Complexity economics insights for the Seventh Carbon Budget

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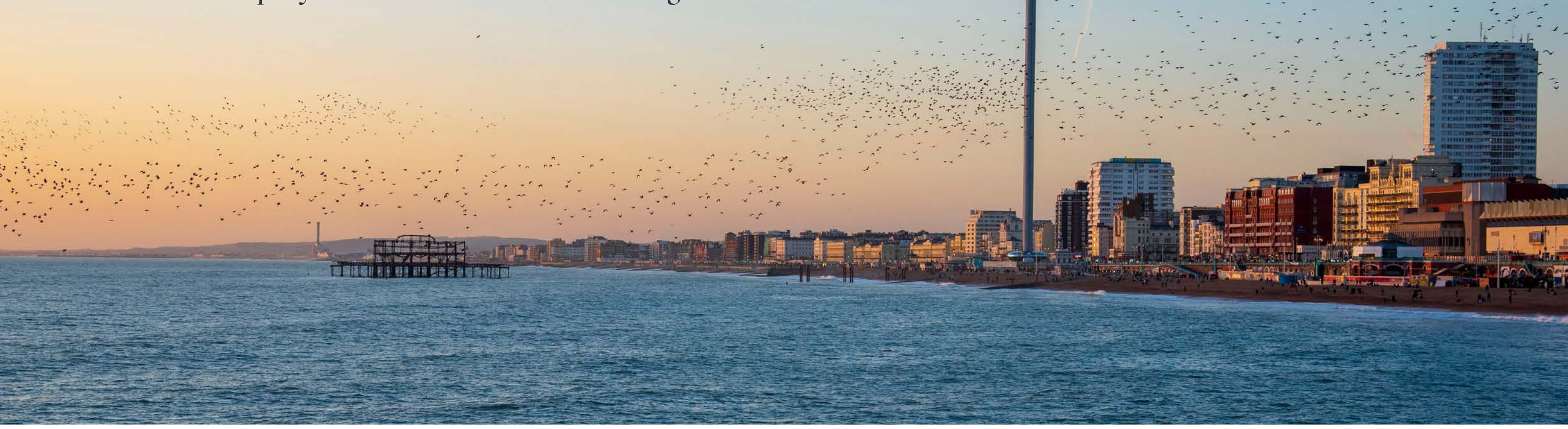

The path to Net Zero requires hundreds of changes to technologies and practices across every sector of the economy. Changes will be transformational, not marginal. Complexity economics and complexity science methods are particularly well suited to this type of problem.

This briefing for the Environmental Audit Committee's Seventh Carbon Budget inquiry showcases four research programmes from the University of Oxford's Institute for New Economic Thinking that we believe could help inform the Seventh Carbon Budget:

1. Macroeconomics for the Seventh Carbon Budget
2. Forecasting technology deployment
3. Systems mapping
4. Inequality impacts, linking micro and macro models

Key findings

- Decarbonisation will change too many aspects of the economy at once to rely on marginal models. Systems mapping and agent-based models are two options that account for feedback loops, tipping points and complexity.
- Solar and wind energy costs have consistently fallen faster than forecasted. Accelerating their deployment will bring down the costs of Net Zero.
- The UK's role as an early adopter has helped 'de-risk' renewable energy technologies, fostering the exponential decline in costs that all countries are now benefiting from.
- Energy costs are a bigger portion of spending for poorer families. 'Polluter pays' policies like carbon taxes need mitigations like rebates or they widen inequality.

What is complexity economics?

The economy is a **complex adaptive system**. The consequences of any action depend on interactions with a multitude of other actions, on the circumstances at the time, on the local context, on policies. There are feedback loops and tipping points. Economists have learned the hard way the challenges this poses to prediction, to identifying cause and effect, and to establishing shared and settled understandings of how the economy works.

The economy shares these characteristics with a range of other complex adaptive systems: brains, forests, cities and beyond. These are the types of systems where the whole seems more than the sum of the parts. These systems have emergent properties.

Complexity science is a community of methods, theories and researchers that seeks to understand these complex adaptive systems. It often uses computational techniques developed by physicists and mathematicians for the study of biological and social systems. It is always interdisciplinary, with assumptions driven by the research question rather than disciplinary boundaries.

Complexity economics applies this approach to economic systems. The Complexity group at the University of Oxford's Institute for New Economic Thinking is one of the world's leading centres for the study of the economy as a complex adaptive system. INET research predicted the impact of covid-19 lockdowns on the UK economy as early as May 2020. INET collaboration with researchers from the Bank of England informed their financial stability analysis after the Global Financial Crisis. We have recently begun a programme of research on the Seventh Carbon Budget.

1. Macroeconomics fit for the Seventh Carbon Budget

INET Oxford's pioneering macroeconomic model simulates interactions between individual people, companies, banks and governments to generate an overall forecast for economic growth, employment, inflation and more. It is part of an emerging field of data-driven macroeconomic models. As far as we know, it is the only model of this class for the UK. It also works for all OECD countries.

