The Coalition of Finance Ministers for Climate Action

Policy packages for cost-effective transitions: learning from the past, simulating the future with the Future Technology Transformations models, and case studies from the Economics of Energy Innovation and System Transition project

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A contribution to the 'Compendium of Practice from a Global Community of Ministries of Finance and Leading Organizations: Economic analysis and modeling tools to assist Ministries of Finance in driving green and resilient transitions'

Topic: Addressing the climate policy questions facing Ministries of Finance: the economic and fiscal impacts the green transition

June 2025

Access the full Compendium at www.greenandresilienteconomics.org

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This contribution was prepared at the request of, and with guidance from, the Ministry of Finance of Denmark as Lead of the Coalition's Helsinki Principle 4 initiative 'Economic Analysis for Green and Resilient Transitions' and its Steering Group, with input from its Technical Advisory Group. The views, findings, interpretations, and conclusions expressed are those of the authors. While many Coalition members and partners may support the general thrust of the arguments, findings, and recommendations made in this contribution, it does not necessarily reflect the views of the Coalition, its members, or the affiliations of the authors, nor does it represent an endorsement of any of the views expressed herein by any individual member of the Coalition.

Ministries of Finance generally want their countries to make the low-carbon transition in a cost-effective way. Their interests typically include keeping public expenditure low, avoiding undue increases in price of energy, commodities, and services, and managing the transition in a way that does not adversely affect the competitiveness of industry. Since clean technologies can provide some energy services at a lower cost than fossil fuels, achieving the transition cost-effectively can also mean maximizing the savings (Way et al., 2022).[1]

Cost-optimization models are often used to identify the least-cost technology mixes to aim for in a given sector, within a given emissions target. But these do not indicate which policies will deploy the new technologies cost-effectively. Simulation models can be used for this purpose, comparing policies individually and in combination.

This contribution presents brief examples of findings from simulation models, together with key points from empirical studies that provide context and complementary lines of evidence. The case studies presented here are taken from the Economics of Energy Innovation and System Transition project,[2] and this contribution also summarizes material from the recent report of the C3A Innovation Hub program (Sharpe et al., forthcoming).

Seeing the pattern in technology transitions of the past: different policies are effective at different stages

The IPCC has described what is needed to meet internationally agreed climate change goals as rapid and far-reaching system transitions in each of the emitting sectors of the global economy, "unprecedented in terms of scale, but not necessarily in terms of speed". The "not necessarily" refers to the fact that technology transitions have happened many times before, and sometimes they have been rapid.

Studies of past technology transitions have discovered patterns in their progress and identified the types of policies most likely to accelerate a transition in each of its early, middle, and late stages (Geels and Schot, 2007). The Multi-Level Perspective on transitions organizes this understanding into a conceptual framework, whose policy implications can be roughly summarized as follows.

- In the "emergence" stage of the transition, uncertainty is high, and a variety of new technologies are developed and tested in small market niches until a dominant design emerges. Governments can accelerate this process by supporting research, development, and demonstration projects, and by using policies such as public procurement or targeted subsidies to establish niche markets for the first deployment of new technologies.
- In the "diffusion" stage, the new technology begins to spread through markets and society, competing directly with the incumbent technology system. Governments can accelerate the diffusion process with any policies that give the new technology an advantage over the old, including regulations, subsidies, taxes, and investments in infrastructure.
- In the "reconfiguration" stage, as the new technology becomes dominant, economic systems and structures are adapted and reorganized around it. Governments can accelerate this process by supporting the development of complementary technologies (those that make the core new technology more useful), reforming markets, extending new infrastructure networks, and training workers to adapt to the new industries.

In the early stages of the transition, policies that directly support the deployment of new technologies—such as targeted subsidies, public procurement, or concessional lending—tend to be particularly effective because they benefit from positive feedback loops in technology development and diffusion. These self-amplifying processes including learning-by-doing (the more a technology is

1 Way et al. estimate that a fast global transition to zero emissions across all energy and industrial sectors could save around $12 trillion compared with continuing to burn fossil fuels.
2 A collaborative project by researchers in the UK, China, India, and Brazil, to better understand the economics of the low-carbon transition. For more information see at https://eeist.co.uk/.

made, the more it improves), economies of scale (the more it is made, the cheaper it gets), and the emergence of complementary technologies (the more it is used, the more other technologies emerge that make it more useful). Taxes on the incumbent technology do not necessarily benefit from these positive feedbacks early in the transition, because they may simply incentivize the incumbent system to operate more efficiently.

Further into a transition, it may be possible for taxes, subsidies, or regulations to help the new technology cross a tipping point where it becomes more attractive than the old technology to consumers, producers, and investors, so that beyond this point the transition continues with self-accelerating momentum (Lenton et al., 2022, footnote 4).

Understanding current successes in the low-carbon transition: cutting costs and creating jobs

Some of the most outstanding successes in low-carbon transitions experienced so far can be seen as part of this emergence-diffusion-reconfiguration pattern. The rapid progress of solar power toward now being "the cheapest electricity in history" (IEA, 2020) has been driven by early support for research and development (R&D) in the U.S., and Japan, followed by bulk public procurement; then feed-in tariffs and portfolio standards in Europe, China, and eventually many other countries (Clark et al., 2021; Nemet, 2025).

