Boosting growth and productivity in the United Kingdom through investments in the sustainable economy

Dimitri Zenghelis, Esin Serin, Nicholas Stern, Anna Valero, John Van Reenen and Bob Ward

Policy report

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Summary

UK investment: too little, too volatile and insufficiently forward-looking

It is now widely accepted that the UK has a major productivity growth problem, with chronic underinvestment across both the public and private sectors being a key cause. Continued low public investment, as laid out in the Chancellor's Autumn Statement of 2023, and ongoing barriers to business investment in productive and sustainable assets, are inconsistent with success in international markets and will likely lead to more stagnation.

Investing in the opportunities afforded by the global transition to an efficient, resilient and inclusive economy needs to be a bigger part of restoring productivity and output growth for the UK to gain a competitive lead in the innovative markets of the 21st century.

Too 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 not energy-efficient or climate-resilient – this raises costly risks. These include creating stranded assets, significant financial losses in polluting and emissions-intensive sectors, and an insecure, unaffordable and unsustainable energy supply. It will also mean that the UK fails to adequately tackle climate change, biodiversity loss and environmental degradation, including water and air pollution. As the Office for Environmental Protection has pointed out, the UK is not fully on track to meet any of the 10 goals set by the Government in the Environmental Improvement Plan in 2023. In contrast, a sustainable, inclusive and resilient economy would produce significant benefits for productivity growth, driven by innovation and efficiency, which would reduce harmful waste and pollution and support people's health by planning more liveable cities and by improving access to nature.

Investment policy should be forward-looking, based on what the economy can be rather than what it has been in the past. Decision-makers should no longer be caught out by the rapid pace of change. The Government's Green Book appraisal and evaluation guidance highlights the limitations of cost–benefit approaches when dealing with policies designed to steer transformational, systemic change. An alternative risk–opportunity analysis approach is less reliant on historical trends for data and can help shape clean, digital future markets by steering paths, inducing innovation and kickstarting the clean innovation machine. The alternative of fostering fossil fuel technologies of the past, without setting up complementary institutions to resist influence from incumbent vested interests, poses significant economic risks.

Innovation is key to reducing costs, boosting efficiency and profiting from opportunity

The competitive economy of the 21st century will be based on resource-efficient innovation. But this requires early investment in a range of future-proofed assets to substitute fossil fuel and resource use, and to reduce waste and pollution.

Innovation to drive down costs and get more out of the resources the UK uses will be key. Research shows that developing British excellence in innovation has knock-on effects: knowledge spills over from one technology to another, boosting productivity, and strengthens skills and expertise in the workforce.

As a centre of innovation, the UK is well placed to lead the competitive race to build knowledge networks and supply chains for the goods and services of the 21st century. Once a country or region embarks on a high-innovation, high-productivity path, that path tends to reinforce its technological lead with new knowledge clusters and supply lines, attracting high-skilled jobs and promoting the country's competitive advantage.

Digitisation and responsible use of artificial intelligence (AI) will be central to the transition to a sustainable and efficient economy, optimising systems through real-time monitoring and management and contributing to the speed, efficiency and effectiveness of the new economy.

Government must immediately boost investment

Investment needs to cover all key sectors: energy, transport, housing and industry, plus agriculture and waste. It affects how land is used and shapes the connectivity of cities. It helps tackle climate change, biodiversity loss and environmental degradation, including water and air pollution, across the country. Productivity is driven by efficiency, and investment in resource and energy efficiency gets more out of the country's resources and drives competitiveness in global markets. The investments inevitably will be front-loaded, substituting capital for fossil fuels, and reducing waste and pollution.

Much of the needed investment will come from the private sector, but government has a basic role to play in helping to guide investors towards profitable, future-proofed assets and strategically creating new markets, while enabling workers to participate in the 21st century economy.

We estimate that 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, to deliver on the need to tackle climate change, biodiversity loss and environmental degradation, and to be economically productive, efficient and competitive in the future.

Together with a coherent set of public policies to drive innovation and address gross systemic inefficiency, **this would help crowd in private investment in tackling climate change, biodiversity loss and environmental degradation, and could form part of a rise in annual overall public and private investment that taken together is equivalent to at least 3% of GDP, or £77 billion**.

It is clear that the imperative to create a sustainable, inclusive and resilient economy is one of the starkest and most radical drivers of human ingenuity, inducing innovation and boosting efficiency and productivity. The growth story that will be created will be much more attractive than the dirty, destructive models of the past. Connected cities in which people can move, breathe and live fruitful and productive lives can be expected to attract knowledge clusters and high wage jobs to supply the 21st century economy. A sustainable agricultural sector would boost biodiversity, reduce pollution and waste, and improve food security. Inclusivity is key, to enable full utilisation of the country's diverse human resources, enable regional levelling up and promote social justice. Left unaddressed, distributional impacts during the transition to net zero can act as sources of friction that slow down and derail efforts.

New methodologies are needed to utilise the economic toolkit

It is impossible to forecast accurately what impact the deployment of key technologies and systems will have on costs and productivity. But what is known with great confidence is that delay or inaction will substantially increase the costs and close off opportunities. In key sectors, deployment stimulates cost reductions and cost reductions induce increased deployment. Moreover, the spillovers and impacts from one sector to another, and more broadly to institutions and consumer behaviour, are large.

