify growth opportunities (but are not specific to the low carbon transition).

202 Covers 71 countries. Data is typically updated using IEA and OECD data then supplemented with data from academic papers where possible.

X. Appendix: Mapping of policy questions to analytical tools

Table 11: Mapping of policy questions to analytical tools

Label	Policy question	Relevance
A	How can innovation and investment in low carbon technologies drive economic development and improve a country's economic prospects?	Industrial strategy frameworks (horizontal and innovation-driven) Macroeconomic models
B	Which technologies have the greatest potential for further innovation and cost reduction, in each of the sectors most affected by the low carbon transition?	Probabilistic learning curves
C	How can policies best contribute to accelerating clean technology innovation, cost reduction, and diffusion?	Market-shaping framework MLP on transitions Risk–opportunity analysis Robust decision-making Systems mapping with causal loop diagrams
D	How much can clean technology costs be reduced by factors subject to domestic control and influence, and how much will they depend on international factors?	No tools specifically relevant to this question were identified.
E	How can countries identify sectors or product categories relevant to the low carbon transition in which they could be internationally competitive?	RCA Economic complexity analysis Gravity models Labour market models
F	Which policies are likely to be most effective in increasing a country's competitiveness in a technology or sector, in the context of the low carbon transition?	Market-shaping framework Innovation-driven industrial strategy frameworks Risk–opportunity analysis Robust decision-making Systems mapping with causal loop diagrams Sector-specific ABMs
G	How will the low carbon transition affect supply chains and jobs, globally and nationally?	Labour market models Macroeconomic models
H	What will be the macroeconomic effects – on employment, economic growth, and the trade balance – of sector-specific technology innovation and diffusion policies?	Macroeconomic models (particularly disequilibrium macro models) Labour market models
I	How should the transition be funded? How can policies best mobilise private investment into clean technologies?	Sector-specific ABMs

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This report shows how different types of analytical tools lead to different policy insights and why, providing invaluable insight into why the choice of tool matters. By breaking down the pros and cons of dominant and emerging analytical approaches into simple language, and summarising the difficulty level for capacity-building, this report informs the process of weighing up a range of important trade-offs.

Hon. Matia Kasaija, Minister of Finance Planning and Economic Development, Uganda

What are the drivers of the low-carbon transition? How best to represent them and quantify their effects? How useful are such analytical tools to policymakers' daily decisions? These are a few of the questions addressed in a systematic way by this report. It brings critical insights into the essential capacities that ministries of finance need in order to be equipped for 21st century policymaking. Essential food for thought for the Coalition of Capacity for Climate Action (C3A).

Etienne Espagne, Senior Climate Economist, World Bank and Director of C3A

This report highlights how finance ministries can play a central role in shaping policies that drive the low-carbon transition, and unlock new economic opportunities. The case studies provide useful examples of country leadership, including from Coalition members, in developing and deploying frontier analytical capabilities for informed policy.

Ralein Bekkers, Co-Chair (Deputy of Dutch Finance Minister), Coalition of Finance Ministers for Climate Action

This report provides useful and actionable insights into the different forms of new analytical tools and approaches that can be used to assess policies and measures aiming to drive green innovation and competitiveness. This can help ministries of finance with new perspectives on technological development and structural transformations that can complement existing tools and analytical frameworks.

Mads Libergren, Senior Advisor, Ministry of Finance of Denmark

Decision-making frameworks and analytical tools are rarely a sexy topic. But they matter greatly for delivering the low-carbon transition. This report acknowledges and embraces medium term uncertainty. It shows how a dynamic evaluation of risks and opportunities, through the lens of feedback loops, induced technology cost reductions and balancing diverse interests, provides profoundly different but more resilient and future-proofed policy recommendations, compared with more traditional and widely-used approaches like cost benefit analysis. It is time that policymakers integrated structural change, uncertainty and diverse trade-offs transparently and systematically into policy decision-making. This report is a critical step forward in explaining why and how to make robust policy choices and deliver the cost-effective investment the world needs.

Dimitri Zenghelis, Senior Advisor, The Bennett Institute, University of Cambridge

Systems dynamics modelling has been used in Indonesia for decades to inform clean development pathways by providing insight on complex cross-sectoral interdependencies and cascading impacts of hypothetical decisions. It is fantastic to see a clear story articulated on why such modelling approaches are useful, and I hope it gives others the courage to explore such lesser known but deeply important tools.

Medrilzam Medrilzam, Minister Senior Advisor on Equality and Regional Development and Acting Director for Forestry and Water Conservation, National Development Planning Agency (BAPPENAS), Indonesia

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