In the UK, targeted deployment subsidies cut the cost of offshore wind by around 70% over the decade, making it a cheaper source of electricity generation than gas.[3] In Brazil, subsidies together with concessional finance drove the fastest expansion of onshore wind power of the large emerging economies, creating over 150,000 jobs.[4] In India, public procurement was central to cutting the cost of efficient lighting by 85% in four years, and bringing electric lighting to many homes for the first time.[5]

These successes illustrate the effectiveness of targeted policies that create demand for clean technologies in the early stages of the transition, enabling their deployment, and driving innovation and cost reduction through positive feedback loops. A systematic review of academic studies on induced innovation in energy technologies and systems found strong evidence for this effect, as well as for carbon pricing playing a positive role, and suggested that rather than relying on any single policy instrument, governments should implement packages of policies crafted to overcome the multiple barriers to the transition in any given sector (Grubb et al., 2021).

In some of the fastest examples of low-carbon transitions, the effect of tipping points is visible. In the UK, a tax that made coal power more expensive than gas power, in the context of other policies driving rapid growth in renewable power, helped achieve a power sector decarbonization roughly eight times faster than the global average over the decade 2010–2019.[6] In Norway, a subsidy-and-tax combination that made electric vehicles (EVs) cheaper to buy than equivalent petrol cars was central to a policy package that drove the world's fastest transition in road transportation (Sharpe and Lenton, 2021).

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3 https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/policy-innovation-and-cost-reduction-in-uk-offshore-wind
4 https://eeist.co.uk/download/667/
5 https://eeist.co.uk/download/681/
6 The carbon intensity of the UK power sector decreased by 8.9% per year between 2010 and 2019, while the global average power sector carbon intensity fell by 1.1% per year over the same period. See Drax (2020) Electric insights quarterly July-Sep 2020, and International Energy Agency: Carbon intensity of electricity generation in selected countries and regions, 2000-2020.

Modeling the way ahead: comparing the effectiveness of alternative policy options

The Future Technology Transformations (FTT) model simulates the process of technology diffusion in some of the high greenhouse gas-emitting sectors of the economy.[7] In each sector, the model represents competition between technologies in markets where industry actors or consumers are aiming to maximize profits or minimize costs. These actors make decisions in a context of uncertainty, and so they have diverse expectations as well as preferences. Policies can influence their decisions by changing the relative cost or availability of different technologies. New technologies benefit from increasing returns to scale, with deployment driving cost reduction in line with empirically observed learning curves.

Here we give three examples of the FTT model's application, which each provide policy insights relevant to a different stage of the transition.

Steel in the emergence stage[8]

The steel sector is in the emergence stage of the low-carbon transition, with technologies for near-zero emission primary steel production being tested in pilot plants but barely beginning to enter the market at commercial scale.

The FTT model was used to compare three policy packages in addition to a baseline "no policy" scenario (Figure 1). These were defined as follows.

- The "stick" policy package: policies that raise the cost or constraint the output of carbon-intensive steel production, specifically: i) a carbon tax, starting at €50 per tCO_2, gradually growing to €298 per tCO_2 in 2045, and levelling off afterwards; ii) phase-out regulations on carbon-intensive technologies that prevent the construction of new plants, starting in 2021; and iii) an energy tax, starting in 2021, of 25% on coal and gas.
- The "carrot" policy package: policies that directly reduce the cost of, or increase demand for, clean steel technologies, specifically: i) upfront subsidies on capital, starting in 2021, at 25% on carbon capture and storage (CCS) applications and 50% on hydrogen-based steelmaking and scrap recycling; ii) subsidies on low-carbon energy carriers, starting in 2021, at 25% on electricity, charcoal and biogas, and 75% on hydrogen; and iii) Government procurement, starting in 2025, translating into a 0.005% per annum addition to hydrogen-based steelmaking capacity.
- The "carrot and stick" package: a combination of the two policy packages described above.

The simulation of the baseline scenario suggests that in the absence of policy, steel production will likely remain dominated by coal-burning blast furnaces. The "stick" policy package makes this traditional production method more expensive, and in response, the industry moves toward the cheapest alternative: recycling of scrap steel and a shift to electric arc furnaces. However, the supply of scrap steel is constrained, so full decarbonization cannot take place. Carbon-intensive intermediate iron products increasingly become incorporated in electric arc systems, and the sector remains stuck in a high-emitting state.