Such reinforcing, potentially self-fulfilling, systemic feedback is unstable and makes detailed predictions impossible: all leading analysts were caught out by the pace of change in key renewable and energy efficiency technologies. Nevertheless, this feedback is happening worldwide and at an accelerating pace. It makes policy all the more important, because its effects are amplified. It also heightens the costs of weak, inconsistent or delayed policy and calls for a coherent strategy. There are limitations to setting policy by looking in the rear-view mirror; we suggest in this report practical approaches to assessing risk and opportunities from a sustainable transition.

The economy creates opportunities faster than they can be modelled, so analysis and policy must be adaptive.

Designing the future is easier than forecasting it

We have no detailed quantitative grasp of what an intelligent, sustainable and resilient economy will look like by 2050. What we do know, with confidence, is that anticipating, managing and steering any transition is likely to reduce costs.

Conventional cost–benefit approaches are inappropriate tools for assessing non-marginal structural change. The key cost parameters change as a result of the actions we take and the innovation pathways we generate.

Technological and behavioural adjustments with reinforcing feedback are hard to model. Perhaps this is why they are too often ignored by economists. In fact, these dynamic processes imply that forecasting optimal pathways is unhelpful. The best that can be done is to guide the economy in the appropriate direction.

Rather than attempting to provide long-term forecasts, economists would do better to focus on better informing decisions regarding future risks and opportunities, while guiding technological and behavioural innovation tipping points.

The Office for Budget Responsibility and the Treasury could usefully undertake a thoroughgoing review of their forecasting methodologies, setting out their approach to modelling large-scale risks and opportunities in compliance with the recommendations of the Government's Green Book guidance relating to strategic investment.

The risk–opportunity assessment needs to go beyond the impact on growth and productivity of a specific investment (often termed the 'growth multiplier'), given the path-dependent and systemic nature of a structural transition. The effect of each policy and each investment depends on its interactions with others and cannot be assessed individually. A broader strategy is required to assess value for money.

Investment and growth would set public finances on a sustainable path

The direct public finance required to support this transition should not be expected to worsen public debt/GDP dynamics. Indeed, by facilitating long-term resilient growth, borrowing to invest is the only way to secure enduring public debt sustainability. As with all risk–opportunity-based strategies for assessing a structural transition, the precise magnitude of the change cannot be quantified. But the alternative of paring back or delaying 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.

A key distinction needs to be made between real resource costs, which are lost to the economy, and investment costs, which yield future returns. The public sector should take further strides to monitor public and broader national net worth, recognising that raising debt to enhance core assets bolsters financial sustainability.

Sustainable growth also comes from productive investment right across the economy, some of it in less technologically innovative 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. This is a whole-economy transformation.

There will be upfront investment costs to delivering the transition to sustainable, inclusive and resilient growth, but targeted and temporary borrowing for good public net investment reduces the debt-to-GDP ratio over time and is fiscally responsible. Scarce public resources should be 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.

The path of interest rates is critical for debt sustainability, particularly as capital is substituted for fossil fuels. However, the evidence suggests there is little shortage of global desired saving. Moreover, once current capacity constraints begin to abate, nominal and real interest rates will likely drop back to historically low levels.

Fiscal rules need to be adjusted to account for the net investment in core assets and the preservation of net worth. It is incomplete accounting to ignore the asset side of the balance sheet and focus solely on the liability side.

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. By contrast, inaction would likely prove costly to economic competitiveness and financial resilience and require costly remedial support later on.

Credibility and coherence create an enabling environment

Stimulating sustainable investment in highly regulated sectors including energy, transport and housing need not require huge sums of public expenditure on deployment or innovation. Equally important is clear, credible and predictable policy intervention, which is often financially costless.

Consistent predictable and coordinated policy frameworks, based on a national growth, innovation and skills strategy, can provide investors and companies with greater clarity and confidence that investment will be profitable in the sustainable and carbon-constrained markets of the future.

To attract private capital, the Government needs to make clear its commitment to an innovative and competitive sustainable economy through creating and enabling a stable policy environment, and make efforts to catalyse private finance. Resource and carbon pricing (that raises public revenues) and ambitious standards or regulations are highly effective ways to shift private activity. R&D and deployment policies, systemic reform and new institutions will also complement direct infrastructure investment.

Guiding expectations is critical to abating perceived policy and regulatory risk and lowering capital costs. Evidence shows that when economic actors anticipate a supportive framework, they will seek to profit from new markets and act in ways that reduce the costs of a new technology by deploying sustainable and resilient investments.

Choices need to be made, technologies induced and markets created

Strategic choices need to be made – there is no such thing as a technology-neutral choice. Avoiding change is a choice that will, unavoidably, advantage incumbent technologies that have extensive legacy assets (physical, human and knowledge), deep pockets and established lobbying networks, even if they are ultimately more expensive.

Inevitably, there will be some instabilities and setbacks along the way, which must be anticipated and managed, but investments in sustainable technologies and infrastructure are set to reduce costs for UK businesses, improving productivity and profitability over time. This in turn would fuel increasing returns to scale in production, where investment in knowledge begets increased output and resources for further investment: a virtuous-growth spiral.

Inconsistent, weak or delayed policies have consequences: against the backdrop of a global structural transition, these consequences can be amplified. The economic risks of the UK being behind on some of the fastest growing markets are substantial. Markets increasingly recognise that the infrastructure, skills and ideas of the past century can quickly become a liability and asset valuations and capital costs will increasingly reflect this.

