Is reaching net zero a growth and prosperity plan?

Economics, tools and actions for a rapidly changing world

How to cite this paper

Zenghelis, D. , Costa-Allendes, A. , Stephenson, S., Nemo Ramirez, C., Wale, W., Hunnable, H. (2024). Is reaching net zero a growth and prosperity plan? Economics, tools and actions for a rapidly changing world by the Cambridge Zero Policy Forum. *Cambridge Open Engage*. doi:

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The author wishes to thank the following for their significant contributions to the report:

Nick Bridge (Foreign Secretary's Special Representative for Climate Change, 2017-23)

Sarah Dry (University of Cambridge)

Cordula Epple (The UN Environment Programme World Conservation Monitoring Centre)

Emily Farnworth (University of Cambridge)

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The author wishes to thank the following for being interviewed by colleagues on the report:

Feargal Brennan (University of Strathclyde)

Diane Coyle (University of Cambridge)

Cameron Hepburn (University of Oxford)

John Loughhead (University of Birmingham)

The author also wishes to thank the following for their contributions to events that helped shape the report:

Matthew Agarwala (University of Cambridge)

Claire Barlow (University of Cambridge)

SJ Beard (University of Cambridge)

Sophy Bristow (University of Cambridge)

Stephen Davison (University of Cambridge)

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Frank Kelly (University of Cambridge)

Andy King (Flint Global)

David King (University of Cambridge)

Loic Lannelongue (University of Cambridge)

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Design and layout: Janice Reed Design Limited
www.janicereed-design.com

Communications support:

Paul Casciato (University of Cambridge)

Rebecca Leam (University of Cambridge)

Cambridge Zero Policy Forum

The Cambridge Zero Policy Forum is a multidisciplinary community of senior academics contributing evidence and expertise to public policies for the transition to a sustainable, inclusive, and resilient net zero society.

The Forum is Co-Chaired by Prof Emily Shuckburgh (Director, Cambridge Zero), Dr Rob Doubleday (Executive Director, Centre for Science and Policy), and Emily Farnworth (Director, Centre for Climate Engagement, Hughes Hall). The secretariat to the Policy Forum is provided by CSaP.

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The Centre for Climate Engagement (CCE) plays a unique role in bringing leading expert research to a targeted audience of chairs and non-executive directors to accelerate climate leadership on boards in the private and public sectors. The CCE is ideally placed to develop insights drawing on academic expertise from across the University of Cambridge and the wider research community, together with independent expertise from the business sector.

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Foreword
Foreword

Foreword
Foreword

The decisions of the next decade, particularly on infrastructure and innovation, will dictate whether the UK locks into high carbon emissions or transitions to a sustainable, resilient, and intelligent economy. A big push on investment is central to building competitiveness as an attractive high-wage, high-skill economy with the means to break out of the low public investment, austerity, doom loop that has held the UK back. A new model of growth and development is in our hands, and the UK has the science and innovation base to lead, but action must be clear, swift and strong. A clean growth story for the 21st century involves many opportunities along the way. The rewards are great, but the obstacles and difficulties are real. Strategic investment is key.

Sustainable, resilient and equitable growth requires integrating natural capital and social equity into economic analyses and actions. This means placing rapid structural, systemic and technological transformation at centre stage. As the world invests in the clean economy and the technology and science advances, the overwhelming obstacles lie predominantly in economics, politics, and society. Drawing on a range of academic disciplines including history, geography, international relations, and social psychology, this is the new agenda for economics and the social sciences and the basis for resilient and sustainable investment and policymaking.

The incoming government faces an array of challenges. Tough policy decisions are needed, most notably on public-sector spending and debt management. Dealing with the climate crisis cannot be treated as an exception to how we approach other challenges facing our society. Crucially, we must stop relying on narrow, project-by-project cost-benefit analysis for strategic decisions. We must look more broadly at programmes, strategies and systemic change, as well as project-by-project. If Treasury is serious about dealing with the challenges of growth and productivity and climate mitigation, then it must be willing to reassess its decision-making process, culture and the limitations of the Green Book. Creating effective policy to drive low carbon growth will also involve considering how we deal with public-sector debt and compare investment against broader public-sector spending. Given the challenging state of the current public finances, these decisions will also be met with scrutiny and debate. This we should welcome as part of unlocking the growth opportunities and becoming a global leader.

As a country, we can seize the challenges and opportunities and deliver a comprehensive strategy. The investment, innovation and structural reforms that will allow us to meet our climate targets will also drive the growth and prosperity we need.

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Executive Summary

Delivering resilient net zero investment has implications for taxes, public-sector spending and debt and cannot be treated as separate to how we approach other societal and economic challenges.

Executive Summary

Strategic decisions are being made worldwide and, so far, economists have been scrambling to keep up with, let alone to understand, the pace of change. This has made for poor policy advice.

Marginal incrementalist views and analytical approaches are ill-placed to inform decisions based on large, non-marginal, structural shifts. Economists using inappropriate tools have not only got the future wrong, they have made the future wrong because they have delayed action and supported costly and ineffective policies.

Drawing on multidisciplinary expertise from the University of Cambridge, The London School of Economics and Political Science (LSE) and beyond, this report finds that if the Chancellor is serious about reviving UK growth, a coherent clean investment strategy is the only choice.

Understanding the dynamics of innovation and structural change requires the use of a broader range of analytical tools. Economic modelling has a role to play in assessing risks and opportunities and guiding optimal policy choices, but what matters most are the insights, not the flawed predictions they provide. A shift to risk-opportunity analysis and options theory means that decisions can now be taken to shape the future supply side of all economies, invest in future-proofed assets, and avoid locking into redundant infrastructure, skills and ideas. Our report concludes that a variety of models, complemented by a range of qualitative and non-modelling analytical approaches, with different strengths and weaknesses, can articulate risks and inform choices.

Narratives matter now more than ever. Conflicting narratives of catastrophic climate risk and transformative economic and social opportunities versus reports that the costs are too difficult to bear, not least given current financial constraints, have been hard to reconcile. They are increasingly prone to being drawn into 'culture war' postures. On the one hand, the bulk of global electricity generation investment has been in renewables, because they are cheap, on the other hand, a commitment to rapid emissions reductions is presented in terms of the costs of cutting emissions relative to a fossil fuel dominated system. This narrative is often backed up with detailed financial accounting of the costs and, to a more limited degree, benefits of action. It begs the question, if decarbonisation was so good for growth, why were businesses and governments not investing in it anyway?

Such debates breed confusion, indecision and inaction. They also generate low investor confidence and, increasingly, a loss of economic opportunity and resilience. This report analytically explores the powerful role of expectations.

What remains undeniable is that the global economy is undergoing three major transformations, involving general purpose technologies in clean energy; artificial intelligence (AI); and automation. The race to supply markets of the 21st century is on. As a centre of innovation, the UK is well placed to use its strong scientific base to help transform its economy, developing new knowledge clusters and supply lines and to compete with other countries to develop new skills, technologies, and markets. Yet the economic discussion is stuck in a rut mostly about financing costs.

A clean transition requires investment in efficient capital to replace a resource-hungry, labour-intensive and inefficient energy system mostly based on burning things. The pace at which clean technologies have outcompeted fossil fuel incumbents in key sectors like electricity and cars has caught everyone by surprise **and rendered cost estimates for greenhouse gas mitigation grossly over-stated, as technologies deliver cheaper and more efficient energy.**

The transition has been driven by price reductions in scalable, replicable and modular clean technologies, whose deployment leads to cost-reducing learning-by-doing, economies of scale, and network and spillover effects. Recent evidence suggests that such investment also stands to induce creativity and innovation across the economy.

The challenge is to increase the efficiency of capital, not just the investment rate. There needs to be more investment, and of the right kind. This marks a clear role for government to steer investment in a sustainable, resilient and intelligent direction, compatible with the technologies, markets and behaviours of the 21st century.

Clearly, not all clean investment will add capacity or reduce costs. For some activities, such as carbon capture and storage (CCS) of emissions, cleaning up will come at a net additional cost with limited additional growth benefit, except in so far as the UK develops a market lead in exporting the technology. Other activities, such as limiting airport expansion, will constrain growth while still others, such as retrofitting and insulating buildings, are relatively low-tech and labour intensive, even though they do generate net returns from greater efficiency. There will also be wasted money invested in technologies that fail to deliver as expected (EU over commitment to hydrogen is cited as an example). Policymakers must also anticipate and limit rent-seeking on the part of businesses seeking to benefit from public support.

However, **in wide swathes of the UK economy, decarbonisation goes hand in hand with creating a more innovative, efficient, productive, and globally competitive economy.** With the world rapidly decarbonising and pursuing resource efficiency, investment will be essential if the UK is to maintain competitiveness.

Those arguing that clean investment is growth-inhibiting and unaffordable, need to set out the counterfactual, high carbon investment strategy, and show that that would be more resilient and productive than a low carbon alternative.

Delaying action and free riding on the investment in new technologies made by others may seem superficially attractive, but it is costly with the UK missing out on a competitive race to supply some of the world's fastest growing new markets. At a time of accelerated change, a 'technology-neutral' choice often means favouring incumbent sectors with the deepest pockets, at the expense of society. The biggest barriers to a sustainable, inclusive and resilient economy are not technological or economic: they are political and behavioural. Inertia and inaction are costly.

Investment in the clean transition needs to be at the heart of the UK productivity and growth strategy over the coming decade. Most of the necessary investment will come from the private sector. Government has a central role in setting expectations and guiding investors towards profitable, future-proofed assets, and strategically creating competitive new markets, while enabling workers to participate in the economy of the 21st century. Additional public investment is needed in grids and in retrofitting the housing stock. Estimates vary: but in our judgement the UK needs to increase annual public investment by around 1% of gross domestic product (GDP). This would lift the UK out of bottom place in the G7 league table for investment and make up for decades of underinvestment in its physical, natural, social, knowledge and human capital. Having skin in the game would promote confidence in private investors that the government would provide supportive policies.

With public debt in the UK, as in many countries, already around historic highs relative to GDP, there is understandable concern about the ability to pay for further, debt-financed, public investment. The government has an obligation to manage the public finances responsibly and capably, so as to minimise financial market vulnerability.

Unlocking investment requires assessing the full benefits, not just the costs, of investment. Fiscal arithmetic is distinct from fiscal and structural policy. It would be inefficient and unfair for net investment to be funded by current revenues, given that returns accrue in the future. This means borrowing to invest. To enable this, the UK fiscal rules need to be modified. In particular, the UK should move from being constrained by the inherited blunt and arbitrary debt rule, which lies at the very heart of the UK's investment and growth problem. **The UK can take the lead in using innovative debt sustainability rules based on net worth, which is what matters. Oversight from competent independent institutions like the Office for Budget Responsibility (OBR) would help ensure credibility and prevent politicians from abusing the system.**

Borrowing long-term at low cost for highly productive investment is fiscally responsible. This would be true for value for money assessments of individual public investment, but even more so with all the private sector multipliers associated with a scaled-up transition. Not making that investment is not only fiscally irresponsible but also fails to take growth opportunities and makes the climate and environment worse. It would commit the UK to the 'doom loop' of public austerity and low productivity growth associated with a continual squeeze on public investment to balance the books.

The government needs to run a current budget surplus, or close to it, to pay for day-to-day spending over the economic cycle. Together with structural policies like pension auto enrolment designed to boost domestic saving, this creates space for additional investment by boosting national saving. The alternative will be adding investment without limiting excess consumption which will mean upward pressure on interest rates and the need to borrow more from abroad to raise investment. This warrants the government to reconsider its commitment to not raise key taxes such as Income Tax, Value Added Tax (VAT), National Insurance and Corporation Tax, which account for 75% of revenues. The risk otherwise is that the burden of much needed tax revenues falls disproportionately on investment and saving. In the more medium term, AI and machine learning can help improve revenue collection and counter fraud, tax evasion and error and the efficiency of government while the reform of property and land taxation can provide a fair and efficient way to raise significant sums in revenue.

The government can promote confidence in private investors through a credible, consistent, and co-ordinated policy framework. This would be based on a national growth and innovation strategy and include an overhaul of the planning system and an integrated skills strategy, recognising that choices have to be made. It also requires a co-ordinated array of policies including standards and regulations, procurement and pricing. Perhaps counterintuitively, the most effective policies were found to have been those that supported the creation of new markets rather than those pricing polluting activities. A combination of policies to push supply and create demand for low carbon goods and services stands to provide investors and companies with the clarity and confidence necessary to steer private investment at little cost to the HM Treasury (HMT). Narratives matter and have real world consequences, because investment is driven by expectations.

This means laying out a compelling and attractive long-term vision for the future to which policymakers, the private sector, other key actors, and the public subscribe and support. It also means policies must be well designed to minimise rent-seeking, and focus on building long-term economic capabilities, thereby avoiding the replacement of market failure with policy failure. Attention must be paid to the impact of regulation and administrative burdens on innovation in high tech sectors.

Delivering resilient net zero investment has implications for taxes, public-sector spending and debt and cannot be treated as separate to how we approach other societal and economic challenges. Having created the macroeconomic space through sensible fiscal rules and a strategy to support public and private investment in clean infrastructure, skills and ideas, the government should consider early implementation of twelve supportive policies to induce innovation in key sectors.

Creating a strategic framework

1. **Publish a Strategic Green Growth Plan by early 2025 to embed credible policies for net zero** through complementary investments in social and physical infrastructure, focusing on education, training, healthcare, and connectivity. This would be most effective as a whole-of-government effort, co-ordinated by the Cabinet, HMT and the Department for Energy Security and Net Zero (DESNZ), that clarifies which areas should be prioritised as part of the government's portfolio approach, how contingent plans will be implemented and who will pay for the transition. The strategy must unlock the power and potential of regional devolution so that local government can raise revenue, invest and borrow through greater fiscal autonomy and drive local investment that is tailored to the community.

2. **Support the modification of UK fiscal rules to enable more effective investment in productive assets.** This could be enhanced by consolidating UK public investment banks (UK Infrastructure Bank, British Business Bank, UK Export Finance) into a single scaled-up policy bank, capable of issuing bonds independently under a government mandate and/or by removing public grants from the balance sheet of the Exchequer.

3. **Increase public investment in research and development (R&D) towards 1% with an aim to boost whole economy R&D to 3% of GDP by 2027,** with an emphasis on flexibility enhancing technologies for the electricity grid, innovative low-carbon farming practices, industrial heat, sustainable aviation and greenhouse gas removals. The government should extend R&D tax credits and introduce targeted incentives matching those in the US Inflation Reduction Act (IRA) in support of workers and skills.

4. **Strict restrictions and a default stance against granting new exploration licenses should be implemented for all fossil fuels,** unless new projects can demonstrate that UK production could result in lower global emissions. Existing production should use fiscal tools such as the Energy Profits Levy and the Investment Allowance to redirect investment towards low carbon energy, thus contributing to phasing down fossil fuel production. North Sea oil is relatively high marginal extraction cost. Broadly speaking, that means that if the oil price stays high or rises, the best policy would have been to shift faster to renewables, if the oil price falls, the assets will be stranded as it will be uneconomical to extract the costly oil.

Getting the economics right.

5. **Deploy a wider range of complementary approaches to quantitative modelling.** By 2026, update the Green Book appraisal guidance to include policy appraisal tools such as risk-opportunity and options theory analysis to better capture non-marginal, dynamic changes in the economy and policy.

6. **Policymakers should understand, anticipate and manage disruption and be aware of distributional issues.** If poorly managed, a backlash against climate policies can delay or even make them fail.

Getting the institutions right.

7. **Establish within HMT a Growth and Strategic Transition Team to lead on growth and productivity, with integrated strategies on net zero, digitalisation, and AI.** To guide this institutional capacity upgrade, consider organising workshops with leading academics on economic structural change, aiming for 500 policymakers to be trained within three years.

Putting in place the right regulatory signals.

8. **Restore the commitment to end the sale of new fossil fuel cars and vans by 2030, mandate landlords to upgrade the energy efficiency of rental properties to achieve an energy performance certificate (EPC) rating of C by 2028 and eliminate the 20% exemption for the phase-out of new boilers by 2035.**

9. As part of the National Planning Policy Framework review, **identify and remove planning barriers that particularly affect low carbon technologies.** Prioritise this reform for onshore wind farms by removing burdensome requirements for community support and site suitability which are hard to demonstrate, and for heat pumps by relaxing the requirement for a one metre distance from property boundaries.

Getting the policies right to induce private investment.

10. **Eliminate energy levies that distort the price of electricity and deliver on the long-awaited rebalancing of electricity and gas prices to incentivise and facilitate electrification for consumers and businesses.** Passing these levies through electricity bills previously helped fund low carbon deployment. These levies will now need to be funded in alternative ways. HMT could consider moving these costs onto general public spending, or shifting them to fossil fuels. Each option should be evaluated with careful consideration of economic and distributional impacts.

11. **Effectively implement Contract-for-Difference (CfD) auctions** to deliver the 50 GW of offshore wind by 2030. This is best done while also developing new policy mechanisms to support the deployment of a portfolio of flexibility options. This will require new business models to reflect demand flexibility, hydrogen, storage, interconnection capacity and gas carbon capture use and storage (CCUS).

12. **Continue supporting policies such as the Boiler Upgrade Scheme and the Social Housing Decarbonisation Fund,** setting grant levels in line with not only heat pump costs but also with energy efficiency measures that must be done prior to installation, to ensure there is a real incentive in adopting low-carbon heating. These schemes should be monitored and assessed against grant uptake and redesigned where necessary to ensure heat pump rollout aligns with UK climate commitments.

Success requires taking due account of HMT culture as much as it requires robust analysis. A weak mission from the Chancellor would result in stasis and missed opportunities. The ability to harness the HMT's analytical firepower to implement innovative ideas depends on the quality of its political leadership. Recognising the international context will mean building international trade, investment and security links, securing supply chains for the key raw materials necessary for the clean transition, and collaborating with EU partners on carbon and electricity markets.

01

Introduction
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The timing of this report reflects that fact that despite the clear ambition from the new government, the macroeconomic debate is stuck in a rut.

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01

Drawing on the latest evidence from a range of disciplines, this joint University of Cambridge and London School of Economics and Political Science (LSE) policy report aims to assist decision-makers in HM Treasury (HMT) and beyond by offering constructive suggestions on how to help steer the UK economy through this transition, on to a path that boosts productivity, incomes, and employment, while maintaining healthy public finances and sustainable public debt.

The report asks fundamental questions: is reaching net zero a growth and prosperity plan? If so, how much do we need to invest, can we afford it, and how do we pay for it? Are there less ambitious options which might be economically expeditious? To answer this, we need a conceptual understanding of the nature of the challenge and the drivers of innovation and structural change. This further calls for a broadening of the analytical toolkit with profound conclusions for policy recommendations.

Two dominant narratives

Climate risks have been known for some time, and the latest scientific assessments suggest climate risks have been understated in size, impact and urgency, with risks earlier assessed as outliers already being realised. The potential for catastrophic outcomes and the breaching of irreversible thresholds grows every year. A risk assessment points out that if the world continues its current emissions trajectory, there is a probability in the range of 5 to 20% of exceeding 4 degrees Celsius by 2100, a temperature considered catastrophic (King et al., 2015). Even at 2 degrees, which is almost certainly going to happen, models suggest a 2-20% chance of unmanaged risk (ibid.). This is an existential risk to take, and on the face of it, hard to explain, considering that we set regulations to reduce the likelihood of a building collapsing during an earthquake and a worker's death on the job to tolerable levels of 0.2% and 0.1%, respectively (Sharpe, 2023).

Moreover, we are starting to get used to breaking new climate records, including extreme temperatures and various devastating natural disasters, only to see them surpassed again the following year. For instance, in the 1980s, natural disasters averaged 292 per year, while in the 2010s, the number went up to 689 events yearly (HMT, 2021a).

Climate models struggle to simulate earth system complexity and things like extreme risk around feedback loops, aggregated and cascading impacts and tipping points. The climate model shows a flood in Vietnam, but it doesn't, for example, describe the impact on global supply chains or inflation; nor would it be able to demonstrate the potential impact of concurrent or multiple bad harvests; or the cumulative impact of soil degradation, flood, drought, air and water pollution, greater transfer of zoonotic disease, spread of anti-microbial resistance, and so on, which is what really matters politically economically, societally and environmentally.

Scientists warn that many tipping points could be activated at 1.5-2.5 degrees so, we could be sounding a much clearer and more imminent alarm about the lock-in that has already occurred. The lags imply that today's climate is a result of the emissions of 10-15 years ago and more significant changes can be expected in the 2 degrees plus scenario that is almost certain.

Furthermore, the economy relies on nature for ecosystem goods and services such as raw materials, surface and groundwater, climate regulation, pollination, and disease and erosion control (Ruta et al., 2021; UNEP-WCMC, 2024; WEF, 2020). Much renewable natural capital, like forests, fisheries, and biodiverse ecosystems can suffer irreversible decline once depleted below a certain threshold. Despite this, the economy's dependence on nature is often overlooked (Dasgupta, 2021; Zenghelis et al., 2020a).

A WEF report found that half of the world's gross domestic product (GDP) is moderately or highly directly dependent on nature, therefore, exposed to risks from nature losses (WEF, 2020). A report by UNEP-WCMC (2024) finds that 10% of UK banks and insurers' financial assets (£179 billion) are highly or very highly directly dependent on ecosystem services, while 42% (£751 billion) are moderately directly dependent on ecosystem services. This underscores the risk of disruption of supply chains, economic production and financial instability as nature loses its capacity to provide those ecosystem services.

The urgent case of reducing emissions has never been stronger. Yet, despite all the alarming evidence of the risks of climate change and the costs of inaction, action has been slow to reflect this urgency. Fossil fuels continue to be burned at scale, and energy-related carbon dioxide (CO2) emissions continue to rise, reaching a new all-time peak in 2023 with an increase of 1.1% relative to 2022 (Friedlingstein et al., 2023). A key narrative used to explain this lack of action is that the costs are difficult to bear. Much attention has focussed on the cost and burden of transforming the global economy away from carbon-intensive fossil fuels and other greenhouse gas-emitting activities.

However, a more positive narrative is increasingly brought to bear. The possibility of triggering immense and potentially irreversible climate risks is even more disconcerting when considering that early action can provide near-term opportunities and benefits, which are valuable irrespective of their impact on climate change. Thanks to the expansion of clean energy and far greater efficiency in new electric-based systems, the world is close to reaching a peak in the use of fossil fuels and is on course to see most of its electricity generated by renewables within the next few decades.

The increase in global temperatures is disrupting the delicate balance of our natural ecosystems, and there is a growing risk of reaching critical tipping points that could trigger cascading effects. Under the Paris Agreement, the world committed to limiting global warming to 2 degrees above pre-industrial levels, with efforts to keep it below 1.5 degrees by 2100.

Between 1990 and today, the UK has halved its greenhouse gas emissions while delivering growth in line with the G7 average (CCC, 2024). In 2019, the UK became the first major economy to pass a net zero emissions law, committing to bring all greenhouse gas emissions to net zero by 2050. However, progress has decelerated, necessitating bold action for the UK to reach its goal and regain its initial leadership.

A fundamental obstacle to action is the existence of two conflicting narratives. The commitment to rapid emissions reductions is often presented as an opportunity to boost investment, efficiency and competitiveness in new markets, and innovative and sustainable growth (Skidmore, 2023). This framing is usually presented in terms of opportunity and risk with limited quantification. On the other hand, a commitment to rapid emissions reductions is presented in terms of the costs of cutting emissions relative to a fossil fuel dominated system, which is assumed to be cheaper. Given the current financial constraints, it is often deemed too expensive. This narrative is often backed up with detailed financial accounting of the costs and benefits of action (Krishnan et al., 2022). It begs the question, if decarbonisation was so good for growth, why were businesses and governments not investing in it anyway?

This report is designed to address this question and consider whether seeking to attain net zero in the UK is an opportunity for innovation, efficiency, and prosperity, or if it is an expensive commitment at a time of stretched resources that can more urgently be devoted elsewhere. These narratives understandably confuse policymakers, and the truth is more finely balanced, involving trade-offs, risks and opportunities. They also confuse investors, thereby raising the risk premium associated with investing in decarbonisation. Finally, the presence of such a range of narratives provides an opportunity for ideology to step in with an unwarranted 'growth vs environment' debate. This relies on pre-existing beliefs and opinions, feeding 'culture war' narratives, rather than basing policy recommendations on evidence. This report seeks to work with HMT to present not only the negative case against inappropriate modelling tools (which is already highlighted in the government's own appraisal and assessment guidance, the Green Book), but answer the question if not this, then what?

The most dynamic energy transition the world has seen is set out in this report. It examines the process of innovation and the reinforcing feedbacks driving technology prices down through increasing returns to production and discovery. It investigates how best to approach the question of early versus late action in the context of positive and zero-sum games, where innovative companies, sectors and nations may benefit from early moving. It assesses the broad range of assets, physical, human, intangible and natural, in which the UK should invest to avail itself of new opportunities, and avoid being locked into outmoded infrastructure, jobs, and ideas. It then outlines the limitations of standard economic frameworks and models, recognising conventional approaches are ill-suited to the study of dynamic structural change and recommends a set of more diverse approaches.

The timing of this report reflects that fact that despite the clear ambition from the new government, the macroeconomic debate is stuck in a rut. Proponents of decarbonisation, who see the clean transition as an investment opportunity, are at seemingly irreconcilable odds with those who emphasise the additional expenditures, or 'cost'.

There can be a reconciliation. In a fully employed economy, any new real expenditure has a 'cost' as it displaces other expenditures, leading to permanent loss. However, if the expenditure is an investment, it expands capacity and future output, ultimately making the economy larger. Hence **the investment expenditure is not permanently lost to the economy. On the contrary: it makes the (future) economy larger than it would have been otherwise.**

Closely linked to this is a second debate: whether raising debt to augment or enhance, rather than simply maintain, core assets is fiscally irresponsible, or whether adding to public and broader national net worth bolsters financial sustainability and reduces vulnerability. **This report argues the latter and notes that there is no productive alternative to clean resilient and intelligent investment, given the direction the global economy is clearly headed.**

Structure of this report

The key aim of this project is to allow decision-makers, in the public and private sectors alike, to anticipate, manage, and shape the rapidly shifting landscape of risk and opportunity.

The project seeks to provide:

- a full and comprehensive understanding of the nature of the decarbonisation challenge; and
- a set of conceptual frameworks and fit-for-purpose analytical tools for assessing the problem and guiding policymakers.

Further, our report affirms the importance of the fact that structural change, and climate action in particular, is endogenous – that is to say, its future evolution depends on its own past history. Hence, it recognises the fundamental importance of policy to stimulate the market, and the role that supporting institutions will play in this transition.

After this introduction:

- **section 2** sets the scene, outlining the role of policymakers and presenting the emerging evidence on risks and opportunities.
- **section 3** looks at the process of innovation. Reinforcing feedbacks play a huge role in driving technology prices down and generating increasing returns and a positive sum game from which everyone potentially benefits. It also investigates how best to approach the question of early versus late action in the context of zero-sum games, where countries that move fast pay the early investment cost but can win and retain competitiveness in rapidly growing world markets.
- **section 4** looks at different types of transition risks and opportunities. It assesses the broad range of assets, physical, human, intangible and natural, in which the UK should invest in to avail itself of new opportunities, and avoid being locked into outmoded infrastructure, jobs, and ideas. Key to the assessment will be fiscal costs, macroeconomic implications, and geopolitical consequences.
- **section 5** looks at the limitations of standard economic frameworks and models. It reaffirms that static approaches, such as cost-benefit analysis (CBA), are not well suited to the contexts of dynamic structural change, increasing returns, and mounting uncertainty. A more diverse set of approaches broadly encompassed under risk-opportunity analysis (ROA) are proposed to assess the path to net zero.
- **section 6** presents specific policy recommendations for the UK.
- **section 7** concludes.

02 The UK's economic challenges

Those arguing that clean investment is growth-inhibiting need to clearly set out a counterfactual: a high-carbon investment strategy that would be more productive over the coming decades

The UK's economic challenges

02

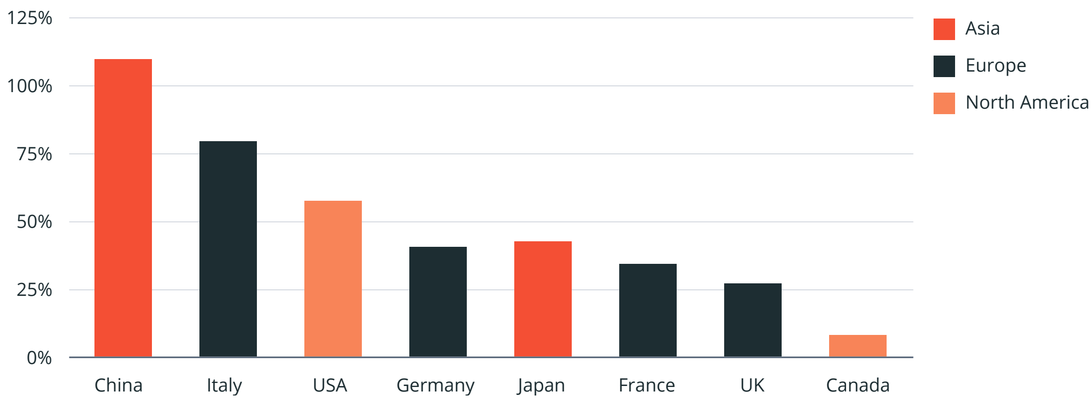
2.1 Policymaker objectives and challenges

The recently elected Labour government has made twin commitments to 'kickstart' growth and to 'make Britain a clean energy superpower'. Delivering on these commitments will require a departure from recent actions (such as continued fossil fuel extraction in the North Sea and delaying the phase-out of internal combustion engine vehicles). It will also require new (analytical) tools to incubate these two forms of growth. The Climate Change Committee (CCC) has made clear that it expects falling operating costs will offset the annual investment costs required to reach net zero before 2050 under their Balanced Pathway.

There is powerful evidence that policy risk, driven by mixed and muddled public policy signals, is holding back investment, stifling growth, delaying the transition and limiting opportunities. Change is politically challenging, and inertia is often hard to overcome (see section 3.2). This makes innovation path-dependent (Aghion et al., 2014a). Investment needs to be funded in part through lower consumption and higher domestic saving (see section 4.5). In general, the losers from any change know how much they stand to lose and can out-lobby the potential winners, which are diffuse sets of future consumers and households as well as sectors and industries which have yet to scale up and, therefore, with little (political) power in the present.

Despite policy commitments such as the Net Zero Strategy (DESNZ & BEIS, 2021) and falling prices for renewable technologies, the UK has fallen behind comparable countries' deployment of clean electricity (Figure 1). To remain competitive and deploy the requisite clean energy the UK will need to overcome a number of bottlenecks and barriers including grid connection queues, labour shortages, and increased costs and planning delays.

Figure 1: Growth in installed renewable energy capacity (2018-2023, G7 + China)



Source: International Renewable Energy Agency (IRENA) (2024).

2.2 The emerging evidence on costs and opportunities

The scale of the decarbonisation challenge is enormous, with a transformation over two or three decades on a scale comparable to an industrial revolution. Decarbonisation requires substantial capital investment that will, in many cases, replace a system reliant on large labour operating costs, for example relating to supplying transporting, refining, distributing and burning fossil fuels in the future. Wind and solar, by contrast, once installed operate at close to zero marginal cost. This distinction is key to understanding the evolution of costs and deployment of new clean technologies worldwide.

The CCC places the required annual investment in the transition between 0.5-0.6% of GDP over the next decade. This remains a significant investment (around £50 billion annually by 2030) but is a small proportion of the UK's (relatively low) annual investment. Some consider this to be an overestimate of the net investment cost, as it takes a false baseline which ignores the economic and human cost associated with continued fossil fuel use, much of which—like particulate pollution—is distinct from climate impacts (Black et al., 2023)[i]. Moreover, this investment produces other intangible benefits including reduced exposure to energy price volatility from geopolitical tensions. Finally, investment that drives technology progress could unlock growth opportunities in sectors that are currently under-explored or marginalised in current net zero planning such as aviation and cement.

In the short run, financing these investments will entail an economic cost between now and 2030, since the efficiency gains and growth potential accrue most significantly after the capital is rolled out. But most of this should be seen as an investment cost. In the meantime, redirecting investment towards reducing reliance on fossil fuels may crowd out other efforts at expanding production capacity and disrupt existing labour allocations. However, even the short run hit to productivity may be transient given potential cost savings from actions such as domestic retrofits, which can be scaled up quickly, alongside other immediate benefits, such as those from reduced particulate pollution and the rapid growth in new markers.

The US currently benefits from very cheap shale gas, keeping energy prices well below those in Europe. But renewables, and not shale, offer the greatest prospect for falling energy costs in Europe. In the short run, however, costs of investment in new energy will need to be distributed to households either through taxes or higher utility bills (or both).

There are a range of opportunities and benefits that accompany a clean transition that are not fully accounted for within conventional policy analysis[ii]. This report sets out the main contours of what these risks and opportunities look like for a transition to a net zero economy, along with a framework that would allow for the full spectrum of considerations to be taken into account, supporting more informed policymaking.

2.3 The macroeconomics of investment

Much attention has focussed on the cost and burden of transitioning the UK economy away from carbon intensive fossil fuels and other greenhouse gas emitting activities. The Institute for Fiscal Studies (IFS) (2024a), citing the Office for Budget Responsibility (OBR), recently wrote:

> "We should be careful not to equate investment with 'growth-enhancing' spending: not all investment is productive and not all investment will enhance the supply side of the economy. In particular, much 'green' investment can be thought of as allowing us to produce the same amount of GDP in a less environmentally damaging way, rather than allowing us to produce more GDP. That doesn't mean that we shouldn't do it, but it does mean that we should be sceptical about claims that it will pay for itself by providing a major boost to growth." **(OBR, 2024a).**

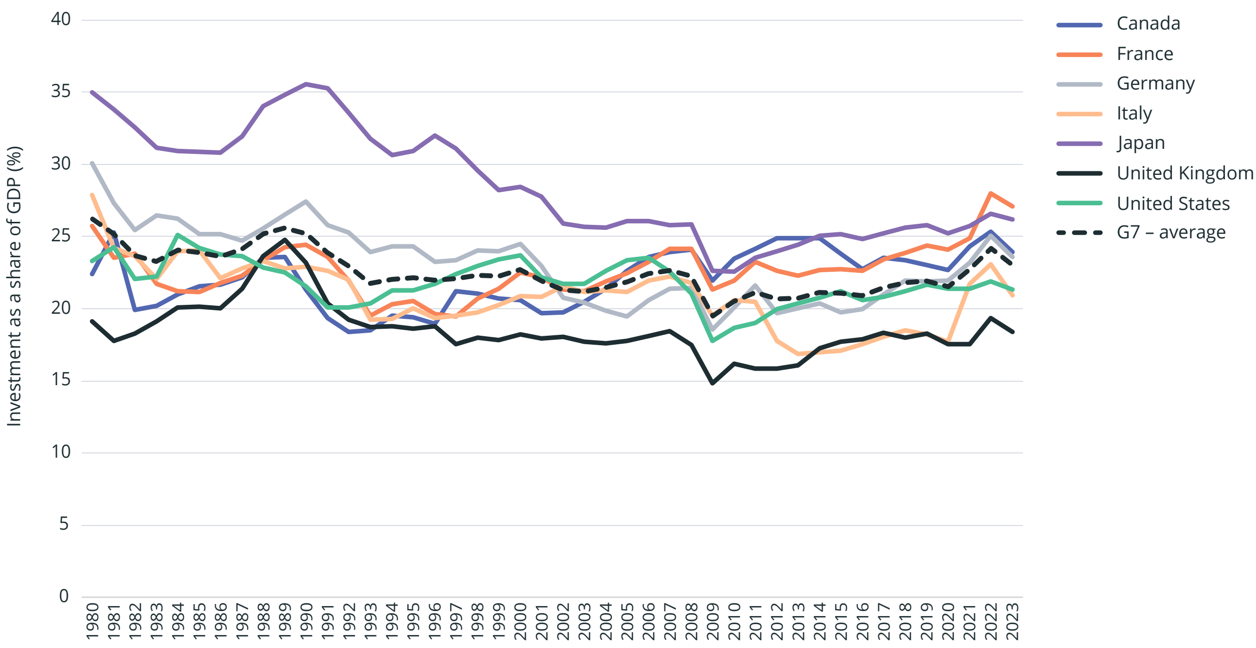
Despite the clean technology revolution which is changing the way we generate energy, travel and heat and cool our homes; much of the discussion about a clean transition is still framed in terms of trading off growth for environmental benefits. This seems to contradict the Labour talk of a green prosperity plan. It is also at odds with the growing body of evidence.