The "carrot" policy package promotes a switch toward hydrogen-based steelmaking. Public procurement enables the new technology's first deployment, and the subsidies help replicate it and increase its scale. However, while this prevents the growth of high-emitting production pathways, it

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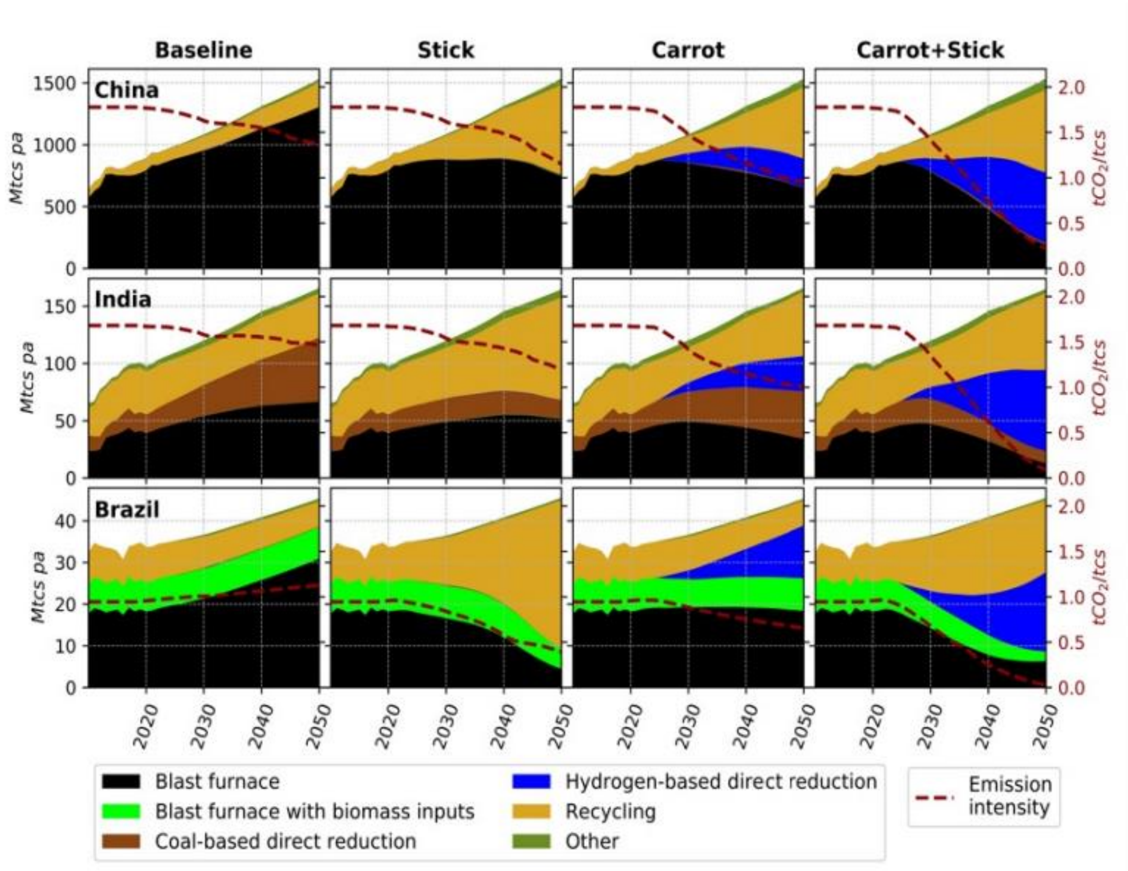
7 The Future Technology Transformations model was developed by Jean-Francois Mercure, and its component models representing the sectors of power, light road transportation, heavy road transportation, heating, and steel, have been further developed by other researchers. It can be used to inform the choices between policies for the low-carbon transition in these sectors and can be linked to the nonequilibrium macroeconomic model E3ME to simulate the macroeconomic implications of those policy choices (Mercure, 2012; Mercure et al., 2018; Knobloch et al., 2019).

8 This section is a summary of the policy brief: Vercoulen, P., Cesaro, Z., and Winning, M., *Prospects and strategies for low carbon steel*, https://eeist.co.uk/download/803/

does not achieve a substantial reduction. Combining the "carrot" and "stick" policy packages is significantly more effective. These packages are mutually reinforcing: in China and India, their combined effect on the growth of hydrogen-based steelmaking is nearly double the sum of their individual contributions and eliminates most of the traditional high-emitting production.

Figure 1. The effects of three policy packages on the technology mix and emissions of the steel sector in China, India, and Brazil



Source: Vercoulen, P., Cesaro, Z., and Winning, M., Prospects and strategies for low carbon steel https://eeist.co.uk/download/803/. *(Reproduced with permission)*

One of the many uncertainties involved in the transition to clean steel is the future price of hydrogen. The assumption of high or low hydrogen prices in the model changes the relative shares of different technologies in each of the scenarios but does not change the finding that the combination of "carrot" and "stick" policy packages is more effective than either package alone.

Road transportation in the diffusion stage[9]

The road transportation transition is in the diffusion stage, with EVs already spreading rapidly through the largest markets and accounting for 18% of all cars sold globally in 2023 (IEA 2024a).

The FTT model was used to compare four of the main policies used to support the decarbonization of this sector, at varying levels of stringency.

- Purchase subsidies for EVs, at: i) the "current" (2020) level in the specified market; ii) the level required to achieve ownership cost-parity with an equivalent internal combustion engine vehicle in the year 2022; and iii) the "high" level (150% of the 2020 level); and iv) the "very high" level (200% of the 2020 level).