Coherent strategy and new institutions must be created

Institutional capacity, better understanding of the nature of the problem, and incentives to deliver change rather than just set targets are required. Public institutions should invest in the capacity and expertise to fully understand the process of structural change, the returns to investing in core assets and the management of risk and uncertainty.

It should be made easier for policymakers to be held to account for inadequate infrastructure, expensive leaky houses, uncompetitive firms and vulnerability to global energy crunches, as well as congested, polluted cities. Access to core enabling assets such as health, education and skills can provide positive returns within years. Better measurement of public net worth is a prerequisite.

The UK requires a dedicated, independent policy institution, focused on finding solutions to the productivity problem. It would need to ensure that industrial policies are embedded in a lasting and coordinated growth strategy, along with policies to ensure that risks and opportunities are shared. It should explicitly and transparently consider where there are synergies and trade-offs between sustainability and productivity objectives over different timescales, and what this implies for policy.

There is a need for a skills strategy to accompany the growth strategy. This would be based on strategic sectors and technologies, including clean, resource-efficient technologies and AI.

Managing disruption is key

The biggest challenges to the transition to a sustainable, inclusive and resilient economy are not technological or economic: they are political and behavioural. Management of dislocation is central to equity and to successful action and political feasibility. Fundamental structural change inevitably involves dislocation in the workplace and changing relative prices, with some costs rising before ultimately falling.

Near-term political risk from disruption relating to a clean transition must be recognised and mitigated. Care must be taken to understand and respond to the distributional impacts of all policies as part of a coherent skills and growth strategy. Workers will need to be reskilled and retooled so they can benefit from the opportunities of the new economy. People on low incomes will need support as early investment costs of the transition are passed on.

Grasping opportunity and minimising risk

The transition to a sustainable, inclusive and resilient economy is a genuine opportunity for the UK to drive innovation and competitiveness and rekindle productivity growth. This requires a coherent, credible and targeted set of policies to raise living standards, manage disruption and unlock new, intelligent and sustainable forms of growth.

1. Introduction

The UK faces large-scale investment needs across both the public and private sector. On the public investment side, government faces constraints on the ability to increase taxes further and with a high debt to GDP ratio and high interest rates, there are concerns around the sustainability of increasing borrowing for investment. But there is mounting evidence, as we document, that targeted and temporary borrowing to invest in sustainable technologies and infrastructure would prove cost-effective and beneficial to the UK's living standards and economic competitiveness by increasing productivity and economic growth. The alternatives of low investment or unsustainable investments in high-carbon technologies and infrastructure would only generate sluggish growth, limited profits in the marketplace of the future, and stagnant levels of productivity. Investing in inefficient and outmoded assets that will be stranded, devalued and replaced later would also generate higher costs over time.

Investments in core assets, including physical, natural, knowledge, human and social capital, drive growth in income and opportunity. Both the *scale* and *nature* of the investment matter. Investment expands the array of productive assets which, by their nature, drive labour productivity, earnings and income. These assets (or forms of capital) can be *produced* (the buildings and infrastructure we rely on), can be *human* (the skills and training of our workforce), can be *intangible* (the ideas, processes and institutions which we deploy), or can be *natural* (the essential building blocks of socioeconomic possibility: the clean air, water, stable climate and biodiversity on which we rely).

At a time when the economy is undergoing significant structural change, the *direction* of investment is as important as its size and type. This must recognise the rapid evolution of global structural change such that new assets are resilient, future-proofed and take full advantage of the opportunities of the 21st century, while minimising the risk of becoming destroyed, devalued, redundant or stranded.

In the past one to two decades, many parts of the world have experienced a macro position in which planned investment has been too small in relation to planned saving, which has resulted in persistent near-zero neutral real interest rates and low productivity growth, as we show. The recent rise in nominal interest rates 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.

This report sets out the need for long-lasting institutional and policy frameworks that can induce investment in a broad range of assets. These assets drive technological, institutional and behavioural innovation. The report is intended to guide policymakers to manage a structural transition, by taking advantage of the opportunity associated with the sustainable, intelligent and resilient economy while minimising the disruption and the risks associated with assets being left redundant and devalued in the economy of the 21st century. **The report makes the case for a strategic approach,** noting that inaction is a choice that raises the cost of capital, reduces competitiveness and favours inefficient and unproductive economic activity.

Structure of the report

- **Section 2 describes the UK's three-decade-long poor performance on investment and productivity,** highlighting the need for substantial investment, over the next two decades in particular, to boost productivity that in turn drives wage and income growth.
- **Sections 3–4 explain why investment in the transition to a sustainable, inclusive and resilient economy, and restoration and enhancement of physical, natural, human, knowledge and social capital, will be particularly productive,** enabling the UK to benefit from some of the fastest growing global markets. Much of this comes from addressing multiple market failures – situations where a pure market outcome misallocates resources: for example, because polluters do not pay for the damage they cause or innovators do not benefit from the research they undertake,

resulting in too much pollution and too little innovation. These market failures interact and lead to inefficiency and a failure to realise potential in the new dynamic and growth opportunities. Such investment will drive greater innovation, efficiency and productivity while boosting the country's competitiveness.