Those arguing that clean investment is growth-inhibiting need to clearly set out a counterfactual: a high-carbon investment strategy that would be more productive over the coming decades. High carbon and fossil fuel intensive investments were productive in the past, but it is far less clear that they offer better growth prospects for an economy like the UK than the alternatives for the decades to come. There also needs to be investment in demand-side incentives which support the creation of markets rather than an over-reliance on supply-side investment.

Essential clean investment is indeed 'growth-enhancing' and productive. Net zero comprises one part of a new growth and productivity strategy. Yet there is no rivalry for fiscal resources and ministers' attention. It is increasingly recognised that this is not a case of either investing in housing, schools, hospitals and skills or investing in 'clean', as the two are complementary – all infrastructure should be efficient and resilient. In this report, we assess the genesis of this analytical confusion and show that it not only delays action, it also has the potential to raise costs and slow growth.

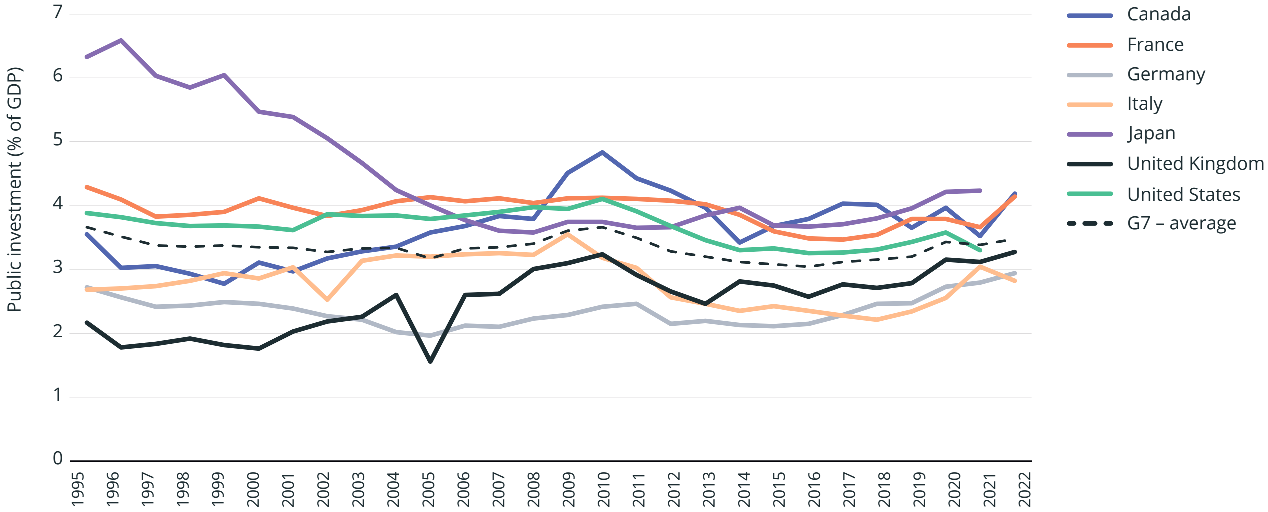
However, a broader framing is required. The UK has already lost out through lack of investment and lack of innovation. Since 1995, UK investment has been 17% of GDP on average, the lowest of the G7 economies. Over the last 20 years, the UK invested 4.7 percentage points less in total than the G7 average of GDP and the UK's gross fixed capital formation has been below that of the US, France and Germany (see Figure 2). The UK's investment rate has taken a particular hit following the global financial crisis, remaining 0.7 percentage points lower on average in the years since the crisis compared with the 14 years before it (Zenghelis et al., 2024). This underinvestment has resulted in a fall in the rate of growth of capital per person and per employee, with a consequent and measurable impact on productivity and growth (ibid.; Brandily et al., 2023).

Figure 2. Investment rates for G7 countries, 1980–2023



Note: 2023 values are estimates. Investment is defined as gross fixed capital formation.
Source: Authors' analysis based on investment data from International Monetary Fund (IMF) (2024).

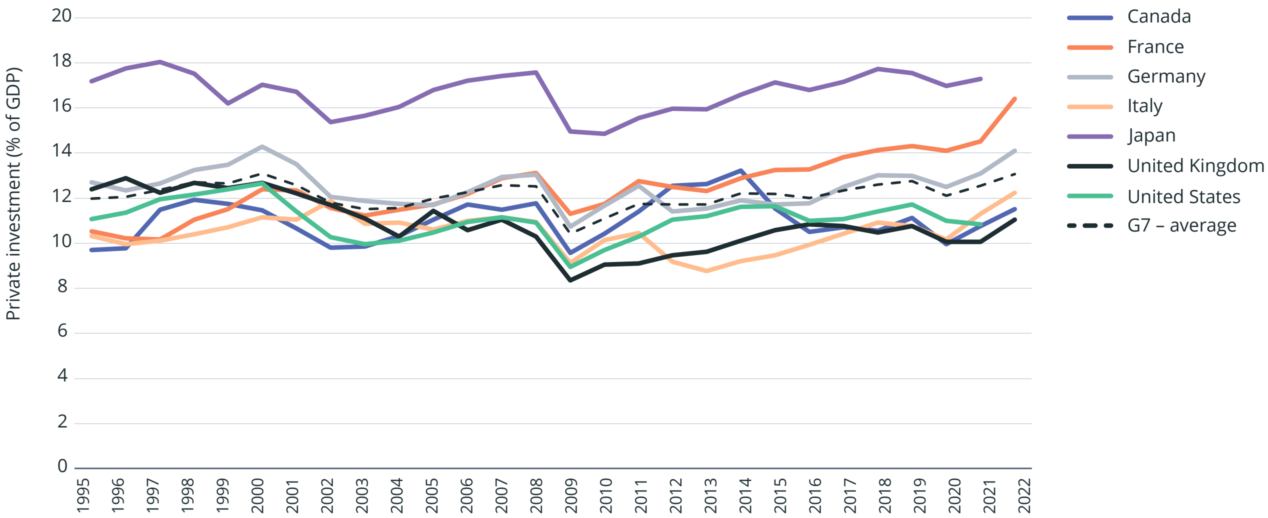
Figure 3. Public investment rates for G7 countries, 1995–2022



Note: Public investment rate is defined as the portion of gross fixed capital formation that falls on government (as opposed to corporations or households) as a share of GDP.

Source: Authors' analysis based on investment data from IMF (2024) and investment by sector from Organisation for Economic Co-operation and Development (OECD) (2023).

Figure 4. Private investment rates for G7 countries, 1995–2022



Note: Private investment rate is defined as the portion of gross fixed capital formation that falls on corporations (as opposed to government or households) as a share of GDP.

Source: Authors' analysis based on investment data from IMF (2024) and investment by sector from OECD (2023).

Low levels of investment mean low potential GDP growth as it results in low growth of the stock of productive capital. Lower growth in the stock of capital reduces short run productivity growth per person and also total factor productivity growth through slower increases in knowledge and knowhow (Romer, 1990). This is a primary driver of low productivity growth seen in the UK (HMT, 2021a). The UK's weak productivity growth has directly translated into lost growth in wages and income: real wages grew on average by 33% per decade from 1970 to 2007, but have flatlined since the global financial crisis (Curran et al., 2022). Fifteen years of lost wage growth has cost the average worker £10,700 a year (ibid.). Over the last two decades, UK public and private investment has lagged that of the EU, which in turn has lagged that of the US. UK productivity growth has mirrored this. Of course, other factors are at play. Exposure to the 2008 Financial Crash, Brexit and restrictive planning will all have impacted investment and productivity. But given the centrality of investment in driving growth in both economic theory and evidence, the UK's inability to raise earnings and living standards is less of a mystery.

As the UK's productivity growth and investment levels have stagnated, inequality between both households and regions has remained stubbornly high compared with other European countries (Curran et al., 2022). More worrying, from the point of view of economic opportunity, has been the widening inequality in access to core assets such as connectivity, transport, housing, medical facilities, education and childcare (ibid.). It is these assets that determine an individual's ability to improve their circumstances and avail themselves of the opportunities from innovation in technologies and markets.

Investment in R&D is also required to drive the technologies, processes and institutions necessary to support the clean economy and grow intangible capital (Zenghelis et al., 2024). Sustainable, inclusive and resilient innovation is critical in generating absolute returns for the economy (Geels et al., 2021). The UK can build on its strong academic, science and research base and innovative strengths in sustainable technologies. The UK has only 1% of the world's population and around 3% of GDP, but its science sector is, according to one study, responsible for 16% of the most highly cited articles globally (Elsevier, 2013). The country ranks fourth overall in the Global Innovation Index, largely due to the strengths of its university research and innovation system.

The underlying question is who pays for the investment? Most will come from private investors seeking returns, but because much of the investment is in networks and ideas with public returns that are hard to monetise privately, some must come from the state. This raises questions of finance and how to manage public sector debt and debt sustainability. This critical issue is discussed in section 4.5.

03

Growth and prosperity through a clean transition

The world is in the midst of a renewable energy revolution, led by wind and solar energy utilising battery storage and far more efficient electricity networks.

Growth and prosperity through a clean transition

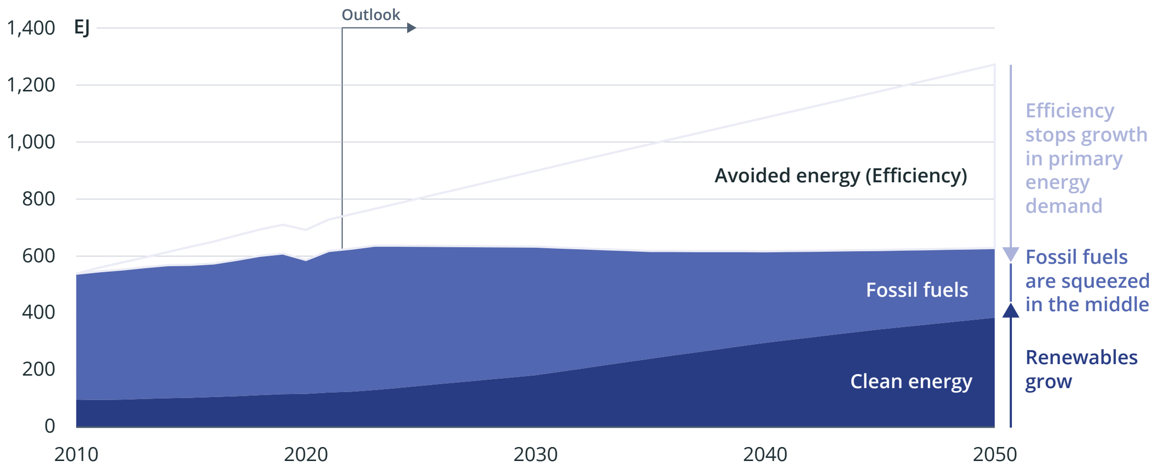
03

3.1 End of the fossil fuel age

Like the Stone Age, the Iron Age and the Bronze Age before it, the fossil fuel age was a leap forward in human development. And like the previous eras, it too has had its day. Thanks to the expansion of global clean energy, fossil fuel emissions grew at a much lower rate in the last decade (IEA, 2024a) and are likely to peak in the next few years (Bond et al., 2024). For instance, fossil fuel electricity generation went from an annual average growth rate of 3.5% between 2004 and 2013 to 1.3% per year from 2014 to 2023 (Ember, 2024). Electricity demand continued to rise as the world electrified and emerging economies experienced economic growth, explaining the increase in energy-related emissions. Yet, the rise in solar and wind generation meant that the share of electricity generation from fossil fuels was 22% lower in 2023 than in a scenario without these energy sources (ibid.).

Furthermore, the shift to renewables has a powerful reinforcing impact on reducing demand for primary fossil fuels. Because energy from electricity is so much more efficient than alternatives, the gap between primary energy input and useful energy output (the stuff that keeps lights on, houses warm and cars moving) continues to shrink (Bond et al., 2024). In other words, less primary energy is needed to achieve the same level of final energy when using electricity and corresponding components (such as Light-Emitting Diode (LED) lights and battery electric vehicles (BEVs)). We get more energy because we lose less. Figure 5 highlights the growth in final energy demand since 2000. More of this demand is met by renewables and efficiency gains, squeezing out the role of fossil fuels in final demand.

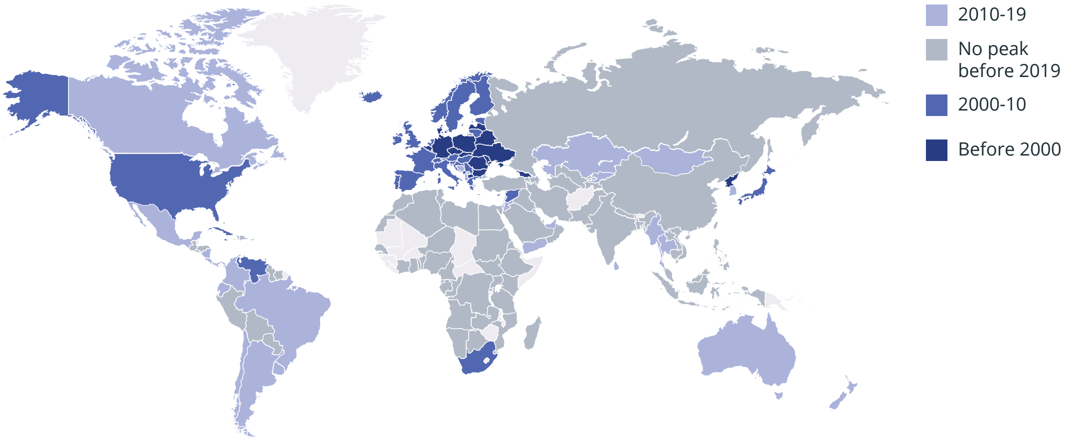
Figure 5. Global primary energy demand (EJ)



Source: Bond et al., (2024).

The world is in the midst of a renewable energy revolution, led by wind and solar energy utilising battery storage and far more efficient electricity networks. For over a decade, investment in renewable electricity generation has outpaced investment in coal, gas and oil generation combined (IEA, 2024b). New clean technologies are rapidly being developed in other sectors, with technological tipping points and breakthroughs continually being reached. As the stock of existing fossil-based power plants is retired, the International Energy Agency (IEA) expects renewables to replace coal as the largest source of electricity generation worldwide by 2025 (ibid.). In 2023, solar and wind reached a milestone and provided 30% of total global electricity generation. When combined with nuclear clean energy, they were responsible for 40% of electricity. More than half of the world's economies are already at least five years past a peak in electricity generation from fossil fuels (Ember, 2024). Moreover, as shown in Figure 6, 60% of the world has passed its peak of fossil fuel energy demand. These changes are already disrupting markets, and disruption raises distributional issues, especially for workers and producers in incumbent sectors.

Figure 6. Peak fossil fuels
Countries already past peak and decline in fossil fuel energy demand



Source: Via Rocky Mountain Institute (RMI) based on IEA data.

3.2 Understanding the process of knowledge formation and innovation

New low carbon technologies have experienced spectacular price reductions, which can be explained by rapid deployment and reinforcing feedbacks, which conventional analytical approaches have failed to capture. There is mounting evidence of a positive sum game where everyone potentially benefits from price reductions. The path-dependence of innovation makes the case for government policies that have a crowding-in effect on private investment.

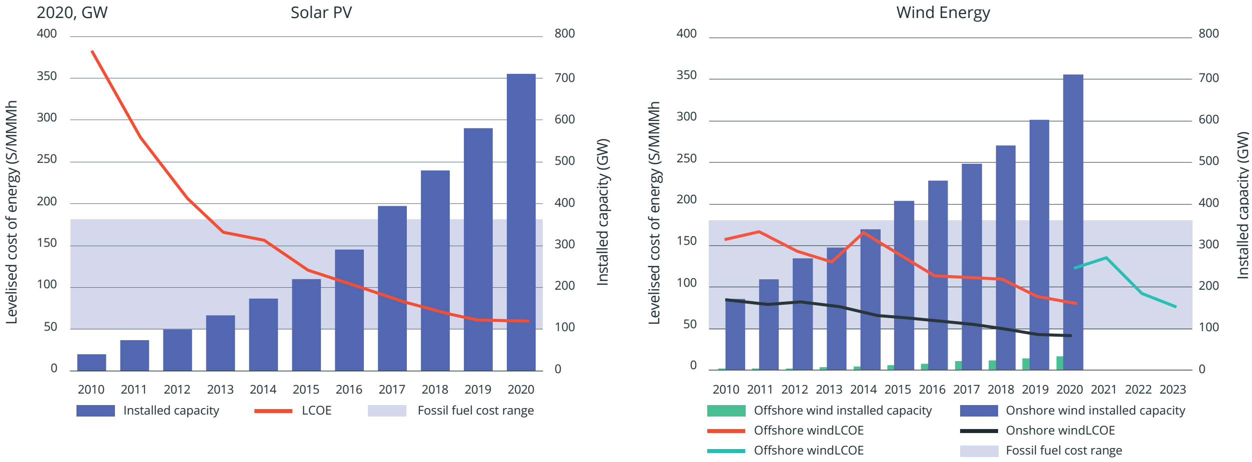
Price decline and deployment of clean technologies

Historically, economic assessments of the cost and rate of deployment of decarbonisation technologies have been pessimistic relative to experience in key sectors such as renewables, electric vehicles and battery storage (Grubb et al., 2021). A large gap has emerged between projected and realised costs, suggesting that the models being used are inadequate, at least from the perspective of prediction.

The cost of key technologies, such as solar photovoltaic (PV) electricity generation, has fallen by over 80% over the last decade. More mature and capital-intensive technologies, such as wind, have seen reductions of around 50% over the same period (IRENA, 2017). The sun doesn't always shine, and the wind doesn't always blow, but critical sources of electricity storage are also seeing cost reductions of similar magnitudes. Lithium-ion battery prices have fallen 90% in real terms between 2010 and 2020 (HMT, 2021a). Due to self-reinforcing effects, these industries and technologies are experiencing spectacular and innately unpredictable (see section 5.2) cost reductions and rapid deployment.

Reinforcing feedbacks in the relationship between the deployment of new technologies and their price are often missed. While it is true that, as technologies become cheaper, the incentive to deploy them increases, the more pertinent relationship goes the other way. It is deployment that, in many cases, is the critical driver of cost reductions. Many technologies are subject to increasing returns to investment and a version of Wright's law; for example, every doubling in the deployment of solar PVs, windmills, or batteries results in a roughly 20-40% reduction in cost per unit (Louwen et al., 2016; van der Ploeg & Venables, forthcoming). Deployment over recent years has been rising at nearly 20% to 30% a year, resulting in costs falling by around 10% yearly (Farmer & Lafond, 2016; Way et al., 2022). Figure 7 shows the strong inverse relationship between deployment and clean technology costs.

Figure 7. The deployment and cost of renewables



Note: Fossil fuel levelised cost of electricity (LCOE) indicated as shaded blue range at $50–177/MWh.
Source: Grubb et al. (2021).

Box 1. Economic theory of transitions

The economy is ever evolving.

Theories of economic change and endogenous growth are neither new nor unconventional. They find strong roots in the history of economic thinking. Put together, the contributions of Adam Smith, Joseph Schumpeter, John Maynard Keynes, Friedrich Hayek, and Paul Romer provide us with an all-rounded understanding of economic transitions.

Adam Smith's insight into specialisation and market efficiency lays the ground for the understanding of economic evolution, with an "invisible hand" that shifts declining sectors to more efficient uses of labour and capital (Smith, 1776). The theory of creative destruction by Schumpeter supplements this view, by providing a dynamic account of the development of technologies, markets and comparative advantages, through the determination of innovation and entrepreneurship as disruptive yet progressive drivers of transitions (Schumpeter, 1942). 'Creative destruction' introduces an intrinsically evolutionary process whereby it is necessary for capitalism to comprise the continuous process of replacement of old industries by new innovations (Schumpeter, 1942). Being dynamic in nature, it brings forth not only new products and markets but also increases efficiency and raises standards of living.

Keynes adds to this account by emphasising that there is indeed a role for government to intervene in periods of suppressed demand, such that supply can be created by demand —a role to make the transition smoother, come the crisis (Keynes, 1936). Though he recognised the inevitability of economic transitions, Hayek emphasised the role of price changes in informing consumers of changing market conditions, believing in a decentralised form of decision-making which contrasts with Keyne's view of government intervention (Hayek, 1945).

Lastly, through his emphasis on knowledge as an internal driver of growth, Romer underlines the necessity to invest in human capital and innovate to make transitions possible in general and, in particular, to advance the economy beyond its current stage of development (Romer, 1990).

Each of these theories captures another dimension of economic transformations, whether it is the market forces underpinning change, innovation being disruptive, managing instability, the importance of institutional frameworks, or knowledge and human capital at the centre.

In the case of the UK, it is quite telling that a decade ago, offshore wind electricity generation was considered an inefficient and expensive way to reduce emissions (Helm, 2015). Burning biomass was a cheaper alternative. The government defied the dominant approach of choosing the least cost technology and developed an offshore wind industry. The UK developed the Contracts for Difference (CfD) scheme, which guarantees a price for the electricity that companies generate. It pioneered this regulatory innovation that provides price stability and enables clean energy to emerge and thrive. The scheme is being adopted across the globe. Deployment of offshore wind through the implementation of CfD drove costs down from £120 per mega watt hour (/MWh) in 2015 to £40/MWh in 2019, a fall of 70% (Curran et al., 2022). The 2024 CfD strike price of £50.9/MWh (all expressed in 2012 prices) reflected rising interest rates, higher raw material prices costs, and rising project costs[iii]. The industry supported 31,082 jobs in 2021 in the UK (Offshore Wind Industry Council, 2022)[iv].

It is evident now that taking the alternative option of biomass supported by natural gas, instead of wind, would have been unwise, as offshore wind is a more reliable and cost-efficient source of energy for the UK (NRDC, 2018). Moreover, it is a cleaner source of electricity as biomass generation involves importing wood pellets from North America with transport emissions, potential land-use environmental impacts in those countries, and air pollution concerns (Brack, 2017).

Economists previously devoted much time casting renewables as costly for taxpayers and questioning their effectiveness in solving climate risks due to their limited scale. Some proposed the elimination of the CfD and their replacement with technology-neutral energy auctions (Helm, 2015). By the same token they advocated for gas as a cheaper alternative with a seemingly higher potential for reducing emissions. Critically, this view overlooked the reinforcing dynamics that led to price reductions.

Studies of past technology transitions have discovered patterns in their progress (Geels and Schot, 2007).

- **In the 'emergence' stage,** uncertainty is high and there are numerous potential new technologies vying for dominance. Governments can accelerate this stage by supporting R&D and demonstration projects, and through public procurement to develop niche markets.

- **In the 'diffusion' stage,** the new technology spreads through markets and society, competing with the incumbent technology. Governments can accelerate the diffusion rate through regulations, subsidies, taxes and investments in infrastructure.
- **In the 'reconfiguration' stage,** the new technology becomes dominant and social and economic systems and structures are reorganised around it. Governments can then regulate markets and encourage retraining and infrastructure to support the development of complementary technologies that make the core technology even more useful.

Rapid transitions and reinforcing feedbacks

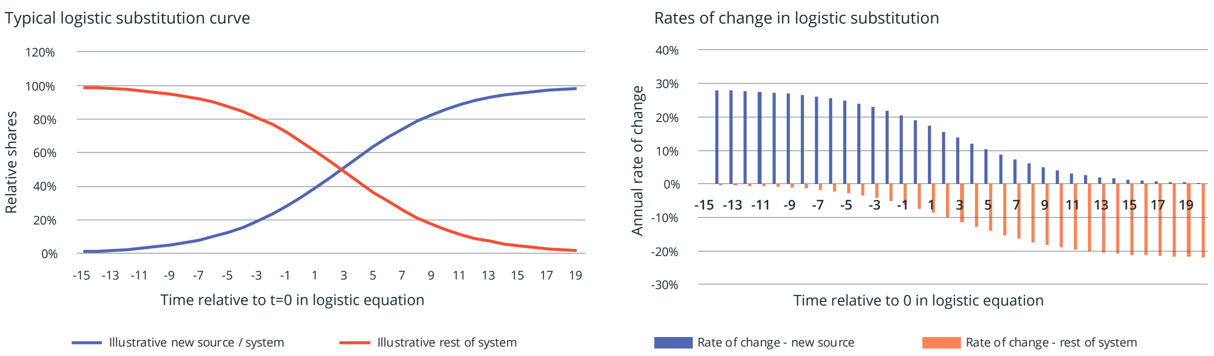
Central to assessing the risks and opportunities of a clean transition is understanding the process of innovation and how this plays out when labour and resource-intensive processes are replaced with capital and knowledge-intensive technologies like renewable energies, electric vehicles (EV) or batteries. Commodity-based systems, such as fossil fuels, are subject to diminishing returns to scale and, hence, have limited scope for operational costs to fall as demand rises. The cheapest resources to extract and transport are harvested first. To burn more fossil fuels requires tapping ever more remote sources and deploying ever more complex extraction processes.

By contrast, new technologies are characterised by powerful economies of scale in discovery and production costs (F. W. Geels et al., 2021). Indeed, the potential for cost reductions from innovation and technological learning is higher for clean technologies than for fossil fuels: the costs of certain clean technologies have dropped almost exponentially in recent decades, while the price of fossil fuels (per joule of energy generated) has remained roughly constant for more than a century (Way et al., 2022). The reason for this is that the latter operating expenses (OPEX) based system is highly reliant on increasingly expensive labour to dig, transport, refine and burn fuels.

These economies of scale in new technologies can make change much faster than expected and pose a challenge to empirical analysis based on backwards-looking data, which tends to overstate the costs of change and understate the benefits. This static view overlooks the nature of innovation, and the reinforcing feedbacks experienced by these new technologies. Therefore, the analysis of clean technologies needs a framework compatible with systemic change, non-marginal[v] transitions, technological discontinuities, and uncertainty (F. W. Geels et al., 2021).

This is a key aspect of market creation and the early exploitation of S-shaped deployment curves. Looking backward at deployment and price trends for such systemic network technologies, in the early period running up to the inflection point, affords a poor guide to future developments (Figure 8).

Figure 8. S-shaped deployment of network technology

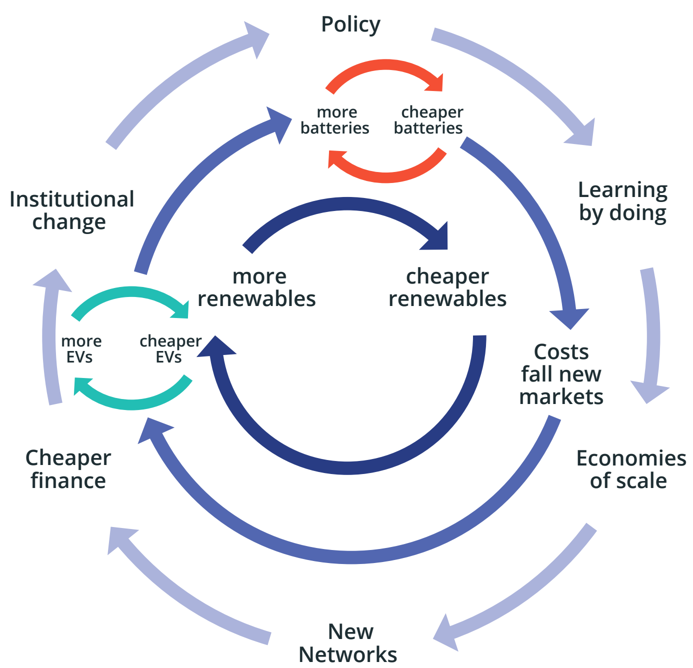


Source: Grubb (2018).

Several factors drive feedback effects. Commonly cited is learning by doing and experience curves in production, distribution and maintenance. Additionally, clean technologies benefit from economies of scale in production, fabrication, and distribution. Gigafactories for batteries and massive plants for solar PVs, as well as global distribution networks initially require high fixed costs. However, once these initial fixed costs are covered, the cost per unit item decreases rapidly. Consequently, the lower unit costs encourage further increases in output (Acemoglu et al., 2012).

However, reinforcing feedbacks do not end there (see Figure 9 and Box 2). A host of other systemic reinforcing feedbacks also drive price dynamics. Network effects, co-ordination effects, and complementary technologies are generated to feed into new technological systems; the more the new technology is used, the more other technologies emerge that make it more useful. For instance, when new hardware is invented, developers typically create software to optimise its functionality. As the software improves, there is an increased incentive for widespread adoption of the new hardware. Evidence from patent citation data suggests that knowledge spillovers from clean technologies are 40% higher than from dirty technologies and are similar in size to those originating in the IT sector (Dechezleprêtre et al., 2017). Another study found that in the case of solar PVs technology spillovers to other sectors played a crucial role in enabling innovations and advancing them towards the market (Kolesnikov et al., 2024).

Figure 9. Reinforcing dynamics



Source: Author’s analysis.

Box 2. Interrelated reinforcing feedbacks which drive structural transitions

- **Learning effects:** Learning-by-doing and experience curves resulting from expanding deployment have been key factors in the sharp reduction in cost for solar PV, wind power and batteries.
- **Economies of scale in production and distribution:** Costs also come down because of the unit-cost benefits accrued from larger production and distribution networks. This reflects large, fixed costs where, once the initial fixed costs have been incurred, low unit costs encourage increased output.
- **Combinatorial technologies and network and co-ordination effects.** This is closely related to economies of scale but reflects the greater advantages of moving in tandem with others, such that the gains are higher the more economic agents are taking similar action. Sometimes the networks involve spillovers across sectors. iPhone component technologies, for example, were comparatively well known before the smartphone went on the market but were combined by Apple in such a way that the resulting new product swept the world. Apple began a bandwagon effect that revolutionised mobile communications. The more people with smartphones, the more developers created clever apps to work with them, the more people wanted to own a smartphone and so on.
- **Sector spillovers:** Not only have sustainable technologies been shown to have predictably higher cost-reducing learning rates but they have also been shown to have positive productivity spillovers into other sectors of the economy. Using data on 1 million patents and 3 million citations, Dechezleprêtre et al. (2017) suggest that productivity-enhancing spillovers from low-carbon innovation are over 40% greater than from conventional technologies (in the energy production and transportation sectors).
- **Social and institutional feedback:** Law is based on social norms, the predominant behaviour within a society, and these norms are the ultimate drivers of legislative change (Posner, 1997). Business and trade union lobbies from expanding new industries can play a role in strengthening policy support for emerging technologies (Meckling et al., 2015).
- **Finance.** As new technologies and sectors mature, the risk premium associated with investing in supporting assets falls. By contrast, the risk of stranding and redundancy in incumbent assets raises the risk premium to investors, increasing the cost of capital for fossil fuel investment and supporting the transition. A recent European Central Bank (ECB) study found that Eurozone banks are charging higher interest rates to high-emitting companies compared to companies with lower emissions or with a plan to cut emissions. Moreover, while tight monetary policy increases the cost of credit and lending to all firms, greener companies suffer lower increases in their cost of debt as banks price in climate related risk (Altavilla et al., 2024).
- **Consumer tastes and behaviour:** Consumer tastes are an important factor in the attribution of future value to goods and services and can change rapidly. Consumers routinely influence one another, leading to positive feedback, crowd effects and changing consumption patterns.

A technology breakthrough that reduces energy costs will likely generate a more favourable political environment to support the technology and limit the alternatives. It is also likely to generate stronger consumer tastes favouring the new technology. For example, if your neighbour has a solar PV on their roof that cuts their bills, you are more likely to purchase such a unit and vote for a party that subsidises its adoption. Social norms, politics and institutions tend to move in lockstep. New lobby groups will emerge, disrupting the incumbents. Consumer tastes and preferences will also change in lockstep. The clean transition comes with innovation in ideas, technologies, business models and changes in preferences that reinforce one another and trigger a virtuous circle with sustainable reinforcing dynamics. Feedback loops in social norms, institutions and behaviour become important drivers of the transition (see Box 2) and drive expectations of its scale.

The result is that the transition, once underway, is both faster than expected and unstoppable, catching many by surprise, rendering cost estimates for mitigation grossly overstated and delivering cheaper and more efficient energy. The key driving force behind this transition, which has helped get over the inertia in the system, has been the desire to achieve systemic change aimed at decarbonising the economy to limit global warming, detoxifying the environment by reducing emissions and impacts of other pollutants, and dematerialising economic growth by decoupling it from resource use and minimising adverse impacts from resource extraction (Dasgupta, 2021; Ekins & Zenghelis, 2021).

Box 3. Norms, institutions and behavioural feedbacks

Systemic change goes beyond technological innovation. An excellent example is the transport sector, the UK's highest emitting sector, representing 28% of greenhouse gas emissions (DESNZ, 2024b). The integration of a broad range of policies is required. As passenger cars represent 60% of the sector's emissions (Department for Transport, 2023), EVs will play a vital role, and the reduction of prices that the sector has experienced is promising (Systemiq, 2021). Policies should be implemented to promote deployment, establish the required charging infrastructure and rapidly replace the fleet.

However, additional policies are needed for a sustainable and equitable mobility transition. Public transport is an efficient substitute for personal cars and should be promoted as an attractive alternative. More trains, light-rail, underground and buses, which can also be electric, are required. Public transport can be complemented by active mobility, such as walking, cycling, and other modes for people with mobility impairments. Reinforcing feedbacks are also at play here, as network effects, system complementarities, and spillovers exist. For instance, building cycle lanes will encourage more people to cycle, and people will also then demand more infrastructure. Cyclists will influence their relatives and friends into similar behaviours, hardwiring it in the common mentality. Politicians are then held accountable for providing this infrastructure as the preferences of new constituencies shift in favour of these policies.

This virtuous circle shifts systems and generates a new lock-in with a more sustainable form. For instance, the London congestion charge was quite controversial when it was implemented in 2003. The city has experienced the benefits of reduced congestion and air pollution, and increased revenues channelled to the public transport system, and there is no plan to dismantle the system.

The economic rationale behind cities is to be resource-efficient, bring people, resources and ideas together, and increase productivity due to agglomeration economies. Congested, polluted, and noisy cities are rarely attractive places for people. Liveable cities with public transport and active mobility infrastructure could help limit urban sprawl and generate multiple co-benefits in health, pollution, and general well-being. New technologies and business models, such as shared services, transport on demand, mobility as a service, telework, and e-commerce can be complementary and promote urban development that is less resource and carbon-intensive and more equitable.

Creating virtuous reinforcing feedbacks by steering expectations also involves understanding real world social and psychological phenomena (Tanase, 2024, see Annex 2). The evidence suggests that individuals tend to significantly underestimate how much others worry about climate change, and the level of support for climate policies. This pluralistic ignorance is combined with a lack of collective efficacy, with people lacking a belief that the group to which they belong can deal with the challenges climate change presents, which poses obstacles to the advancement of net zero policy and acts as a key barrier to public engagement with climate change. People are willing to act on climate change but want assurances from other actors, including business and government, that they will do the same (Demski, 2021). As the Skidmore Review recommends, transparency and clear government public engagement may enhance collective efficacy, with multiple actors in society working together to assure people their actions are not isolated (Demski et al., 2019).