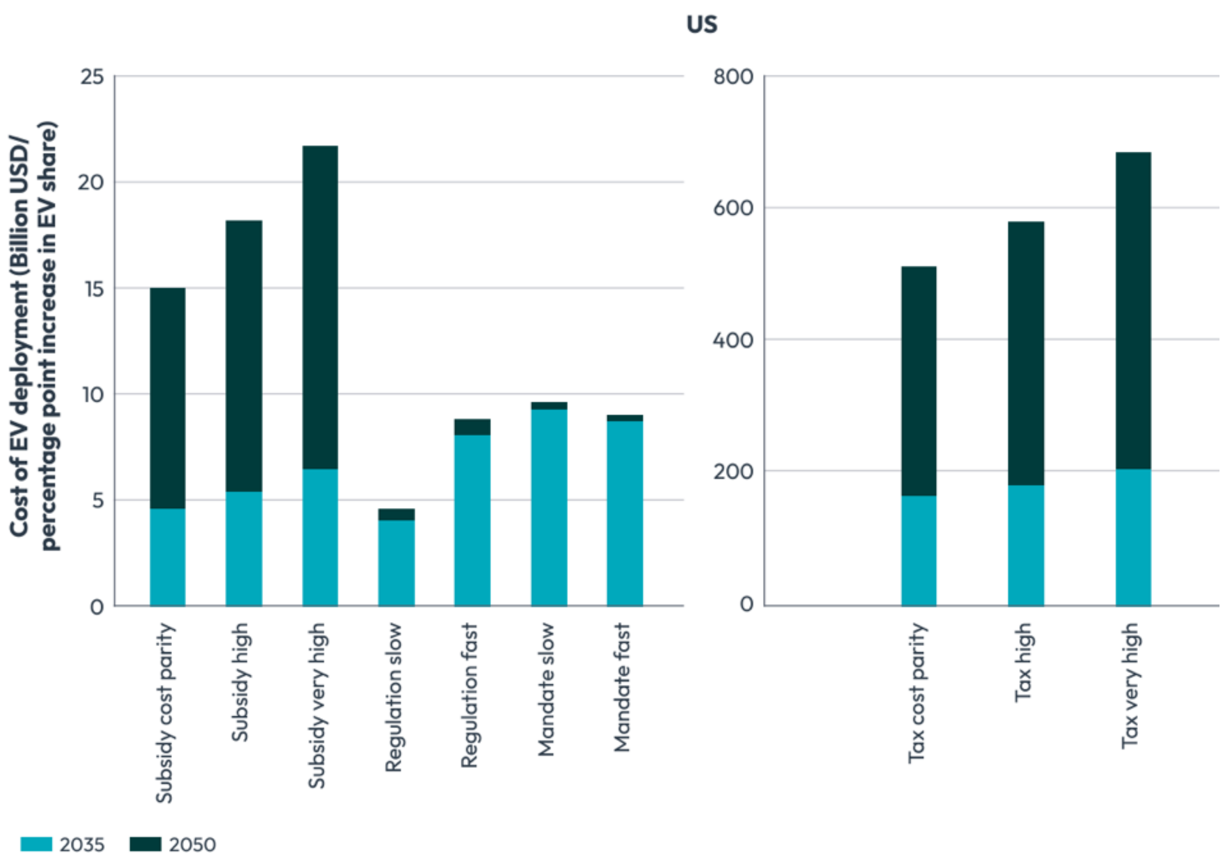
9 This section is a summary of the policy brief: Lam, A., Mercure, J-F., and Sharpe, S., *Policies to pass the tipping point in the transition to zero-emission vehicles*, https://eeist.co.uk/wp-content/uploads/2023IIB078-EEIST-EV-Policy-Brief-AW-1.pdf.

- Taxes on internal combustion engine vehicles at: i) the level required to achieve ownership cost-parity with an equivalent electric vehicle in the year 2022; ii) the “high” level (150% of the 2020 level); and iv) the “very high” level (200% of the 2020 level).
- Efficiency regulations: “slow,” requiring the carbon intensity of new vehicles (carbon emissions per kilometer) to reduce linearly from its level in 2022 to 50% of that level in 2035; and “fast,” requiring the carbon intensity of new vehicles to reduce linearly from its level in 2022 to zero by 2035.
- Zero emission vehicle mandates: “slow,” requiring 50% of new vehicles to be zero emission vehicles by 2035; and “fast,” requiring all new vehicles to be zero emission by 2035.

The policies were compared individually in terms of their effectiveness in achieving the transition, the cost-effectiveness of electric vehicle deployment, cost-effectiveness of emissions reduction, and cost reduction of EVs achieved by 2035 and by 2050, in each of the world’s four largest car markets: Europe, the U.S., China and India.

The results suggested that regulatory policies will likely be the most effective in driving the transition. Subsidies and taxes, even at very high levels, appear likely to be relatively ineffective when used alone. Zero emission vehicle mandates emerge as more effective than efficiency regulations, because they force a faster shift to the new technology, activating the feedbacks of deployment and cost reduction. For the same reason, the “fast” mandate achieves a deeper reduction in the cost of EVs over the simulated period than any other policy.