- **Section 5 outlines the benefits of sustainable investment to the UK's energy security.** Much of this investment could be provided by the private sector, but additional public investment will be critical to leverage these flows of private finance.
- **Section 6 explains how the high interest rate environment has affected the prospects for investment.**
- **Section 7 illustrates how targeted and temporary public borrowing for sustainable investment would reduce the debt to GDP ratio over time,** and is thus the only fiscally responsible option. These sustainable investments would drive fundamental structural and systemic change in the UK economy, profoundly improving cities, land, energy, transport and water. How these systems change and interact over the next two decades will be crucial to shaping the economy, as well as to productivity and growth. While this makes it impossible to predict a precise impact from each sustainable investment, the risks to the UK economy of weak policy and low or unsustainable investment are severe.
- **Section 8 outlines key implications for policy,** recognising that these do not necessarily mean high public spending, but could include setting of standards and regulations, and may even raise additional public revenues (for example, through carbon pricing). Most important of all is policy coherence and effectiveness and attention to fairness. Policies that are clear, credible and aligned, and not prone to unexpected adjustment or reversal, and that can gain and maintain crucial public support would be most likely to attract investment and boost prosperity.
- **Section 9 presents summary recommendations for government and concludes.**

2. The UK needs substantial investment

The UK has a major productivity growth problem

Output per hour worked in the UK has risen by just 0.7% a year on average since the global financial crisis (authors based on Office for National Statistics [ONS], 2023a). This is much lower than the average annual growth rate of 2.1% that occurred in the 14 years prior to the crisis (ibid.). The UK is not alone in seeing a slowdown in productivity growth since the financial crisis, but it is one of the worst affected advanced economies (Oliveira-Cunha et al., 2021). Indeed, had the UK's annual output per hour continued to grow on its pre-crisis trend, it would have been 24% higher than it was in reality in 2023 (Van Reenen and Yang, 2023).

The UK's productivity levels are also lower than those of some of its main peers: the UK market economy is about 28% less productive (in real value added per hour) than the United States, 13% less productive than France and 14% less productive than Germany (ibid.).[1]

Productivity matters for living standards. 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 (Resolution Foundation and Centre for Economic Performance [RF and CEP], 2023a). Fifteen years of lost wage growth has cost the average worker £10,700 a year (ibid.).

Moreover, as the UK's productivity growth and investment levels have stagnated, inequality between both households and geographical places remains very high compared with other European countries (RF and CEP, 2023a). More worrying from the point of view of economic opportunity and wellbeing 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 an economy has to offer.

Increasing the UK's growth rate requires a substantial investment programme

The UK's chronic underinvestment in fixed capital has been a key feature explaining its relative underperformance in both productivity growth and levels and the relative decline in living standards (Van Reenen and Yang, 2023; Brandily et al., 2023).[2]

Figure 2.1 shows that the UK's investment rate (including public and private investment) has been below the G7 average for some time. In the period from 1993 to the present day, gross fixed capital formation averaged near 18% of GDP in the UK: in the US it averaged 21% and in France and Germany 22% of GDP (authors, based on IMF, 2023b). Compared with the rest of the G7 as a whole, the UK invested 4.7 percentage points less as a share of GDP annually on average over this period (ibid.). The UK's investment rate has also taken a 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 prior to it (ibid.). This underinvestment has resulted in a fall in the rate of growth of capital per person and per employee (Brandily et al., 2023).

Boosting investment will be crucial for raising the UK's growth and productivity growth rates. Indeed, the World Bank (2024) demonstrates the positive impact of investment and growth strategies on economic performance, using worldwide examples. Furthermore, analysis of international data shows that sustained 'growth accelerations' (periods where GDP per capita is high over a long period) are strongly associated with 'investment' booms (periods where the growth in capital stock per person is high over a long period) (Brandily et al., 2023).[3] There is also compelling evidence that infrastructure investment

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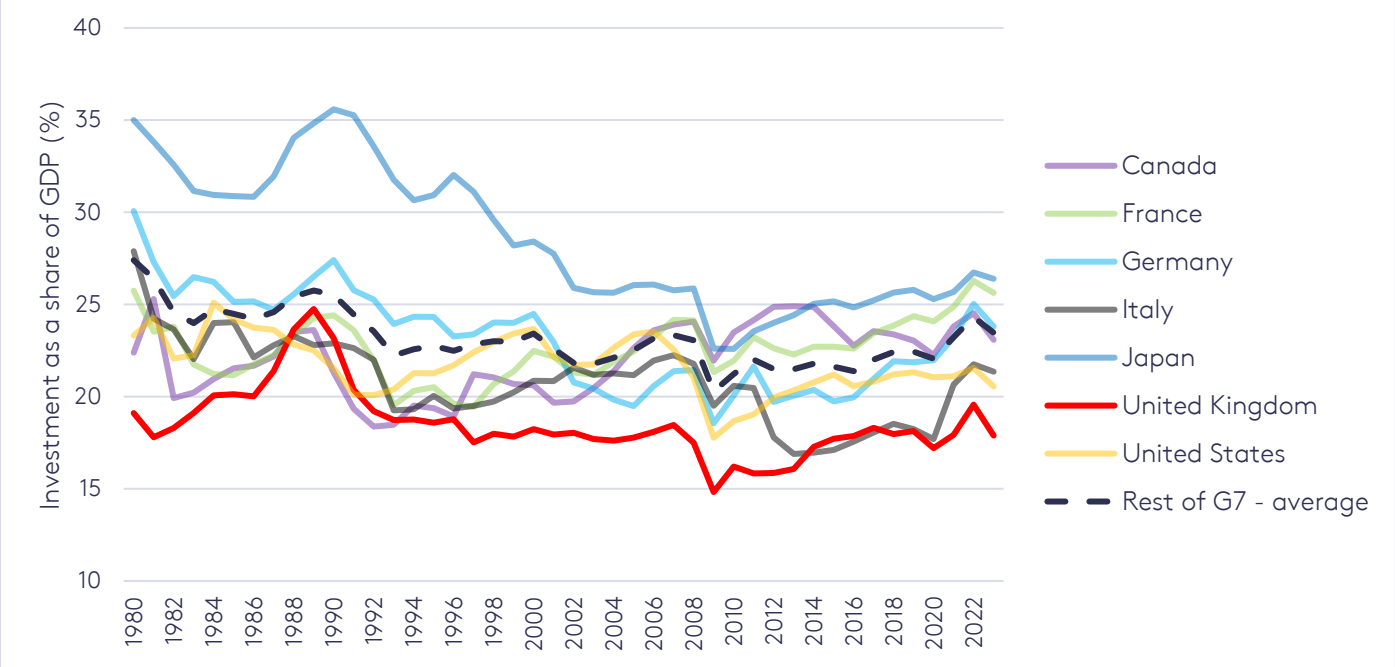
[1] Productivity figures for the market economy are more reliable than those for the whole economy, as public sector output often lacks a market price and has to be estimated through various methods including, in some cases, inputs (which assumes zero productivity change).