Understanding and engaging with the role of perceived policy fairness and psychological distance is also critical. A perceived unequal burden of certain policies, including for instance wind farms, on a group of people while elites are seen to benefit (Ejelöv & Nilsson, 2020) also poses a significant barrier to public support for net zero policies. Negative views of policy are also further compounded by psychological distance, where benefits of a policy decisions being further into the future decreases policy support, regardless of how great the future benefit would be (Sparkman et al., 2021). A focus in publicly orientated messaging about short term and local co-benefits of policies, for instance job creation or air quality improvements, along with transparency about long term aims, which creates a positive vision for transformative change, serves to tackle psychological distance and make groups feel engaged with and supported by policy around the transition.

Emphasising how investing in net zero serves other aims, which may more closely align with citizens' immediate concerns, is therefore useful for creating space for policy and also making a cost-effective transition a self-fulfilling prophesy. Highlighting risks, as well as opportunities, can also be motivating. Russia's invasion of Ukraine has raised significant concerns about the UK's energy security and independence (FCDO, 2023), and direct impacts have been felt with significantly higher energy bills for most UK households (Lawson, 2023). Framing the transition to net zero as one of energy security can further build a support coalition for policies while demonstrating the transition to be an opportunity to reduce energy bills stands to appeal to a wide section of society who might not otherwise be supportive of spending decisions that advance net zero (Climate Outreach, 2024). Emphasising such direct and short-term benefits can also be used to tackle populist climate scepticism and break down partisan divides. Policies can be framed as speaking to concerns including local air quality, nature protection, and national sovereignty, can appeal to broad sections of society including elements of the populist right (Schaller & Carius, 2019).

These processes generate a positive sum game in which everyone potentially benefits from the cost reduction of low carbon technologies. Conventional analyses that ignore these effects, or treat them as exogenous to the model, generally overstate the cost of climate action, leading to costly policy delays (Grubb et al., 2021; Peñasco et al., 2021a). Delay itself increases overall decarbonisation costs, by postponing the reinforcing feedback between deployment and cost reductions, making high-cost estimates potentially self-fulfilling (van der Meijden & Smulders, 2017).

Innovation is 'path-dependent'

These reinforcing feedbacks are not experienced to the same extent in conventional technologies because operating costs rely on the repeated use of finite resources and increasingly expensive use of manual labour. Still, despite all the reinforcing feedback and price reductions that clean technologies have experienced, the path-dependent nature of innovation impedes the rapid shift from dirty to clean technologies.

Understanding the nature of innovation is key to grasping the challenges of a rapid transition. Innovation is path-dependent due to high network effects and switching costs embedded in physical infrastructure and technologies. Firms tend to direct innovation toward what they are already good at, while scientists work in sectors and regions where similar research is undertaken using similar production capabilities (Aghion et al., 2014b, 2016; Hidalgo et al., 2007). Furthermore, institutions, culture, and political systems are also path-dependent, and inertia is relevant, affecting the nature of innovation. Examples abound, including the QWERTY keyboard, Roman roads in the UK, the persistence of colonial institutions long after independence and social media platforms (Aghion et al., 2016).

Rather than suggesting that staying on the same course is inevitable, these processes suggest that taking early action can steer the economy onto a new course. The incumbent system has an innate advantage with incumbent firms possessing large supply networks, deep pockets and hefty lobbying power. Consequently, governments have a role to play in levelling the playing field for new entrants with potentially superior technologies, processes and products.

By investing and regulating to reduce the costs of new clean technologies, they can manage risk and crowd-in private investment (Grubb et al., 2023). There is evidence that shows that clean transitions are highly path-dependent: countries that successfully invest early, corner future green product markets. Moreover, a firm's choice over whether to innovate 'clean' or 'dirty' products is influenced by the practice of the countries where its researchers or inventors are located and the technology and supply adjacencies of existing sectors (Aghion et al., 2016; Hidalgo et al., 2007). Therefore, investing early in these sectors will determine medium and long-term outcomes.

The powerful role of expectations and narratives

Investment is critical to the generation and deployment of new technologies, and investment is driven by expectations. An economic system based on dirty technologies can be stuck in an inferior Nash equilibrium. Expectations are shaped by historical experiences and established practices can be self-fulfilling (Zenghelis, 2019). Businesses, investors and policymakers are unlikely to invest in clean technologies where they expect the cost of these technologies to be prohibitively expensive, available finance is limited to niche areas and risk premiums are high, and there is limited market opportunity. Strategic complementarities mean the payoff is a function of how many others do. Agents will not take the risk if they believe that no one else will act, and the suboptimal equilibrium will persist.

Now suppose agents believe everyone else will invest in low carbon innovation and technology deployment. In that case, they will expect technology costs to fall, finance to go from niche to mainstream, the policies and support from institutions to be established, and rapid market opportunities to evolve, and they will invest. Then, as others do the same, expectations become a self-fulfilling prophecy, inertia is overcome, and a dirty system is replaced with a clean one. Expectations are thereby forward-looking as future technologies, tastes, and behaviours influence the value of current investments (ibid.).

Expectations thus form part of the reinforcing feedback process, whereby economists using the wrong tools not only get the future wrong, they make the future wrong, due to the power attached by decision-makers to, often biased, forecasts (Krugman & Madrick, 2015; Zenghelis, 2023). Private investment is determined by future returns. Hence expectations are at the core. Private finance is required to meet the scale of the net zero transition and one estimate is that around £3-6 trillion additional investment is needed to drive the green and resilient transition a year worldwide by 2030 (Bhattacharya et al., 2023; COFM, 2023). Yet less than a quarter of this is being mobilised and only around a quarter of finance ministries are actively involved in the Nationally Determined Contributions (NDC) development process (COFM, 2023).

Understanding and emphasising the real prospect of cost reductions achieved through scale and investment helps induce private investment. The repeated under estimation of the cost decline of modular technologies will have led to an under investment in these technologies by private finance.

This needs to be balanced with the risk of overly optimistic deployment and price expectations that led to project failure in the deployment of carbon capture, usage and storage (CCUS) in the UK over the last two decades (NAO, 2017). To strike the right balance between these two competing challenges, changing the perception of risk and opportunity is key to unleashing clean finance.

Policy plays a crucial role in guiding behaviour and anchoring shared expectations for effective co-ordination and collective action (Zenghelis, 2019). In the context of the shifting date for ending internal combustion engine (ICE) car sales, the early date for 2030 had the effect of crowding in investment and lowering the risk premium under the certainty of a market for electric vehicles in the near future. The former Government's decision to delay the phase-out deadline to 2035 undermined this investment (see section 4.3 below). Other measures included relaxing regulations for homeowners to replace gas boilers with heat pumps. The process of innovation in key technologies tells us that the very act of investing is what is likely to bring costs down and policy reversals send the wrong signals to investors. The technological revolution is now so well established that narratives are rapidly and inexorably changing (see Figure 10).

Figure 10. Where we are now and where we are headed

The debate will be very different in 2030

When the facts change, people change their minds. Repricing follows:

Area	2015	2024	2030
Cost of renewables	Expensive	Cheap	Super cheap
Societal pressure for change	Niche	Moderate	Intense
EVs	Toy for the rich	A second car for the rich	A cheaper car for all
Renewables	Grid can't take 20%	Grid can't take 70%	Leaders enjoy cheap energy
Net zero	<1% of world has targets	90% of world has targets	90% of world has plans
Global fossil fuel demand	Growth	Plateau	Decline
Hard-to-solve areas	CCS	Lots of technological solutions	Lots of commercial solutions
Geopolitics	Climate make good speeches	Renewables nice to have	Renewables a key tool of power
United States vs. China	China pollutes too much	China makes too many climate solutions	China and United States compete
Financial markets	ESG	Carbon offsetting	Minsky Moment
Corporations	Greenwash	Green premium	Green prize

Source: Bond et al. (2024).

3.3 Competitiveness in the green economy

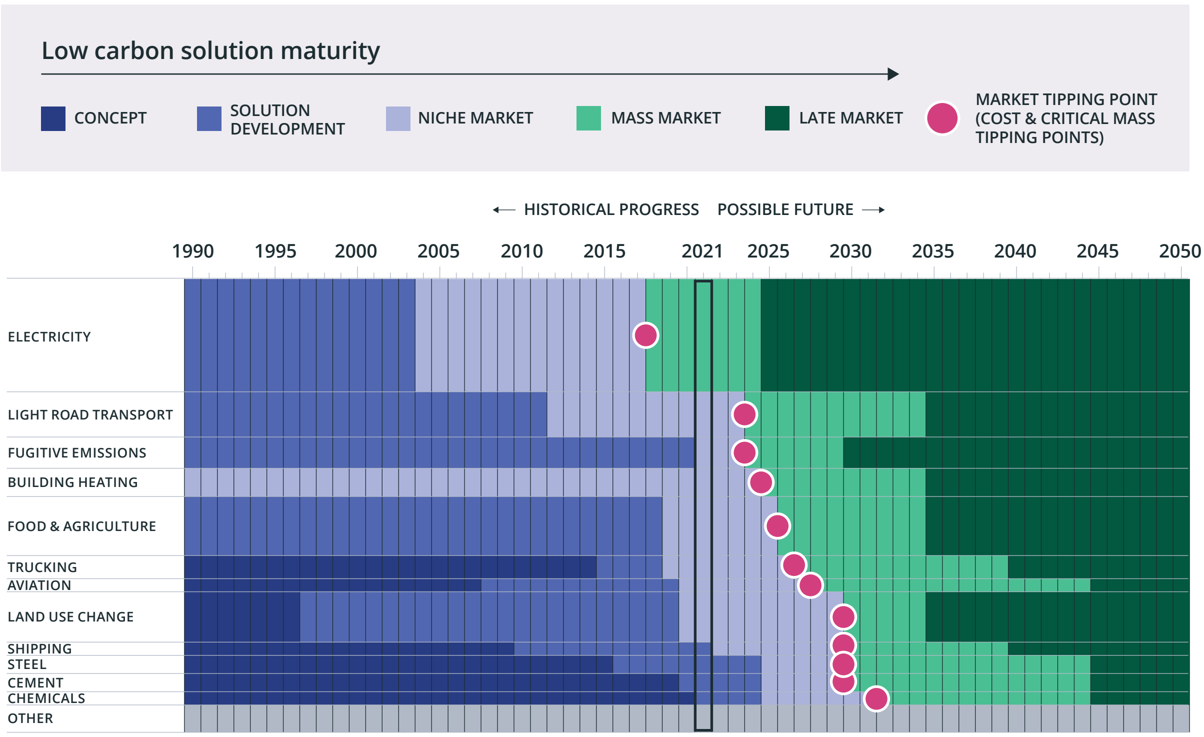
As well as the positive sum game from induced innovation and cheaper technologies which benefit all, there is also a zero-sum game associated with early investment. This reflects potential gains to economic competitiveness as some clean technologies reach tipping points. Increasing returns suggest a spatial advantage to firms and countries that move early to develop new clusters, supply lines and corner markets before competitors. In the UK's case, there is a need for a tailored strategy to take advantage of global trends in green markets.

Potential tipping points

The evidence on technology and behavioural transformation indicates that the transition to net zero in key sectors can be quick and profitable. After a tipping point is crossed, reinforcing feedback loops take hold of that reinforcing progress, so greater solution deployment encourages even faster deployment.

The rate of technology change is such that, by some estimates, a third of emission producing firms and sectors are now challenged by cost-competitive clean alternatives. By 2030, that number could be close to two-thirds, as currently hard-to-abate sectors become cost-competitive once such tipping points are reached (see Figure 11).

Figure 11. Commercial tipping points by sector: Historical progress and indicative future timeline



Source: Systemiq (2021).

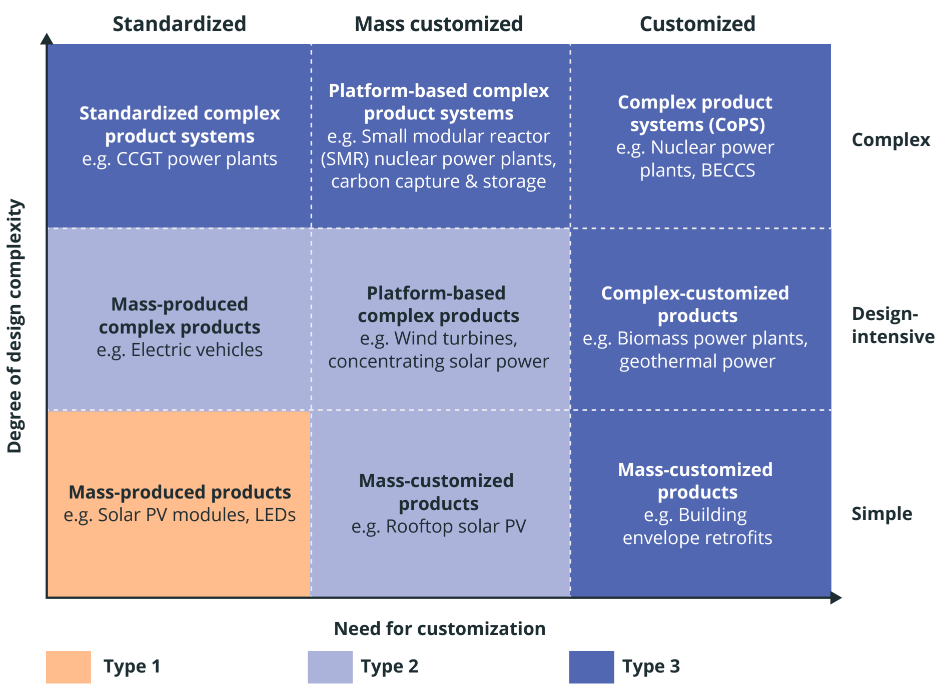
Figure 11 shows that in addition to the mentioned technologies that have already experienced spectacular price reductions, other technologies also hold great potential. The speed of human innovation and the dynamics triggered by returns to scale are allowing clean technologies to challenge dirty ones. After a long and intense period of resistance from incumbent industries, clean technologies are reaching tipping points, switching from one network to another. It is worth remembering that electricity and cars were considered hard to abate sectors ten years ago.

Expectations are generating positive feedback loops in innovation, mindsets, and institutions.[vi] Private companies and governments worldwide are accelerating investments to meet new targets, which could lead to price reductions. Investments in low carbon solutions for aviation and steel show promising signs. For example, the UK signed a mandate establishing that 10% of aeroplane fuel must be sustainable aviation fuel (SAF) by 2030. Additionally, investments in plant-based meat and cultured meat are growing exponentially. Cultured meat could reach price parity in 2030-32 (Systemiq, 2021). Yet, the outlook for other sectors is less optimistic.

For example, heat pumps and carbon removal projects are not being deployed at the scale needed and nature-based solutions lack financing. These sectors also require demand-side push to support market creation. Incentives for purchasing SAF, for example, remain minimal.

In particular, replicable and modular technologies have a higher likelihood of experiencing price declines (Malhotra & Schmidt, 2020). They are more likely to experience the reinforcing feedbacks due to deployment and returns of scale. Figure 12 shows a classification of different types of technologies in terms of design complexity and customisation. Solar PV cells generating electricity in diverse places worldwide are basically the same; they are standardised products with low levels of design complexity. LEDs are also examples of this type of technology. Conversely, CCUS and nuclear energy are personalised and complex technologies which are less likely to experience price reductions. Other technologies are of an intermediate type. It is hard to tell exactly where green steel, cement, aviation, and other sectors stand but many can be expected to be classified as type 2 technologies identified in Figure 12.

Figure 12. Energy technologies classification based on design complexity and need for customisation



Source: Malhotra & Schmidt (2020).

Ultimately, which technologies will experience the price reductions remains uncertain, but patterns are emerging. It is likely not all investments will see returns in the form of innovation and efficiency, but many will. Less productive investments which are necessary to reduce emissions, such as direct air capture, may ultimately, be cross-subsidised by the resources freed up by many of the more efficient new technologies. It is impossible to know with certainty what the world would look like. However, Figure 11 shows what the world could look like and the risk of being 'caught by surprise', once again. Certainly, planning on the world remaining as it is today with only small marginal changes will mean overestimating costs and will result in delayed action increasing the likelihood that this becomes a self-fulfilling prophecy.

The clean transition is a story of risk and opportunity. It is impossible to predict how collective institutions and behaviours evolve, nor can one forecast exactly what economic sectors will be the most successful. However, missing the opportunity to participate in these green markets would result in a significant loss. Many sectors are showing promising signs, and it is feasible that they will cross tipping points.

Early mover advantage

The growth potential from clean investment is absolute, in terms of economies of scale in production and discovery, representing a positive sum game of induced innovation. At the same time, it is relative in terms of gaining a competitive advantage by building knowledge clusters, skills and supply lines ahead of competitors. Moving early before competitors can be considered a zero-sum game: act now before others eat your lunch. A gain to the UK could be another country's loss in terms of cornering new markets, technologies and behaviours. Therefore, there is an incentive to establish a competitive production base by being an early mover. There is certainly an environmental risk of delaying action, but delaying action also means missing the opportunities to profit from fast-growing new markets. This recognises the risks of being a laggard in a rapid and structural economic transition.

Investing in new technologies is not risk-free, and early movers will face uncertainties and challenges related to developing new technologies. Early adopters face high costs in terms of R&D and will need financial support and policies that promote the deployment of new green technologies. This can create the temptation to hold back and freeride on cost reductions generated by other countries' investments. It is true that UK consumers will benefit from the consumer surplus of cheaper foreign imports. But, it will also mean the potential net loss of jobs and access to new rapidly growing markets for UK manufacturers and traders of goods and services.

For some sectors, adopting a fast follower strategy can be beneficial. First movers can gain early market dominance and establish competitive advantages but face higher risks and costs. Fast followers can leverage the experiences of first movers to innovate more efficiently and enter the market with lower initial investment, though they must find ways to effectively compete and differentiate from established players. In the solar energy industry, China, was a fast follower and capitalised on Germany's early investments and innovations. It scaled up production efficiently, and rapidly reduced costs and improved manufacturing processes resulting in an advantage over other manufacturers.

Although it is a challenging task, and the benefits cannot be calculated with certainty, failing to take early strategic action would leave the UK economy less able to compete in the 21st century and more likely to face enduring problems of insufficient investment, low productivity, and stagnant growth. The evidence of what other countries have achieved already makes a compelling case for gaining a comparative advantage in certain sectors that generates long-term growth.

If a clear strategy is in place, substantial upfront investments have the potential to be more than offset by long-term economic benefits. China has achieved this admirably, establishing a dominant position in renewable energies, batteries and EVs. China's share exceeds 80% in all manufacturing stages of solar PVs (IEA, 2022, see box 3). China also leads lithium-ion battery manufacturing capacity, with nearly 85% of the global capacity (IEA, 2024c). Moreover, it is leading in the uptake of EVs, with 40% of its sales being electric, followed by the EU with 20% and 10% in the US (IEA, 2024d). In 2023 China accounted for 60% of the world's electric vehicles and a similar proportion of global wind turbine manufacture.

Clean energy represented 40% of China's GDP growth in 2023 (mostly solar, storage, and EVs), according to a Centre for Research on Energy and Clean Air analysis for Carbon Brief (Myllyvirta et al., 2024). It achieved this by developing a strategy and implementing a combination of subsidies and incentives for manufacturers and consumers, access to finance, regulatory changes, and other support schemes. Moreover, China is taking advantage of its big internal market as most of its clean production is consumed domestically and is used to drive growth.

Box 4. China setting the p ace of the clean transition

China is the world leader in battery manufacturing capacity (McKerracher, 2024). Despite still being the world's largest emitter of greenhouse gases, and with growing emissions, China's focus on green technology and limiting emissions is critical to global ambitions to meet 2 degrees targets (IEA, 2021a).

China's decision to invest heavily in renewable and battery technology and to cut its emissions is likely driven by a wide range of factors, likely including economic and geostrategic reasons. It has seized an early mover advantage and a technological lead for, which are indicative of central government thinking about wider risks and opportunities in the policy design around low carbon technology.

The risk of not moving

Throughout the early 2010s, China faced air pollution and environmental crises, with large numbers of overt public protests across the country over dangerous levels of microparticles in the air in cities, the construction of chemical plants (Waldmeir et al., 2012), along with multiple incidents of large-scale lead poisoning and water supply contamination (Reuters, 2012). As regional governments were forced to make concessions to quell protests, discussion began about whether GDP growth alone, long the primary metric of success, should be the only factor in China's continued rapid development journey (Jiangtao, 2012). Despite a lack of formal democratic accountability, the Chinese government does take considerable notice of public views and works to ensure public support and satisfaction, with the pragmatic aim of 'maintaining stability at all costs' (The Economist, 2016; Thibault, 2012).

It was in the context of growing protests about air pollution and the environment that the Chinese government began to develop meaningful environmental protection policies. Although the 12th Five Year Plan, launched in 2011, included some specific targets to reduce air pollution and invest in clean energy (National People's Congress, 2011), protests and a growing public awareness of environmental issues appear to have driven more meaningful commitments to limiting environmental damage made by the Ministry of Environmental Protection in 2013 (Duggan, 2013), which resulted in limits to coal power station construction and pollution taxes (Asia Society Policy Institute, 2021).

Changing values amongst the public, including a specific shift to environmental concern and post-materialist values (Wang et al., 2023), are also likely to have influenced broader policy on climate damage, including President Xi's 2014 commitment to peak emissions by 2030 (McGrath, 2020).

Although China's emissions targets may seem weak, it is very much possible to apply the lens of risk management to the Chinese government's decision to pivot to decoupling economic development and growth from climate harm and limiting air pollution. In particular, the desire for stability, and the subsequent response to protests with specific and active policies designed to curb pollution, must be seen as a pragmatic risk management exercise. Regardless of whether or not the sustainability commitments made in 2013 and more recently had a substantive impact on limiting global climate damage, the decision to advance them at all, and acknowledge economic growth must not come at the cost of environmental damage (Duggan, 2013), should be perceived as a mechanism by which the Party addressed growing dissent and minimised the specific risk of not acting to appease protestors.

The continued support of the coal industry should also be seen through the pragmatic lens of seeking space to allow for decarbonisation by appeasing the powerful coal lobby over the transition, even when coal generation is known to be more costly than renewable.

The opportunity of action

Decisions to invest heavily in low carbon technology, including advanced battery technology and electric vehicles, have also been strongly motivated by the opportunities being an early mover. Other global leaders in auto manufacturing have failed to gain the momentum needed for EVs, with, for instance, uncoordinated policies, a strong auto-lobby and populist ideology all undermining Germany's transition from ICE vehicles (Book et al., 2024). China, however, has been able to steer its command economy to dominate the global EV industry, leveraging its advances on battery technology and creating resilient domestic supply chains. This reflected a recognition that it would struggle to match the west on advances combustion engine technology, but had an opportunity to leapfrog on electric vehicles which would also meet growing environmental requirements.

Much of this growth has been driven by a co-ordinated policy system incorporating strong investment in relevant education and R&D, learning by doing (Stauffer, 2021), state subsidies (Kennedy, 2024) and strong support from regional governments (You, 2024). A particular focus has been given to developing educational courses that equip people entering the labour market with the skills they need to work with battery technology (Bradsher, 2024), while a research investment has resulted in 65.5% of widely cited technical papers on battery technology coming from China, compared to 12% from the US (Ibid.). The Made in China 2025 strategy, launched in 2015, has sat at the core of creating this policy environment (Gong & Hansen, 2023), focussing on rapidly developing high-tech supply chains and industrial capacity, providing a protected niche for early and mid-stage development technologies (Ibid.), and funding research and innovation capacity building (International Council on Clean Transportation, 2021).

Clean technology acts as a strand in China's broader strategies, including Made in China 2025, to build domestic manufacturing capacity that is not reliant on foreign technology (Institute for Security and Development Policy, 2018), and to make it globally competitive with industrialised economies, including the US (Ibid.). With electric vehicles in particular, China has been able to use its strong domestic supply chain and early mover advantage to become a global player, overtaking Germany and Japan for car exports by 2023 (Huang & Xia, 2024). This aligns with broader Chinese strategy and foreign policy decision making, including a desire to develop self-reliance in key industries (de Soyres, 2024) and be a global economic superpower (Cordesman, 2023).

The decision to develop battery technologies and EVs, investing in education, research and state subsidies while also carving out niches for developing industries to grow in form part of China's broader national aims to transition its economy, avoid a middle-income trap and compete with the US (Zenglein & Holzmann, 2019). Decision making has been indicative of a focus on potential opportunities and the way policies fit into broader strategic aims, as opposed to being limited to thinking on siloed benefits and known costs.

The Chinese success story has precipitated aggressive protectionist trade barriers in the US, as announced in May 2024 by President Biden. By acting slowly, European car makers are now having to contend with the consequences, in terms of profits and jobs, of being slow to progress to the electric vehicle manufacturing sector. They have also announced tariffs on Chinese imports. These trade measures, the Inflation Reduction Act (IRA) and creating incentives to produce semiconductors (CHIPS) and Science Act, underline the advantages of moving early and cornering markets, as well as geopolitics and security concerns (as outlined in Box 5).

Box 5. The political economy of the US Inflation Reduction Act

The US' 2022 Inflation Reduction Act (IRA) covers a wide range of policy areas, but most notably includes an estimated $369 billion of spending over 10 years for energy and climate change related investment and tax credits (Fleming & Bounds, 2022)[vii]. The sectors covered include renewable energy sources, electric vehicles, batteries, heat pumps, and more.

There is no published cost benefit analysis to support the IRA, but ex post cost benefit analysis performed by the US Department of the Treasury has demonstrated that it would provide a quantifiable net benefit, with the true economic benefit likely to be considerably higher than originally quantified (Levinson et al., 2024). The exercise calculates the costs of tax reductions and subsidies of the IRA and compares them to the benefits of reducing emissions. The estimation uses a monetary benefit of $200-300 per ton of carbon dioxide equivalent emissions, concluding that the benefits are higher than the costs (US Treasury, 2024).[viii]

The motivation behind the IRA was fundamentally political, with geostrategic interests (Jones & Rickert McCaffrey, 2024), a desire to gain early mover advantage (Seiple, 2022), a desire to boost technology investment in left behind regions (Van Nostrand & Ashenfarb, 2023), and considerably limiting and mitigating against climate damage (Van Nostrand & Levinson, 2023), all driving forces behind the act, alongside an aim of limiting inflation.

Analysis suggests that the IRA will create over 8 million jobs related to clean energy and technology (Pollin et al., 2023), and evidence demonstrates that within its first year it created at least 170,000 new green jobs (though these estimates are not calculated net of displaced jobs in fossil fuel and other affected sectors) and fuelled $278 billion in new investment (Broom, 2023). It also specifically targets regions that have experienced stagnant or lagging economic growth and below average wages and education progression rates, with 81% of clean energy investment announced since the act going to areas with below-average weekly wages and 86% going to areas with below average education progression rates, as measured by college graduation (US Treasury, 2023). In developing low carbon energy and battery technology in regions which need the most investment, the US is both mitigating against the physical risks, while also providing much needed investment that can boost economic convergence for left behind places (Zandi et al., 2022).

Though not stated as an official objective, one aim of the act is to entrench political support and make the measures resilient to a change of Federal government and Congress. However, the IRA's support for EVs and clean power remains at risk of being reversed if President Trump returns to the White House (MIT, 2024) and may face challenges from a more sceptical Congress. It is probably not a coincidence that much support has been extended to politically critical swing states. Georgia alone has received $23.8 billion of investment for green industry supported by the IRA, with in excess of 30,000 jobs created across 41 different infrastructure and manufacturing projects (Climate Power, 2024).[ix] Allowing foreign manufacturers like Kia to benefit from subsidies and tax credits if they bring supply chain elements and attractive jobs, is also cementing American's place as a global manufacturing and clean technology superpower. The IRA is further enabling the US to develop considerable comparative advantage in a number of developing technologies (Attinasi et al., 2023), for example in clean hydrogen and CCUS (Seiple, 2022).

There is also a critical national security element to the acts, most notably around shielding US industry from geopolitical volatility and ensuring that the US does not fall substantially behind China with regard to technology (Nuccitelli, 2023), an explicit aim of the CHIPS Act (Moser, 2023). With tensions rising around trade relationships and Chinese military assertiveness (Center for Preventive Action, 2024), the US has been working to strengthen domestic supply chain resilience (Sullivan & Reese, 2022)7. Energy security and technology sovereignty is of critical importance to this (Bateman, 2022). The IRA therefore represents a major step in investing in US infrastructure and strengthening domestic manufacturing, which both protects the supply chain and boosts growth in left-behind regions.

The economic benefits of strengthening domestic supply chains and ensuring technology and energy sovereignty are secure are difficult to quantify. No-one can predict to any degree of certainty what the future of the US' geopolitical position will look like, and the extent to which tensions may escalate or reduce with different countries, and consequently it is very difficult to view the geostrategic role of the IRA through any sort of cost benefit lens. Indeed, security concerns have been a major factor behind US energy policy pushing the expansion of oil and gas production over same period.

The US is now the world's largest oil producer (US Energy Information Administration, 2024). National security is fundamentally centred around minimising risk and ensuring resilience, and shares similarities with how the UK should consider transformative change to ensure it reaches its net zero targets and builds climate resilience. Both are based not on benefits that can be definitively modelled but on potential benefits and opportunities in different scenarios.

Despite public costs which some estimate to be as high as $1.2 trillion cost (Della Vigna et al., 2023), the IRA will have enormous impact on the US and the world's climate trajectory. It is expected to contribute up to a 48% drop in emissions compared to 2005 levels by 2035 (Bistline et al., 2023), bringing it far closer to achieving its ambition of net zero by 2050, cutting excess deaths due to air pollution (Rajagopalan & Landrigan, 2023) and lifting people out of poverty with good jobs. It also puts the US in a stronger position to compete in fast growing global markets, having previously lost ground to other major trading blocs. By derisking investment in innovation and creating positive incentives for low carbon solutions, the government has made a political decision to use climate mitigation as tool for growth.

The Chinese and US case studies are strongly suggestive of how the UK could seek to focus on net zero and the development of low carbon technology to fit into the wider system, particularly around how it can serve strategic energy independence needs while providing well paid, highly skilled jobs for British workers. By perceiving transition policies as opportunities for job creation, upskilling and technical progress rather than burdensome costs, the UK can build on its technological advantages and deliver growth while supporting left behind regions.

UK strategy in potential 'clean' sectors

The UK has a productivity, underinvestment, and growth problem (Van Reenen & Yang, 2024, see section 2 above). Increasing total factor productivity (TFP) requires innovation to get more from our resources through smarter uses of materials, people, machines, and ideas.

The UK has innovation and scientific strengths including high-quality universities and R&D ecosystems, a venture capital industry with innovative start-ups and firms, a lead in exports of service sectors, an extensive coastline with a shallow seabed and a labour force that could adapt its skills to the new economy (HMT, 2021a). In 2020, there were 430,000 jobs in the low carbon economy with a turnover of £41 billion (Skidmore, 2023). Moreover, the UK is the 9th biggest exporter of clean goods and services globally (Curran et al., 2022). With a well-crafted strategy and appropriate investments, the UK can build on its advantages to boost productivity and growth (CBI, 2023).

Importantly, the green economy represents an opportunity to address regional disparities and the levelling-up agenda. In the UK, less productive regions specialise proportionately more in clean technologies compared to more productive regions. Additionally, clean investments generate high returns within these regions (ibid). This highlights the importance of targeted clean investments to ensure equitable and sustainable growth. The US experience provides a good example. Data on announced clean investments after the IRA shows investment is concentrated in areas with low income, lower college graduation rates and energy communities historically reliant in fossil fuels (US Treasury, 2024).

The UK is in a strong position to embrace technological change, utilising a strong base in scientific innovation, strategic risk management and deep financial and capital markets. According to one broad estimate of the UK net zero economy —which includes emerging sectors, such as renewables, carbon capture, and green finance accounting for around 4% of whole economy gross value added, — the sector grew 9% in 2023 compared to a 0.1% GDP growth in the overall economy (ECIU & CBI Economics, 2024). The UK has a revealed comparative advantage in tidal, offshore wind, and possibly modular nuclear and CCUS (Curran et al., 2022)[x]. Other areas of potential opportunity include environmental monitoring equipment, natural risk management, turbines, advanced semiconductors and water management treatment.[xi] By contrast, the current lack of scalability, standardisation and modularity and in production make it unlikely that tidal, nuclear and CCUS will experience early price reductions and feedback loops, and this needs to be taken into consideration, even if they remain key components of UK decarbonisation pathways. This is primarily because they do not possess the characteristics that facilitate price reduction through scale and innovation (low complexity and customisation). Potential UK manufacturing opportunities also exist in small modular reactors, biorefineries and hydrogen as well as advanced battery technologies (Hart et al., 2015; The Faraday Institution, 2024; UK Parliament, 2024; UKRI, 2024).

Apart from sectors where a country already has a comparative advantage, it can be easy for countries to become competitive in new but 'adjacent' green products that require production know-how, capabilities and factor inputs similar to their existing domestic capabilities. Economic complexity and network science, which deploys machine learning techniques to explain, predict, and guide changes in economic structures, is increasingly used to judge sectors with latent opportunity (Hidalgo, 2023; Hidalgo et al., 2007; Mealy & Hepburn, 2020; Mealy & Teytelboym, 2022).

Manufacturing is not the only potential beneficiary, and the service and knowledge sectors represent an exciting opportunity for the UK. The UK was the second largest service exporter in 2019 (HMT, 2021a). There are multiple UK firms specialising in clean services and around 40% are related to demand-side management and digital technologies (Curran et al., 2022).

Evidence suggests that adopting clean technologies, in combination with digital technologies and artificial intelligence (AI), induces creativity and innovation across the whole economy and generates new learning and experience along the way (Andres et al., 2022; Dechezleprêtre et al., 2017). One study estimated that low carbon finance is expected to grow faster than any other low carbon sub-sector of the economy (Corfe & Rosales, 2022).

Low carbon financial services could generate an export opportunity of up to £7.5 billion per year in 2030, rising to £17 billion per year by 2050 (ibid). The role of UK universities in combination with London's global finance and consultancy expertise to lead and finance a truly smart, cutting-edge clean transition is almost unparalleled. An industrial strategy needs to be broader than 'picking winners' to focus on enabling conditions and principles.

The UK also is a leader in the biotech and life sciences sectors. Innovative bio-based materials, fuels and production processes can support the clean transition and bio-protein development can enable food chains to shift away from meat. Examples include next generation algae-based biofuels, plastic substitutes, reductions in fertiliser use through innovative crops, and alternative chemical synthesis processes which use dramatically less energy.

Building from an existing comparative advantage is pragmatic. A comparative advantage can also be created by becoming a first-mover in new markets. Combining existing comparative advantages with a more disruptive approach may have a greater long run impact (Zenghelis et al., 2024). Indeed, it was by defying its comparative advantage that South Korea became a smartphone superpower rather than a global leader in exporting rice. A strategy could benefit from both approaches, focusing on what the UK is good at and leaving the door open for strategic jumps to other promising sectors. For instance, China saw it couldn't compete with ICE cars and decided to take a disruptive approach, focusing on EVs instead (Diaz Anadon et al., 2022a). A number of UK sectors stand to form part of a profitable UK growth strategy.

- **Floating offshore wind:** the UK can build from its revealed comparative advantage in offshore wind energy, as it has the highest installed capacity in Europe and second in the world (DESNZ, 2023a). Floating wind turbines are built on a floating platform in deeper sea waters, allowing for more flexible locations and profiting from better wind conditions.

Moreover, they are less disruptive to seabed habitats and have lower visual impacts, though other environmental impacts exist and must be considered to limit their impact (Maxwell et al., 2022). The UK has set an ambitious target of deploying 50 gigawatts (GW) of offshore wind energy for 2030, potentially supporting 90,000 direct and indirect jobs, and of which 5GW will be floating offshore (HM Government, 2023a).