Figure 2. Cost of EV deployment (US$ billion/percentage point increase in EV share)



Source: Lam, A., Mercure, J-F., and Sharpe, S., Policies to pass the tipping point in the transition to zero-emission vehicles, https://eeist.co.uk/wp-content/uploads/2023IIB078-EEIST-EV-Policy-Brief-AW-1.pdf. (Reproduced with permission)

In terms of cost-effectiveness in the deployment of EVs, the mandates and efficiency regulations generally outperform the subsidies, while the taxes are by far the least cost-effective. Beyond these general findings, the results indicate how the relative cost-effectiveness of different policies can vary by country and by stage of the transition. In the U.S., subsidies appear more cost-effective than regulations and mandates early in the transition, when the cost premium of EVs is high, but the reverse becomes true later in the transition as electric vehicle costs come down—as shown in Figure 2. For similar reasons, subsidies are less cost-effective than regulations from the outset in China, where a greater proportion of EVs are already cost-competitive with combustion engine vehicles.

The model has also been used to simulate the effect of different combinations of these and other road transportation decarbonization policies. While combining policies tends to result in a faster transition, an important finding is that some policy packages can achieve more than the sum of their parts, resulting in additional cost and emissions savings, whereas others achieve less than the sum of their parts. The greatest gains occur from combining zero emission vehicle mandates with taxes and efficiency regulations applied to combustion engine vehicles—an approach that increases the availability of the new technology at the same time as reducing the attractiveness of the old (Lam and Mercure, 2021).

The power sector approaching reconfiguration[10]

Clean power accounted for around 80% of electricity generation capacity additions globally, in 2023 (IEA, 2024b). In the leading markets, the power sector transition is approaching the reconfiguration stage. Governments are beginning to plan new market structures to balance supply and demand in electricity systems dominated by variable renewable generation. This includes determining how best to incorporate technologies such as energy storage and demand-side response, which are complementary to the core technologies of renewable generation. Governments are also grappling with the social implications of the expected decrease in demand for coal.

The FTT model projects that without any new policies, solar power—with the cost of energy storage included—is set to become the cheapest form of power generation almost everywhere in the world within the next few years (see Figure 3). This result arises because the model incorporates the positive feedback between deployment and cost reduction, and because solar has a steeper learning curve than wind (while there is no significant learning curve for power from coal, gas, nuclear, or hydro). This dynamic leads to projections that differ significantly from those of some other models; for example, the FTT projects that solar could account for over half of global electricity generation by 2050, whereas the IEA's baseline scenario produced at the same time as this study projected a 20% share for solar by 2050 (IEA, 2021).

Faster global deployment implies faster cost reduction, and the FTT model projects that the cost of solar and storage could be half the cost of coal power by 2030 in regions including the EU, U.S., China, India, Japan, and Brazil. When governments decide whether to support or allow new investments in coal or gas power plants, it can be useful to consider projections such as these from a range of models, while being mindful of their assumptions and limitations and the associated uncertainties.

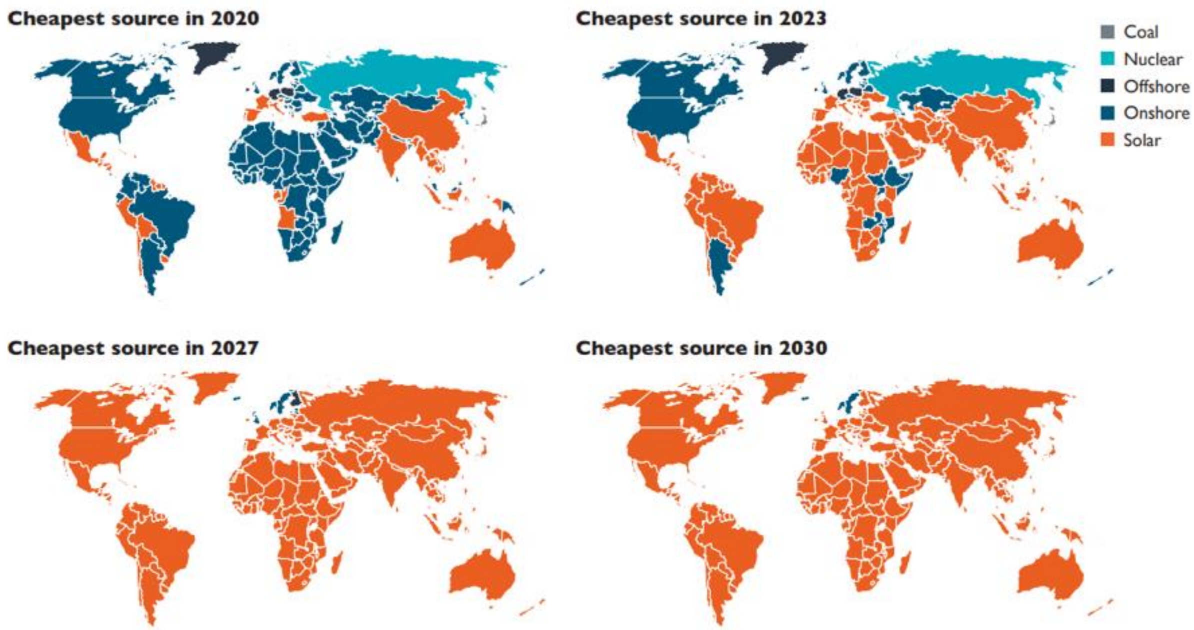
Simulation with the FTT model suggests that renewable subsidies or carbon prices will make little difference to the pace of the global transition to clean power over the coming years. This is consistent with the fact that renewable power is already cheaper than coal or gas power in most of the world. In contrast, it suggests that regulatory policies that force coal power out of the system could make a significant difference (Nijsse et al., 2024). Policies that are not explicitly modeled, such as the rate of expansion of electricity grids, the speed of permitting for renewables, and the cost of capital in developing countries could also make a difference.