[2] The slowdown in 'Total Factor Productivity' has been large in all countries. In addition, the UK has not benefitted from an acceleration in human capital accumulation of the kind seen in France and Germany (Van Reenen and Yang, 2023).

[3] By looking across the cycle, these studies account for the fact that higher growth causes higher investment, which itself drives higher growth. By raising demand faster than supply can keep up with, such accelerations in investment are not always sustainable in the short run, and can

boosts growth (Ramey, 2020), and the G7 economies demonstrate a positive correlation between GDP growth and investment in capital as a share of GDP over the past four decades (see Stern et al., 2021) – see Figure 2.1.

Figure 2.1. Investment rates for G7 countries, 1980–2023



Note: 2023 values are estimates. Investment is defined as Gross Fixed Capital Formation.
Source: Authors' analysis of International Monetary Fund, World Economic Outlook Database, October 2023 (IMF, 2023b)

How much is needed and where?

To make up for decades of underinvestment in its physical, natural, human, knowledge and social capital,[4] to deliver on the need to tackle climate change, biodiversity loss and environmental degradation, and to be economically productive and competitive in the future, the UK needs to increase annual public investment by the equivalent of at least 1% of GDP,[5] or £26 billion (at current prices),[6] as part of a rise in annual overall public and private investment equivalent to at least 3% of GDP, or £77 billion. Indeed, if UK *private* investment had matched the average of France, Germany and the US since 2008 – which would have required additional investment of just over 2% of GDP each year – the UK's GDP today would have been nearly 4% higher, enough to raise average wages by around £1,250 a year (Brandily et al., 2023).

This sustainable investment should enable the UK to accelerate action in tackling climate change, biodiversity loss and environmental degradation, including air and water pollution. The annual report of the Office for Environmental Protection, published in January 2024, found that the UK is not fully on track to meet any of the 10 goals set by the Government in the Environmental Improvement Plan in 2023. It concluded that more investment was needed across a range of areas.

reflect an overheated economy. This effect is commonly referred to as the multiplier-accelerator effect. The multiplier makes output rise following an increase in investment, and the accelerator makes investment increase when output increases. Once expansion starts, the level of output growth consistent with more investment levels off, growth slows and the accelerator weakens, slowing the expansion. Lower growth then leads to a reduction in investment and causes incomes to decline, a process that breeds unsustainable cycles.

[4] Some of these outlays, including investments in teachers and the provision of core social support, are scored as current consumption and do not enter the investment figures. However, by delivering future returns they can be conceptually considered investment in human, knowledge and social capital.

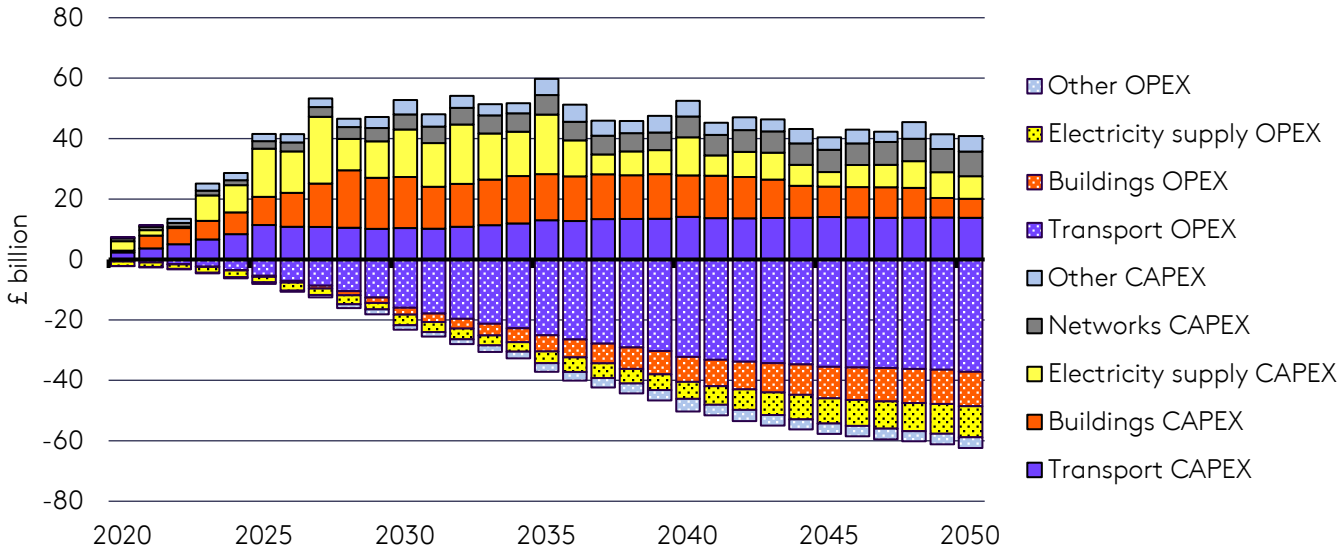
[5] UK public sector investment is expected to be 3.6% of GDP in 2024, but will fall to 3.1% in 2028–29 under current plans to hold capital departmental spending flat in cash terms (OBR, 2023c). Cross-country studies of the effectiveness of public sector capital in boosting private sector output suggest governments should be investing around 4.5% of GDP (Odamtten and Smith, 2023).