Our model is a prototype in rapid development. It has the potential to offer fine-grained assessments of the impacts of economic shocks and policy changes on different subsets of the population, segmenting by income, wealth, gender, age and more.

We are working with DESNZ to deploy this model to assess policies under consideration for the Seventh Carbon Budget. This would be the first time a Carbon Budget has been accompanied by an assessment of the impact on macroeconomic variables like growth, unemployment and inflation. We aim to publish preliminary findings in 2026.

Our model is very different to UK TIMES, the model DESNZ have used for previous carbon budgets. UK TIMES identifies the lowest cost pathway to reach Net Zero, subject to various viability constraints. This is a challenging problem, as every technology has a different profile of investment and spending needs, and these often interact.

UK TIMES is a valuable tool in the Carbon Budget process but there are many reasons why the lowest cost Net Zero plan might not be the best for jobs, growth or inequality. A low-cost pathway based on current but static assessments of costs might miss reinforcing feedback loops and tipping points that dramatically alter the costs of different technologies. A low-cost pathway might rely heavily on cheaper imports rather than investing in domestic production capacity. A low-cost pathway might prioritise richer people for green subsidies, given that they are responsible for more emissions. A low-cost pathway could miss more expensive policy options that have co-benefits for health and biodiversity.

We hope our modelling can complement UK TIMES by tackling these dilemmas. By building in INET's research on technology deployment patterns, we hope to identify pathways that leverage feedback loops and tipping points. By using a model that explores the productive structure of the UK economy, we will be able to assess how interventions affect import dependence, and whether structural changes favour capital-intensive or labour-intensive industries. As our model is agent-based, explicitly modelling a diverse sample of households, we can assess how different policy options will affect different segments of the population.

Research referenced:

Forecasting Macroeconomic Dynamics using a Calibrated Data-Driven Agent-based Model
Wiese, S., Kaszowska-Mojsa, J., Dyer, J., Moran, J., Pangallo, M., Lafond, F., Muellbauer, J., Calinescu, A., & Farmer, J.D. *INET Oxford Working Paper*, 2024. https://www.inet.ox.ac.uk/publications/no-2024-06-forecasting-macroeconomic-dynamics-using-a-calibrated-data-driven-agent-based-model

Economic models and frameworks to guide climate policy
Hepburn, C., Ives, M.C., Loni, S., Mealy, P., Barbrook-Johnson P., Farmer, J.D., Stern, N., & Stiglitz, J. *Oxford Review of Economic Policy*, 2025. https://doi.org/10.1093/oxrep/graf020

2. Forecasting technology deployment

Renewable energy costs have consistently fallen faster than official forecasts. Solar costs have fallen by a factor of 5000 since photovoltaic cells first came to market in 1958. Net Zero policy can do more to leverage this exponential trend in renewable energy deployment, accelerating up the S-shaped deployment curve.

INET Oxford researchers have developed techniques to use historical data to forecast the "learning" rate at which the costs of new technologies fall as their deployment increases. These forecasts predict that a fast transition to Net Zero would be vastly cheaper than a slow transition – saving $8 trillion. This fast transition is ambitious but feasible: it assumes renewable energy deployment grows slightly slower than their current exponential rates for a decade, before slowing to grow at around 2% each year.

Looking specifically at wind and solar technologies, INET researchers forecasted the cost of hardware and wider costs of balancing the energy system. Since 1990 the cost of solar photovoltaic modules and solar's grid balancing costs have declined roughly exponentially at rates of 12% per year. Wind turbine cost has declined roughly exponentially by 4% per year, but grid costs for wind have not fallen. This suggests that global wind costs will steadily approach a floor of around 35 USD/MWh, reaching 43 USD/MWh in 2050, whereas global solar costs will continue to decline exponentially, falling to 3-15 USD/MWh in 2050 and even lower later in the century.

Research referenced:

A fast clean energy transition would save trillions
Way, R. & Farmer, J.D. 2023. *INET Oxford Research Briefing.*
https://www.inet.ox.ac.uk/files/OMS-energy-transition-v7.pdf

Empirically grounded technology forecasts and the energy transition
Way, R., Ives, M.C., Mealy, P., Farmer, J.D. (2022) '. *Joule*, 6 (9): 2057-2082.
https://doi.org/10.1016/j.joule.2022.08.009

Will national renewable costs continue declining?
Baumgärtner, L. & Farmer, J.D.. 2025. *INET Oxford Working Paper.*
https://www.inet.ox.ac.uk/publications/no-2025-12-will-national-renewable-costs-continue-declining

Technology deployment patterns vary between countries

INET research finds that countries taking leadership – deploying early, but more slowly – enable a second cohort of 'fast followers'. The UK is historically an early adopter of technologies, such as mobile phones and the internet. As an early adopter this means we tend to be slower to adopt as we play an active role in de-risking new technologies.