The UK has two floating offshore wind farms in operation. The Hywind Scotland (since 2017) and Kincardine (since 2018), both adding 78 megawatts (MW) to the electricity grid. Moreover, 78GW of offshore wind capacity are currently in the UK pipeline, of which 40% is floating including the projects of Bellrock, Ayre, Broadshore, Arven, and Green Volt (Blackridge, 2024; DESNZ, 2023a). They were awarded through the CfD scheme, which will continue to be key for the sector's development[xii].

- **Aviation:** As a science, technology and aerospace leader, the UK is well positioned to participate in developing and leading a future for clean aviation. The future for the aviation sector is unclear – its particular requirement for high energy density carriers make some more standard decarbonisation options challenging. Without progress the sector will be more and more exposed as an outlier in an increasingly clean economy. However, there is strong industry and government support for action and multiple pathways to reduce the sector's impact. At the same time the growth of aviation and associated manufacturing in Asia represents a potential disruption and shift in the sector. The UK has the opportunity to be at the forefront of new aviation technologies and approaches if it manages the sector strategically (HM Government, 2017).

  A recent report outlines a five-year plan to set the aviation sector on a course to net-zero emissions by 2050 (University of Cambridge, 2024). It sets four main areas of action. The UK could play a leading role in each of them. One area of potentially huge early opportunity is addressing non-CO2 impacts, notably contrails.[xiii] This will be a low cost route to cutting aviation's climate impact by up to 40%, but it requires clear government leadership to enable new flying patterns and systems.

  A similar area of immediate potential is supporting more efficient flying by prompting new flying patterns, new aircraft models, and a modernisation of the global airline fleet. These changes would create value for companies and economies in the aircraft production and support sectors.[xiv]

  SAF offer immediate carbon emission reductions using existing aircraft engines and infrastructure. However, they can only be scaled sufficiently if there is a clear strategy to manage the impacts of producing the necessary biomass, and a shift to innovative production pathways – such as hybrid power and low-carbon synthesised fuels.[xv]

  Finally, there are numerous transformative technologies that offer routes to decarbonising aviation without needing to manage the heavy biomass and energy cost that SAFs offer. There is a need to urgently assess the potential of these technologies, including hydrogen combustion, hydrogen fuel cells, synthetic fuels, methane and more, each of which could offer solutions. By investing on frontier technologies now, governments have a unique opportunity to reshape aviation, just as electric vehicles reshape the automotive industry, avoiding a pathway dependent on biofuels.[xvi]

- **Green hydrogen:** This is produced through water electrolysis, which separates hydrogen and oxygen using renewable energies with no emissions. Hydrogen has multiple applications, most especially in chemicals and could mean solutions for hard-to-abate industries: shipping, aviation and eventually steel and cement. With time, power systems can be expected to reach 80%-90% renewables-based capacity factor penetration, with intermittency issues resolved through interconnectors, demand response management and batteries. The remaining 10% to 20%, however, will be tougher to deliver and hydrogen, which can be stored for long periods at unlimited quantities, will likely play a role. Many countries, including the UK[xvii], have national green hydrogen strategies. Ambitious policies are being implemented, and companies are investing in its deployment. Still, green hydrogen is capital and energy intensive and is currently more expensive than grey hydrogen (produced with fossil fuels) and blue hydrogen (produced with fossil fuels and CCUS).

Scaling up could lead to price reductions, but yet the effects remain small. The main production cost comes from the price of renewable electricity, and further deployment of renewables could continue to reduce its price. Electrolysers also represent a significant cost component and scaling up its production could make it cheaper. IRENA (2020) estimates that up to 85% of the cost of green hydrogen could be reduced in the long run through these mechanisms. According to another estimate, green hydrogen from new plants could become cheaper than grey hydrogen from existing plants by 2030 in five countries (Schelling, 2023).

It is crucial to accurately assess hydrogen's potential contribution to achieving net zero emissions, given the significant lobbying efforts from the fossil fuel industry, which stands to benefit by repurposing existing infrastructure for hydrogen storage, transport, and use. Additionally, if hydrogen is not sourced entirely from renewable energy, a substantial portion would likely be derived from natural gas, maintaining a reliance on fossil fuels (Vetter, 2021).

Electricity is a more efficient decarbonisation pathway in most sectors, including cars, domestic heating, metro trains, buses, motorbikes, and mid-low temperature industrial heat (Liebreich, 2023). However, hydrogen offers competitive opportunities in some areas, such as fertiliser and methanol, where hydrogen is the only alternative for decarbonisation. Others, like long distance haulage and shipping, synthetic jet fuels, and steel, have high potential and, with support for innovation, it is likely that hydrogen will have a decent market share (ibid.). Electrolysis from renewables can create hydrogen for inter-seasonal storage, but the equipment is capital intensive which means it is ill-suited for use with surplus renewable energy (where costly capital would otherwise lie idle for long periods). Overall, high capital costs make hydrogen a viable option in hubs for heavy industry, but efficiency losses and high transportation costs (relative to electricity) currently limit its use elsewhere.

- **AI and digital economy:** The low carbon service sector is an area of huge potential growth for the UK, including science, design, engineering, legal, software and financing services (HMT, 2021a). AI together with sensor technology, digital twins and smart integrated systems (and with time quantum computing), can play a key role in measuring and managing resources in multiple sectors. As it can process large amounts of data, it can identify patterns that optimise resource use, reduce waste and other environmental impacts (Onyeaka et al., 2023). The UK has a strength in digitalisation, with potential to specialise in smart grids, grid flexibility, environmental protection and pollution control (Curran et al., 2022). Through AI and machine learning the UK could develop software services that can be sold in the global market. Additionally, there is potential for the UK to be a major hub of green finance and green venture capital (HM Government, 2023b).

  Despite the potential environmental benefits of AI, the energy demands of large-scale AI data centres pose environmental challenges due to significant electricity consumption and associated carbon footprints as well as water use (Goldman Sachs, 2024). The emissions of tech giants, such as Google and Microsoft, have risen rapidly, and continue to rise, and data centres could consume 9% of total electricity in the US by 2030 (EPRI, 2024). To deal with such demand and emissions growth, the development of energy efficient chips is critical, as they offer improved performance with reduced power consumption and water usage. This could be another niche area worth exploring for the UK. There is also an issue around addressing the spread of misinformation about clean tech and how the search engines and social media platforms need to address this to support uptake.

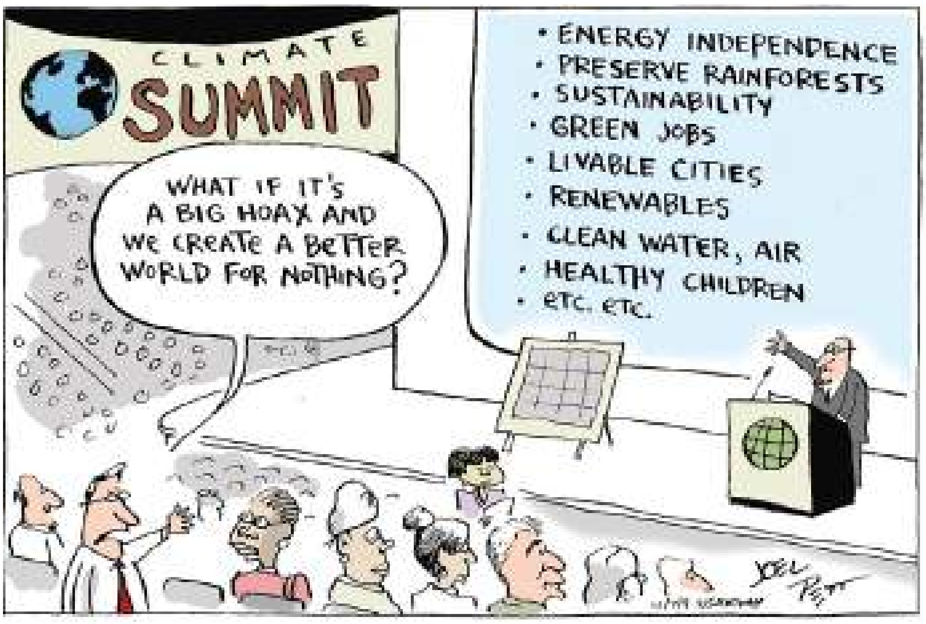
- **Heat pumps:** They are devices used for heating and cooling buildings by transferring heat from one place to another. They run on electricity and provide a solution to decarbonise housing, the second highest-emitting sector in the UK after transport. Unfortunately, while Europe has increased heat pumps installations with notable success in Scandinavia, progress in the UK has been slow (CCC, 2024). Despite an available subsidy of £7,500, upfront costs remain high for households, and deployment has been slow, with only 72,000 new installations in 2022, well short of the 600,000 annual target (CCC, 2023). Important challenges that need to be addressed include the high price of electricity relative to gas and the need to retrofit buildings for energy efficiency so that heat pumps can be made to work efficiently (HMT, 2021a).

The bulk of heat pump costs (around 60%) correspond to equipment costs; the rest primarily comprise labour cost (Hardy et al., 2016). The large-scale deployment of this technology in the UK could reduce costs in the main through reduced installation costs. Therefore, faster deployment of heat pumps would be beneficial. However, it is unlikely that this will bring down total costs to reach price parity with gas boilers. Heat pump equipment is imported and is a mature technology with a low price reduction scope (DECC, 2016). Still, in an unanticipated and unlikely scenario where heat pumps have a high share of the global boiler market (=>50%), equipment costs could be reduced through an influx of cheap imported heat pumps, with total reductions expected in the 30-50% range (Hardy et al., 2016).

3.4 Should 'growth' be the objective, or is it the problem?

Growth is not the problem, material use is. Some contend that striving for growth is itself the problem. They point to the fact that few countries have achieved absolute decoupling of output from resource use and pollution (though it is arguable that the UK and much of Europe has, even after adjusting for the offshoring of carbon intensive industrial production to feed domestic consumption (see CCC (2024)). The evidence suggests that the focus on growth is a dangerous distraction. Innovation can deliver substantial decarbonisation through making better use of resources (section 3.2). It is material use and polluting products that are damaging to the environment and to wellbeing, not statistical artefacts in the form of chain-linked estimates of 'real' growth, which are functions of what we value and have no meaning in terms of levels comparisons through time. This fundamental misrepresentation fuels unfounded claims that decarbonisation is too 'costly' to achieve and would deliver falling living standards and lost jobs (Zenghelis, 2021).

What matters is decarbonisation and dematerialisation, not GDP. It is our contention that this representation is expressed the wrong way round: ambitious climate action could deliver growth through efficiency gains, innovation and productivity improvements. New value creation from people employed in building renewables, supplying finance and engineers, restoring wetlands and preserving forests, to name a few activities, would all feature in estimates of GDP as new expenditures, incomes and output replace old. Moreover, in the short run, growth is essential to create the resources to pay for the innovation and investment requires to transition the economy and build the political will. Policy-driven consumption reductions such as Allied rationing after World War Two and Soviet rationing in the Cold War produced negative ecological outcomes.[xviii]



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04

Transition risk in a changing world

Fiscal rules lie at the heart of this UK's growth problem. There is no such thing as a fixed 'fiscal headroom' when it comes to stimulating good investments. Debt is not a 'burden' when it is used to fund resilient and productive assets rather than consumption

Transition risk in a changing world

04

The transition to a clean economy will mark a systemic change to the current structure and make up of our society. In particular, the way we produce and consume energy will be radically different. The UK transition will take place against the backdrop of a wider restructuring of the global economy. This section explores the major contours of a clean transition, the potential risks that are present and the consequences of these risks, in terms of impacts on growth and the wider need to decarbonise our economy.

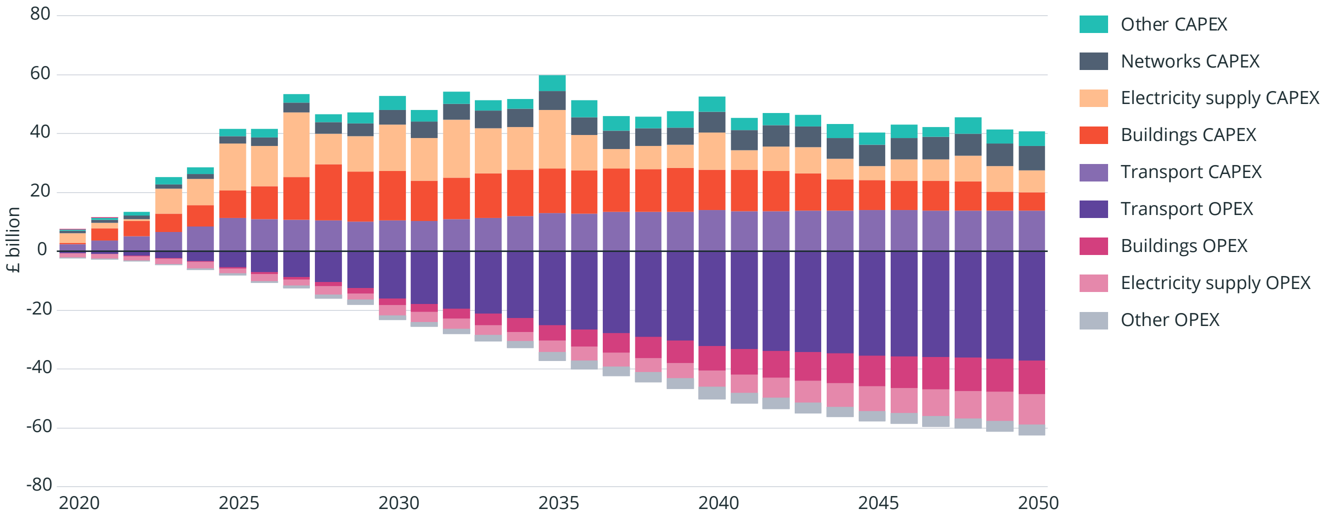
4.1 A new economic paradigm: the end of fossil-fuelled growth

Not only does transitioning away from fossil consumption mark a historic shift in energy production in its own right, it also reflects a broader economic transition, given how much of our economic and financial practices are built on fossil fuels (Malm, 2016). Growth since the industrial revolution has been driven by ever greater consumption of fossil fuels (Frankhauser & Jots, 2017). Energy sources based on 'work done', rather than heat from burning things, is clearly shown to be more efficient. Renewables are also becoming ever more efficient, driven by innovation in the weightless, knowledge economy, and are not subject to constraints related to accessing fossil fuels. However, energy created this way is often not dispatchable and can be harder to store, which reduces its flexibility and application to certain forms of transport like aviation, shipping and haulage, but here too technology is rapidly evolving to overcome technical barriers (Mission Possible Partnership et al., 2022).

The world is shifting from a resource and labour intensive OPEX to a knowledge driven capital expenditure (CAPEX) based energy system[xix] with implications for the relationship between energy consumption and energy production and the role of innovation. Estimates of the cost breakdown for energy technology in the UK in 2016 showed that 10% of the costs of a gas turbine are borne upfront, compared to 74% for round 3 offshore wind and 87% for large scale solar PV (BEIS, 2016). This has significant implications for how the costs and benefits of transition will play out and means that upfront investment is needed.

The UK's CCC estimates that the country needs to ramp up its annual additional investment (relative to a no-action counterfactual) to over £40 billion as early as 2025, and maintain it at a 'new normal' level of around £50 billion from 2030 to 2050 to bring UK emissions to net zero by 2050 (see Figure 13). This additional investment is equivalent to less than 1% annually of projected GDP over this period. The OBR has estimated that about £14 billion of this annually by 2030 will need to be public investment. The CCC and others have argued that if this is well executed and embedded in a new growth strategy for the UK, such an increase in investment will not only be fully offset by the operational cost savings it delivers over time, but will also deliver high returns in terms of productivity, new opportunities and the environment (Stern & Valero, 2021). Falling OPEX costs significantly outweigh the additional costs expected through the transition (with approximately £60 billion cost saving in 2050 compared to £40 billion CAPEX spending).

Figure 13. Capital investment costs and operating cost savings in the CCC's Balanced Net



Note: CAPEX refers to additional annual capital investment. OPEX refers to savings due to operational cost reductions.
Source: CCC (2020).

However, large upfront capital requirements make the transition vulnerable to interest rate rises. The CCC estimates that increasing interest rates from 1.5% to 7.5% would raise financing the costs of the transition by 30%. (Robins, 2020; Zhou et al., 2021). The shift from CAPEX to OPEX systems is likely to have far reaching implications as the methods for structuring the financing of these developments shift to reflect the changing cost structure, with larger implications for how energy deployment in financed and accounted for on balance sheets. Any higher capital intensity also makes the transition vulnerable to the impact of prolonged high interest rates.

4.2 Grey in a greening world: risks associated with not transitioning to 'clean'

If the UK is slow to transition, against a backdrop of global decarbonisation, it will be in danger of losing out on the benefits to industry and innovation, and being left with stranded physical, human and intangible assets. Recent announcements and policy developments demonstrate the major advances in climate action that are occurring globally. The passage of the US' 2022 IRA evidences the direction of travel in the world economy towards clean energy technologies. In 2023, there has been a $284 billion of investment in new manufacturing, clean energy deployment, electrification and carbon management in the US, representing a 36% increase from the previous year (Rhodium Group & MIT CEEPR, 2024). In Q1 2024 there was $11.4 billion invested in battery technology alone.

Public and private investment in China has made it the largest deployer of clean energy globally. China's recent advancements in EV manufacturing are likely to significantly reduce the cost of EVs globally in coming years. It is increasingly clear that China has been able to carve out key subsectors in the clean economy, driving cost reduction and owning the market. As noted earlier it is striking that clean energy sectors accounted for 40% of Chinese GDP expansion in 2023, the largest sectoral driver of economic growth in the country (Myllyvirta et al., 2024).

Other countries are waking up to the dangers of falling behind and channelling huge sums into clean transitions. Countries with car makers that were that were slow to adopt battery technologies risk the loss of jobs, supply chains and export markets. The EU has passed major legislation both leading on efforts to decarbonise and also in response to moves made in the US and China. In response to the passage of the IRA in the US, the EU Commission responded with the Net-Zero Industry Act (2023) which aims to bolster its own clean technology manufacturing. More recently in 2024 it announced new tariffs on China EVs (following the lead of the US) in order to protect its domestic manufacturing sector.

Taking the lead in a competitive playing field therefore requires early supportive and 'enabling' government intervention. Again, this new agenda and the questions facing economic-decision makers naturally demands new and complementary types of analytical approaches.

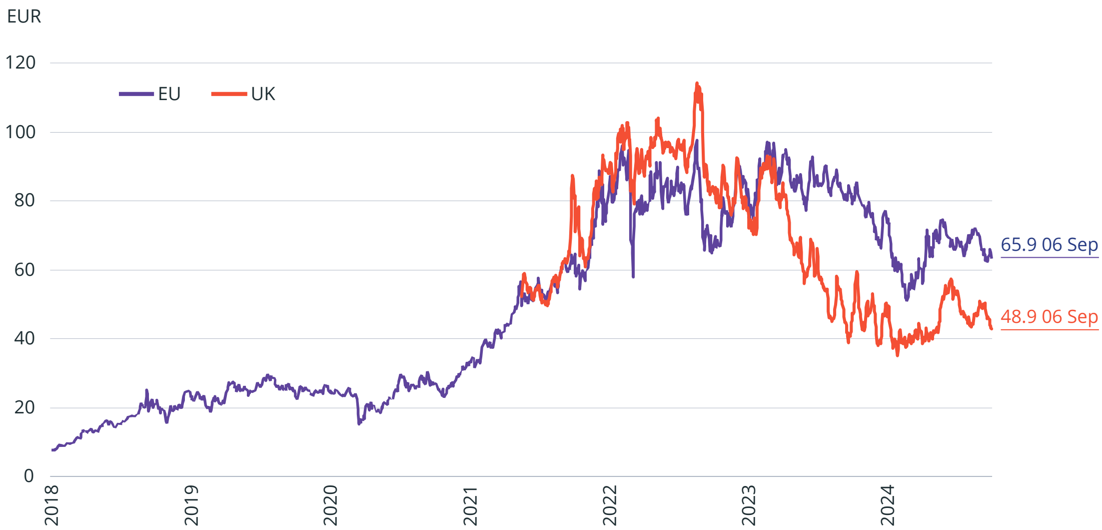
Failure to plan for these global trends poses significant risk to the UK economy. Prior to the General Election in July 2024, the UK had not developed a policy response to these global actions and risks being left behind without action. Since the election the new Labour government has announced plans for a new state-backed clean energy investment vehicle: GB Energy, and has announced plans to expand the development of offshore wind on British seabed owned by the Crown Estate backed by £8.3 billion in state funding (BBC News, 2024).

Stranded, outmoded assets and the risk of being locked out of clean markets

Trade is likely to be affected. In the year to March 2024, UK exports were £860 billion, £400 billion of this was goods, the remainder being services. Our largest single trading partner, the EU, is looking to place emissions standards on imports, making it more costly, and therefore less competitive to export greenhouse-intensive goods to the European market. While the carbon intensity of British products is relatively low by global standards due to the UK's relatively clean electricity system and minimal use of coal (Ritchie, 2023) the UK emissions price has been around 30% below the European equivalent, reflecting a longstanding gap in apparent stringency since the UK left the EU Emissions Trading System (EU ETS) in 2021 (Figure 14).

If the UK fails to decarbonise in line with the demands from its major exporting partners, it could run the risk of losing access to key markets on which the UK relies. The UK is particularly vulnerable to the application of an EU Carbon Border Adjustment Mechanism (EU CBAM) with the EU[xx] as the UK ETS price compares unfavourably in terms of climate ambition. The UK is introducing its own carbon border mechanism[xxi]. The EU CBAM is already prompting increased climate action in India, South Africa and other major EU trading partners inducing a drive to the top from creating incentives. But a failure by the UK to align climate policies or co-ordinate or keep pace with the EU's level of policy stringency for industrial sectors, could risk important UK exports being penalised by the EU CBAM. This could entail large financial transfers to the EU, amounting to €1 billion or more annually.[xxii]

Figure 14. UK and EU ETS prices (expressed in euros)



Note: UK ETS prices converted to EUR with daily GBP/EUR exchange rate.
Source: Macrobond dataset, via Independent Economics.

Integrated carbon pricing and a border adjustment are vital in incentivising a UK energy transition. Failure to integrate carbon and energy markets into a comprehensive trade policy with the EU threatens costly trade frictions. It also risks exacerbating supply chain bottlenecks and price pressures to the UK's renewable sector. Full linkage of UK and EU schemes affords the most efficient route to decarbonisation. It would reduce UK-non-EU trade frictions, prevent curtailment of renewable power supplying Northern Ireland (which unlike Great Britain is part of the EU Single Electricity Market) with trivial loss of UK policy autonomy. Moreover, income from auctioned allowances affords a much needed source of public revenues. Such convergence could yield £3 to 5.8 billion for the exchequer, according to one estimate,[xxii] but there is a need to move quickly if the regulatory frameworks are to be established in time to prevent deterring investment and raising UK energy costs.

Collaboration with the EU on energy is a smart entry point to rebuilding relations. As the UK is no longer part of the European Internal Energy Market[xxiv] capacity on most interconnectors from the EU to Great Britain is allocated using explicit capacity rights. This is inefficient and inflexible. The current arrangement in the Trade and Cooperation Agreement also fails to support efficient operation and investment in cross-border interconnectors, especially more complex hybrid interconnectors (a new generation of subsea technology that will connect clusters of offshore wind farms to multiple countries). A system of price coupling between the EU and UK, which does not require joining the Internal Energy Market, is necessary to realise the untapped potential of the North Sea, in order to maximise benefits for EU and UK consumers and enable future investments.

The UK is a major exporter of fossil fuel related services, including finance, surveying and engineering. In part due to the UK's historic role in the industrial revolution and the initial use and expansion of fossil fuels, the UK retains significant technical expertise in the wider services that support the fossil fuel economy. This includes the trading, shipping and financing of fossil fuel projects. While this expertise has historically been successfully exported and underpins a large portion of our services based economy to date (Marriot & Macalister, 2021). Demand for these services will fall in the medium to long term if the global economy begins to shift away from new fossil fuel expansion and infrastructure and begins to shut down fossil fuel infrastructure all together. If the UK service sector fails to transition in line with the global economy (see section 4.3 below) there is significant risk of a number of service assets being stranded over the coming decades.

Moving beyond extraction

The low carbon technology future is expected to be significantly less resource intensive than our current fossil fuel system. Analysis suggests that peak demand for critical minerals could reached in a decade (Walter et al., 2024). If this can be delivered, by accelerating the electrification process through the steps outlined in this report, then near zero battery mineral mining could be possible by 2050. Battery material recycling can be achieved at 90-94% efficiency replacing the vast majority of virgin battery material demand.

To achieve the post-extraction future for critical minerals six additional steps have been identified as needed: new battery chemistries, making batteries more energy-dense, recycling their mineral content, extending their lifetime, improving vehicle efficiency, and improving mobility efficiency (Walter et al., 2024). Delivery against this timeline would require a cumulative 125 million tons of battery materials. By contrast, demand for lithium, cobalt and nickel for the production of EV batteries was 0.66 million tonnes in 2023 (IEA, 2024c) while total mined materials for the low carbon transition was around 7 million tonnes (IEA, 2021b; Ritchie, 2023). While supply is exceeding demand for these battery minerals in the short term, keeping the price of batteries down and facilitating the expansion of BEVs, there is concern about the implications of lower cash flows and narrower margins for mining companies (ibid.). A careful and proactive approach is therefore needed to expand capacity and facilities rapidly over the next decade while also proactively creating the circular supply chains that are required to replace current mining practices.

Nevertheless, it remains clear that both sufficient supply is available, and that the extraction needed for a circular future is significantly less resource intensive than current practices. The 125 million tonnes of virgin minerals required over the next 3 decades is 17 times smaller than the amount of oil extracted and processed to meet global road transport demand annually (Walter et al., 2024).

Dependency of volatile and costly fossil fuels

As an economy the UK remains highly dependent on foreign sources of energy, consuming around 52 million tonnes of crude oil and natural gas. The country still produces around 38 million tonnes, but that output continues to decline. While this poses immediate questions around the price of oil and gas with Russia's war against Ukraine, it also poses long term challenges for the UK economy. Continued dependence on fossil fuels exposes the UK to high and volatile energy costs, undermining our energy security, future living standards and economic competitiveness.

In the very recent past the country felt the domestic effects of rapidly increasing oil prices which generated the need for government support schemes, drove falling living standards due to a cost-of-living crisis and wider inflationary effects, and impacted the cost of borrowing and mortgages as a result. This had implications for inequality and sustained political support for climate investment (see section 4.3).

The UK has also experienced increases in the cost of borrowing. This posed a risk to the transition through the inability to secure new offshore wind investment in the latest CfD round in the UK. Although CfD strike prices fell very rapidly in recent years, with 2023 prices being 70% lower than 2018 ones, costs and consequently prices have risen due to the higher cost of capital and inflation in the supply chain (CCC, 2024). The government didn't receive any bids in CfD allocation round 5, due to a failure to adjust strike prices to deal with these cost pressures (ibid.). The negative cyclical impact of higher interest rates and supply chain issue should not be a surprise for such a capital-intensive sector, yet the secular trend in wind technology costs remains firmly downwards. A new round with higher guaranteed electricity prices was launched by the new government in September this year. 131 projects won state contracts. Offshore wind also secured contracts, however, the government is still far from the target of quadrupling offshore by 2030.

Into the bargain, the UK maintains large subsidy schemes for the fossil fuel industry which maintains our dependency on fossil fuels as an energy source and hides their true cost. In response to the energy crisis, £78 billion (OBR, 2023) was spent supporting consumers between 2022-24 mostly in the form of fossil fuel subsidies, although £30 billion or so was clawed back in windfall taxes[xxv]. These time limited subsidies come on top of a further £58.55 billion in explicit and implicit subsidies in 2022, corresponding to 2.3% of UK GDP in that year[xxvi] (Black et al., 2023). Subsidies are also implicit in the unequal carbon taxation applied to energy. In particular, the carbon taxing of electricity and the exemption for domestic gas consumption imposes a significant price disparity between the two and disincentivises domestic electrification, a key source of economic and employment growth over the coming decades (Stephenson & Allwood, 2023). By charging 5% instead of 20% Value Added Tax (VAT) on domestic fuel bills, the UK effectively subsidises gas by the missing 15%.

Globally, IMF research shows that £7 trillion is spent a year on subsidising fossil fuels including both direct and implicit subsidies (Black et al., 2023). Such subsidies act to hide the true cost of fossil fuels, which is further obscured upward price pressure from supply restrictions by cartels such as the Organization of Petroleum Exporting Countries. The net result is that the market price is obscured, while billions of dollars in global publicly funded domestic subsidy flow directly to oil producing countries. The sustainable economy can incur major savings from forgone fossil fuel purchases. By one estimate, in the first seven months of 2022, renewables helped the UK avoid the need to buy around £12 billion of gas (Brown, 2023). Savings could have been even larger, had the UK pursued a faster transition to renewables and energy efficiency. Besides, an IMF study estimates that the GDP multiplier of green investments in renewables is on average 2.2. to 2.5 times higher than investments in fossil fuel energy (Batini et al., 2021).

In the longer term, if the UK remains dependent on foreign fossil fuels while the global economy decarbonises at a faster rate, the UK places itself at risk of greater price and supply shocks. The concern over dependence on imported fossil fuel is already being recognised worldwide. Ethiopia, for example, has banned the import of non-electric cars to speed up the transition from fossil fuels. This was done to reduce the state dependency on fossil fuel imports.

Capturing the opportunities of clean growth

The global economy is undergoing three major transformations involving general purpose technologies in clean energy, AI and automation. It is becoming apparent that marginal incrementalist views and analytical approaches are ill-suited to strategically build a prosperous and resilient economy in the twenty-first century (Mercure et al., 2021; Peñasco et al., 2021b). This report has previously set out the innovation, productivity and growth opportunities available in a transition. This requires investing in complementary assets that raise productivity and offer the greatest potential (Aghion et al., 2016) to compete in global carbon-constrained markets of the future.

The IEA's net zero scenario suggests that decarbonisation could produce a net 9 million new jobs globally (14 million offset against 5 million lost in the move away from fossil fuels) and add 4% to global GDP by 2030 (IEA, 2021c). However, without the necessary policy regime to support it, the UK will be unable to capture its full share of these benefits.

The government aims to reverse many of the previous government's retreats from policy aimed at driving low carbon deployment and innovation, such as the delayed ban on new ICE car sales which undermine the UK as a place for investment in clean technology. It recognises that actions that reduce trust in the government's net zero strategy inhibit investment in the technologies required for a transition and endanger growth opportunities for the UK.

Box 6. Businesses are calling out for stable regulation

The new government has promised to reintroduce the ban on the sale of new ICE cars from 2030 to 2035. The previous government's pushing back the date for ending ICE car sales by five years undermined certainty in the market for electric vehicles, with the Society of Motor Manufacturing Traders describing the move as "very confusing", causing investors to move their money elsewhere where greater returns and certainty can be found. Gerry Keaney, CEO of the British Vehicle Rental and Leasing Association, on the announcement of the delayed 2030 new ICE car ban said that it will "frustrate many".

"Those that have made huge financial and strategic investments in this technology and mobilised their customers and workforces for decarbonisation will be worried that government is applying the brakes... Others will be grateful for the extra breathing space this delay provides. They will be hoping that it gives more time for costs to come down and consumer attitudes to change. We await the further details that will show the true impact of today's announcement. It is important that progress isn't paused and momentum can be maintained. Either way, everyone is likely to have less trust in the government's net zero strategy and will think a lot harder before committing to any of its future strategies or roadmaps." (IT Fleet Automotive, 2023).

4.3 Risks associated with the transition: shifting finance, economics and power

As with any major shift in our economic system, the transition poses a number of risks that need to be accounted for and mitigated against. As observed in response to climate policy implemented globally, far-right parties have sought to leverage the fear and misconceptions associated with a green transition to achieve power and prolong a fossil powered economic system. Without public, and particularly 'working family' support for the transition, the sustained action that unlocks the growth and productivity opportunities explored in this report will not materialise.

The transition must be just

A clean transition will require a fundamental reorganisation of how our economy is structured, powered and organised. This cannot be achieved within one electoral cycle and will, at a minimum, take place over the timeframe of decades as existing technologies are scaled up and deployed and new technologies are innovated. In order for the transition to be sustained, it will require maintaining public support and ensuring that the benefits that arise from the transition are felt by the communities where the change takes place.

A policy framework that does not fundamentally account for the root causes of the societal and global unrest jeopardises the necessary conditions for a transition.[xxvii] Anti-climate movements will then continue to undermine the transition and the corresponding growth potential that it can deliver. Indeed, existing supply shocks that raise the price have fossil fuels have had significant distributional impacts with the poorest hit worse than those more affluent (Ari et al., 2022). Paradoxically, there is evidence that this has further eroded political support for clean energy policies and strengthened the anti-climate political movements as seen in the recent 2024 European Elections. Markkanen & Anger-Kraavi (2019) argue that in order to succeed, climate policy should aim to explicitly reduce inequality.

4.4 Global and geopolitical risk: the need for action in a rapidly changing world

Any transition will occur against a backdrop of other systemic changes within the global system. These interactions may be positive or negative. Positive interactions, such as increased automation and digitisation; for example, increased digitisation in buildings, can reduce energy consumption through greater knowledge of building use and occupancy (WEF, 2024). Negatives interactions include climatic weather impacts, which disrupt clean supply chains and increase dependency on fossil fuels (Leslie, 2022).

This context reinforces the need for flexibility and resilience within the system for a transition to both respond to changing global conditions and protect against their potential consequences. By understanding the current global context in which decarbonisation is playing out, we can begin to see the types of changes that may occur over the next three decades as well as the mechanisms through which flexibility and resilience can be built into a system transition.

Climate change

Climate change itself will also pose a significant risk to the global economy and mitigation efforts more specifically. The world is already seeing the major impacts that global warming is having through the increased strength and frequency of events like wildfires and flooding (EM-DAT, CRED/ UCLouvain, 2024). This poses significant costs on the countries where these events take place and can hinder the transition away from fossil fuels, thereby causing a feedback loop which further embeds fossil infrastructure (Laybourn et al., 2023).

The impacts of climate change have further knock on impacts on the global economy through the second order effects of natural disasters as well as the impact on globally significant infrastructure. Droughts in Spain are in part responsible for a 89% increase in the cost of olive oil in the UK between 2022-24, further feeding into the cost of living crisis, fuelling public dissatisfaction with political parties and reinforcing the rise of anti-climate political movements. At the global level, reduced rainfall in Panama has lowered the water level of the Panama Canal reducing the through capacity of the passage and reducing the number of ships that can pass through in a day, causing shipping delays (Ruiz & Shintani, 2024). This has the potential for further ramifications on prices and global shipping more broadly. Furthermore, the ramifications of climate impacts are beginning to undermine the insurance industry that underwrites such disasters. Swiss Re, one of the world largest insurers has warned that the sectors is significantly underestimating the risks associated with natural disasters. A recent analysis estimated that models of insurance costs from climate disasters have been off by a factor 10-20% for recent disasters and global insured losses from natural disasters exceeded $100 billion in 2023 for the third year in a row (Bryan, 2024). In the UK, the costs to the economy of flooding events in 2015-2016 are estimated to be £1.6 billion (CCC, 2021).

Regardless of future emissions reductions, one estimates suggests that a near 20% reduction in global income by 2050 due to climate change is already baked-in and unavoidable. This is many times larger than all estimated mitigation costs associated with achieving 2 degrees of warming (Kotz et al., 2024). One can quibble with individual projections, but overall, climate change has the potential to act as a major obstacle to growth. Both in its direct effects, causing large-scale physical damage to communities through natural disasters, and second order effects that impact prices, trade, and have the potential to undermine mitigation action itself.