[6] Based on the Office for Budget Responsibility's Economic and Fiscal Outlook of November 2023 where the UK's outturn nominal GDP for 2022–23 is estimated at £2,552 billion (OBR, 2023c).

This investment needs to be in the sustainable economy in its entirety, encompassing not just what are conventionally labelled as 'green' industries but also in reducing the environmental damage caused by economic infrastructure, from schools and hospitals to roads and information management systems. Such an investment programme will mean working with the investment cycle, as redundant capital is retired and replaced. Even when it comes to replacing worn-out capital, sustainable investment will still be front-loaded, because it will be substituting capital for dependence on fossil fuels across systems in energy, transport, buildings and industry. Put simply, resource-efficient capital, for example making schools and hospitals more energy-efficient, is more expensive upfront than the seemingly cheaper leaky alternative, but it pays for itself through lower bills (for example, see Fetzer et al., 2022). Place also matters and significant investment in the UK's cities outside London will be needed, to improve economic performance and opportunity across the country (Brandily et al., 2022; UK Urban Futures Commission, 2023).

While we consider a broader definition for what constitutes sustainable investment, the UK's Climate Change Committee (CCC) makes an assessment specifically of the capital investment requirements of the technological transformation required to bring UK emissions to net zero by 2050. It 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 (Figure 2.2). This additional investment is equivalent to less than 1% annually of projected GDP over this period. The Office for Budget Responsibility has estimated that about £14 billion of this annually by 2030 will need to be public investment. If 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 (see Figure 2.2), but will also deliver high returns in terms of productivity, new opportunities and the environment (Stern and Valero, 2021).[7]

Figure 2.2. Capital investment costs and operating cost savings in the CCC's Balanced Net Zero Pathway



Note: CAPEX refers to additional annual capital investment. OPEX refers to savings due to operational cost reductions.
Source: Sixth Carbon Budget, Climate Change Committee (CCC, 2020)

Savings rates and sources

Were the UK to carry out a substantial investment programme without borrowing from abroad and without running significant current account deficits, it would need to increase its saving rate (see Section 7). Over the period 2010 to 2023, the UK's average saving rate lagged behind almost all the other

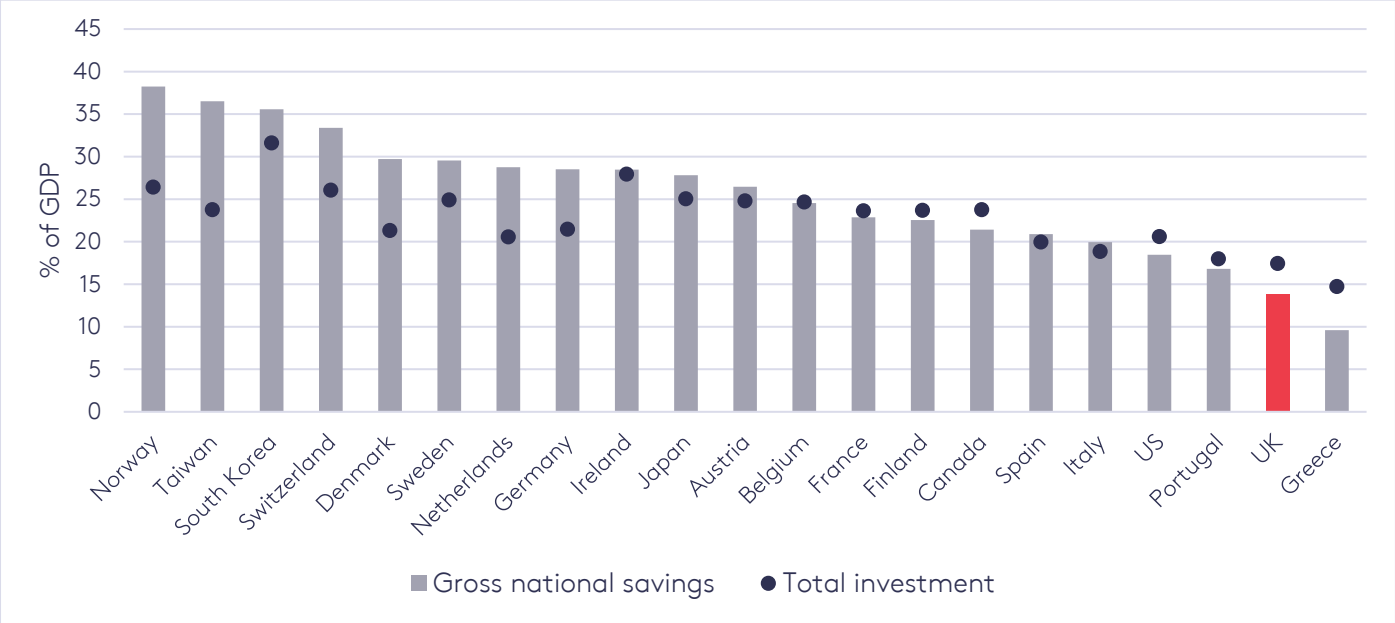
[7] Also see Section 4 for a discussion of the co-benefits of decarbonisation and Skidmore (2023) for an extensive review of the evidence on the economic and environmental opportunities for the UK from transitioning to a net zero economy.