The model also shows how different choices regarding future market design could interact with technology choices to produce higher or lower electricity prices. The outcomes of these choices for

10 This section is based on Nijsse, F. et al., *"Is a solar future inevitable?" How to shape policies to capture the opportunities of cheap solar*, https://eeist.co.uk/download/927/ and Vercoulen, P. et al., *Unstoppable renewables and marginal pricing in China, India and Brazil*, in Barbrook-Johnson, P. et al., *New economic models of energy innovation and transition: addressing new questions and providing better answers*, https://eeist.co.uk/eeist-reports/new-economic-models-of-energy-innovation-and-transition/.

GDP and employment can also be seen when the FTT is coupled with the macroeconomic model E3ME.

Figure 3. Maps showing the energy source with the lowest levelized cost of electricity (including necessary storage) in 70 world regions, in 2020, 2023, 2027, and 2030



Note: The biggest shift occurs between 2020 and 2027, which sees a range of technologies give way to solar PV as the cheapest form of energy.
Source: Nijsse, F. et al, "Is a solar future inevitable?" How to shape policies to capture the opportunities of cheap solar https://eeist.co.uk/download/927/. *(Reproduced with permission)*

In this study, three technology choices and two market designs were compared in combination. The technology choice scenarios were the following.

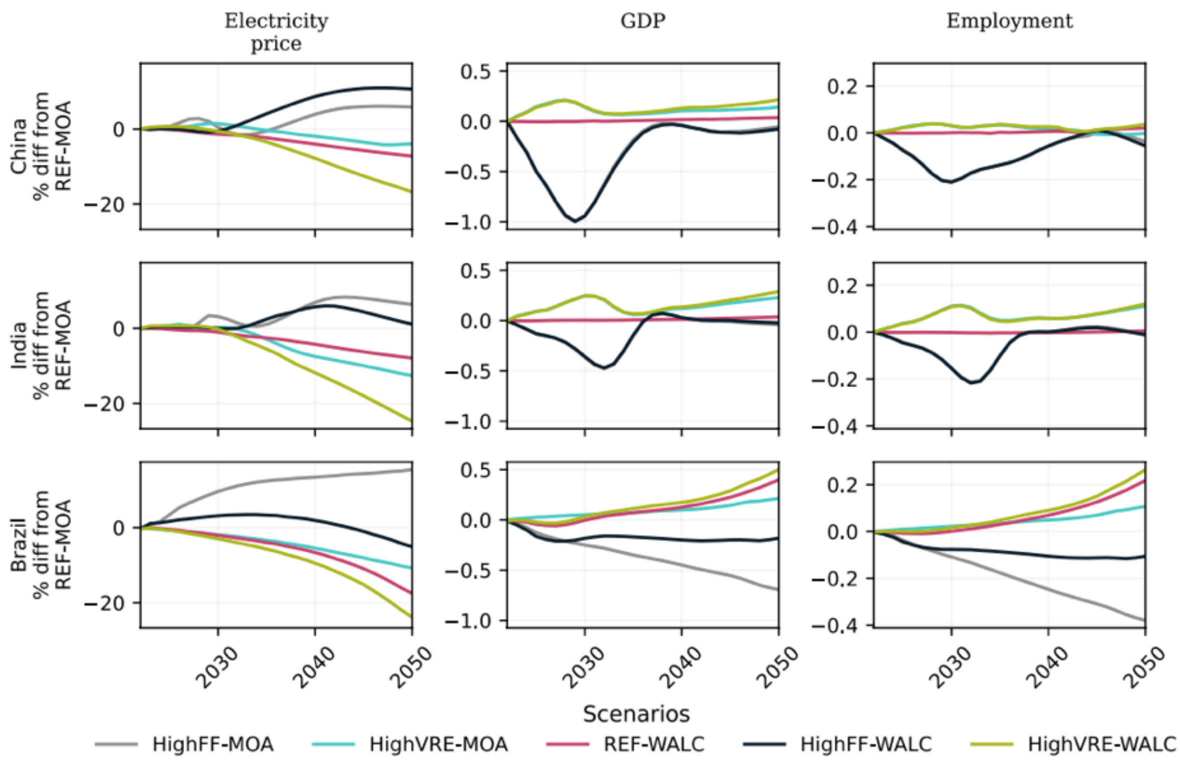
- Reference scenario: each power generation technology continues to diffuse on the trajectory it has been given by current policies.
- High variable renewables scenario: a capacity cap is applied to coal and gas power (this results in solar and wind diffusing more rapidly to meet demand) .
- High fossil fuels scenario: the diffusion rates of solar and wind are constrained, representing the effect of any barriers to their deployment (this results in coal and gas power increasing to meet demand).