The scale of these global risks reinforces the need for countries to be flexible and resilient in their approach to low carbon investment. Reliance on a single foreign source for key resources and goods for the transition puts the supply chain at significant risk, particularly given the increased trade tensions between the US and China. Additionally, these emerging geopolitical trends pose risks to digitation, electrification and the potential growth opportunity from AI.

The UK should ensure that it has, where possible, flexible supply chains that can adapt to sudden disruptions and increase the resilience of these supply chains by creating domestic manufacturing capacity where possible, and reducing reliance on less stable geographic regions where not.

Trade wars and the markets of the future

Perhaps most critically for its interaction with clean growth and innovation, the role of China and the recent erection of trade barriers for clean technology poses a substantial challenge for a growth and prosperity plan built on innovation. To date China has been responsible for driving down the price of low carbon technologies including solar PV and batteries, and most recently EVs (Hilton, 2024). This has resulted in both the US and the EU placing increased tariffs on Chinese technologies in order to protect and grow their domestic manufacturing bases. In 2024 the US introduced new tariffs on Chinese made clean technology which include a 100% tariff on Chinese EVs, a 50% tariff on solar cells and a 25% tariff on the value of lithium-ion batteries (US Government, 2024). European tariffs on Chinese EVs vary by manufacturer but will be as high as 37.6% (European Commission, 2024).

US and EU tariffs on Chinese imports are misplaced. China has been subsidising production in sectors which have experienced substantial cost reductions, in line with Wright's law, which would otherwise not have entailed. As a result of which, they are shaping and supplying domestic markets and cornering global ones. China's domestic EV market is larger than the rest of the world's put together. This is quite distinct from a policy of deliberate overcapacity and under-pricing to gain global market share. Importers such as the UK are benefiting from China's investment, having been late to invest in developing their own sector. A trade war will simply add to costs and slow global growth. At this stage, importing cheap BEVs is probably the best way to kick start a UK transition by creating demand for chargers and associated infrastructure. It would be better to subsidise domestic production, if there is any chance of a future UK comparative advantage.

Protectionist moves such as these tariffs have the (perhaps unintended) potential to allow for domestic markets to grow and potentially scale and innovate in order to compete with Chinese production. However, they also risk delaying some of the deployment and rollout of clean tech in domestic markets that are crucial to the transition. Without positive plans to create domestic manufacturing for renewable energy technologies in the UK, the emergence of a trade war poses great risks to the UK, potentially constraining supply lines and slowing access to growing clean world markets and technologies. Strategic decisions include whether to focus on domestic production of the key energy generation technologies such as batteries and solar PV or, if not, how it will be able to guarantee access to these crucial technologies, including through greater co-operation with potential future manufacturing hubs like the US and the EU. Notably in some sectors such as solar PV, there is currently insufficient capacity within the global market, already dominated by Chinese goods, which limits profitable domestic growth and innovation opportunities.

The increased geopolitical tensions observed between the US and China and increased trade barriers reflects a wider shift in international relations between the East and West. There are growing concerns over the Chinese position on Taiwan, and the role that Taiwan plays in global semiconductor production (and important role that semiconductors play in the growth opportunity from AI) places this relationship under further stress. For the UK, increased trade restrictions both on clean technology and semiconductors poses significant risk to the country's ability to grow and increase productivity.

Global shifts in trading patterns and barriers pose questions for how the UK interacts with major trading blocks. Reduced alignment with Europe presents the potential that the UK will be negatively impacted by the introduction of carbon-border adjustment mechanisms (see section 4.2 above). It further lacks the manufacturing capacity to align with the US model of imposing tariffs on the imports of Chinese clean technology to provide space for domestic producers. Nevertheless, as set out in section 3.3, there are a number of service sector including academia, engineering, consulting and financial services alongside manufacturing (including small scale aviation and energy efficient chips) where comparative advantages exist. However strategic decisions need to be made on how the UK engages with the major global trading blocs and their respective roles in future trade and decarbonisation, as well as how to leverage the UK's own strategic niches.

Artificial intelligence

One of the key concerns surrounding the geopolitical tensions between the US and China is the development of AI and the need for computational power, the majority of which is currently manufactured in Taiwan. In addition to the impacts on trade, AI has far-reaching implications, including (but not limited to) economic growth, employment and energy consumption. Moreover, it is expected to further accelerate low carbon technology through the acceleration of tipping points in the deployment of new technologies (Stern & Romani, 2023).

The growth of AI and digitisation, in tandem with a new energy economy, underscores the need for an economic strategy. Beyond the potential positive impacts of AI to reduce emissions, for example through more efficient real-time management of resources, AI is expected to have a major impact on the global economy affecting 40% of all jobs (Cazzaniga et al., 2024). This rises to 60% of jobs in developed economies, complementing jobs in half through AI integration leading to enhanced productivity whereas the other half of impacted jobs could be partially or entirely replaced by AI (ibid.). Consequently, a radically different politics may be required to respond to changing employment markets and ensure that the benefits associated with AI are not solely captured by corporations at the expense of displaced. While some reorganisation of the labour market is essential and may also provide increased employment capacity for the jobs that are expected to expand under the transition. This effect, particularly when observed over a global scale, requires careful consideration and management so that the benefits are realised and shared by society.

AI highlights the need for a risk-opportunity based strategic decision-making toolkit at the heart of government. AI is expected to have a series of further disruptive impacts that are as yet unknown, although potentially reinforcing other observed trends. For example, the rise of export controls of sensitive and dual use technologies with military applications will likely have major disruptive effects on markets, global supply chains and corporate licenses (The Oracle Partnership, 2019). These structural pressures underscore the importance of the UK to have a strategic plan for economic transformation which clearly guides private investors by credibly articulating the country's ambitions.

Weighing up trade-offs and benefits

The transition to a net zero economy, in parallel with the growth of the intelligent digital economy, poses risks in addition to the opportunities previously presented. Failure to provide the level of investment needed to transition the economy will prevent the UK from grasping new and sizable growth opportunities and leave the country with outdated and redundant technologies and dependent on volatile global fossil fuels markets and imports of clean goods and services.

While risks with the transition remain (both political and economic) these can be minimised and mitigated against by retaining flexible and adaptive policy, that prevents lock in to outmoded assets and behaviours, keeps options open to respond proactively to new and radical changes, and minimises the disruption and adverse distributional impacts associated with transformative change.

These risks take place against a backdrop of wider global trends and risks including shifting trade patterns, AI and the impacts of climate change. Investment in resilient assets is fundamentally linked to all of these and cannot be considered in isolation. There is no real trade-off between transition and growth.

4.5 Fiscal policy and public debt management

Paying for investment: upfront funding is available

The shift from OPEX based energy infrastructure costs to CAPEX based development highlights the need for significant investment that can and should be delivered through borrowing. Fiscal sustainability requires investing in assets that generate sustainable private and public returns.

The direct public finance required to support this transition should not be expected to worsen public debt to GDP dynamics. Indeed, by facilitating long-term resilient growth, borrowing to invest is the only way to secure enduring public debt sustainability. If public borrowing is used to invest in the productivity of public assets (Buiter et al., 2020), or to enable private assets to become more productive, it can generate growth and tax revenues that allow debt interest to be repaid (Coyle et al., 2019; Robins et al., 2020). All debt is not created equal, when it comes to debt sustainability. It is not sensible to treat debt accrued to finance consumption as the same as debt accrued to finance investment in the asset side of the balance sheet. A healthy private company or a responsible individual recognises this, and government should too. As part of a comprehensive wealth approach, natural capital accounts can guide investment in assets that are likely to become devalued or stranded. Such macro considerations indicate the need to adopt a broader balance sheet perspective (Coyle et al., 2019; Zenghelis et al., 2020b).

Clean investment is broadly defined. This discussion is not about 'the environment' versus 'schools and hospitals'. Sustainable growth comes from productive investment right across the economy, some of it in less technologically sophisticated sectors such as home insulation, improved grids and social support such as skills retraining, housing, health, education and transport, to enable people to take advantage of the opportunities of a changing economy. Other activities, such as limiting airport expansion and deploying carbon capture and storage (CCS) will increase costs and constrain growth. As with all risk–opportunity-based strategies for assessing a structural transition, the precise magnitude of the benefits cannot be quantified, but the investment costs are known and upfront. This is not a reason for delay. Paring back on vital investment at this critical time is likely to prove to be economically and fiscally irresponsible as well as environmentally damaging. The balance of risks and opportunities is clear and is illustrated by evidence.

Use of scarce public resources should be temporary and targeted at sectors close to a technology or behavioural tipping point. Indeed, the bigger political risk is that fixating on investment costs results in a failure to notice and avail of the biggest opportunity for economic renewal in a generation. Once the UK's sustainable innovation system is up and running, government support can be phased down, as new, more efficient and productive industries increasingly outcompete the old and generate their own global revenues and inward investment (see Figure 11). By contrast, inaction would likely prove costly to economic competitiveness and financial resilience and require costly remedial support later.

Reforming public sector debt rules to enable investment and build net worth

With public debt in many countries already pushed to historic highs, relative to output, there is understandable concern about our ability to pay for all this public investment. A series of unexpected events, the financial crash, Covid and the Russia's war against Ukraine, have pushed up public debt in the UK and elsewhere. Managing the public finances well reduces vulnerability to future debt crises and the threat of debt default and insolvency, especially if interest rates rise or growth disappoints (Cochrane, 2020).

There is evidence that public bondholders have become more nervous in recent years and will punish undue profligacy (Gómez et al., 2024). Some cite the panic in the UK gilt market over Liz Truss' economic plans as evidence of fragility and the power of bond vigilantes. But financial markets were intolerant of the Kwarteng Autumn 2022 budget measures, which were deemed unsustainable because borrowing was intended to fund tax cuts which would mostly drive consumption rather than investment and fail to address the inadequacies of core public sector assets. Public profligacy is indeed a danger to bond holders, if the debt is not used to build up growth supporting assets. Bondholders will recognise that the main constraint to UK growth is decades of underinvestment.

Fiscal sustainability builds confidence and enhances intergenerational equity, by reducing the likelihood that one generation of taxpayers will have to pay for the profligacy of previous generations. There are many definitions of fiscal sustainability including "the ability of a government to maintain public finances at a credible and serviceable position over the long term" (OECD, 2013) and "the ability of a government to sustain its current spending, tax and other related policies in the long run without threatening its solvency or defaulting on some of its liabilities" (European Commission, 2019).

Income and asset growth is the key to debt sustainability, as anyone with a mortgage will recognise. It undermines the denominator in debt-to-GDP ratio and weakens the flow of net fiscal revenues necessary to meet interest payments and pay down debt. As Table 1 below shows, growth offers the only secure avenue for bringing the ratio down again. By contrast, aiming to balance budgets prematurely, after such a traumatic economic shock, is likely to prove self-defeating. The OBR estimates that the productive potential of the economy is a key driver of debt sustainability. It estimates that a 0.1% increase in UK productivity growth would reduce the ratio by 25 percentage points over the next 50 years, and a full one percentage point increase, equivalent to a return to pre-financial crisis rates of productivity growth, could contain debt below 100% of GDP throughout the next 50 years (OBR, 2024b).

Yet in its forecasts, the OBR currently considers only the demand side effects of public investment and assumes multipliers are zero after five years. Public investment, in other words, has no impact on long run productivity (Suresh et al., 2024).

Table 1. Options for reducing the public debt/GDP ratio

	Nominal	Real
Reduce numerator (debt)	**Default, restructure or creditor 'haircut'** • Cost to economic reputation • Increased future borrowing costs (default premium)	**Austerity (cut spending/raise taxes)** • Taxes up/public spending down • High cost to economy and society • Can be ineffective (because of denominator effect)
Increase denominator (GDP)	**Inflation** • Effective, but at economic cost • Hard to restore monetary credibility • Uneven distributional impact on society • Increased future borrowing costs (inflation premium)	**Growing the economy and raising GDP** • Effective if sustained • Positive impact on numerator by raising net public revenues • Positive for the economy and society

Improving the health of the population, a key consequence of reducing particulate pollution associated with burning fossil fuels, could reduce the rise in debt by a further 40% of GDP. Urban air pollution is a major cause of respiratory illness, cardiovascular disease and early mortality. The Committee on the Medical Effects of Air Pollutants (COMEAP, 2010) estimates that, in the UK, premature deaths resulting from a single particulate pollutant, $PM_{2.5}$, currently total around 29,000 per year[xxviii] Global welfare losses due to pollution are estimated by one study to amount to 6.2% of global economic output (Landrigan et al., 2018).

There is no magic ceiling to public debt-to-GDP ratio. Total government debt as a percentage of GDP in Japan was a sustainable 238% in 2019 (Jubilee Debt Campaign, 2020). What matters is not the level of public debt to GDP, but its quality in terms of generating sustainable investment and growth. It is the latter that secures prosperity and provides the foundations for public debt sustainability.

The UK should move away from being constrained by arbitrary accounting rules from undertaking profitable and much needed public investment. Fiscal rules lie at the heart of this UK's growth problem. There is no such thing as a fixed 'fiscal headroom' when it comes to stimulating good investments. Debt is not a 'burden' when it is used to fund resilient and productive assets rather than consumption. The government creates fiscal space by promoting investment in core public assets which generate future returns.

A recent letter from former officials and academics emphasises the critical need for increased public investment and calls for a change of fiscal rules and the OBR's mandate (O'Donnell, 2024; O'Donnell et al., 2024). OBR analysis suggests that delaying action on net zero, could raise public sector debt by 23% by 2050, compared to an early action scenario by 2050 (OBR, 2021). Investing now is cheaper than delaying action.

To preserve fiscal responsibility, there is an overwhelming case for dropping the existing public debt rule and tightening rules on balancing the current budget over the cycle. One option is to err towards a current budget surplus[xxix]. This will be challenging, but prioritising investment requires tough choices over higher taxes or lower current spending. Appropriate fiscal risk analysis requires a comprehensive view of the public sector balance sheet, explicitly accounting for the uncertainty inherent in fiscal forecasting. The Office for National Statistics (ONS) already measures the broadest balance sheet aggregate that can be produced under existing statistical accounting frameworks, the public sector net worth (PSNW), as well as public sector net financial liabilities (PSNFL), a narrower measure which includes some illiquid assets recognised in the national accounts. These two measures of the government's balance sheet are based on internationally recognised and comparable standards.

The net worth of the UK's public sector has been steadily falling. Having turned negative for the first time since estimates began (in the mid-60s) in 2010, the public sector net worth excluding public sector banks had fallen to a £715.4 billion deficit at the end of December 2023 (ONS, 2024). This reflects low and volatile investment (Ebdon & Khatun, 2021). Among rich countries, only Portugal has performed worse (Odamtten & Smith, 2023). Data on public assets, especially intangible and indirect ones such as knowledge availability and the human capital of UK workers, is harder to assess than financial debt. Public assets are also difficult to liquidate at short notice in a crisis. But both measures capture the value of investment versus consumption and should be presented alongside measures of debt when trying to assess responsible debt management. Verifying net worth forecasts through OBR validation would help further instil market credibility.

Capital costs associated with the transition may also be brought down by reducing the perceived risk premiums. Research looking at the carbon risk premium of companies found that strong country level policy and support lowered the risk premium for companies looking to transition (Bats et al., 2024). Investors are therefore likely to apply a higher risk premium to low carbon activities in the UK when there is a lack of climate policy stability and support (see discussion in section 4.2 on delayed phase out of new ICE petrol and diesel cars). A stable policy environment in which businesses feel there are risk adjusted returns and growth opportunities to be had from investing in clean assets can reduce the cost of capital, spurring investment and providing a positive feedback that drives greater investment, further reducing the 'green' risk and driving the premiums down further.

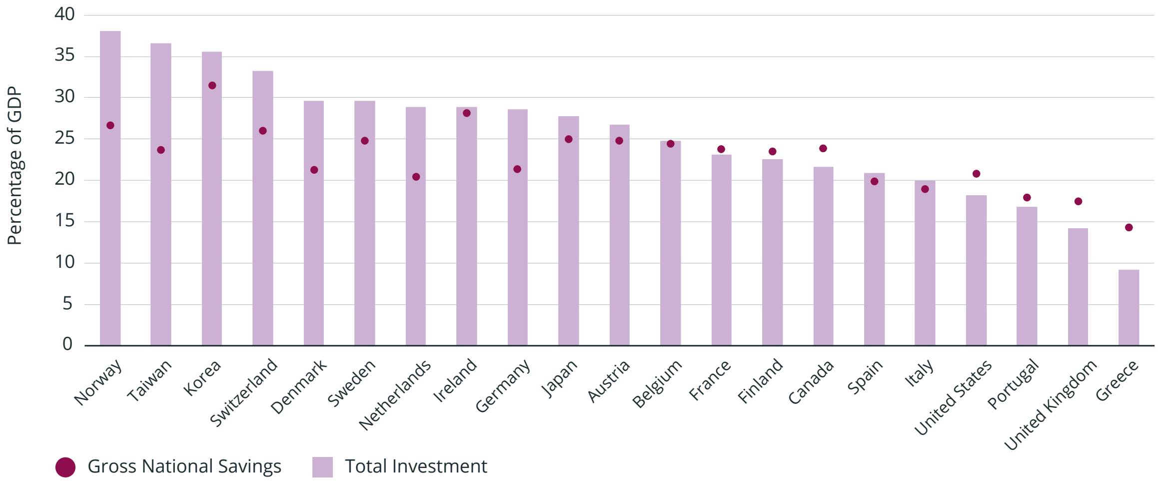
The path of interest rates is critical for debt sustainability, particularly as capital is substituted for fossil fuels. In the past one to two decades, global planned investment has been historically low in relation to planned saving, which has resulted in low productivity growth. Proof of this is that real interest rates have been near zero for more than a decade and investors are hungry for positive real returns (Zenghelis, 2023; Zenghelis et al., 2023).[22] The rise in nominal interest rates from December 2021 does not fundamentally alter this underlying shift towards stagnation, nor is it explained by a rise in desired investment.

One of the features of the past two decades is that investment in advanced economies has not risen in the presence of 'free money' (Zenghelis et al., 2023). Part of the answer is likely to do with a lack of monetisable projects, reflecting mounting perceptions of policy risk in a world of rapid structural change, where credible leadership and consistent public intervention are of increased importance.

There is no shortage of available finance and, although neutral real interest rates are unlikely to return to negative levels for a prolonged period, an abundant supply of global saving is likely to continue (Stern & Zenghelis, 2021). Real rates may settle at a somewhat higher value than in recent decades, perhaps 1% or more, not least in response to clean infrastructure investment demands and reflecting a political shift towards active industrial policy to drive investment (Blanchard & Summers, 2023), but by historical standards the opportunity to absorb saving for productive investment looks likely to remain high. It is important to note that slightly higher UK long term Treasury yields would go hand in hand with higher UK growth expectations and should not necessarily be viewed as a sign of market anxiety.

The UK has a fundamental and debilitating saving problem, which is raising capital costs. UK households, government and firms have not saved enough to fund the UKs relatively paltry investment demands (Figure 15). It will need to increase its domestic supply of savings to avoid reliance on global sources of investment and a widening current account disparity (Zenghelis et al., 2024). Failure to grapple with excess consumption (which is the precise reciprocal of deficient saving) risks raising the cost of capital and crowding out private investment. This is because boosting public investment, without curbing consumption and boosting saving, will (all else equal) prompt the Bank of England to raise interest rates to offset the extra inflationary demand, thereby crowding out private investment with undesirable consequences for UK growth (Zenghelis, 2024). It will also boost the UK's already sizeable current account deficit, as investment requires in borrowing from abroad. This results in vulnerability to shocks, insufficient retirement savings for many, and implies that the returns to UK investments accrue to investors overseas. The UK relies increasingly on the kindness of strangers.

Figure 15. Gross national savings rates and total investment rates for selected advanced economies, averages between 2010 and 2023



Note: 2023 values are estimates. Investment is defined as Gross Fixed Capital Formation.
Source: Authors' analysis based on data from IMF (2024), informed by Wolf (2023).

Raising revenues to fund necessary day-to-day spending, while boosting saving, requires the government to reconsider its commitment not to raise key taxes such as income tax, VAT, national Insurance and corporation tax, which account for 75% of revenues (IFS, 2024b). The risk otherwise is that the burden of taxation focusses disproportionately on a narrow tax base that deters investment and saving. The government should instead reinforce Pigouvian taxes, such as fuel duties and carbon pricing targeted at certain activities to change behaviour, while applying broad based Ramsey taxes designed to raise revenues at minimum distortion to the economy. The UK tax system is inefficient, complex and unfair, yet attempts to reform has lacked leadership (Mirrlees et al., 2011). Appropriate use of the tax system to tackle pressing economic challenges argues for reneging on expedient pre-election promises. Politically, this might best be done sooner rather than later.

Given the scale of the investment requirements, precluding small increases in income tax, VAT, national insurance and corporation tax will limit the government's ability to fund necessary investment without creating new efficiencies and distortions. The UK has more VAT exemptions than most countries. This distorts spending choices and raises administrative costs. The poorest households, to which these exemptions are focused, could be amply compensated for their loss through other payments which leave them better off while still providing net tax revenue. In the medium term, one of those most efficient and fair means to raise revenues is to reform property and land value tax. This could be done in the interim through making council tax bills roughly proportional to the value of property. The politics are tricky, but if properly explained, managed and phased the rewards could be great.

Falling revenue from other sources

The state also generates significant revenue from fossil fuel production and consumption while also subsidising fossil fuel production. Revenue includes royalties on production, and taxation on use including fuel duty. These can be expected to decline over the coming decades if the production and consumption of fossil fuels declines. Funding public spending will therefore require both new sources of revenues and existing tax regulations to be rewritten, to respond to changing markets and consumer behaviour. For example, current vehicle excise taxes in the first year are based on the emissions associated with the car, and subsequent years differentiated by fuel, with electric vehicles paying no Vehicle Excise Duty (VED).

While this approach has been successful in incentivising the uptake of EVs (and potentially shifting attitudes away from the most polluting vehicles), the OBR now expect to see a significant reduction in tax revenue as a greater percentage of the vehicle fleet is electric.

A complete phase out of petrol and diesel vehicles would constitute a loss to the Exchequer of £7.4 billion, based on 2023/24 VED revenue alone (Masala, 2023). Further revenue lost over the coming decades will be seen from reduced fuel duty which is currently set at £0.5295/litre and raises around £25 billion annually.

Alternative approaches to raising revenue have been discussed and include restructuring current VED rates to target the size and weight of the car in order to disincentivise the purchase of sport utility vehicles which are more energy intensive, require larger batteries and cause greater damage to the road due to their weight. Road pricing strategies have also been discussed to replace fuel duty. Road pricing, similar to schemes seen in Spain and France, could have further behavioural implications for driving, incentivising a shift towards greater use of public transport particularly over long distances if the pricing scheme worked to equalise the cost between public and private transportation. Another alternative for the structural shift of motorists away from petrol and diesel cars is expanding the carbon pricing regime. Despite the temporary nature of such a regime they could help raise revenues during the transition (HMT, 2021a).

Further fiscal space for financing the clean transition would be available if the government was to adjust several accounting measures that place us out of step with other major economies. This includes the current policy of paying interest for UK bank reserves held at the Bank of England. Data made available by the UK Parliament Treasury Committee (2024) shows that over £9 billion was paid to UK high-street banks in 2023.

The fiscal treatment of UK policy banks limits their effectiveness. UK Export Finance (UKEF), the British Business Bank (BBB) and the UK Infrastructure Bank (UKIF) are all subject to UK fiscal rules which mean that they must compete against other public spending for funding and adjust their investment plans to fit within wider fiscal rules. As would as any potential National Wealth Fund. Alternatively, the government could shift public spending so that public grants are taken off the balance sheet and distribute lending from public institutions on low carbon projects at below market rates. This has been successfully implemented in Germany where the public investment and development bank disburses over 20 times the funds currently given out by UK public investment banks (King & Jameson, 2024).

Box 7. Enabling infrastructure investment, Germany's KfW

Germany's KfW (Credit Bank for Reconstruction) is a policy and development bank with a mandate from the German government designed to promote and facilitate investment and development in target industries. Critically, it operates outside Germany and the EU's fiscal rules, and is able to take on its own liabilities by issuing bonds on the market (Priewe, 2022). Despite not being subject to fiscal rules, the KfW's obligations are guaranteed by the German federal government, and it enjoys a AAA rating and low bond yields that track federal government bonds (King & Jameson, 2024). With its ability to raise funds on the market, the KfW is able to raise, and therefore invest, considerably more than UK policy banks. In the financial year to 2023, it provided €77.1 billion in domestic finance, with total investment over 10x that of all of the UK's central policy banks (KfW, 2024a).[xxx]

The UK could consolidate its many public investment banks (the UKIF, the BBB and UKEF), and establish a scaled-up policy bank that was able to take on its own liabilities by selling bonds on the market, and independently make investment decisions within a mandate provided by the government, while maintaining investor confidence by having Treasury backed bonds. Such a bank could feasibly be positioned outside the UK's current fiscal rules, allowing for a focus on long term investment (King & Jameson, 2024). By setting up such a policy bank, the UK government could increase investment for net zero-focussed infrastructure, research, and technology development where private investors are hesitant, leveraging private investment while reducing the pressure on public finances. Consolidation would incur significant costs and time, and an alternative option for achieving greater lending scale might be rationalisation through an umbrella organisation with independent subsidiaries. This range of opportunities for the UK's public financial institutions needs exploring.

05

A new economic framework for a new style of growth

Path dependency in innovation and the importance of expectations suggest that rather than trying to predict the future, economists could better help policymakers anticipate, manage and steer the course of the transition

A new economic framework for a new style of growth

05

5.1 How can economics inform strategic choices

The dynamics identified in this report raise conceptual challenges and promote a discussion on the most appropriate tools to inform decision-making in the context of structural change (see Geels et al., forthcoming 2025; Barbrook-Johnson et al., forthcoming 2025; COFM, forthcoming). For context the Treasury's core objectives are to:

1) place the public finances on a sustainable footing,
2) ensure the stability of the macro-economic environment and financial system, enabling strong, sustainable and balanced growth and,
3) increase employment and productivity, and ensure strong growth and competitiveness across all regions of the UK through a comprehensive package of structural reforms.

The third objective includes improving employment, productivity and economic growth. This relates to boosting economic efficiency, driving innovation and safeguarding competitiveness. The UK must also seek to develop competitive industries in rapidly changing global markets, utilising new technologies in digitisations and AI while minimising disruption, recognising distribution issues and reducing regional inequality (Stern, 2024).

Central to these objectives, HMT also needs to account for macroeconomic imperatives relating to sustainable growth and controlling inflation, subject to an estimated policy reaction function from an operationally independent Bank of England. It has to factor in distributional impacts, ensuring food and energy security, the cost of living and a wide range of social demands. This requires assessing infrastructure gaps, creating opportunities for jobs and skills that can benefit disadvantaged regions and meeting social demands.

Medium term macroeconomic strategies have to assess multiple objectives against a diversity of interests and agents. HMT will have to address all these challenges alongside pressing infrastructure, security and demographic demands with limited public financial resources.

Much of the discussion around a net zero transition therefore rightly centres on its expected benefits and costs, in terms of potential opportunities crowded out, and new opportunities created by assessing full risk-adjusted returns on clean investment. Decision makers face the task of deciding how technological change is directed, where limited public funds should be spent, how to induce private investment, and how to secure reliable supply lines. Economic tools and models should play a useful role in offering advice on these policy options, shedding light on their political feasibility (Hallegatte et al., 2023). However, it is inconceivable that one model will answer all these questions simultaneously.

That models cannot replace strategic choice and judgement in decision-making is self-evident. Crucially, and as the government's Green Book for appraisal management and evaluation has long recognised, conventional static modelling is of limited use in assessing and informing transformational change. Modelling will not be able to provide the optimal pathway to net zero or the most appropriate industrial strategy to profit from green markets. Due to the complex nature of technological innovation and systemic change, strategic decisions drive the process.

At the national level, China's industrial strategy was based on strategic vision and has transformed the country into the leader of some of the most important green markets (see Box 4). East Asian countries development experience also shows how strategic vision can drive economic growth (see Box 8). South Korea's structural transformation from rice to ships, chemicals and steel and then to electronics is a successful case study.

There is no evidence that an appraisal tool like CBA or prolific modelling was responsible for these decisions. Similarly, our contacts at the US Treasury have told us that although post-hoc modelling has been undertaken, models played a limited part in driving the IRA. Rather, the evidence suggest that these were strategic decisions based on industrial policies aiming to promote high value added sectors in South Korea (Amsden, 1992) and respond to China's competitive lead in clean technologies, which is seen as vital to US interests.

Whether it is the US' IRA or earlier New Deal, space and arms race, Japan's institution of a Ministry of International Trade and Industry (MITI), or Germany's support for its car industry, it is hard to find an example of any country that has prospered for a sustainable period without an active industrial strategy.

Box 8. East Asian case studies in strategic direction

The East Asian 'miracle' refers to a group of countries that experienced high growth rates and sustained them over a long period of time. These countries achieved 6-7% per capita growth per annum between 1950 and 1990 (Chang, 2011). This development experience represents an unprecedented phenomenon in economic history.

The first group of New Industrialised Countries (NICs) included Hong Kong, South Korea, Singapore and Taiwan. Japan is often included in the analysis as it experienced a similar growth path. These countries grew at high rates and for long periods, thereby catching-up with the advanced economies (Palma, 2009). While the paths taken by these economies differ, they share common features, and they are an example of active industrial policy being able to generate a growth enhancing upgrade of the economy.

The East Asian development experience was export-led and was based in the specialisation of value-added products. Palma (2009) describes how the NICs decided to challenge their Ricardian comparative advantages by shifting towards a concept of dynamic comparative advantages with the aim of competing in international markets in manufacturing sectors with long-term productivity potentials. These sophisticated sectors proved to have strong linkages with the rest of the economy, and the growth of exports was accompanied by high growth rates.

Lane (2022) shows empirical evidence on how the Heavy and Chemical Industry drive aimed at creating a dynamic comparative advantage shifted Korean manufacturing into value-added markets and created durable industrial change.

The state was actively involved in trade and industrial policy. A number of scholars (Amsden, 1992; Chang, 1993; Ffrench-Davis, 2005; Juhász et al., 2023; Palma, 2009; Rodrik, 2005) argue that selective policies that targeted specific sectors explain the East Asian success. The role of the state included coordinating activities, leading sectors, creating State Owned Enterprises, establishing joint ventures and specifications of local requirements, using export subsidies and tariffs, and other incentives to promote sectors of high productivity. The state thought strategically and compelled the private sector to invest in productive capacity diversification, redirecting their resources to finance the economic upgrade.

Lessons from emerging economies may seem remote to the interest of a mature economy such as the UK, with a large legacy infrastructure of physical, human and intangible assets. However, at a time of rapid structural change, even advanced economies need to take strategic positions regarding the future viability of their economic structures.

Venture capital provides insight into how breakthrough and profitable opportunities are identified and exploited at the firm and sector level. It exists because it allows investors to take risks on ventures with uncertain outcomes, where the potential for success is not obvious to everyone (Mercure et al., 2021). Risk is central to the value creation process, and CBA does not play into this. As set out in section 4, managing risk will increasingly form part of a credible economic strategy at a time of rapid change.

The key strategic decisions facing HMT

Given this context, there is a list of key decisions on which HMT will require analytical support, to drive dynamic structural change. These include, but are not limited in scope to:

1. **the need to direct investment.** Current models of growth, which underpin HMT modelling are defined largely by physical and human capital. Other factors such as the technology under which these assets are used are determined by residual. In the context of a rapidly changing world, with new clean technologies and AI and automation, analysis has to progress beyond this narrow focus. It will need to be based on a balanced accumulation of physical, human, intangible knowledge, natural, and social capital.[xxxi] This will require new types of analytical approaches. It requires clarity on what is understood by 'cost'. In a fully employed economy, any additional real expenditure that is undertaken has a 'cost', in the sense that it will come at the expense of some other contemporaneous expenditure. This displaced expenditure is thereby permanently lost. However, to the extent that the increased expenditure is an investment, it expands capacity and increases future output, hence the expenditure is not permanently lost to the economy. On the contrary: it can make the future economy larger than it would have been otherwise.
2. **the need to manage risk.** The choice to rapidly decarbonise an economy is a fundamental strategic investment decision taken by HMT, other Finance Ministries and economic decision-makers, centred around the management of very large risks. Each face a choice between very different growth paths with hugely different consequences. Again, this will require new types of analytical approaches. It requires a deeper understanding of risks and returns, whereby an investment may be assessed in terms of its option value, drawing on real options theory. For example, through paying a premium to avoid locking into potentially stranded infrastructure, or investing in research and skills which allow producers to avail of the opportunities of new growth markets.
3. **the need to drive competitiveness and comparative advantages.** Evidence shows that countries that successfully invest early in capabilities have greater success in diversifying into future green product markets (Hidalgo, 2023; Hidalgo et al., 2007; Mealy & Hepburn, 2020; Mealy & Teytelboym, 2022). Increasing returns, associated with learning by doing and economies of scale in key technologies, also breed clustering and agglomeration at the spatial level. This imparts an advantage to moving early to develop new clusters and supply lines and corner markets before the competition. Because early movers gain at the expense of laggards, this can be thought of as a zero-sum game. As highlighted in section 4 China's early strategic investment in EVs, batteries and solar PV allowed Chinese firms to corner the market in fast-growing global sectors[xxxii] The evidence shows that we can't perfectly predict what comparative advantage the UK will have, but being an early mover in new market helps.

5.2 'All models are wrong, but some are useful'

The phrase 'all models are wrong, but some are useful' is attributed to the British statistician George Box. It emphasises the fact that while no model can perfectly represent reality due to different simplifications and assumptions, they can still prove to be useful tools. As formal instruments, models with varying strengths and limitations can be used for prediction, to understand parts of— or an entire— system, processes, and underlying dynamics, and to assess possible scenarios (COFM, forthcoming).

The predictable predictive failure of cost-benefit analysis

What role can quantitative models and qualitative assessments provide in informing these key questions? Models are formal instruments and can serve a diverse set of purposes by providing a simplified representation of reality for testing thought experiments (Ellenbeck & Lilliestam, 2019). They have different levels of complexity, aggregation, and abstraction but provide a consistent framework for analysis and comparison (Barbrook-Johnson et al., forthcoming 2025)[xxxiii]. They impose a discipline on the modeller to articulate assumptions and parameters.

It is important to recognise that models have failed to supply helpful predictions of key features of the structural change needed to drive the clean and resilient transformation. A key example is the historical over estimation of the cost of decarbonisation, relative to experience, in key sectors such as renewables, EVs and battery storage (Grubb et al., 2021; Way et al., 2022)[xxxiv]. It has been argued by some prominent groups that the biggest progress made on climate has occurred despite, not because of, the recommendations of conventional economic models (Diaz Anadon et al., 2022b).[xxxv]

Increasing returns, multiple equilibria and non-marginal structural change challenge the appropriateness of the assumption of equilibrium. Sensitivity to initial conditions, triggers and investment paths can lead to very different outcomes. Therefore, validating models on past data is not sufficient[xxxvi]. There is also a significant identification problem in statistical analysis. How much of the fall in the price of renewables is due to deployment and how much of the deployment is due to the fall in the price of renewables?

Models that offer useful insights about the future could be useless at replicating the past. Yet, simplified toy models which are 'wrong' in obvious ways, can provide very useful insights.

This strongly indicates that economic modelling to inform policy choices needs to move beyond single equilibrium constraints and focusing on static allocative efficiency, to understand the processes which generate dynamic efficiency and multiple equilibria. Conventional analytical tools, based on static optimisation and CBA, are not fit for purpose.