advanced economies (see Figure 2.3). In 2019, the UK's net national saving was 0.6% of GDP, less than one-tenth of the OECD median (Brandily et al., 2023).

Funding net investment in sustainable and inclusive growth through borrowing from abroad implies foreigners increasingly owning more UK assets than UK citizens own abroad, with the returns to investment increasingly accruing to non-UK citizens. A key source of domestic saving is household pensions. Policies such as an increase in the minimum savings rate within auto-enrolment, for example by levelling up the minimum contributions by both employers and employees to 6 percentage points, would increase the returns to British consumers from domestic investment in the economy of the 21st century (ibid.).

Domestic saving can be undertaken by government, households and firms. Successful firms most often invest retained earnings and borrow from consumers who want to save for pensions and other occasions, returning the proceeds from investment to households in the form of dividends and interest. In the UK, this is too often not the case, with companies returning more in dividends and interest and limiting their net borrowing to invest. At the same time, consumers and the public sector undertake net financial borrowing for current consumption and investment part-funded by proceeds coming from foreign savers (Stern and Zenghelis, 2021). This is unlikely to be sustainable. It also raises the unappealing need to rein in UK current consumption, in order to make room for domestic investment without further recourse to borrowing from other countries.

Figure 2.3. 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 of International Monetary Fund, World Economic Outlook Database, October 2023 (IMF, 2023b), drawing on Wolf (2023).

Assessing risk and opportunity in times of structural change

A further policy challenge relates to quantifying the benefits from policies designed to steer structural change. The fact is, these cannot be quantified against arbitrary counterfactuals. We have no detailed picture of what a clean or dirty economy will look like by 2050. What we do know, with confidence, is that a delay in anticipating and managing any transition is likely to increase costs.

The current policy agenda requires steering the UK economy through technological change, innovation, reskilling people and repurposing financial and public institutions. Conventional approaches fail to adequately account for the dynamics of societal and technological change (Stern, 2018). Risks are underestimated, and economic opportunities from innovation are generally not assessed in practice.

The Government's Green Book Appraisal and evaluation guidance highlights the limitations of cost–benefit approaches in the case of non-marginal, irreversible, systemic transformations that are subject to uncertainty (see Annex 7, HM Treasury, 2022). Fundamental uncertainty makes precise costs and benefits unknowable. When the South Koreans took a strategic decision post-war to diversify out of rice production and into ships and steel, and thereafter into electronics, no one attempted to quantify or compare paths through cost–benefits. The best that can be done is to give illustrations of the consequences of decisions in the face of risks and opportunities.

A number of authors (e.g. Mercure et al., 2021) recommend a risk–opportunity analysis (ROA) approach and conclude that in place of inaccurate quantification. Sharpe et al. (2021) state, "the preferred policy option can be determined by the decision-maker based on a qualitative judgment of the scale of the opportunities and risks, compared to the cost of the intervention. This will necessarily be a subjective judgment (since it incorporates a weighing of outcomes in different dimensions), informed by an objective assessment of likelihood and magnitude of possible outcomes in each of the relevant dimensions."

Notwithstanding the modelling difficulties, the rapidly changing landscape of risk and opportunity requires strong action and we know enough about policy to begin travelling down the path of an attractive low-carbon transition (Stern 2018). It is clear that reaping the benefits of a more productive and sustainable economy requires capital investment upfront, but its influence on output (net value added) is likely to be very strong, particularly when taking into account the reduced dependence on the flow of fossil fuel inputs that will occur in the future (and additionally the reduced requirements for mining, transportation and refining capacity). The challenge is as much about increasing the efficiency of capital as it is to increase the investment rate.[8] The nature and quality of the investment are as important as the quantity, marking 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.

[8] The Incremental Capital-Output Ratio (ICOR) is a summary statistic for the high returns on intelligent, resilient and future-proofed investment. The growth rate is the investment rate divided by the ICOR. It is the product of the rate of investment and the productivity of investment. The ICOR is the reciprocal of the marginal product of capital and is often used to assess the amount of capital required to sustain a particular growth rate.