The market design choices were: a) a market in which the electricity price reflects the cost of the marginal unit of supply, as is often the case in liberalized markets (labelled as the merit order approach (MOA), in Figure 4); and b) a market in which the electricity price reflects the weighted average levelized cost (WALC) of generation. This may become an important choice for governments in future, since the high capital costs and extremely low operating costs of solar and wind power could mean that a market where the price reflects the marginal operating cost becomes increasingly inefficient (Grubb, 2022).

The modeled results (shown in Figure 4, in which all results are compared with the reference scenario with MOA market design) consistently indicate lower electricity prices in the high VRE scenarios than in the high fossil fuel scenarios, reflecting the lower cost of renewables. At the same time, the WALC market design achieves significantly lower electricity prices than the MOA market design. This is because in the MOA market, the price is often set by more expensive fossil fuels, providing large profits to variable renewable and nuclear generators when prices are high. In all three of the countries modeled, the high-VRE WALC scenario achieves the lowest prices.

As in the previous example, the model results also show some interesting differences across countries. In China and Brazil, the reference technology scenario with WALC market design outperforms the high VRE scenario with MOA market design, but in India, the opposite is found. This is because India has the highest share of solar power in its system, and toward the end of the simulation there are a substantial number of hours in the year when the marginal cost of renewables sets the price in the MOA market, instead of the marginal cost of fossil fuels.

Figure 4. Comparison of electricity prices, total employment, and GDP of each scenario in percentage difference to the REF-MOA scenario in China (top row), India (middle row), and Brazil (bottom row)



Source: Vercoulen, P. et al., Unstoppable renewables and marginal pricing in China, India and Brazil, in Barbrook-Johnson, P. et al., New economic models of energy innovation and transition: addressing new questions and providing better answers, https://eeist.co.uk/eeist-reports/new-economic-models-of-energy-innovation-and-transition/.

In each country, the scenarios with low electricity prices also have more positive outcomes for GDP and employment. This is because lower electricity prices reduce household energy bills and industrial production costs, both of which enable increased consumer spending. Increased construction activity also contributes to positive effects on GDP in high-VRE scenarios. The outcomes for employment are similar, with the largest net gains occurring in the high-VRE scenarios. These net changes in GDP and employment mask larger changes taking place in different sectors, in each country.

Conclusions

Since, as the IPCC has described, the process of meeting climate change goals is that of system transitions in each of the greenhouse gas-emitting sectors of the economy, it is policies at the sector level that will largely determine the pace of the transition and many of its economic consequences. The examples presented here show that the choice of policy in each sector can strongly influence the cost of the transition as well as the costs of goods and services important to economic activity.

The findings of the three modeling studies are broadly consistent with the lessons from past technology transitions described by the Multi-Level Perspective, and also with countries' recent experiences in the low-carbon transition. All three forms of evidence suggest that the most effective policy combinations are different at the different stages of a transition. After viable solutions emerge from R&D, targeted investment, through policies such as subsidies or public procurement, is particularly effective. As the new technologies begin to compete against incumbents, taxes, subsidies, and regulations can all support their further diffusion and cost reduction. Later, as the new technologies become more established, price-based measures have less effect, and more depends on market reforms, infrastructure investments, and other interventions to ensure their efficient integration into wider social and economic systems.

The fact that policy combinations can achieve more than the sum of their parts—as shown in the steel and road transportation studies above—highlights the need for MoFs to work closely with other parts of Government in the low-carbon transition. Greater cost-effectiveness will likely be achieved if fiscal and regulatory policies are deliberately aligned than if either is used alone.

For governments that want to understand the likely macroeconomic effects of their low-carbon transition policies and strategies, sector-specific models that simulate the process of technology diffusion can be an important complement to macroeconomic models. A model such as FTT can be operated by an analyst with a reasonable level of computer programming skills. However, a model's outputs are only one input to policy analysis. The ability to interpret these within a broader knowledge of the relevant sectors will be essential to the provision of good analysis to inform decisions.

References

Clark, A., Songli, Z., Ives, M., and Grubb, M. (2021) *Appendix 2: Solar PV in Germany and China*. EEIST. https://eeist.co.uk/download/808/.

Geels, F. W., and Schot, J. (2007) Typology of Sociotechnical Transition Pathways. *Research Policy* 36(3), 399–417.