Prediction about the structure of the economy in 2050 is effectively impossible. Models should instead be used to help our understanding, rather than to make (unconditional) forecasts, as we transition to net zero. Many technologies are thereby subject to increasing returns to investment. Such complex path-dependent dynamic processes are likely to be unstable and prone to tipping points which lead to rapid 'unexpected' change. They are unlikely to be incremental, marginal, linear, or smooth and do not lend themselves to accurate model forecasts, even where robust evidence on technology costs is available (Mercure et al., 2021).[xxxvii]

Conventional CBA used for policy appraisal and identifying costs and benefits plays a key role in determining which projects go ahead on the margin (assuming the structure of the economy remains unchanged). CBA tended not to support the policies to deploy renewable and clean technologies, because the new technologies were expensive at first, and there were cheaper ways to cut a marginal tonne of emissions at that moment in time.[xxxviii] The projections routinely overestimated future clean technology costs.[xxxix]

Insights matter more than prediction

In the case of low carbon transitions, the value of models will not primarily derive from their forecasting ability (see 5.3). They cannot and should not be expected to predict structural change, nor should they be judged primarily on their empirical performance. What a good endogenous model does provide is insights into the process of change and innovation. This is not just about a better model with better numbers. Models of structural change can inform scenarios and help understand the evolution of pathways.

Models can serve as tools that can provide civil servants and policymakers with relevant insights to inform policy. Models can help to understand the processes and mechanisms driving structural transition, informing and supporting strategic decisions (COFM, forthcoming). They can benefit from systems mapping, complexity analysis, and corresponding theoretical and agent-based models, which are not based on equilibrium, to assess the likely evolution of change. These models can be enriched with insights from diverse academic disciplines.

This means that a more encompassing, political understanding of the nature of the problem is required. Decision-making frameworks and associated economic models need to encompass the self-reinforcing role of expectations and strategic complementarities, whereby the pay-off for policymakers, businesses and consumers from investing in clean technologies, institutions and behaviours is a function of how many others do the same. In the longer run, such feedbacks increasingly give low carbon technologies the advantage over incumbent, dirty technologies (see section 3.2). As a result, some policymakers including the US Council of Economic Advisors, are exploring new models and frameworks that can take a more holistic and realistic approach to informing policy design.

5.3 Risk-opportunity analysis (ROA)

Narratives change expectations and create facts

Misguided forecasts of the price of key technologies can delay action. Big models employed by the Intergovernmental Panel on Climate Change (IPCC) have underestimated the reduction of the price of technologies over the past two decades, leading to the conclusion that net zero is extremely costly. These models have difficulty incorporating expectations properly and strategic complementarities. By ignoring the cumulative nature of innovation processes, the reinforcing feedbacks, and the government's role in crowding private investment, such assessments have failed to predict the rapid cost reductions witnessed in renewable generation and battery technologies. They miss the critical part of the story that costs come down as a function of what we do and, as such, are endogenous. These forecasts risk become self-fulfilling, influencing policymakers and delaying action (Barbrook-Johnson et al., forthcoming 2025; COFM, forthcoming).

It is important for policymakers to be aware that a whole suite of climate-economy models in common use typically assume that mitigation is costly (often by design). The challenge is that this narrative can, and often does, prove self-fulfilling, limiting expectations and damaging outcomes (see section 3.2). The opinion over recent decades that solar was and would continue to be 'eye-wateringly expensive', once embedded in a complex model, influenced policy choices and slowed down the transition.

Models and their ad hoc assumptions are a feature of what economists call the 'endogenous' nature of the economic system, where the structure of the system is a not fixed, but is a function of the choices and decisions we collectively make.

The case for decarbonisation is then undermined by misleading assumptions about technological progress and the unrealistic use of 'unique equilibrium static optimisation' assumptions, compounded by often implausibly low estimates of climate damages (Stern et al., 2022). Conventional analyses then routinely lead to policy delay (Grubb et al., 2021; Peñasco et al., 2021b). And delayed investment in rapidly improving renewable technologies such as solar PV, wind and batteries, itself increases overall decarbonisation costs, by postponing the reinforcing feedbacks between deployment and cost reductions (van der Meijden & Smulders, 2017).

A greater appreciation by decision-makers of the importance of narratives as essential in coordinating climate action is now critical (Akerlof & Snower, 2016; Shiller, 2017). This must be combined with a greater appreciation that economic models are at their best when they communicate 'insights not numbers' (Peace & Weyant, 2008). The risk facing HMT is therefore that inappropriately understood models, which are poorly designed for the task at hand or poorly applied, make for bad communication devices, which incorrectly influence expectations, deter innovation and delay investment.

Path dependency in innovation and the importance of expectations suggest that rather than trying to predict the future, economists could better help policymakers anticipate, manage and steer the course of the transition (see table 2). In this context, the economy should be understood as a dynamic ecosystem that decision-makers must shape, rather than as a static machine in which the best we can do is fix certain parts (Sharpe, 2023). The focus should be on shaping the future and managing the associated risks rather than passively observing how the global green revolution happens around us. The choices we make in the present will have long-lasting effects and will help avoid locking into unsustainable investment and development patterns.

Policy to support clean innovation should be powerful but temporary. Acemoglu et al. (2012) build on this understanding to make a powerful theoretical case that once the "clean innovation machine" has been "switched on and is running," it can be more innovative and productive than the conventional alternative, with a positive impact on GDP levels and growth. For example, renewable energy generation is already cheaper than incumbent energy technologies (Way et al., 2022).

For policymakers, this raises questions as to whether the market can be expected to find solutions without public intervention and the strategic role of government in steering the transition away from fossil fuel incumbency. Government intervention can play an important role in catalysing action that drives systemic change. However, given the system level considerations this entails, policy analysis also needs to take a systemic or holistic view of change.

By the same token, the danger is that the frequency with which the current government stresses how conditions will get worse before they get better undermines economic prospects. The more that a prediction gets repeated, the greater the likelihood that it becomes reality. This goes to the heart of how economies function, and governments' role in shaping expectations. Keynes showed how unfunded public expenditure can bring the economy out of a slump where total spending is below productive capacity due to a collapse of private sector confidence, borrowing, and expenditure.

But there are supply side parallels to achieving sustainable growth, in which strong investment begets rising incomes, which beget strong investment, such that non-inflationary growth becomes self-perpetuating as investment expands capacity. Crucially, this process requires confidence in the future. To extend Keynes, not only is GDP held up by its own bootstraps, but growth requires the belief that they will keep tugging (John Llewellyn, Independent Economics, 2024). The government must take on that attempting to improve the fiscal fundamentals, while talking confidence down, could prove entirely counterproductive.

A framework addressing uncertainty and structural change

This study has set out the need for strategic planning to set the economy on the most resilient, best-placed path to account for new opportunities at a time of rapid but manageable change. Traditional economic approaches and models are not useful tools for governments to identify and take advantage of the opportunities emerging from new markets.

Conventional analysis based on marginal change, which adopts static (rather than dynamic) optimisation, can yield biased and misleading advice. CBA is of limited use in contexts of structural change, uncertainty, path dependence, and diversity of interests deriving from heterogeneous agents. ROA is a generalised case of CBA where risks are large or unknown. It is a general framework that allows the assessment of policies or strategies based on broader risks and opportunities that are more suitable for structural change (Kapur et al., 2024; Mercure et al., 2021).

ROA embraces dynamic efficiencies, rather than static economic efficiency. For example, interventions like regulations can appear costly and inefficient as they seemingly impede the free market, but by steering innovation and behaviour they can lead to dynamically efficient outcome. It allows for the fact that strategic choices need to be made. It reflects the fact that there is no such thing as a technology-neutral choice. Not intervening will, unavoidably, advantage incumbent technologies and sectors, even if these are not the most productive and efficient in terms of prospects.[xl]

Given the path-dependent and systemic nature of a structural transition, assessments need to go beyond the impact on growth and productivity of a specific investment (applying what is often termed the 'growth multiplier'). The effect of each policy and investment depends on its interactions with others and cannot be assessed individually. The return on public investment in a clean project will depend on the policy context within which it is made.

Capturing a wider set of risks and opportunities

A broader analysis is required to assess value for money, encompassing the full set of risks and opportunities. ROA can be understood as a structured approach to thought, analysis, and judgment. It allows users to find strategies to minimise risks and navigate uncertainties while simultaneously maximising opportunities and capitalising on potential benefits. Moreover, risk and opportunities are endogenous, and a function of the decisions taken and investments made to shape the economy's path. The framework offers a more holistic and systemic approach to decision-making, influencing how policymakers think and formulate strategies and specific policies, which contrasts fundamentally with CBA.

A risk-opportunity analysis allows for a wider range of considerations that cannot be captured by conventional analysis, but is informed by a range of disciplines, including technological engineering, historical transitions, systems thinking, geographical contagion models, and the formation of expectations from social psychology. Table 2 sets out some of the major factors that need to be considered when analysing investment in climate mitigation, low carbon industrial policy and other non-marginal policy initiatives.

Tools for policymakers

Policymakers must take on the important dynamics in economies of scale in production and discovery, increasing returns, complementary systems technologies, social norms and strategic complementarities and expectation formation. A selective array of clearly specified, well targeted and properly understood models can guide more efficient investments in the right technologies (Aghion et al., 2016; Stern & Valero, 2021).

ROA allows the strategic case, which is often left outside a CBA estimate, to be integrated in a way that more broadly guides policymakers in assessing risks, opportunities and broad value of policy choices. It is clear that a range of complementary approaches to quantitative modelling approaches are typically needed. In such a transition, analytical frameworks and tools, such as the ROA and systems thinking, informed and complemented by the use ofxli.

This addresses the problem whereby with CBA, the primary economic policy objectives are left outside the economic assessment, making analysis irrelevant or, worse, misleading. When complemented by a range of qualitative and non-modelling analytical approaches, including[xlii], a variety of models, all with different strengths and weaknesses, can help provide an understanding of the mechanisms and process of structural transition, even if none can accurately predict them.

It is equally important that the economics profession – which dominates the creation of modelling tools for economic decision-makers – goes faster and further in ensuring model design and tools are informed by the experiences from an array of disciplines. These range from broader economic theory (for example insights from Schumpeter, Hayek, Smith and Romer), technological engineering, historical accounts of structural transitions, geographical contagion and urban planning models and the formation of expectations from social psychology.

These types of more diverse approaches — blending quantitative and qualitative approaches — often lead to a greater emphasis on good risk management, applying the precautionary principle to robust responses, rather than seeking "optimal" policies produced by conventional cost benefit analysis (Peng et al., 2021).

History, case studies, narratives, and political economy considerations are generally missing in general equilibrium assessments, but can prove extremely useful. There is information and evidence from past successes and failures. Recent low carbon technology transitions in China, India, Brazil and Europe can provide valuable lessons (Sharpe, 2023).

Targeting and tipping interventions

One of the main critiques of CBA for project appraisal is that using it would have ruled out policies that have proved successful, including offshore wind in the UK, solar power in Germany, Chinese batteries or innovative complex products like Tesla EVs, to name just a few. Ex post costing of scenarios is compatible and complementary with a ROA approach, see for example the US Treasury's CBA exercise of the IRA (see Box 5 in section 3.3). Also useful are scenario analysis based on a hypothetical construct that allows assessing a range of possible futures (TCFD, 2017).

In the same way they are not meant to generate precise forecasts but rather to provide insights from situations different than the business as usual scenario, ideally with a best, central and worst-case scenario. They allow users to assess opportunities and possible failures relevant in contexts of uncertainty (Mercure et al., 2021). They broaden the thinking through a range of cases and allow strategic planning.

Conventional static economic analysis highlights the importance of carbon pricing on the margin to steer behaviour. Pricing is important, but in a dynamic system, more effective policies are found to be those that target investment towards emergent technologies through subsidies, cheap finance, or public procurement. These policies were successful because they strengthened the self-amplifying feedback of technology development and diffusion and the creation of new markets. The policies comprised sensitive Interventions with outsized impacts (Hepburn et al., 2020a; Mealy et al., 2023), which pushes a technology beyond a tipping point whereafter its success is secured.

In the UK, targeted subsidies cut the cost of offshore wind by around 70% over a decade, making it a cheaper source of electricity generation than gas (Jennings et al., 2020), while an £18 per tonne price on carbon triggered a rapid decline of coal's share in the electricity mix from 40% to nearly zero in less than a decade (Sharpe & Lenton, 2021). The last remaining UK coal plant (Ratcliffe-on Soar) is set to close before the end of the year[xliii].

In Brazil, subsidies together with concessional finance drove the fastest expansion of onshore wind power of the large emerging economies, directly employing over 150,000 jobs in 2016 (Grubb et al., 2023). 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 (IEA, 2023). In Norway, a subsidy-and-tax combination that made EVs cheaper to buy than equivalent petrol cars was central to a policy package that drove the world's fastest transition in road transport (Sharpe & Lenton, 2021).

Some economists criticise some of these policies in favour of carbon pricing and border tax adjustments, which are non-discriminatory (Helm, 2015). Reliance on pricing polluting activities to internalise damages, though first best in terms of static allocative efficiency (the textbook economic case) often generates only incremental change in incumbent sectors, such as fossil fuel burning, making them more efficient, delivering modest emission reductions. When the challenge is inducing structural change, this is unlikely to be dynamically efficient and may even delay transformation. By contrast, more active policies that targeted investment towards emergent technologies through subsidies, cheap finance, regulations or public procurement were successful at inducing development of radically different new technologies, which are far cleaner and cost-effective (Grubb et al., 2023). The political feasibility of impactful pricing and taxation is limited due to the powerful fossil fuel lobby. Subsidising alternatives has proved to be less controversial and the evidence shows that the combination of policies has successfully promoted clean alternatives.

The combination of policies is more effective than the sum of the parts. Economists increasingly accept that a low carbon transition is not about addressing a single, or even a few, externalities through the use of a small number of appropriate, but independent policy tools such as carbon pricing and taxation. Instead, the challenge requires overcoming multiple market governance failures, and driving the path of change (Acemoglu et al., 2023; Pisani-Ferry & Posen, 2024). Objectives cover emissions, R&D, particulate pollution, networks, information, security, risk asymmetry and capital market failure and so on.

Models can support innovation policy by helping apply evidence on the process and drivers of innovation and deployment to rapid cost-cutting innovation in technologies with similar characteristics, for example, relatively simple, modular and standardised (e.g. solar PV modules), as opposed to more complex, construction intensive and bespoke kit (e.g. nuclear power plants or CCUS).

Examining historical transitions like railroads, electricity, and internal combustion engines can inform low carbon transitions and industrial strategies by highlighting past barriers, investment leaders, and the timing of key developments. Understanding these patterns and leveraging narratives to co-ordinate action (Akerlof & Snower, 2016; Shiller, 2017) can guide effective implementation. Inappropriately understood or poorly applied models make for bad communication devices, which incorrectly influence expectations, deter innovation, and delay investment (COFM, forthcoming). Indeed, economic models will do better by communicating insights rather than precise numbers (Peace & Weyant, 2008).

There are several theories of change that can prove useful, including the snowball effect and game theory. The former can be relevant because it illustrates how small and initial actions can lead to larger and more impactful changes over time and can support the understanding of climate or technological tipping points, reinforcing feedbacks and self-fulfilling expectations. This is also relevant to international cooperation, as climate policies adopted by a few countries can set examples and create pressure for others to follow suit[xliv].

Understanding the dynamics of change also involves understanding real world social psychology phenomena such as pluralistic ignorance and psychological distance, where people cannot accept harm locally if the threat is not felt more immediately. For example, the narrative of being energy-independent can be particularly impactful (see Box 3).

Structural breaks require active policy choice and investment choice. Portfolio theory is a framework for constructing optimal portfolios that maximise returns for a given level of risk (Markowitz, 1952), which has been key in investment management. The framework assumes that individuals are risk-averse, so for the same level of return, they will choose the portfolio with less risk. This augurs for diversifying investment in an array of different assets that are not highly correlated and the investor is better protected from systemic risk. Portfolio theory can be applied to the UK industrial strategy, building a portfolio that identifies the optimal mix of investments that offer potential or expected return for a given level of risk. Set against this, is the need to make strategic choices on which assets are future-proofed and which are not.

This is why Way et al. (2019) entitled their informative paper "When Wright meets Markowitz" which neatly captures the nature of the challenge. Understanding the correlations between different sectors and the likely cascade of risks, should form part of a comprehensive industrial strategy to create a more resilient economy (Geels et al., forthcoming 2025).

Sector-specific models that simulate the process of technology diffusion can be an important complement to macroeconomic models. They are dynamic models that project how the costs of technologies decrease as their deployment scales including reinforcing feedbacks. Lam et al. (2023) projected that the cost parity tipping point of EVs will be in 2024 in Europe, 2025 in China and 2026 in US for medium cars. Moreover, they conclude that international cooperation would bring forward the tipping point. Nijsse et al. (2022) projected that the cost of solar energy including the cost of energy storage would decrease 60% between 2020 and 2050. Moreover, in 2027 it is expected to be the cheapest energy source in almost every country of the world. Though these cannot be taken as forecast, given the dependency of costs on factors such as the policy environment, they give clear insights into how the world could evolve in ways static models are unable to.

Future Technology Transformations (FTT) models simulate the technology composition of sectors that are key for net zero and include key policies is inputs. FTT models exist for power generation, road transport, heat and steelmaking covering 88 technologies (Vercoulen et al., 2021). Mercure et al. (2018) model the diffusion of petrol, diesel, hybrid, EV, compressed natural gas and motorcycles for light duty vehicles under different set of policies for different regions. Vercoulen et al. (2021) simulate steel production by different technology groups in India, China and Brazil under different policies: carrot, stick and a combination of both.

Risk-opportunity analysis allows for a wider range of considerations that cannot be captured by conventional analysis. It is informed by a range of disciplines, including technological engineering, historical transitions, systems thinking, geographical contagion models, and the formation of expectations from social psychology. Table 2 sets out some of the major factors that need to be considered when analysing investment in climate mitigation, industrial policy and other non-marginal policy initiatives.

Table 2. Major factors of a ROA for the UK

Key to consider	Opportunities	Risks
Tipping points	Marginal policy changes can trigger a tipping point in which a clean technology can outcompete its dirty alternative. E.g. small carbon floor price tipping coal out in favour of gas in the UK. The Systemiq report shows multiple sectors close to reaching tipping points, including the considered hard-to-abate sectors (Systemiq, 2021). Opportunity to trigger tipping points that will create new markets, generating profits, innovation and growth.	Tipping points are places of great uncertainty both in their precise location and eventual end state. While passing tipping points for clean technologies can drive rapid change, over reliance on them can introduce risks, particularly given the complex socio-economic factors that may influence or delay their impact. For example, a price-parity tipping point for electric vehicles may not deliver the desired effect without sufficient charging infrastructure and elimination of range anxiety. Where tipping points are successful, they can lead to the devaluation or stranding of assets held in the incumbent technology. Timing also matters. Moving too soon may limit the returns on clean investment, even if the transition of the sector remains inevitable in the future.
Path dependency	Countries that successfully invest early in green capabilities have greater success in diversifying into future fast growing clean product markets (Liu, 2019, Hidalgo et al., 2007; Mealy and Hepburn, 2020; Mealy and Teytelboym 2022). Investing in low carbon sectors will prevent economies from being locked into an unsustainable path. Transitioning away from dirty path dependence can pave the way for a sustainable green trajectory with its own reinforcing dynamics.	There is always some risk in moving too early (first mover rather than fast follower). Aligning down the wrong or non-optimal pathway may produce adverse consequences. For example, the current dependency on fossil fuels results in the UK's dependency on fossil fuel imports, which make it susceptible to price volatility from conflict. Aligning with the wrong clean technology choice may leave UK sectors isolated with limited interoperability or trading partners (e.g. consider hydrogen powered passenger cars), which risks losing the economic opportunities that come from a transition.

Key to consider	Opportunities	Risks
Learning by doing	Learning by doing is an opportunity to work with scientists, engineers and designers to develop supply lines and products which corner new markets. An active strategy is required to win in the zero-sum game building capabilities in promising sectors. Opportunities are available in terms of innovation, spillovers, jobs, profits and growth.	A scattergun, or stop-start approach to green investment and policy will not allow for costs to fall, supply chains and skills to develop, or deployment to scale. Without long term planning and increased certainty, infrastructure and other mega-project delivery will fail to deliver the necessary returns. For example, the failed approach to UK nuclear (Helm, 2015).
Digitisation and Artificial Intelligence	Digitisation and AI can reduce emissions in economic sectors. For instance, in the energy sector, smart grid development and demand management can mean significant reductions of electricity use. AI can boost productivity, innovation and growth, and a green industrial strategy should consider how to benefit from these two structural transformations. (See Zenghelis et al., 2024 and Stern and Romani, 2023). The UK can build upon existing capabilities in the service economy, first-class universities and knowledge research clusters.	The growth of digitisation and artificial intelligence places significant stress on power systems, reducing the spare capacity available for electrification and requiring an even faster build out, which is at odds with the constraints and bottlenecks of building out a clean energy system. The application of AI to climate mitigation also reinforces the misconception that the solutions are purely technical, and may risk delaying the institutional and societal shifts necessary to decarbonise and unlock the associated benefits.
Geopolitics	In echoes of the Cold War 'space race' between the US and the Soviet Union, mounting geopolitical tensions have unexpectedly prompted a race to the top in developing clean goods and services, as the US IRA, in part a response to China's early competitive lead in clean sectors, exemplifies. In a complex geopolitical context, cooperation will remain more important than ever. The UK should seek cooperation strategies with the EU and other allies to ensure openness to trade and common regulatory standards. A response to the growing use of trade barriers could be to focus on niche sectors not subject to the current geopolitical dispute.	Increased geopolitical rivalry and conflict places the transition at greater risk. Increased tensions can distract from the international coordination and cooperation required to deliver a global transition.
Financial	Opportunity to reduce reliance on assets that risk being stranded as policies become more hostile, new clean technologies undercut older alternatives, and litigation risk mounts. Opportunities for becoming energy secure and reducing the risk and volatility of changing international energy prices, with the mentioned implications in terms of public funds. Multiple cost savings as clean technology is more efficient and generates higher returns on investment. Resources from economic growth can contribute to public finances.	Capital intensive projects see greater risk from high and volatile interest rates. Interest rate volatility is increased due to the effects of climate change on infrastructure, food and trade, amongst others.

Key to consider	Opportunities	Risks
Taxation	Taxation of dirty sectors at least temporarily during the transition. For example: taxes on carbon, meat, waste management and polluting. General taxation from new economic sectors and from growth and from the productivity boost resulting for more efficient systems.	Fossil fuel-based activities currently provide significant government revenue through royalties and taxation. This includes royalties on fossil fuels extracted from the North Sea, as well as taxes including green levies and fuel duty. Eliminating fossil fuel consumption will also reduce the government's tax base with currently nothing set to replace it.
Political economy	An industrial policy has the opportunity to address regional inequalities. Places where the impacts of the transition away from carbon-intensive activities will be felt most acutely could benefit from growth in low carbon sectors and manufacturing jobs. Less wealthy areas already specialise proportionately more in clean energy and these sectors will continue to benefit them. Re-tooling and re-skilling workers to benefit from the opportunities of the new economy must be part of the transition. This may also help address concerns from the anti-environment movement.	The green transition risks disrupting existing political-economic relationships, particularly with respect to the geographic distribution of jobs. Current regional jobs for specific sectors such as fuel refining, transport and automotive manufacturing are expected to be disrupted and will require attention to reskill workers and ensure regional industry gaps left by changing workforces are replaced. While the transition is anticipated to produce new jobs, a green economy will ultimately be less labour intensive (i.e. as it is more productive, it requires less labour to deliver more output).
Political economy cont.	Growth and prosperity will create resources to compensate those most impacted, helping to create a positive narrative. This narrative can be reinforced by institutions, politics and changing social norms.	Additional policy action, including spending on skills and complimentary capital investment, is required to ensure that people aren't left behind and that there is a fair distribution of the economic benefits that come from a green transition. Labour shortages, for example in construction of low carbon buildings, renewables and electricity grid expansion may put pressure on labour markets, wages and inflation and drive inward migration.

Key to consider	Opportunities	Risks
Trade	Trade presents opportunities for jobs and growth, including the opportunity to participate in fast growing international markets exporting green products and services. Cornering new markets as a fast mover will allow the UK to experience benefits being enjoyed by other countries, with opportunities in manufacturing and a range of supporting services. As a medium-sized economy, the UK cannot rely solely on its domestic markets. Accessing larger international markets through trade presents a significant opportunity for various good and services.	Current supply chains for clean technologies are significantly dependent on international trade and remain susceptible to interruptions in trade supply chains. Many of the capital goods necessary for the green transition will be imported, placing pressure on the UK trade system, if domestic alternatives are not developed. The benefits accrued from domestic production and manufacturing of these goods may also be diminished, ceding these opportunities to economic rivals.
Large scale infrastructure deployment	Investing in the required infrastructure will allow the deployment of clean technologies that create benefits for the environment and the economy. There is no trade-off between clean and other investment. More efficient and climate-resilient houses, schools, hospitals and rail networks using cheaper energy will benefit all. Large scale deployment plays a key role in price reductions. Deploying infrastructure should be seen as a necessary investment with long-term returns and not merely as a resource cost.	Current large-scale infrastructure needed to underpin the transition (i.e., offshore wind, nuclear and rail) takes place over the timespan of decades. Projects conceived this year will not start operating until the mid-2030's, considering the need to pass through bottlenecks such as planning permission and grid connection. Without proper accounting for these timelines and the ability of government bodies such as the OBR to make investment decisions over the timeframe of decades, the UK will not see the increased deployment speed necessary to drive mass electrification. Infrastructure investment will also require labour, especially in construction. A lack of early recruitment and training to scale up workforce capacity, may result in inflation and higher interest rates.

06

Policy recommendations

The UK will soon be developing policies that can help meet the upcoming Seventh Carbon Budget (2038-2042). This is an opportunity to demonstrate UK leadership on climate.

Policy recommendations

06

This section draws on the analysis in the report. It makes recommendations so that our institutions can manage and steer change relating to fiscal frameworks to induce innovation, policies and regulatory signals to drive investment and economics to understand transition and capacity. Twelve standalone recommendations are set out with rationales.

Countries worldwide have moved from questioning the need for action to crafting sectoral policies that align with their strategic goals. At scale industrial policy has made a comeback in the US and the EU and has for decades featured in China. As this report outlines, there remain opportunities for the UK to corner and support green markets as the world transitions.[xlv]

There is no neutral technology choice as this will inevitably benefit incumbents.[xlvi] Rather than questioning the government's ability to pick winners,[xlvii] the focus should be on its ability to let losers go (Juhász et al., 2023).[xlviii] The UK needs a Strategic Green Growth Plan that will embed credible net zero policies and facilitate the wider reorientation of the economy to one that enables transformational change through the production of compatible industries.

Recommendation 1: Publish a Strategic Green Growth Plan by early 2025 to embed credible policies for net zero

- A Strategic Green Growth Plan will require a whole-government approach[xlix] to policymaking, co-ordinated by the Cabinet, HMT and DESNZ. The plan should clearly set out policies that can result in low carbon investments, but it will also require complementary investments in wider social and physical infrastructure, such as education and training, access to healthcare and digital and physical connectivity. A coherent strategy based on growth, innovation and skills will enable the private sector to invest in the green economy (Zenghelis et al., 2024).

6.1 Creating a strategic framework to encourage productive investment

The UK is in a race to transform its economy and compete with other countries to develop new skills, technologies and markets.

Public investment

The core objective is to induce and direct investment. It is counterproductive (as well as economically incoherent) for the government to repeat the mantra that capital spending should be held back because there are too many unfunded commitments. Investment spending is either a good idea, in which case it should be funded by borrowing, or it should not be undertaken. Invoking austerity and talking down prospects of public support needlessly reduces private investment appetite per public pound spent.

Scrimping on investment in core assets risk a perpetuation of the doom loop the UK has faced since 2008, whereby fiscal rules constrained capital spending, thereby restricting productivity and economic growth. The stagnation in wages and profits, which undermined fiscal revenues, worsened the public finances prompting another round of austerity cutbacks. Without breaking out of this vicious cycle, the government will need to scale back its growth and welfare ambition.

Labour's manifesto committed to "reforming our economy". The new government recognises the need to drive public investment to boost growth and productivity. Yet the level of public investment as a proportion of national income is projected by the OBR to fall this parliament under Labour's plans. To secure credibility and induce private investment, the government will be expected to front some money and have 'skin in the game'. This will most often take the form of direct public investment in core infrastructure, assets or grants, subsidies and guarantees to the private sector.

The clean digital transition will be capital-intensive upfront. Our judgement is that an increase in annual public investment of equivalent to around 1% of GDP is necessary to shift UK productivity and economic growth out of its malaise. This would pull the UK out from bottom place among the G7 for public investment and promote confidence in private investors.

- The UK could consolidate its many public investment banks (the UKIF, the BBB and UKEF). This would establish a scaled-up policy bank that is able to take on its own liabilities by selling bonds on the market, and independently make investment decisions within a mandate provided by the government, while maintaining investor confidence by having Treasury backed bonds. Such debt should be excluded from the fiscal rules on the principle that it can only be extended to create wealth generating assets (King & Jameson, 2024).
- In our judgment, deploying resources to execute creative manoeuvres to push things off official public balance sheet, so as to create space for necessary action, is very much second best. A preferable system explicitly values borrowing to invest in building assets, by better assessing public and whole economy net worth (section 4.5).[i]
- Public investment into specific technologies and sectors can allow private firms to participate in growing green markets, support innovation and productivity growth and build supply chains and jobs in the UK (Mercer et al., 2024). Establishing a state-owned energy company, Great British Energy, and a National Wealth Fund have these objectives in mind. However, clarity is required as to what role these entities play which cannot be provided by private firms.

Investing in future-proof core assets to avoid outdated, carbon-intensive infrastructure, skills and ideas that may become devalued and stranded is a necessary, if not sufficient, condition for improved UK productivity growth prospects. Investment decisions taken today will shape the UK economy for the coming decades.

- Direct investment will be required in power grids, public buildings, urban management, recycling and waste management, railways, water management, land restoration, adaptation/resilience, and some ports and CCUS capacity.
- Policy must target home insulation and energy efficiency where this could reduce households bills as well as alleviate pressure on energy demand and electricity grids. This requires clear incentives and innovative finance as well as overcoming non-financial barriers to retrofit, including hassle and time, for example by offering pre-announced and co-ordinated retrofits on a neighbourhood by neighbourhood basis. The government should consider de-risking investment into home retrofitting by relying on funding and grants from the UKIF (CCC, 2024).

Fiscal rules

The public debt rule currently does not discriminate between a borrowed pound spent acquiring productive assets and a borrowed pound spent on current consumption. This is a fatal flaw. From a macroeconomic point of view, the government needs to create space for additional judicious investment by amending the debt rule to recognise that investment funded by debt is growth enhancing and, by generating returns, sustainable (Zenghelis, 2024).[ii]

- A shift to measuring public sector net worth (PSNW and the narrower public sector net financial liabilities PSNFL) alongside debt is long overdue (section 4.2). OBR medium term forecasts must include risk adjusted supply side as well as the demand side, impact of public investment (Suresh et al., 2024). The longer-term aim should be to develop full UK wealth accounts, including more robust estimate of the public sectors direct and indirect net worth, accounting for the asset along with the liabilities side of the public balance sheet (Coyle et al., 2019; Zenghelis et al., 2020b).

Recommendation 2: Support the modification of UK fiscal rules to enable more effective investment in productive assets.

Boosting saving and raising revenues

Additional public investment will induce higher policy interest rates to offset additional demand, crowding out public investment, unless accompanied by measures to temper consumption demand. It would also boost the UK's current account deficit, as it draws in borrowing from abroad. Mitigation entails policies to create space for investment by encouraging domestic saving and addressing the UK's endemic over-consumption (section 4.5).

Raising revenues to fund necessary day-to-day spending, while boosting saving, requires the government to reconsider its commitment not to raise key taxes such as Income Tax, VAT, National Insurance and Corporation Tax. These taxes account for 75% of revenue. Funding spending by raising Inheritance Tax and Capital Gains Tax is progressive, but it also disincentivises the saving required for domestic investment.

- The UK tax system is inefficient, complex and unfair. The UK has more VAT exemptions than most countries. This distorts spending choices and raises administrative costs. The poorest households, to which these exemptions are focused (and who consume a greater proportion of income than the rich), could be amply compensated for their loss through other payments which leave them better off while still providing net tax revenue.[lii]
- The government should instead reinforce Pigouvian taxation of 'bads', such as fuel duties and carbon pricing, while applying broad based Ramsey taxes designed to raise revenues at minimum distortion to the economy.
- In the medium term, one of the most efficient and fair means to raise revenues is to reform property and land value tax. This could be done in the interim through making council tax bills roughly proportional to the value of property.
- Aiming for a current budget surplus, with the support of the OBR, can help bolster UK savings. AI and machine learning can help improve revenue collection and counter fraud, tax evasion and error.
- Structural measures, such as enhanced employee pensions auto-enrolment and Individual Savings Account (ISA) incentives, can help boost UK savings.
- The UK could also channel greater institutional capital from pensions and insurance assets towards productive investments in the next 5 to 10 years (Gordon, 2023; Gordon & Valero, 2023). Pension funds themselves are arguing for a change in the fiscal rules, which are holding investment back. Clean infrastructure projects are particularly attractive for pension funds because they provide a steady stream of income (McDougall et al., 2024).
- Having limited its options on taxation with promises made prior to the 2024 election, the government should take care not to fund necessary current public expenditure and capital maintenance with taxes that are focussed disproportionately on saving (Helm, 2023). This would only further undermine the UK's investment performance, limiting growth and returns.

Devolving power

Pro-growth investment will also require the devolution of decision-making and fiscal autonomy. Greater localised investment and devolution can allow for enhanced consideration of how net zero investment is delivered and who it is delivered for. This can be beneficial for ensuring that investment doesn't repeat historic patterns of reinforcing inequality (Coyle & Sensier, 2020), but also allowing communities to receive the benefits of clean investment first hand. These can be embedded in the context of tangible co-benefits associated with 'place' such as improved local air quality, access to transport and local infrastructure resilience. **The overall economic opportunity is positively shaped by taking a place-based approach.** UK Research and Innovation (UKRI) research finds returns to investment on energy saving increase sixfold when administered at the local and regional level.[liii]

To fully unlock the power and potential of regional devolution requires greater access to funds, greater powers for local government to raise revenue, invest and borrow through greater fiscal autonomy as well as autonomy over investments and decision making to drive local investment that is tailored to the community. This provides local government with the incentives to deliver for citizens and be held accountable for doing so.

Fiscal devolution provides the incentives for development because local regions can reap the rewards. The alternative is that development will likely be opposed at the local level, impeding the new government's ability to invest in growth infrastructure.

Democratisation and inclusion are encouraged as local policymakers can be held accountable for delivery, in place of more 'faceless' bureaucrats in Whitehall. Investment at the local level allows citizens to directly see and attribute the benefits of decarbonisation. Localised investment decisions can also provide a better 'on the ground' understanding of where net zero investment is actually required, as well as the bottlenecks and barriers to achieving positive benefits from the investment.