Although the learning trends that bring renewable energy costs down are global, each country's economic conditions affect the extent to which they actually experience these cost reductions. Global cost trends determine the vast majority of countries' solar costs but the cost of wind power is more affected by local conditions.

UK solar and wind costs are around the median when compared to other countries. When costs are adjusted for purchasing power, UK solar and wind costs in fact appear relatively low. UK wind costs have dropped a lot recently. The UK has a relatively high number of wind and solar policies, and these policies are relatively stringent.

Research referenced:

Who rides the renewable cost curve? Country evidence on prices, learning, and policy
Tankwa, B. & Barbrook-Johnson, P. 2025, *INET Oxford Working Paper*.
https://www.inet.ox.ac.uk/publications/no-2025-17-who-rides-the-renewable-cost-curve-country-evidence-on-prices-learning-and-policy

Technological progress at national level: Increasing diffusion speeds with ever-changing leaders and followers
Tankwa, B., Vasquez Bassat, L., Barbrook-Johnson, P., & Farmer, J.D. 2025. *INET Oxford Working Paper.*
https://www.inet.ox.ac.uk/publications/technological-progress-at-national-level-increasing-diffusion-speeds-with-ever-changing-leaders-and-followers

3. Systems mapping

Systems mapping is a qualitative and participatory approach to modelling the energy system and energy policy, a helpful complement to our other work which is quantitative and technically dense. INET Oxford researchers have used systems mapping to understand where DESNZ might focus its analysis and evaluation capacity across multiple policy areas to best support departmental objectives, and in specific policy evaluations as in the evaluation of the Renewable Heat Incentive.

We have used systems mapping to identify ten 'system archetypes' in the energy transition. These are common dynamic properties of the energy transition seen across many countries, policies, and technologies. Together they offer rules of thumb for how to understand how the transition is unfolding and how policy affects it.

One archetype is the way the exponential decline in renewable energy costs drives increases in demand, furthering deployment and the innovation investments that bring down costs. Policies like feed-in tariffs and public procurement played an important role in kicking off this reinforcing feedback loop.

Another archetype is the way renewables progress is dampened by volatile prices when renewables start to occupy a significant proportion of the grid. Policies like contracts for difference can help maintain investment by creating more certainty in prices. Fostering synergies between renewable energy and energy storage technologies – another archetype – can also reduce this dampening effect.

We have also supported DESNZ's world-leading in-house systems mapping capabilities. DESNZ's Net Zero Systems team has developed system maps of its own, a platform to house and analyse system maps, using these across central government.

Research referenced:

Participatory systems mapping for complex energy policy evaluation
Barbrook-Johnson, P., & Penn, A. 2021. *Evaluation*, *27*(1), 57-79. https://doi.org/10.1177/1356389020976153

System Archetypes of the Energy Transition
Sharpe, S., Collett, M., Barbrook-Johnson, P., Rosenow, J., & Grubb, M. 2025. *S-curve Economics*. https://www.scurveeconomics.org/publications/systems-archetypes-of-the-energy-transition/

4. Inequality impacts of Net Zero transitions

Public acceptability of climate policies and of the whole Net Zero transition depends on a fair distribution of burdens and benefits. Different decarbonisation policies have contrasting consequences for the rich and the poor, for rural and urban communities, for the young and the old, and for people in different corners of the country.

Work by INET researchers addresses these questions for the French Net Zero transition, offering many insights transferrable to the UK. This research coupled a whole economy model with a 10,000-household microsimulation. It used income-specific, long-run elasticities and explicitly modelled electric vehicle uptake and home retrofits through 2025, 2030 and 2035.

Carbon taxes are regressive unless revenues are redistributed. Lower income households spend a larger share of their income on energy and therefore on carbon tax schemes. This is a key conundrum any Net Zero pathway must correct. Lump-sum rebates are critical to counter regressivity in the near term: per capita and poverty-targeted designs can make the net carbon tax progressive. A poverty-targeted scheme lowers the Gini measure of income inequality as well as the poverty rate.

Subsidies for electric vehicles and home retrofits reduce bills and emissions most when they are **targeted at the biggest energy consumers**. Better targeting narrows rural-urban gaps in carbon taxes but makes them slightly more regressive. Increasing the numbers of beneficiaries of subsidies does not decrease emissions nor help inequalities if not carefully targeted.

Higher-ambition pathways can be **pro-growth and pro-jobs**, but distribution can still worsen without compensatory design. Hence the importance of combining **targeted rebates** with **well-aimed tech support** to deliver a Net Zero pathway that is both effective and fair.

Sequencing makes a real difference. Rebates could protect low-income households from prices rise over the next five years, after which point technology may well have scaled enough to begin to cut bills. By the mid-2030s, electric vehicles and home retrofits have the potential to lower average payments even as carbon prices rise.

Research referenced:

Is a fair energy transition possible? Evidence from the French low-carbon strategy
Ravigné, E., Ghersi, F., & Nadaud, F. 2022. *Ecological Economics*, Volume 196, 107397. https://doi.org/10.1016/j.ecolecon.2022.107397

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