Grubb, M. (2022) *Navigating the Crises in European Energy: Price Inflation, Marginal Cost Pricing, and Principles for Electricity Market Redesign in An Era of Low-Carbon Transition*. Working Paper 191, Institute for New Economic Thinking. https://www.ucl.ac.uk/bartlett/sustainable/sites/bartlett_sustainable/files/ucl_isr_necc_wp3_with_cover_final_070922.pdf.

Grubb, M., Drummond, P., Poncia, A., McDowall, W., Popp, D., Samadi, S., Penasco, C., Gillingham, K. T., Smulders, S., Glachant, M., and Hassall, G. (2021) Induced Innovation in Energy Technologies and Systems: A Review of Evidence and Potential Implications for CO_2 Mitigation. *Environmental Research Letters* 16(4), Paper 043007. https://iopscience.iop.org/article/10.1088/1748-9326/abde07.

IEA (2020) *World Energy Outlook 2020*. IEA, Paris. https://www.iea.org/reports/world-energy-outlook-2020.

IEA (2021a) *Carbon Intensity of Electricity Generation in Selected Countries and Regions, 2000–2020. https://www.iea.org/data-and-statistics/charts/carbon-intensity-of-electricity-generation-in-selected-countries-and-regions-2000-2020.*

IEA (2021b) *World Energy Outlook 2021*. IEA, Paris. https://www.iea.org/reports/world-energy-outlook-2021.

IEA (2024a) Global EV Outlook 2024, IEA, Paris https://www.iea.org/reports/global-ev-outlook-2024.

IEA (2024b) *Clean Energy Is Boosting Economic Growth*. IEA, Paris. https://www.iea.org/commentaries/clean-energy-is-boosting-economic-growth.

Knobloch, F., Pollitt, H., Chewpreecha, U., Daioglou, V., and Mercure, J. F. (2019) Simulating the Deep Decarbonisation of Residential Heating for Limiting Global Warming to 1.5 °C. *Energy Efficiency* 12, 521–550. https://doi.org/10.1007/s12053-018-9710-0.

Lam, A., & Mercure, J. F. (2021). Which Policy Mixes Are Best for Decarbonising Passenger Cars? Simulating Interactions among Taxes, Subsidies and Regulations for the United Kingdom, the United States, Japan, China, and India. *Energy Research & Social Science* 75, Paper 101951. https://doi.org/10.1016/j.erss.2021.101951.

Lenton, T. M., Benson, S., Smith, T., Ewer, T., Lanel, V., Petykowski, E., Powell, T. W., Abrams, J. F., Blomsma, F., and Sharpe, S. (2022) Operationalising Positive Tipping Points Towards Global Sustainability. *Global Sustainability 5*, Paper e1. http://doi.org/10.1017/sus.2021.30.

Mercure, J.-F. (2012) FTT:Power: A Global Model of the Power Sector with Induced Technological Change and Natural Resource Depletion. *Energy Policy* 48, 799-811. https://www.sciencedirect.com/science/article/abs/pii/S0301421512005356.

Mercure, J.F., Lam, A., Billington, S. and Pollitt, H. (2018) Integrated Assessment Modelling as a Positive Science: Private Passenger Road Transport Policies to Meet a Climate Target Well below 2 °C. *Climatic Change* 151, 109–129. https://doi.org/10.1007/s10584-018-2262-7.

Nemet, G. (2025) *How Solar Energy Became Cheap*. https://gregnemet.net/book.

Nijsse, F., Sharpe, S., Sahastrabuddhe, R., and Lenton, T. M. (2024) *A Positive Tipping Cascade in Power, Transport and Heating*. www.scurveeconomics.org/publications-and-resources.

Sharpe, S. and Lenton, T. M. (2021) Upward-Scaling Tipping Cascades to Meet Climate Goals: Plausible Grounds for Hope. *Climate Policy* 21(4), 421–433.

Sharpe, S., Murphy, A., Geels, F., Pasqualino, R., Fleming Machado, T. V., Mercure, J.-F. (forthcoming) Analytical Tools for Innovation and Competitiveness in the Low Carbon Transition.

Way, R., Ives, M. C., Mealy, P., and Farmer, J. D. (2022) Empirically Grounded Technology Forecasts and the Energy Transition. *Joule* 6, 1–26. https://doi.org/10.1016/j.joule.2022.08.009.

Drax (2020) *Electric Insights Quarterly July-Sep 2020*. https://www.drax.com/wp-content/uploads/2020/11/201126_Drax_20Q3_005.pdf.

Further resources

- The Economics of Energy Innovation and System Transition project's case studies use a variety of models and other analytical tools; other resources include reports on decision-making frameworks and principles for policymaking in the energy transition.
- UNEP, the OECD, and Institute of Innovation and Public Purpose have all published open-source resources on how to deliver green industrial policies.
- There are multiple open-source resources on the Multi-Level Perspective, including the Forum for the Future's Facilitators Pack.
- Cambridge Econometrics has a list of papers where E3ME and FTT have been used for policy insight, and the World Bank has published a paper on the use of FTT-FLEX, a simplification of the FTT model specifically for small developing countries.