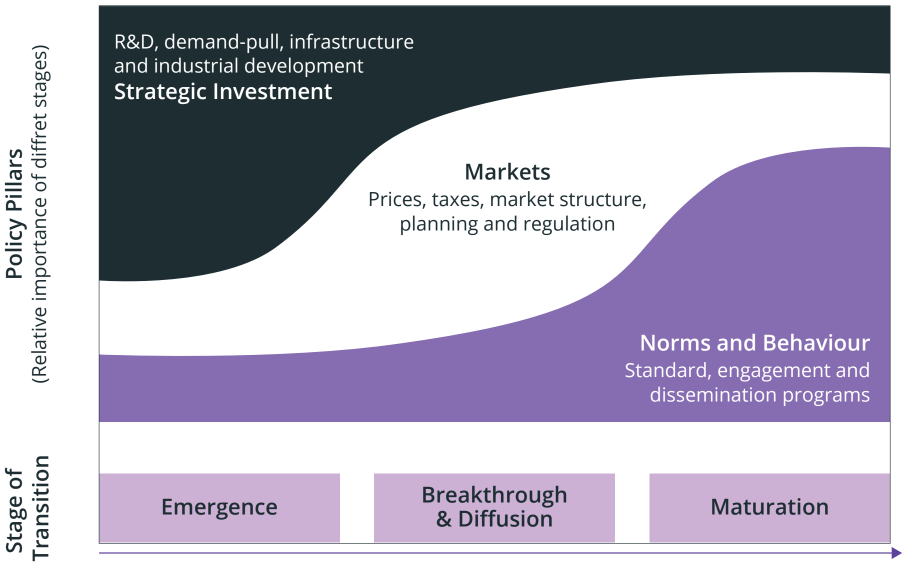
- Liberalising the planning system will be ineffective without devolution, which implies a loosening of fiscal control from Whitehall. Providing local communities with greater access to funds, and autonomy over investment (for example through regional development banks) can provide major social returns. This is distinctly preferable to decision making centralised in Whitehall with little to no local knowledge.
- Devolution encourages local and central government to work together. Government led investment is critical in terms of developing anchor structures, such as railway hubs, and co-ordinating spatial planning (Collier et al., 2018) and in order to ensure that outcomes are distributed fairly.

Supporting R&D

There is an important role for R&D support for invention, development and deployment, including via tax incentives. Given the importance of energy efficiency, many of these schemes will fund net zero projects. These might be 'horizontal', e.g. full expensing of capital investment or R&D tax credits, or more targeted, such as with the US IRA tax credits for clean technologies. There is significant scope for considering where tax incentives for sustainable investments can be enhanced in the UK.

In the early stages of transitioning to zero-emission technologies, targeted investments like subsidies and procurement are most effective, focusing on improving and introducing new technologies to the market. Direct public funding and tax incentives for R&D can help foster the development of technologies that hold significant long-term potential while further from market readiness (Zenghelis et al., 2024). A recent CBI gap analysis found the UK tax system provides relatively strong, if untargeted, support for R&D, but could provide enhanced support for commercialisation and adoption of green technology (CBI, 2024).

Figure 16. Indicative policy mix over the course of the transition



Source: (Grubb et al., 2021).

- The evidence suggests raising public R&D towards 1% of GDP, with an aim to raise whole-economy R&D to 3% of GDP through direct investment, spending on UKRI and higher education, will be central to supporting and direct technical innovation.[liv] Government spending in R&D, for example in defence in OECD countries, has had a positive impact on private sector spending in R&D. This crowding-in effect also generates international spillovers and productivity gains (Moretti et al., 2023).
- The governments' Innovation Strategy proposes to expand the UK's R&D budget (BEIS & UK Space Agency, 2022). However, this seems at odds with the recent decision to shelve £1.3 billion of UK technology and AI projects (Kleinman, 2024). The government may or may not find the expected returns to investment to be value for money, but to put the move down to "difficult spending decisions in the face of unfunded commitments" is not economically coherent. Net investment should not be funded; it is either worth borrowing for, or it isn't. Current spending should be funded.

Recommendation 3: Increase public investment in research and development (R&D) towards 1% of GDP with an aim to boost whole-economy R&D to 3% of GDP by 2027.

- Promising sectors include floating offshore wind, aviation, energy-efficient chips, AI, and numerous service sectors essential to the clean transition from legal services to engineering, consultancy and finance. But the key role of policy is to enable conditions for clean innovation in new sectors to evolve with minimal risk and greatest confidence. As policy becomes clear and coherent, UK entrepreneurs will be incentivised to innovate across a range of sectors and markets.[lv]

Establishing credibility through leadership

Policymakers should not underestimate the importance of credibility, leadership and underlying 'mood music'. Given the scale of infrastructural investment required, most of the investment will be private. This means reassuring investors that broad markets for clean technologies will be created. It will also require tailored incentives which will differ depending on where a specific technology is on the development and deployment S-curve. Policy on the demand and supply side are both critical to stimulate a new market.

Political leadership, with clear vision and goals, is required to promote innovation, economic growth, and a transition towards a clean economy. Businesses need to be convinced that the government will not renege on existing commitments once their investment costs are sunk.[lvi] Policy credibility is especially critical during disruptive structural transitions where risks are significant. Consistency is vital and financially costless (Zenghelis et al., 2024).

- **Credibility in the global clean transition has been assured by the actions of the Chinese, Americans and others.** This transition is already well underway. Nevertheless, UK narratives matter for UK competitiveness. Credibility can be earned through a leadership narrative which is convincing and policies which are consistent, coherent and enduring, and which do not cost the Exchequer. Mixed and muddled signals, inconsistent policy and backtracking on existing policy will raise the cost of capital and deter private investment.

Domestic policies influence the credibility of the UK on the international stage and should therefore be used to create signals that increase international cooperation between countries. As a medium size open economy, the UK needs to leverage its skills and powers on the global stage through the use of 'soft power'. The UK is only directly responsible for just 1% of global (territorial) greenhouse gas emissions, and even when net imports of greenhouse-gas-intensive goods are considered, its share amounts to less than 2% (Zenghelis et al., 2024). Being the first country to industrialise, it is responsible for a slightly larger share of historically accumulated emissions (Carbon Brief, 2021).

Avoiding the worst consequences of climate change, including the drivers of migration, can only be achieved through international cooperation (HMT, 2021a). The UK can play a global leadership role to support a transition to a sustainable, inclusive and resilient global economy. A positive UK effort on net zero is among the UKs most powerful diplomatic and reputational levers.

- **The UK has already played a key role in climate mitigation,** including early leadership on the Kyoto protocol, the success of the 2008 Climate Change Act, the 2019 net zero target, COP26 in 2021, and the independent monitoring of the CCC (Averchenkova et al., 2021). However, it will need to show renewed commitment to retain its global leadership.
- **Credibility at home is key to promoting its soft power abroad.** Successful policies implemented at home, like the early establishment of carbon markets and setting up the CfD scheme, serve as an example that the transition to a green and resilient future is possible and can be profitable.
- **Additionally, there is an opportunity to co-ordinate and join global efforts to develop clean technology markets.** This would allow economic opportunities for UK firms and workers (Mercer et al., 2024). This includes the use of strategic leadership, developing a common understanding of the nature of the challenge, providing concessional finance and sharing technology advances with developing countries.
- It will also require development support to ensure poor countries are not locked into a dying fossil fuel economy, recognising that their contribution to climate warming is negligible.

The UK will soon be developing policies that can help meet the upcoming Seventh Carbon Budget (2038-2042). This is an opportunity to demonstrate UK leadership on climate. Despite the progress made in reducing emissions since 1990, rapid action needs to be taken if the UK wants to reach net zero by 2050 and achieve it in line with pathways outlined in the sixth (and the next) carbon budget.

Reductions in electricity emissions have driven half of the previous emissions as a result of coal phase-out and successful policies to promote offshore wind (CCC, 2024). Efforts and investments need to extend across sectors to meet carbon budgets. Only a third of plans to meet the 2030 NDCs and just a quarter of plans to meet the Sixth Carbon Budget are covered by credible plans (CCC, 2024).

- **By creating clear plans, the Labour government can demonstrate that the UK is committed to meeting its climate goals.** That will ensure investor confidence and signal its intention to be a global leader in climate mitigation. For this objective, the UK should work with the CCC so that government policy is informed by evidence, creating detailed decarbonisation pathways for each sector (Zenghelis et al., 2024). These should clearly outline which technologies, measures, and policies will contribute to sectoral emissions reductions to ensure effective monitoring of the UK's progress towards achieving net zero. The government should bring together relevant policymakers, firms, industry bodies, and civil society in recognition of the government's role in strategic direction and co-ordination, but also its informational constraint.[lvii]
- **A strong UK commitment that could be made on the international scene would be to apply strict restrictions and a default stance against granting new oil and gas exploration licenses** (Mercer et al., 2024). UK fossil fuel production is of high marginal cost and relatively high in upstream emissions, relative to imports (CCC, 2022b). North Sea oil is relatively high marginal extraction cost. Broadly speaking, that means that if the oil price stays high or rises, the best policy would have been to shift faster to renewables, if the oil price falls, the assets will be stranded as it will be uneconomical to extract the costly oil. There are no scenarios in which new oil fields cut costs to consumers and generate profits for the UK.

Recommendation 4: Strict restrictions and a default stance against granting new exploration licenses should be implemented for all fossil fuels.

- Existing production should use fiscal tools such as the Energy Profits Levy and the Investment Allowance to redirect investment towards low carbon energy (Walsh et al., 2022), thus contributing to phasing down fossil fuel production in line with the UK's UNFCCC commitments.
- Collaboration with EU on energy markets, interconnection and electricity prices would be another diplomatic, economic and environmental quick win, with the ultimate aim of rejoining the EU ETS (section 4.2). Collaborating with our key trading partner to secure supply lines for core materials necessary for the clean build-out must also be a priority. The global dash to electrify is already creating bottlenecks in the supply of core materials.

6.2 Getting the economics right

Analytical and modelling approaches to guide policy choice

The precise policy mix must be comprehensive, coherent and mutually reinforcing. Pricing pollution, and internalising the social cost of carbon emissions, is a pre-requisite for efficient and non-discriminatory adjustment. However, studies have found that the policies that led to the most successful transitions to low carbon technologies in China, India, Brazil and Europe, were implemented despite, not because of, the predominant economic analysis and advice based on CBA (Grubb et al., 2023). Perhaps counterintuitively, the most effective policies were found to have been those that supported the creation of new markets rather than those pricing polluting activities.

The reason for this is shown to be that pricing polluting activities often generated incremental change in incumbent sectors, such as fossil fuel burning, making them more efficient, delivering modest emission reductions and delaying more radical transformations to new technologies (section 5.3). By contrast, more active policies that targeted investment towards emergent technologies through subsidies, cheap finance, regulations or public procurement were successful at inducing development of radically different new technologies, which are far cleaner and more cost-effective (Grubb et al., 2023). Economics is up to the task of understanding this, but the tools used must be appropriate.

CBA supported pricing over market creating policies like targeted investment, regulations and subsidies or cheap finance, because new technologies were considered expensive on the margin. However, CBA missed the reinforcing feedbacks that led to cost reductions and further deployment of green technologies.

- Policymakers can use an array of policies to target strategic sensitive intervention points where relatively small policy intervention can have an outsized effect generating reinforcing feedbacks, triggering positive tipping points and changing market behaviour.
  - The UK carbon floor price pushed up the price of coal to make gas cheaper and almost wipe out coal generation in under a decade (see section 5.3), helping the UK achieve power sector decarbonisation roughly eight times faster than the global average over the decade 2010-2019 (COFM, forthcoming; Sharpe, 2023).
  - In Norway, a combination of co-ordinated policies was responsible for changing market incentives and triggering EV uptake. This included carbon pricing, tax exemptions for EVs, reduced prices in parking, tolls, ferries, and allowing EVs to drive in bus lanes (OECD, 2024). In 2023, 80% of new car passenger sales were EVs (CCC, 2024).
  - In India, bulk public procurement of LED lights led to a decline in price, making them affordable and facilitating uptake (IEA, 2023).

These policies were successful because they recognised the drivers of innovation, channelled expectations, strengthened the self-amplifying feedbacks of technology development and diffusion, and supported the creation of new markets.

Conventional policy modelling and analysis has steered investment away from the regions and communities that need it the most, reinforcing unequal access to infrastructure and growth opportunities. Standard CBA models show greater returns to a pound of investment in more productive and affluent regions, and therefore direct funds there exacerbating existing inequalities (Coyle & Sensier, 2020). The government should:

- diversify from widely used economic tools like standard cost-benefit analysis, static optimisation, and integrated assessment models which significantly understate risks and are inappropriate tools for assessing non-marginal structural change. Keeping up with, managing and directing transformative change requires a range of approaches that embraces uncertainty and allow space for innovation and behavioural change.
- undertake systematic efforts to develop policy appraisal tools that are appropriate for the relevant policy questions and can account for the complex and non-marginal dynamics of the system the transition demands.
- updating the Green Book project appraisal and evaluation analysis and guidance for major project appraisal will form part of a broader strategic plan, as distinct from a narrow appraisal where marginal conditions apply relative to a broadly unchanged economic structure.

Recommendation 5: Deploy risk-opportunity analysis using a wider range of considerations that cannot be captured by conventional analysis such as cost-benefit. An array of complementary approaches to quantitative modelling are typically needed.

Enhanced risk management and optionality

Appropriate portfolio management for both the public and private sector is likely to entail a two-leg strategy of diversity and breadth as well as selectivity.[lviii] This can help guide policy and allow firms to be more flexible in dealing with innovation and policy uncertainty (Klingebiel & Rammer, 2011). It can be summarised as avoiding putting all the eggs into one basket as well as one egg in every basket. Instead, eggs should be spread across the best set of baskets available (Way et al., 2019) and monitoring and tracking 'watch fors' relevant to each sector (Cook et al., 2023) (see Annex 1).

- For robust decision-making, policies should aim to be adaptive, keep options open, retain institutional flexibility in light of new and evolving information, and to incorporate learnings (Grubb et al., 2023). They should avoid locking into expensive infrastructure systems and ideas that will be stranded, scrapped, or devalued alongside later regretted policies.[lix]
- Private companies will also need to adopt resilient risk management and hedging strategies. Private companies should go beyond setting targets for cutting their own carbon footprints and instead deploy a broader strategic approach to boost resilience and steer market development. Going beyond Environmental, Social, and Governance (ESG) to lobby for ambitious, long-term rules that drive and reshape entire markets is a critical part of this process. Recent evidence (from major companies such as Unilever to BP) has shown that change must be led from the top down and cannot depend on the goodwill of individual business leaders (Hooper & Gilding, 2024).

Creative destruction and upskilling

"Creative destruction," as described by Joseph Schumpeter (See box 1) is an evolutionary process, whereby capitalism generates a continuous replacement of old industries by new. Being intrinsically dynamic in nature, this process heralds innovation in new products and markets which increase efficiency and raise living standards.

Recognising the pace of change is very rapid, the government can lead the transition through policy such as reforming the planning system and supporting innovation and skills. Indeed, though inevitable and beneficial, it can mitigate the risks of the low carbon transition through the right policies to ensure growth is inclusive for all sections of society. On the other hand, economic dynamism brings with it challenges that require careful attention namely, the displacement of workers, regional disparities, and transitional shocks. Insecurity and resistance to change caused by these disruptions threaten social cohesion and economic stability. What is needed are strong policy prescriptions, which do not obstruct progress but allow people and communities to adapt and prosper in a changing world.

Access to retraining programs, lifelong learning opportunities, and vocational education will go a long way in cushioning workers from possible technological unemployment. Ensuring that workers can upgrade their skills will allow them to shift to new and emerging sectors. It follows that economic dynamism, fuelled by creative destruction, is a two-edged sword: the process cuts away old structures while forging the new.

The burdens will be inequitably skewed towards those working in high-carbon and resource-intensive sectors, who will see their jobs threatened, and those with low incomes who will struggle to adjust to sustainable practices and to afford new green technologies (Kapur et al., 2024; Zenghelis et al., 2024). Policy has an important role to play in addressing these risks.

- **Appropriately designed policies consider how different households will be affected,** and who will pay or lose out, with a change in policy. For example, despite clear benefits for lower congestion and improved air pollution, buy-in for policies such as congestion charges has been difficult to secure (Krabbenborg et al., 2020). The most effective policies are the ones that will realistically be adopted by the public.

Recommendation 6: Policymakers should anticipate and manage disruption and be aware of distributional issues. If poorly managed, a backlash against climate policies can delay or even make them fail.

- **Where livelihoods are disrupted or jobs at risk, a programme of retooling, reskilling and investment support will be required** so workers can avail of the opportunities of the new economy. This should be part of integrated regional investment plans. Specifically, access to retraining programs, lifelong learning opportunities, and vocational education will provide workers with the flexibility they need to adjust to changing demands in the labour market. The role of government will vary across sectors, with focus needed in sectors that will experience a large change in employment, are composed of small and medium businesses, and are particularly concentrated in certain areas (CCC, 2023).

- **Clean technologies currently form a higher proportion of output in less affluent and productive regions compared to more productive ones (Curran et al., 2022). However, absolute levels of clean investment still lag behind more affluent regions.** Therefore, there perhaps remains an opportunity to direct further clean investment into less affluent regions. Skidmore (2023) highlighted that the green transition could support 700,000 direct jobs in 2030 and 1.2m in 2050.
- Targeted social protection and support for clean technologies uptake could be implemented for low-income households (HMT, 2021a). The goal is to ensure that the benefits of the transition are shared widely.

6.3 Getting the institutions right

Transitioning the UK economy relies on more than just good economics and business leadership, it requires well run institutions and political leadership. This means changing how the government operates from within. Each department, and particularly the Cabinet, HMT and DESNZ, must understand their respective role in delivering a Strategic Green Growth Plan while building the institutional capacity to lead on growth and productivity strategies that are integrated with net zero, digitalisation, and AI.

The new Labour government announced the creation of mission boards to drive delivery of government missions, including for clean power by 2030. The government must set out how it intends to achieve such goals. Risk-opportunity analysis provides a helpful structure to guide enabling conditions and identify and create plausible opportunities. Success requires understanding Treasury culture as much as it requires robust analysis. Labour's manifesto committed to "reforming our economy". A weak mission from the Chancellor will result in stasis and missed opportunities.

Success requires HMT to consider more carefully the role of institutional and process innovation. Increasing analytical capacity within Treasury relies not just on changed mindsets, but also flexible processes, and institutions able to learn from past mistakes and take on board new information.

The Treasury is staffed with capable and well-informed economists who are waiting for their chance to influence policy. But such voices are often suppressed by the politics of conservatism and caution, and a fear of change and transformation. It leads to self-contradictory phrases like "we cannot afford investment".[lx] This has led in the past to decision-making that is too short-term; to a lack of credibility with the private sector; and to unduly low investment, resulting in damage to UK competitiveness. **The ability to harness the HMT's analytical firepower to implement innovative ideas, and to recruit new talent, depends ultimately on the quality of its political leadership.**

- **It is important to blend in net zero with all the other political goals,** rather than treating it as an add-on or in direct opposition to them. The Chinese have shown that game-changing action can be induced without leading on, or even discussing net zero or climate change when pursuing a goal. This approach can ease political acceptability, reflecting the integrated nature of building a sustainable, competitive and resilient economy, and make net zero targets much easier to handle.
- **A clear understanding of the changing landscape of risks and opportunities is a prerequisite for applying appropriate analytical approaches.** The benefits that can be reaped, and costs of the transition, will be a function of the choices made and will be conditional on early action.
- **Support will be required to build a conceptual understanding of the dynamics of transformational** change and adopt appropriate analytical tools, going beyond deployment of conventional static optimisation techniques. This means understanding the drivers and evolution of dynamic processes – in technology, competition society and politics that can generate the level of deployment necessary to direct innovation. To achieve the desired objectives, structural change must be internalised and made central to decision-making processes.

Recommendation 7: Establish within HMT a Growth and Strategic Transition Team to lead on growth and productivity, with integrated strategies on net zero, digitalisation, and AI.

Additional measures to enhance institutional strategic capacity include:

- Build capacity and skills training and run open workshops with leading academics in the field of the economics of structural change. Around 500 analysts could be trained in the next three years.[lxi]

6.4 Putting in place the right regulatory signals

Studies show that rather than a single policy instrument, the transition requires a combination of different tools and policies (Grubb et al., 2021, 2023). As we have already seen, tools available include carbon pricing, standards and regulations, support for R&D and deployment, subsidies, public procurement, blended finance, and skill policies. Addressing other relevant barriers, such as the planning system, will also be key (Mercer et al., 2024; Skidmore, 2023; Stern & Valero, 2021). We now turn to the role of implementation.

- Regulation can deliver clear and consistent signals to entrepreneurs. Regulation is necessary to shift financial incentives towards cleaner more efficient supply lines and promote understanding of emissions across the wide scope of production. It will assist UK brands in investing in and better supplying the markets of the future. Mounting regulation risks stifling entrepreneurship and innovation essential to the clean transition. Care must be taken to strike a balance between climate ambition and regulatory and reporting burdens on business.[lxii]
- **By fostering transparency and beefing up regulatory and competition authorities, governments can help ensure that industrial policies are well-designed to minimise rent-seeking and focus on building long-term economic capabilities.** It is important to avoid replacing market failure with policy failure (Helm, 2010; Hepburn, 2010; Zenghelis et al., 2024). Attention must be paid to the impact of regulation and administrative burdens on innovation in high tech sectors.
- The UK has been announcing regulations for the 2030s, which have provided foresight to businesses and consumers, offering time to adjust to upcoming changes. However, in September 2023, a series of commitments on the phase out of fossil fuel technology sales in the 2030s were rolled back by the previous government (Sunak, 2023). Commitments to ending the sale of new fossil-fuel cars and new gas boilers as well as the upgrading of energy efficiency and should be restored right away. These are priority recommendations that have already been highlighted by the CCC (CCC, 2024).

Recommendation 8: Restore the commitment to end the sale of new fossil fuel cars and vans by 2030, mandate landlords to upgrade the energy efficiency of rental properties to achieve an energy performance certificate (EPC) rating of C by 2028 and eliminate the 20% exemption for the phase-out of new boilers by 2035.

Sustainable procurement can have a strong impact in sectors where public procurement makes up a large share of the market. These include sectors such as buildings and construction, public transportation, and healthcare services encouraging the adoption of sustainable practices within the private sector (OECD, 2015). As the transition progresses, tools such as regulations, mandates, carbon pricing, and market reforms play a critical role in shifting investments away from fossil fuels and accelerating the adoption of clean technologies across markets and society.[lxiii] In later stages, policies that enhance social acceptance become central (Grubb et al., 2023).

Planning

An improved planning system will be key to getting infrastructure projects from renewable generators to transmission lines and low carbon houses built on time, while maximising support and investment from the private sector. Addressing process bottlenecks, meaningful engagement with local communities, improving and digitising the use of data, and improving co-ordination between national and local level decision making will be important for achieving a more effective planning system (National Infrastructure Commission, 2023; Skidmore, 2023).

- Onshore wind farm regulation has heavily relied on demonstrating community backing and local suitability of the area (Rankl, 2024). While it is crucial to involve local communities in the decision-making process for onshore wind, this regulation is unique to onshore wind and has been difficult to demonstrate by potential developers, thus resulting in very limited onshore wind deployment. Reaching the 2030 target for a fully decarbonised electricity system means bringing in as many renewables as possible.
- Heat pumps have been constrained by a rule that imposes their installation to be one metre away from property boundaries. The aim was to mitigate noise pollution, however, noise complaints have been infrequent relative to the number of heat pumps installed (DESNZ, 2023b). The rule therefore appears to be an overly restrictive proxy when concerns over noise could be addressed by ensuring heat pumps comply with a 42 decibel limit.

Recommendation 9: As part of the National Planning Policy Framework review, identify and remove planning barriers that particularly affect low carbon technologies. Prioritise this reform for onshore wind farms by removing burdensome requirements for community support and site suitability which are hard to demonstrate, and for heat pumps by relaxing the requirement for a one metre distance from property boundaries.

6.5 Getting the policies right

Electrification

The transition to a low carbon economy will rely on the electrification of many sectors in the UK. It is therefore essential for electricity to be competitive relative to unabated alternatives. Yet, there exist environmental levies on electricity that have the effect of a tax, thus distorting the price of electricity for consumers. This must urgently be rectified to ensure that the economics of decarbonisation are right for consumers and businesses.

- It is urgent that the government addresses any policy distortions to electricity prices to ensure consumers and businesses have a strong incentive to electrify. This requires a rebalancing of gas and electricity prices. For example, removing the cost of Feed-in-Tariffs, Renewable Obligations, and early CfDs in electricity bills would result in a 20% cost reduction for heat pumps, which could cover most of the cost reductions needed for them to be more competitive relative to gas boilers (CCC, 2022).

Recommendation 10: The government should eliminate energy levies that distort the price of electricity and deliver on the long-awaited rebalancing of electricity and gas prices to incentivise and facilitate electrification for consumers and businesses.

Renewables and heat

The imperative of meeting our carbon budgets requires the government to pay particular attention to the role of offshore wind and heat pumps. They also stand to reduce energy costs, but only after initial investment costs are incurred. These are areas in which the government can make robust, 'no regrets' decisions, which keep options open in the face of change.

- Offshore wind deployment has been successful to date, however the 2023 auction round of the CfD that did not secure any new offshore wind tells us that we should not take the system for granted. Detailed policies, such as the reservation price for CfDs might also benefit from institutions that offer regular review, so that policies can change predictably in response to 'news', without unduly deterring investors. In the face of a full decarbonisation of the power system by 2030, these contracts will become all the more essential.

- In the past decade, renewable technologies have found appropriate business models to support the maturing of these technologies, resulting in drastic cost reductions. This has not been the case for flexibility options which are essential to balance electricity demand on a renewable-based power system. As part of the Review of Electricity Market Arrangements, the government should finalise the development of business models for less mature technologies such as hydrogen storage and transportation, while also incentivising battery storage and smart demand management.

Recommendation 11: Effectively implement Contract-for-Difference (CfD) auctions to deliver 50GW of offshore wind by 2030 while also developing new policy mechanisms through which to support the deployment of a portfolio of flexibility options.

Existing grants that support energy efficiency and heat pump installations have a key role to play in reducing upfront costs. Without them, the deployment of heat pumps will not reach the required levels to help bring down their costs in the market. Funding of these grants is likely to be needed throughout the 2030s. The design of the grants should also be assessed against the level of deployment of heat pumps, to ensure that the grants are fit for purpose. A low level of uptake despite generous grants is likely to indicate barriers, including oligopolistic pricing resulting from a shortage of trained engineers as well as costs associated with new radiators and additional insulation, that are preventing households from investing in a heat pump. This should be addressed through changes in the design of the grants and/or in implementing complementary policies (e.g. around skills for the workforce).

- Policy must target home insulation and energy efficiency where this could reduce households bills as well as alleviate pressure on energy demand and electricity grids. This requires clear incentives and innovative finance as well as overcoming non-financial barriers to retrofit, including hassle and time, for example by offering pre-announced and co-ordinated retrofits on a neighbourhood-by-neighbourhood basis. The government should consider de-risking investment into home retrofitting by relying on funding and grants from the UKIF (CCC, 2024).

Recommendation 12: Continue supporting policies such as the Boiler Upgrade Scheme or Social Housing Decarbonisation Fund, setting grant levels in line not only with heat pump costs, but also with energy efficiency measures that must be undertaken prior to installation.

Fuel duties

Scrapping the 5 pence cut in fuel duties announced in the last 2024 Budget of the Conservative government and reversing the trend of a 13-year freeze on fuel duties, would further incentivise behavioural change. Petrol and diesel pump prices in the UK have fallen to their lowest levels in nearly three years. Such a move is economically efficient (in the Pigouvian sense of taxing ‘bads’) but requires political courage to see it through.

07

Conclusion
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This report concludes that investment in the clean transition needs to be at the heart of the UK productivity and growth strategy over the coming decade.

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07

The world is in the midst of a renewable energy revolution. The era of generating energy through inefficiently burning things is being phased out. The transition is being led by wind and solar energy, utilising battery storage and increasingly efficient electricity networks. These are now rapidly pushing down the costs of global electricity generation and use. For over a decade, investment in renewable electricity generation worldwide has outpaced investment in coal, gas, and oil generation. New clean technologies are now rapidly being developed across a swathe of industrial sectors.

A strategy for managing opportunities and risks

The latest evidence from a range of disciplines suggests – clearly, in our judgement – that:

- undertaking a coherent national low carbon transition is the most profitable and resilient economic strategy;
- the alternative, of a high carbon, resource-hungry strategy based on 19th and 20th century technologies, would likely result in economic stagnation, inefficiency, and indebtedness; and
- there is little evidence in support of any case for gradualism or hoping to benefit only from the actions of others.

The net zero transition will create opportunities for economic growth. But it will require investment, much of it driven by policy. If investment is catalysed, the creation of new markets can promote innovation and productivity growth. It represents an opportunity to have a clear plan and design policies that will minimise likely costs, maximise expected economic benefits, contain risk and manage distributional aspects (HMT, 2021a). Reaping the benefits will depend on decisions that the government takes today (Skidmore, 2023). However, it will require a new economic strategy designed specifically to draw in private investment and generate intelligent, clean and resilient growth.

The new context requires new use of economics, and new economics results in new policies. **The net zero transition requires considerable investment.** But at the same time, it recognises that this investment both generates growth directly and creates new and further opportunities for economic growth. Moreover, clear and ambitious policies upfront reduce the need for costly capital replacement down the line, by inducing early growth-enhancing innovation in the private sector.

While the competitive economy of the 21st century will be based on resource efficient innovation, it must be carefully managed. It requires investment in efficient capital to replace a resource-hungry and labour-intensive energy system that is based on burning things. In the process, it is shifting from a system characterised by continuous, high operating expenses to a knowledge-driven, capital-expenditure-based system. This affords significant returns to scale, cost savings, and investment returns. The potential for cost reductions from innovation and technological learning is higher for clean technologies than for fossil fuels: the costs of certain clean technologies have dropped almost exponentially in recent decades, while the price of fossil fuels (per joule of energy generated) has remained roughly constant for more than a century.

Digital technologies and responsible use of AI can further reduce costs, by optimising systems through real-time monitoring and management, thereby contributing to the speed, efficiency, and effectiveness of the new economy. Recent evidence suggests that such investment also stands to induce creativity and innovation across the economy, while generating new experience and learning along the way. The challenge is to increase the efficiency of capital not just the investment rate. This marks a clear role for government to steer investment in a sustainable, resilient and intelligent direction, compatible with the technologies, markets and behaviours of the 21st century.

To be clear: **not all clean investment will add capacity or reduce costs.** For some activities, such as CCS, cleaning up will come at a net additional cost with limited additional growth benefit, except in so far as the UK develops a market lead in exporting the technology. Other activities, such as limiting airport expansion, will constrain growth while still others, such as retrofitting and insulating buildings, are relatively low-tech and labour intensive, even though they do generate net returns from greater efficiency. There will also be wasted money invested in technologies that fail to deliver as expected (EU over commitment to hydrogen is cited as an example). Finally, significant rent-seeking on the part of businesses seeking to benefit from public support must be expected. All these challenges must be recognised and addressed.

However, **in wide swathes of the UK economy, decarbonisation goes hand in hand with creating a more innovative, efficient, productive, and globally competitive economy.** With the world rapidly decarbonising and pursuing resource efficiency, investment will be essential if the UK is to maintain competitiveness in new fast-growing markets.

Those arguing that green investment is growth inhibiting and unaffordable, need to justify the counterfactual, high carbon investment strategy, and show that that would be more productive over the coming decades. We believe this case cannot credibly be made.

The evidence suggests that the UK has no choice but to keep pace with the competition. The Labour Party manifesto was in our judgment right to point out that “markets must be shaped, not merely served”. Decision makers in public institutions thereby have a responsibility to anticipate, manage, and help shape the rapidly shifting landscape of risk and opportunity in clean, digital future markets.

Government should not overextend its hand: but it should, through its policies, do the constructive things that only government can do. On occasion, after careful analysis, this requires that policy help to direct innovation, and kickstart the cost-cutting, clean innovation machine. The overriding thrust should be to encourage, in various ways, Investment that is forward-looking, based on what the economy can be, rather than what it has been in the past.

Race to supply markets of the 21st century is on

The global economy is undergoing three major transformations, involving general purpose technologies in clean energy; artificial intelligence; and automation. **As a centre of innovation, the UK is well placed to use its strong scientific base to help transform its economy, developing new knowledge clusters and supply lines and compete with other countries to develop new skills, technologies, and markets.** Making effective use of British excellence in innovation can generate knowledge spillovers from one technology to another, thereby boosting productivity, and strengthening skills and expertise in the workforce.

In the race to supply new clean technologies and produces, China has a commanding lead, having taken a series of strategic decisions in recent decades. The US and EU have also responded strategically; but, as this report highlights, there are nevertheless sectors where the UK could still benefit from servicing the economy of tomorrow. **There are opportunities to develop capabilities and corner new global markets** that will be a source of jobs, innovation, and growth, and thereby of tax revenues. Conversely, choosing not to invest in the new economy is likely to undermine the health of the public finances.

Given the pace at which the world is moving, the risks associated with slow action and postponing decisions are high. Locking into carbon-based infrastructure, skills, and ideas risks building stranded and devalued assets, and missing out on opportunities. With competitor economies cornering new markets, delaying action in the hope of free riding on the action of others would be risky and short-sighted.

By contrast, a green industrial strategy is an opportunity to secure supply lines and yield the benefits from trade, not least to the benefit of communities in relative decline. Where livelihoods are disrupted or jobs are at risk, a programme of retooling, reskilling, and investment support makes for a just and efficient transition. Paying attention to distributional consequences is also pragmatic in limiting social resistance to change. **The evidence shows that the biggest barriers to a sustainable, inclusive and resilient economy are not technological or economic: they are political and behavioural.**

Economic stability cannot simply mean carrying on with things as they are. Inertia may seem attractive on the face of things, but it is costly. A 'technology-neutral' choice often means favouring incumbent sectors with the deepest pockets, at the expense of society.

At a time of accelerated change, strategic choices have to be made. Building resilience and managing risk and opportunity depends on the right capital allocation. The investment and associated disruption are upfront, which may generate a political incentive to delay. But delay increases ultimate costs and heightens the risks that the UK misses out on a competitive race to supply some of the world's fastest growing new markets.

Enabling investment

This report concludes that investment in the clean transition needs to be at the heart of the UK productivity and growth strategy over the coming decade. The new government understands that delivery of its key objectives relies on robust and sustained economic growth. It also recognises the need to encourage public investment to boost growth and productivity, thereby ensuring that the UK retains an efficient and competitive economic edge.

Much of the transition can be undertaken by working within the investment cycle – replacing old fossil fuel kit for new low carbon alternatives as part of capital maintenance. To this extent, expenditure on the transition is expenditure that would have been undertaken anyway. In addition, **much current investment continues to be in the unsustainable economy,** such as development of new oil and gas fields in the North Sea, and the construction of homes and offices that are neither energy-efficient nor climate-resilient. This raises risks unduly.

Most of the necessary needed investment will come from the private sector. Investment will only be forthcoming if investors feel it will be profitable. Expectations are key, and government has a central role in guiding investors towards profitable, future-proofed assets, and strategically creating competitive new markets, while enabling workers to participate in the economy of the 21st century. In particular, additional public investment is needed in grids and in retrofitting the housing stock. Estimates vary: but **in our judgement the UK needs to increase annual public investment by around 1% of GDP (£26 billion at current prices) to make up for decades of underinvestment in its physical, natural, social, knowledge and human capital and crowd in private investment.**

It is therefore greatly concerning that the level of public investment, as a proportion of national income, is projected by the OBR to fall over the lifetime of this parliament. This stands to thwart the government's growth ambitions.

It would be inappropriate for net investment to be funded by current revenues: given that returns accrue in the future, it is fairer and more efficient that it be funded by borrowing. To enable the necessary investment, the UK fiscal rules need to be modified. In particular, **the UK should move from being constrained by the inherited blunt and arbitrary debt rule, that lies at the very heart of the UK's investment and growth problem.** Even though there is only one obligation to the government, not all public debt is created equal: a pound spent acquiring productive assets, and thereby strengthening the national balance sheet, boosting economic wellbeing, and ultimately paying for itself in increased output should not be assessed on the same basis as a pound spent on current consumption. A healthy private company or a responsible individual would deal with this through assessing its balance sheet rather than a single-minded focus on debt.

Appropriate fiscal risk analysis requires a comprehensive view of the public sector balance sheet, while explicitly accounting for the uncertainty inherent in fiscal forecasting. Fiscal and structural policy (how government spending, revenue raising and borrowing might affect the economy and its productive capacity) is more than just fiscal arithmetic (how the numbers add up under fixed assumptions).

