Analytical tools for innovation and competitiveness in the low carbon transition

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Executive Summary

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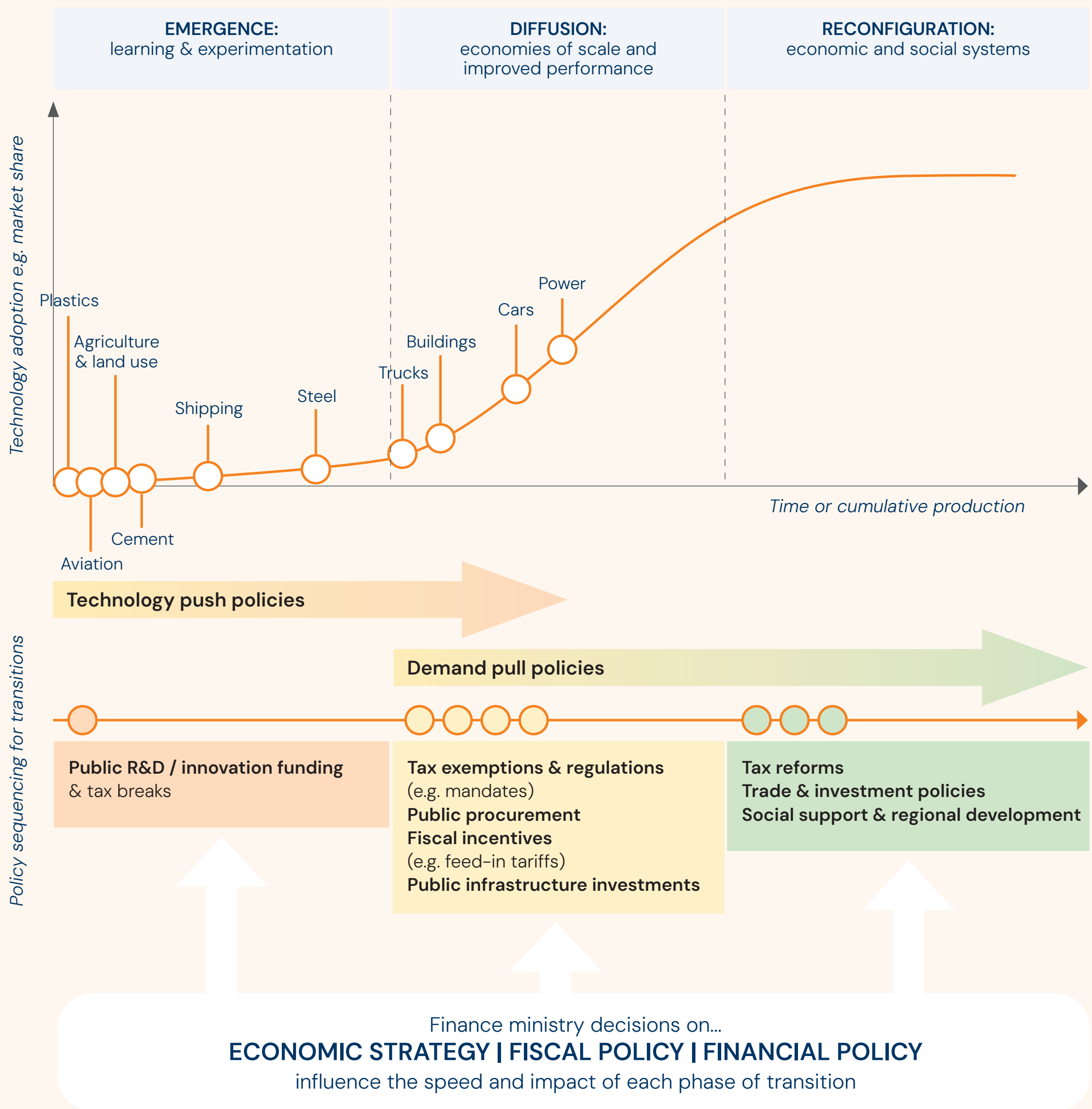
In the context of the low carbon transition, innovation affects finance ministries' core interests. Estimates of the additional investment needed for the low carbon transition range as high as $3.5trn globally each year between now and 2050. At the same time, a transition to zero emissions energy use 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.

The role of finance ministries in the transition

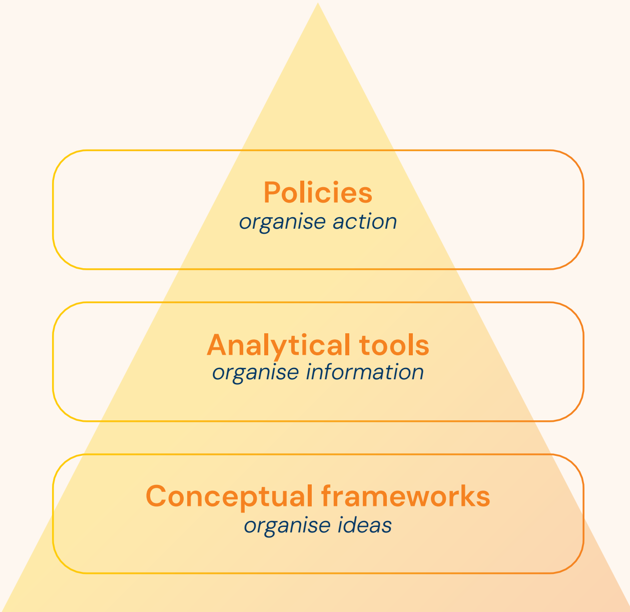


Finance ministries' decisions can strongly influence clean technology innovation, cost reduction, and competitiveness. Innovation does not only happen through research and development. Much of the innovation that reduces costs happens as new technologies are deployed, when industry invests in their improvement, 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 (CBA) is useful in situations of relatively high certainty and marginal change, but has limitations if applied outside this domain. Scenarios and robust decision-making (RDM) 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. The table on page 6 relates the tools of this kind considered in this report to the key policy questions expressed by finance ministries in our consultations. The table on page 5 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.

Ease of use of conceptual and 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			

The structure of the full 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 full 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.

Mapping of policy questions to analytical tools

Policy question	Relevant frameworks and tools
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
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
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
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.*
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
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
How will the low carbon transition affect supply chains and jobs, globally and nationally?	Labour market models Macroeconomic models
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
How should the transition be funded? How can policies best mobilise private investment into clean technologies?	Sector-specific agent-based models

Different approaches generate different insights: 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.
Cost Benefit Analysis (CBA)	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.'[1] At that time, burning biomass was a cheaper way to reduce emissions.
Risk Opportunity Analysis (ROA)	ROA 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.[2] 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,[3] and its long-term contracts for electricity generation are increasingly subsidy-negative.
Cost-optimisation models as input into integrated assessment models (IAMs)	IAMs 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.
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.[4]
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.
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 sector-specific system dynamics model, Future Technology Transformations (FTT), suggests that zero emission vehicle mandates can be significantly more cost-effective than taxes in the road transport transition.
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.
Agent Based Models (ABMs)	Agent-based modelling has found 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,[5] 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.)
Computable general equilibrium (CGE) models	In a study for the European Commission,[6] 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.

1 The Economist (2014). Rueing the waves.

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

3 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.

4 Stavins, R. (2019). The Future of U.S. Carbon-Pricing Policy.

5 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.

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

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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