Within this framework, **any increase in public debt should be restricted to the purchase of new productive assets, which enhance whole-economy net worth.** Replacement and maintenance of old assets, by contrast, needs to be fully funded.[lxiv] **This is the only way to escape the 'doom loop' of public austerity and low productivity growth associated with a continual squeeze on public investment,** which has plagued the UK economy for over a decade.

In our judgment, if this strategy is clearly explained, to the public and investors, both domestic and foreign, the logic would be accepted and the reception would be favourable. **There is all the difference in the world between borrowing to finance investment and borrowing to finance consumption.**

Priorities for public investment include growing the deployment of renewable energy, rapidly scaling heat pump installation, and growing the market share of new electric vehicles. At the same time, broader investment needs to cover energy, transport, housing, urban planning, industry, agriculture and waste.

With public debt in the UK, as in many countries, already around historic highs relative to GDP[lxv], **there is understandable concern about the ability to pay for further, debt-financed, public investment.** The government has an obligation to manage the public finances responsibly and capably, so as to minimise financial market vulnerability.

The government needs to run a current budget surplus, or close to it, over the economic cycle. But it need not – and in our judgement should not – shy away from increasing investment that will add to future output, even if this adds to debt in the near term. And to avoid this putting upward pressure on interest rates, it is important at the same time to design and implement measures to boost domestic saving.

Raising revenues to fund necessary day-to-day spending, while boosting saving, requires the government to reconsider its commitment not to raise key taxes such as income tax, VAT, national Insurance and corporation tax. The risk otherwise is that the burden of taxation focusses disproportionately on a narrow tax base that deters investment and saving. In the more medium term, reform of property and land taxation can provide a fair and efficient way to raise significant sums in revenue.

Finance is not the only barrier. Planning reform is high on the list major barriers to action if the UK is to build renewable electricity and storage capacity and deliver it with new transmission lines.

Guiding expectations is central to abating perceived policy and regulatory risk, and reducing capital costs. Policy backpedalling by the previous government dented business confidence, raised costs, and delayed benefits to households and UK energy security.

Conversely, however, if the government is credible in the way that it manages the transition process, an additional, ancillary, benefit is likely: credibility helps to steer private investment, and at no additional cost to the Exchequer. Consistent, predictable, and co-ordinated policy frameworks, based on a national growth, innovation, and skills strategy, stand to provide investors and companies with clarity and confidence that investment will be profitable in the sustainable and carbon-constrained markets of the future.

The government can promote confidence in private investors through having 'skin in the game' alongside a credible, consistent, and co-ordinated policy framework. This would be based on a national growth and innovation strategy and include an overhaul of the planning system and an integrated skills strategy, recognising that choices have to be made. It also requires a co-ordinated array of policies including standards and regulations, procurement and pricing. Perhaps counterintuitively, the most effective policies were found to have been those that supported the creation of new markets rather than those pricing polluting activities. A combination of policies to push supply and create demand for low carbon goods and services stands to provide investors and companies with the clarity and confidence necessary attract private investment. **Narratives matter and have real world consequences, because investment is driven by expectations.**

Understanding innovation and systemic change

This report finds that a UK clean transition can be quick – much faster than commonly predicted involving years not decades – and profitable. The term 'can' is apposite: the evidence shows the critical role of policy in delivering change at lowest cost. It is possible that multiple sectors will soon see clean technologies competing with dirty alternatives, not least in hard-to-abate sectors including aviation, shipping, steel, and cement. Public and private investments are increasing in sustainable sectors, firms are recognising the risk of depending on assets which may be stranded, the circular economy is thriving, and politicians and citizens are acting.

Recent technology innovation and new market growth have caught governments and investors by surprise and rendered cost estimates for greenhouse gas mitigation grossly over-stated, as technologies deliver cheaper and more efficient energy. The transition has been driven by price reductions in scalable, replicable and modular clean technologies, whose deployment leads to cost reducing learning-by-doing, economies of scale, and network and spillover effects. A host of other systemic reinforcing feedbacks also drive price dynamics. A technology breakthrough that reduces energy costs is likely to draw consumer tastes towards the new technology. It will likely also generate a more favourable political environment to support the technology over rivals. As new technology forms growth, they will gain lobbying power to challenge that of more powerful incumbents. Social norms, politics and institutions tend to move in lockstep.

Economic models and the role of quantitative and non-quantitative analysis

Policymakers face the task of deciding how to direct some areas of technological change; where limited public funds should be spent; and how to induce private investment. The global transition impacts the way practitioners analyse and understand change and the advice they provide to policymakers.

Faced with a worldwide technology transformation, **a number of countries, including China and the US, have concluded that it is no longer appropriate to adopt marginal incrementalist views and analytical approaches.** Hitherto conventional economic thinking, in turn embedded in today's models, tends to be based on static optimisation and cost benefit analysis. **This is ill placed to inform decision makers of large, non-marginal, structural shifts.** This means going beyond project-by-project value for money estimates to determine the worth of transformative investment. The government's own appraisal and evaluation guidance, the 'Green Book', recognises that transformational change requires a broader set of economic approaches beyond narrow static economic analysis and modelling.

Our report reaffirms the limitations of conventional approaches, while fully accepting that appropriate modelling is a critical part of articulating assumptions and enhancing understanding of systemic relationships. At the same time, it has to be recognised that the presence of increasing returns, multiple equilibria, and complex adaptive system feedbacks means that numbers can at best be illustrative when directing structural shifts.

What matters most are the insights that modelling provides, rather than its predictions. The report provides an explicit account of the mechanisms and processes that drive and steer innovation and adoption of new technologies, networks and behaviours — including strategic complementarities, expectation formation, and the role of multiple actors.

New modelling also provides analytical tools to guide optimal policy choices. **A shift to risk- opportunity analysis and options theory means that decisions can now be taken to shape the future supply side of all economies, invest in future-proofed assets, and avoid locking into redundant infrastructure, skills and ideas.** Our report concludes that a variety of models, complemented by a range of qualitative and non-modelling analytical approaches, with different strengths and weaknesses, can articulate risks and inform choices.

Strategic decisions are being made worldwide and, so far, economists have been scrambling to keep up with, let alone to understand, the pace of change. Even more seriously, by focussing on the price tag for the proposed investment, to the neglect of broader benefits, while prioritising the debt over the asset side of the public balance sheet, economists have been responsible for slowing the transition and raising its cost.

Economists using inappropriate tools have not only got the future wrong, they have helped make the future wrong. Overstating the costs of clean technologies delays investment, which undermines progress in reducing costs. Pessimistic predictions thereby generate expectations that in turn become self-fulfilling. The profession can and should do better. This report argues that, **with the appropriate conceptual framework, and an appropriate analytical toolkit, economics has much to offer in guiding and directing strategic decisions, reducing risks, and presenting opportunities associated with various courses of action.**

Leadership and institutions

Transitioning the UK economy relies on more than just good economics: it requires political leadership. Labour's manifesto committed to "reforming our economy". This means national visioning and scenario planning by economic decision-makers at HMT, to lay out what the net zero economy of the future will look like; what existing and new technologies it will be based on; and what new markets need to be created.

This requires strategic analysis of key clean sectors to determine potential dynamic comparative advantage. And it means laying out a compelling and attractive long-term vision for the future to which policymakers, the private sector, other key actors, and the public subscribe and support. It also means recognising that more government does not necessarily mean good government. Industrial policies must be well-designed to minimise rent-seeking, and focus on building long-term economic capabilities, thereby avoiding the replacement of market failure with policy failure. The evidence shows we cannot perfectly predict what comparative advantage the UK will have, but being an early mover in new market helps

Transitioning to a resource efficient clean energy economy will require a systemic shift in the way we live, travel, work and socialise. The technologies that dominate the transition will necessarily change individual and institutional behaviour. The pace of change will create disruption and generate distributional issues. Targeted policies will be required to retool and reskill workers to ensure that the opportunities of the new economy are shared widely. But the evidence clearly indicates that this social investment will pay off, boosting competitiveness as knowledge-based innovation in efficiency affords significant new opportunities and benefits.

It is our judgement that net zero will be central to a growth and prosperity plan. It will require investment, but the alternative is economic stagnation, inefficiency and waste. Major economies such as China and the US have got ahead of the UK in capturing the economic growth opportunities of a clean transition. Despite a period of inaction and muddle, it is not too late for the UK to use its innate scientific advantage to return to the playing field and reap the opportunities.

08

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Annex 1: List of 'Watch fors':

The purpose of 'watch fors' is to assess the extent to which any plausible socio-economic scenario is playing out broadly as envisaged in a world consistent with that scenario. It is used to identify 'consistent' developments, that stand to force, or reinforce, change in the direction envisaged in the scenario; and 'opposing' developments, that work in the opposite direction (i.e. risks to the scenario playing out). For example, in the context of much-used Network for Greening the Financial System (NGFS) scenarios, 'watch fors' can help identify the degree to which the world is following an 'orderly transition', 'failed transition', hothouse world' or specified 'disorderly transition' scenario.

Physical climate impacts/risks
- 1.1 Longer-term shifts/chronic climate patterns
- 1.2 Acute risks
- 1.3 Tipping points
- 1.4 Economic sectors/performance
- 1.5 Adaptive capabilities

Society and policy
- 2.1 Societal/behavioural impacts/ response (e.g. social norms, political moods and momentums)
- 2.2 Political developments and risks & geopolitics (elections, events, stories)
- 2.3 Policy legislation and institutions

Technology developments
- 3.1 Broad shifts in energy transition
- 3.2 Breakthrough climate-improving technologies

Annex 2

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Reflections on behavioural routes to the green transition

Social norms to encourage climate policy support: addressing inaccurate public perceptions and collective inertia:

When considering methods to increase public acceptance of green policies, it can be helpful to address the widespread misperceptions among the public about climate support. Social factors play key roles in human behaviour.

Individuals tend to underestimate how much others worry about climate change[1]. This may inhibit them from taking collective climate action. According to behavioural literature, there is a phenomenon known as pluralistic ignorance[2,3], where individuals erroneously believe they are part of a minority willing to take action on climate issues, assuming the majority is indifferent. This belief contributes directly to collective inertia, encapsulated in the rationale: "Why should I make efforts when others won't?" To combat this, the report could incorporate strategies that communicate clear social norms supportive of climate policies, including recent polling data and the dynamic norm showing increasing support for government climate action over the years. A recent review paper[4] offers a comprehensive overview of possible interventions to promote climate policy social norms.

Increasing perception of collective efficacy to improve public support for climate policies:

Related to this, is the important concept of collective efficacy[5]. Climate change and related global environmental issues are examples of common good dilemmas as defined in Behavioural Economics.

This means that these large-scale global problems are only solvable by collective efforts and not by individuals. As a result, considerations of *collective* efficacy (i.e., are we as a group capable of dealing with this problem?) play a prominent role in motivating individuals to engage in pro-environmental action. Research[5] shows that lack of collective efficacy (the belief that the group to which we belong is incapable of coping with climate change) is a key barrier for public engagement with climate change, and addressing it is important for public acceptance of climate policies. As highlighted in a Government research note[6], evidence[7] shows that people are willing to act on climate change but want assurance that others, including businesses and government, are also doing their part. As such, public engagement may enhance feelings of collective efficacy, whereby multiple actors in society working together can assure people that their actions are not isolated and can create effective change.

The role of elite cutes in the formation of social norms and influence of climate policy support:

Above, my point suggested ideas to communicate strong positive norms of climate policy support operationalized as statistical descriptions of public polling data, but the social psychological experience of norms is multifaceted, and it's worth noting that creating a perception of positive social norm for climate policies can also be implemented through the observations of specific, high profile individuals endorsing climate actions. There is important research[8] showing that political elite communications influence public attitudes about climate change by signalling social norms. One especially potent aspect of social norms, as conveyed by individual political elites, are their emotional appraisals on topics when the politicians discuss it in public, during heated debates against a political opponent, in their official speeches, party program leaflets, or in direct contacts with members of their own constituency.

When planning the communication around the climate strategy of the UK, it can be very helpful to think of which high-profile public figures can act as direct spokesmen, science communicators, advocates within their community, which figures can be perceived as a trusted source of information, and have potential to influence through the social norm they personally set.

Encouraging public acceptance of a climate policy and the role of perceived policy fairness:

Another crucial factor for strategizing public acceptance of the green transition is the perceived fairness of the policy[9]. There is evidence that perceived fairness is often a stronger predictor of climate change policy support than perceived policy effectiveness. This concept, particularly distributive fairness, involves whether a climate policy is seen as demanding an unfair sacrifice from certain segments of the population while primarily benefiting the wealthiest in the short term. This consideration has consistently been identified in the literature[10] as a main reason for the unpopularity of certain policies, such as wind farms, where the local population is seen to bear the inconvenience while the financial and energy benefits are perceived to accrue to an elite. Similarly, meat tax policies have been unpopular as they are seen as disproportionately impacting the most disadvantaged demographics. It could be helpful for the government to develop a communication strategy that effectively communicates the fair, balanced distribution of costs and advantages of proposed climate measures across the UK public.

Communications that address psychological distance biases to improve policy acceptance:

Temporal discounting is a psychological bias whereby greater temporal distance of policy benefits decreases policy support, no matter how important those future benefits may be[11]. As the perceived benefits of policies aimed at curbing greenhouse gas emissions and improving the natural environment extend into the future, public support for these policies declines. Environmental issues, despite their critical importance to our basic needs, are often ranked low in priority globally[12]. Social scientists believe this may be due to the psychological distance with which these issues are regarded; they are often seen as abstract problems affecting future generations or distant populations, making them feel less immediate and urgent[13].

Studies[11,14] indicate that the perception of these impacts as being distant in time and space affects public support just as significantly as the number of lives saved or the economic costs associated with these policies. Consequently, environmental policies that are perceived to primarily benefit future generations or people in faraway lands tend to be less popular.

This highlights the importance of communication strategies that emphasize the immediate and local benefits of environmental policies. By focusing public attention on the impacts that are expected to occur within the next ten years and within one's own constituency (such as job creations, or improved air quality), it is possible to significantly enhance support for these policies. This approach suggests that strategically reducing the psychological distance in how these policies are presented could be a key factor in improving their acceptance and effectiveness.

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Footnotes

[i] The IMF study estimates that 1.6 million premature deaths annually could be averted through reform to fuel pricing (the reform includes direct and indirect subsidies for fossil fuels).

[ii] Attempts to capture these impacts, for example, health impacts through QALY are inherently problematic.

[iii] At current prices, offshore wind is cheaper than the forward price of electricity. In the latest (Round 6) Contract-for-Difference auction (Sep 2024) the strike prices (in 2023 prices per MWh) cleared £67.09 (PV), £68.18 (onshore wind) and £72.65 (offshore wind) when the forward baseload wholesale electricity price in June 2024 was £77/MWh (Newbery & Cheong, forthcoming, with data from: (DESNZ, 2024b; Ofgem, 2024)).

[iv] This includes 19,591 direct jobs and an additional 11,491 indirect jobs.

[v] A non-marginal change is one which involves a change or changes in the structure of the whole economy. By contrast, a marginal change can be assessed on the assumption that the rest of the economy remains unchanged.

[vi] A survey to 231 finance ministries, central bank officials and senior economists of 53 countries, including all countries of the G20, showed that they see clean energy infrastructure investment and clean R&D spending as having high economic growth potential (Hepburn et al., 2020b).

[vii] Although the figure will likely be higher as behaviour adjusts in response to incentives to take advantage of tax credits.

[viii] Of course, the assessment of the benefit is endogenous (the damage done by an additional tonne of CO2 depends on the stock of atmospheric concentrations, which itself depends on emissions of CO2), but the CBA provided an illustrative example of what could be the net benefits, rather than a forecast or assessment of what they will be.

[ix] Solar manufacturing incentives provided for in the Act have attracted a $2.5 billion investment from manufacturer Qcell to build a PV manufacturing facility in the state, while Korean car-manufacturer Kia has opted to build an electric vehicle manufacturing facility in the state so as to benefit from the $7,500 tax credit provided for in the Act for domestically manufactured EVs (Williams, 2024).

[x] The UK has fallen behind Korea, China and France on conventional nuclear, and yet there is no major CCUS commitment in sight, though it is widely regarded as a necessary part of the investment mix for reaching net zero.

[xi] A variety of helpful tools have been developed to assess a country's green competitiveness strengths. See: Andres & Mealy (2023) and Growth Lab (2023).

[xii] Other grants also helped these projects to materialise. This industry presents an opportunity to build capabilities by being an early mover. This is supported by the requirement of a Supply Chains Plan (SCP) for projects of more than 300MW. The SCP aim to develop local supply chains and industries and support the levelling up agenda. Moreover, the intention is to invest in different low-carbon technologies and help bring costs down (BEIS, 2022).

[xiii] Contrails are line-shaped clouds formed behind the aircraft. The persistent formation of contrails contributes to global warming as they trap heat in the Earth's atmosphere. Aviation accounts for around 2.5% of global CO2 emissions. The sector's contribution to climate warming increases to 4% when non-CO2 are considered, and of the non-CO2 contributors, contrails have the highest climate effect (University of Cambridge, 2024).

[xiv] Both goals (Operation blue skies: contrail avoidance and Systems efficiency) can be accomplished with minimal new technology but requires strong market signals and decisive policy actions (ibid.).

[xv] If not properly managed, the competition to secure limited biomass for SAF production could increase emissions in other sectors, undermining aviation's gains.

[xvi] The Aviation Impact Accelerator (AIA) model suggests focusing on long-range flights, which account for nearly 50% of the sector's emissions, requiring the replacement of 5,000 aircraft and the conversion of 50 airport hubs globally. Alternatively, targeting medium-haul aircraft could be politically more feasible, so targeting regions like the EU could be an option, though the resulting emissions reductions would be smaller (University of Cambridge, 2024).

[xvii] UK plans to produce 10GW of low carbon hydrogen production capacity by 2030 (HM Government, 2021).

[xviii] In poorer parts of the world, 'de-growth' risks condemning billions of people to endemic poverty. As an illustration, one estimate suggests the world needs a 400% increase in output to eliminate poverty. Even in rich countries, it is hard to imagine the prospect of large cuts in wages and salaries boosting popular support for environmental measures.

[xix] CAPEX refers to capital expenditure and OPEX is operational expense.

[xx] A Carbon Border Adjustment Mechanism (CBAM) is a charge applied to the carbon content of imports implemented by governments to account for the carbon damage embedded in imported goods, with the ultimate aim of reducing greenhouse gas emissions. A CBAM aims to ensure that companies from different countries face the same carbon-related costs when competing in the domestic market. It is designed to ensure the carbon price of imports is equivalent to the carbon price of domestic production, thereby 'levelling the playing field and preventing the substitution of carbon-intensive activities to jurisdictions with less ambitious decarbonisation regimes. This ensures that the country's climate objectives are not undermined. It also constitutes a strategic effort at the global level to incentivise global collaboration to achieve net zero goals.

[xxi] The UK first introduced carbon pricing in 2002 with the implementation of the Climate Change Levy (CCL). The CCL was a tax on the use of energy in industry, retail, and the public sector. It aimed to encourage energy efficiency and reduce greenhouse gas emissions. The UK then became part of the European Union Emissions Trading System (EU ETS) when it was established in 2005. This was one of the world's first major carbon markets. The EU ETS imposed a cap on the total amount of certain greenhouse gases that could be emitted by installations in participating countries covered by the system. Under the EU ETS, a declining cap is set on emissions of greenhouse gases. Once this limit is reached, the sectors subject to the ETS must then acquire allowances to emit additional carbon. Notwithstanding some imperfections, the ETS system remains a sensible tool to incentivise the low-carbon transition. New UK government is currently consulting on the design of a UK CBAM, after which the UK is set to apply a CBAM to imported goods based on the embedded emissions from 1 January 2027.

The UK aims to mimic the EU CBAM from 2027 in most relevant respects, but there are likely to be differences in terms of timescale and scope. The EU and UK CBAMS will have an impact on trade. Any difference between a charge paid under the UK ETS and a higher EU CBAM charge would be payable, and reporting obligations will apply to all imports from the UK.

[xxii] The EU focuses narrowly on explicit pricing tools, such as emissions trading and carbon taxes, to determine eligibility for CBAMs. Critically, some UK trade partners, including the US, argue that the calculation should not only rely on a carbon price. The US has advocated for a broader approach to assess 'implicit' or 'shadow' carbon pricing, which results from a wider set of policies such as subsidies and other forms of support for clean sectors (Dominioni & Esty, 2023).

[xxiii] Frontier Economics: https://www.frontier-economics.com/media/0j1h3gyw/frontier-economics-linking-uk-eu-carbon-markets-final.pdf

[xxiv] Except for Northern Ireland which is part of the Single Electricity Market.

[xxv] These subsidies amounted to 3.1% of the UK's annual GDP spread across two years. While half is expected to be recovered through the application of windfall taxes, this still amounts to a significant cash transfer to the fossil fuel companies equating to approximately 1.5% of UK GDP across the two years.

[xxvi] Explicit direct UK subsidies to lower the price of fuels amounted to £19 billion and implicit subsidies, such as favourable consumption tax treatment, amounted to £55 billion (Black et al., 2023).

[xxvii] Stressors include decades of growing income and wealth inequality, a more recent cost of living crisis and a wave of popular distrust in politicians and so-called 'elites'. The Gilet Jaunes protest movement that began after the introduction of a carbon price targeting road transport in France underscoring the consequences of not considering the distributional impacts of climate policies.

[xxviii] In the EU premature deaths attributable to PM2.5 were 253,000 in 2021 (European Environment Agency, 2023).

[xxix] The government would effectively seek to offset weak household saving by borrowing less for consumption, to allow for greater investment without excess borrowing from abroad. In an economy with limited capacity and inflationary pressures, making room for investment requires crowding out current consumption. The size of this target surplus can be determined with the support of the OBR and can be reduced once structural measures, such as enhanced employee pensions auto-enrolment, succeed in boosting UK saving or once AI and Machine learning improve revenue collection.

[xxx] The KfW's current mandate is focussed on Net Zero and the UN's SDGs. All new financing the bank provides is required to be in line with a 1.5°C global average temperature rise limit (KfW, 2024a). Around 38% of the bank's investment volumes are in climate action and environmental protection (ibid.), and it provides financing for energy infrastructure projects both in Germany and internationally, including £1.75 billion for the Triton Knoll Wind Farm off Lincolnshire (KfW, 2024b). On behalf of the Federal Government, the Bank has also invested to protect Germany's energy sovereignty, providing €42.4 billion in January 2023 to expand fuel reserves and support energy suppliers (Steitz, 2023).

[xxxi] The requirement will be to invest in assets that will future-proof economies in the growing markets of the coming century, without locking into out-dated carbon intensive infrastructure, skills and ideas that are likely to become devalued and stranded.

[xxxii] Clean sectors accounted for 40% of China's GDP growth in 2023 (Myllyvirta et al., 2024). Other countries are waking up to the dangers of falling behind and channelling huge sums into clean transitions. Some car makers that were slow to adopt battery technologies risk the loss of jobs, supply chains and export markets. Taking the lead in a competitive playing field therefore requires early supportive and 'enabling' government intervention. Again, this new agenda and the questions facing economic-decision makers naturally demands new and complementary types of analytical approaches.

[xxxiii] Models range from simple toy models with closed-form solutions to immensely big and complex models. Widely used Integrated Assessment Models (IAMs) are generally part of the latter, simulating the entire economy and climate. General equilibrium models, such as Computable General Equilibrium (CGE) and Dynamic Stochastic General Equilibrium (DSGE), are standard Economic IAMs (for a full taxonomy on climate-economy models see Barbrook-Johnson et al., 2024). IAMs have been used evaluating future emissions and economic pathways. They have informed international negotiations on climate mitigation policies and influencing national and international strategies (ibid.). These models underpin the majority of models in the IPCC assessments, but have faced widespread criticism for methods of estimation and normative implications (Blanchard, 2018).

[xxxiv] Models used by many governments and international agencies to predict the scale and cost of decarbonisation have often largely missed is the reinforcing feedback in the relationship between the deployment of new technologies and their price. As technologies become cheaper the incentive to deploy them increases. But it is deployment which in many cases is the key driver of cost reductions.

[xxxv] Examples such as UK offshore wind and German feed-in-tariffs for renewables, which in hindsight have been highly effective in stimulating technological innovation and opportunities for investors, were at the time assessed as statically 'inefficient' or growth-constraining under conventional models.

[xxxvi] An established evidence base is hard to draw from when change is happening fast or has not happened yet. For example, even a probabilistic learning curve approach is difficult to apply to new technologies for which little if any historical data is available. New techniques for estimating causal parameters and new data cannot generate accurate predictions in a world of complex dynamics, reinforcing feedbacks and path dependencies. Small parameter or data errors/omissions will lead to wildly different results such that a well specified endogenous model is likely to fit empirical data over longer time periods only by luck.

[xxxvii] Equally, many models typically used by Finance Ministries are not designed to help countries assess potential comparative advantage in the new economy, nor how best to focus strategies on developing supply lines and knowledge clusters in these areas. Failure to do so, including an excess focus on the sectors of the past, exposes the economy to great risk and likely missed opportunities.

[xxxviii] This conceptual failing goes beyond more detailed criticisms over poor or unimaginative HMG analysis relating to investments such as nuclear and high-speed rail. Broader Social Cost Benefit Analysis (SCBA) takes account of a greater

number of spillovers and externalities including positive learning benefits. The failure to apply SCBA is arguably behind some of the UKs worst public decisions, for example through understanding the full benefits of improving cycle infrastructure in compact connected cities. See: (King & Crewe, 2014).

[xxxix] This comes in addition to the fact that conventional optimisation analysis, based on welfare economics seeking to maximise aggregate utility creates a false baseline, ignoring the damage of business-as-usual approaches and failing to capture the myriad of non-monetizable spillover benefits from green investment (Pindyck, 2013; Romer, 1990; Weitzman, 2011).

[xl] Additionally, ROA can better include climate risks. Risks from heavy-tail distributions are particularly important in climate risk, where the likelihood of extreme, high-impact events (like super storms) is higher than previously thought, posing significant risks. These events are large and can catch you by surprise. Therefore, risks are large and unknown.

[xli] ROA is a generalisation of cost-benefit analysis (CBA is ROA with known risks) more appropriate to assess and compare policy options in contexts of uncertainty, large scale non-marginal structural change, and path-dependency especially where there are a diversity of interests (Kapur et al., 2024). ROA, which assesses likely risks and opportunities, remains wildly underdeveloped and underemployed, and further development of applied techniques is urgently required. ROA allows policymakers to think more broadly and dynamically about possible outcomes and risks, while still producing usable and comparable insights. It helps shift the focus from narrow forecasts, to instead exploring possible best- and worst-case scenarios, and identifying mechanisms and narratives estimates of risks and opportunities. It helps make policy decisions robust to an array of outcomes, many of which are endogenously related and often self-reinforcing under different policy choices.

[xlii] Systems mapping (such as causal loop diagrams and systems maps) has emerged as a central tool in the non-quantitative policy analysis toolkit. It is now being used by governments and researchers around the globe, and its use in the last few years has matured such that focus is sharply on practical value and insights. It is most used early in the policy cycle, to generate understanding around the current system, build consensus between stakeholders and policy teams, and support policy design exercises. It is also used in ex post evaluation and learning exercises to assess policy impacts. It is less common to see it used in policy implementation stages. For assessing dynamic feedbacks, the steps in causal loop mapping include: i) identifying the direction of causal relationships between variables and identifying the positive (amplifying) and negative (dampening) feedbacks. The behaviour of the system can be understood as arising from these feedback loops, and the effect of policy options can be assessed in terms of how they would strengthen, weaken, create or break feedback loops. See: Barbrook-Johnson & Penn (2022) and Sharpe (2023).

[xliii] 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: Staffell et al. (2020) and IEA (2020).

[xliv] Game theory explore questions such as: If I am a player in the climate change game why would I sacrifice if no one else does? How does accounting for short-term self-interest alter decisions and change? What are the strategic complementarities whereby my perceived ‘payoff’ depends on the actions of others? Effective climate policies should address these issues by demonstrating that people are not alone in their efforts and by using dynamic norms to reflect changing opinions over time. This approach can shift perceived payoffs, encouraging behavioural change and climate action.

[xlv] Embedding climate action with a long-term growth strategy presents an opportunity to expand wealth (Geels et al., 2021; Valero and Van Reenen, 2023; Zenghelis et al., 2024). Moreover, the net zero transition comes at the time of the digital revolution, so integrating both is beneficial (Zenghelis et al., 2024).

[xlvi] The development of a competitive and thriving UK and now global offshore wind industry showed that picking winners can be successful, having dramatic consequences (Zenghelis et al., 2024).

[xlvii] Even with the right policy structure, it will be impossible for all decisions and investments to come right. Green technologies present ex-ante uncertainty. There is the possibility of unforeseen scientific or technological developments, unpredictable price changes or commercial trends (Rodrik, 2014). In the face of uncertainty, some investments will fail, but as this is understood in the private sector, what matters is not if some projects fail but rather the portfolio’s overall performance (Rodrik, 2014). Successful investments can more than offset failed ones. In this context, Laplane & Mazzucato (2020) discuss the possibility of socialising rewards as well as risks. The Department of Energy of the US supported green investments, including a $500 million guaranteed loan to the solar company Solyndra and

$465 million to Tesla. Solyndra went bankrupt, and public resources were lost as risks were socialised. Tesla's loan agreement contemplated a clause allowing the government to receive three million shares if the loan wasn't repaid. Interestingly, if instead the government had secured those shares upon Tesla's success, the profits could have offset the Solyndra loss and funded other promising ventures (Laplane & Mazzucato, 2020). In the latter, rewards would also have been socialised.

[xlviii] The latter requires a set of institutional safeguards, including clear benchmarks, sectoral monitoring, independent evaluations, and explicit mechanisms to stop support for failing initiatives (Rodrik, 2014; Juhász et al., 2023). Transparent regulations can help prevent rent-seeking by vested interests and natural monopolies (Zenghelis et al., 2024).

[xlix] a whole-government approach will entail co-ordinated action across government departments, including DESNZ, Defra, DfT, and MHCLG, as well as those addressing cross-cutting issues for the transition such as DIT, DWP and DfE, that are supporting sectoral decarbonisation,. Coordination across devolved administrations will be equally crucial. For this, a clear mapping of interdependencies between reserved and devolved powers should help define how these powers might influence decarbonisation efforts across the economy.

[l] Moving assets and liabilities off the government's balance sheet poses challenges for regulation and the danger of private sector asset stripping and debt leverage, as experiences at Thames Water.

[li] Fiddling with definitions, for example by defining public sector net debt to include the BoE may afford the government headroom to meet its fiscal rules, but it does not address the inherent in consistency of treating all debt equal, nor does it provide an incentive to reign in borrowing for current expenditure.

[lii] The government ruled out increases in the rate of VAT, the primary UK consumption tax, prior to the 2024 election, though it did not rule out extending its scope.

[liii] The UKRI study finds that £195 billion of 'place agnostic' one-size-fits all investment is required to meet targets set out in the Sixth Carbon Budget, and this investment releases £57 billion of energy savings (UKRI, 2022). These savings are reflected in lower bills for consumers – whether they be individuals, businesses or other organisations. By contrast, the place-specific scenario requires just £58 billion of investment and releases £108 billion of energy savings for consumers. This means when city regions can adopt the most socially cost-effective combination of low carbon measures based on the specific characteristics, needs and opportunities of their location it requires significantly less investment, whilst creating nearly double the energy savings. The opportunity extends to co-benefits, with the report finding that, "The wider social benefits are significant in both scenarios but the place-specific investment of £58 billion generates wider social benefits of £825 billion. This is compared to £195 billion investment realising £444 billion of wider social benefits in the place-agnostic approach."

[liv] Previous periods of government-directed investment, such as defence innovation during WWII, the Apollo mission, and the COVID-19 vaccine development, can produce innovation in the targeted sectors while also boosting Schumpeterian innovation and knowledge spillovers, which raise productivity across society more broadly (Gross & Sampat, 2023; Mazzucato, 2023; Perez, 2010).

[lv] The cost of capital is an essential component of policy design, as the private sector demands a risk premium on investment to cover policy risk in sectors like energy, transport and buildings that are heavily regulated and policy-driven.

[lvi] Inconsistent policy and backtracking on existing policy approaches can produce an uncertain environment where market actors lack trust in the state commitments, delaying actions and raising policy risk premiums attached to those investments (Zenghelis et al., 2024). Businesses can handle technology, market or construction risks, because they can adapt behaviour accordingly. By contrast they cannot directly control policy risk obliging them to charge a premium to cover it. Indeed, to date coherent action has been lacking in the UK. The delay of a ban for new diesel cars from 2030 to 2035 created new uncertainties and loss of confidence for carmakers and private investors (see Box 6). Additionally, the push back of 10 years to 2035 of the ban of gas boilers in new properties was also a negative signal. It is crucial, then, that policy frameworks are stable and credible. It is particularly concerning when rival economies like China and the US are increasing the incentives to invest in their markets.

[lvii] For information on the Danish model, see: The Danish Government's Climate Partnerships (2024).

[lviii] Policymakers can seek to target strategic sensitive intervention points. A relatively small policy intervention (like the UK carbon support price) can have an outsized effect generating reinforcing feedbacks, triggering positive tipping points and changing market behaviour.

[lix] Retaining optionality enhances the resilience and potential success of the strategy. Businesses and governments should develop a list of 'watch fors' in order to determine appropriate courses of action. This does not mean a lack of commitment to policy decisions, and certainly, striking the right balance is needed. For example, for a time it seemed that hydrogen might be a viable option to replace gas heating, but with time it became clear that heat pumps offered the most cost effective option in most UK regions. After keeping options open, the UK has had to focus on pushing one network technology – electric based heat pumps. At some point a choice has to be made. While outcomes may be affected by unforeseeable elements, achievements and success are primarily driven by strategic choices, implementation, commitment, and the ability to navigate changing environments and adapt accordingly.

[lx] The Dasgupta Review on The Economics of Biodiversity (2021) and the Skidmore review of Net Zero (2023), were excellent Treasury-led analysis. Yet their recommendations were sidelined and the insights they provided failed to attain policy traction. The reason was a lack of mission and the absence of political leadership in the previous government. The ability to harness the Treasury, and the wider civil services', economic firepower to implement innovative ideas depends on political leadership. The Treasury is full of talent which the Chancellor needs to engage.

[lxi] In 2021, the UK Treasury was composed of about 2000 employees. Of these, around 300 are part of the Government Economic Service (GES). The training of 500 civil servants would imply training all member of the GES together with additional analysts and policy analysts beyond that. See: HMT (2021b) and GES (2021).

[lxii] Policy should recognise that a full and comprehensive understanding of current emissions is less important than a coherent forward strategic business plan to invest in future proofed physical, human and intangible assts. Markets will increasing seek the latter when making investment decisions and this will increasingly be reflected in company valuations.

[lxiii] Product-level regulations and standards can be especially effective when constraints are credible, outcomes are clearly defined, and entrepreneurs are given the freedom to determine how to achieve them. In such cases, necessity often drives innovation (Zenghelis et al., 2024) and reduces the cost for businesses and higher consumer prices (HMT, 2021a).

[lxiv] Borrowing should be limited to funding net additions to the capital stock and not that part of gross investment which covers capital maintenance and replacement. On the other hand, there are investment like elements to much current spending. For example, higher wages for doctors, nurses, teachers and judges can be expected improves the quality of public services by attracting and retaining high skilled more productive labour. Because this can be expected to expand whole economy productive capacity and returns, there is a reasonable economic case for some borrowing to support spending classified as current government consumption.

[lxv] In the US, which has no fiscal rules, public debt is now nearly 125% of GDP and rising; in Japan it is over 250%. Europe and the UK have fiscal rules the corresponding figure is around 90%, and 100% respectively.

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