3. Sustainable investment is also productive investment

The rise of clean technologies internationally

The UK's lacklustre performance on productivity and investment has occurred against the backdrop of a major global transformation towards sustainability, one that has the potential to radically boost efficiency, innovation and productivity. Countries that lead this transition stand to benefit through future-proofed, resilient infrastructure, and via building competitiveness in technologies seeing growing global demand.

The 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 (Dechezleprêtre et al., 2017). We are already seeing increasing returns to scale in the discovery and production of clean technologies (Geels et al., 2021; Aghion et al., 2016; van der Meijden and Smulders, 2017). A key reason for the sharp reduction in solar, wind and battery costs is learning-by-doing and experience, which result from expanding deployment. Learning and experience also lower the costs of installation and maintenance. Costs come down too because of economies of scale in production, distribution and maintenance. The unit-cost benefits accrued from larger production and distribution networks reflect large, fixed costs where, once initial fixed costs have been incurred, low unit costs encourage increased output (Acemoglu et al., 2012). 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 has remained roughly constant for more than a century (Way et al., 2022).

Falling technology costs accelerate further deployment and investment in supporting networks, infrastructure and institutions.[9] This in turn makes deploying new technologies more attractive – generating a virtuous cycle of innovation, investment and falling costs. Some economists balk at such a reinforcing form of feedback, because including these would make their models unstable (think of what happens when you put a microphone in front of a speaker) and this has complicated the task of modelling the costs of the transition to a sustainable, inclusive and resilient economy (see also Section 8). But it is a feature of the real world, and failure to anticipate reinforcing feedback effects leads to over-estimation of adjustment costs.

Costs have fallen faster than expected

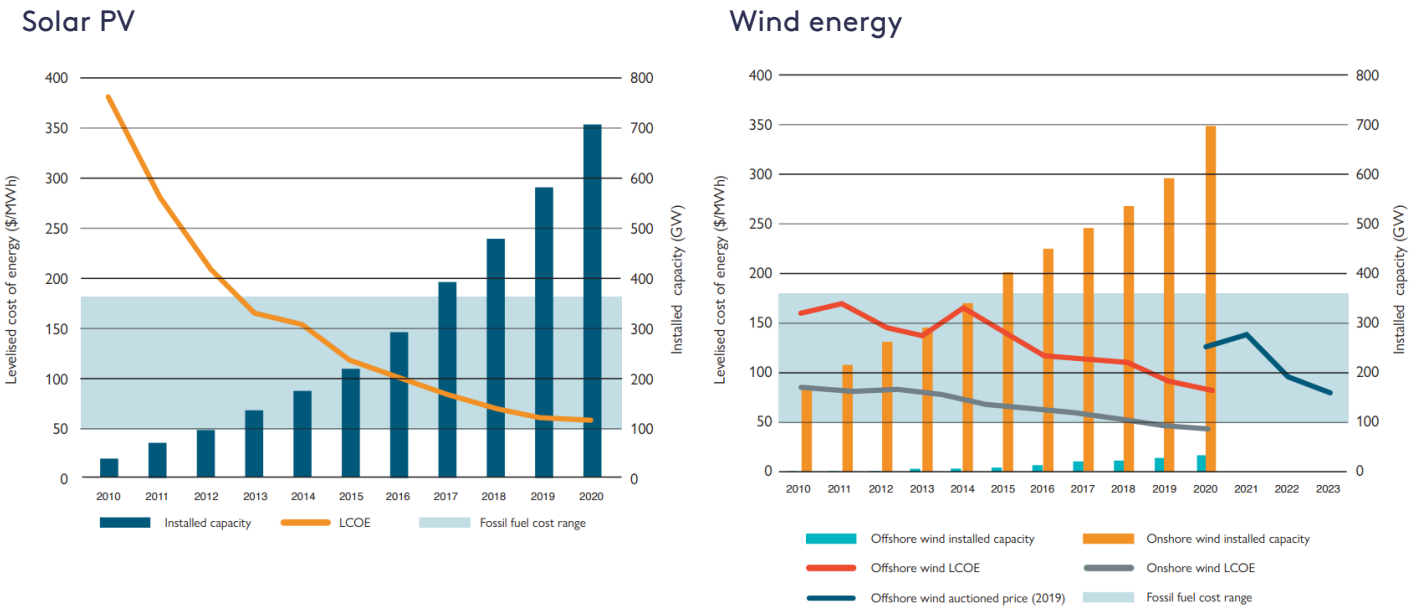
In contrast to pessimistic forecasts from almost all analysts, which we outline below, policies supportive of research into, and development and deployment of new technologies have already driven remarkable and unexpectedly large cost reductions in renewable and other energy technologies.

Over the past decade, the cost across the world of both solar photovoltaic (PV) generation, and battery storage necessary to address intermittency of supply, has fallen nearly tenfold, while offshore wind costs have fallen by more than half (see Figure 3.1, Grubb et al., 2021a; and Way et al., 2022). In many parts of the world, renewable energy is now cheaper than fossil fuel-based alternatives (Holder, 2019).[10]

[9] For example, once electric vehicle (EV) infrastructure is rolled out, the incentives to conduct research and development on electric cars increase relative to combustion engine or fuel cell vehicles. Volvo will stop producing combustion engine cars from 2019 and start focusing its R&D on EVs; other manufacturers are sure to follow.

[10] With every doubling of solar PV deployment, the price drops by 30%; it is currently falling by ~10% every year. Over the past 70 years, the cost per kWh of solar energy has fallen by 99% while the price of coal has remained about the same.

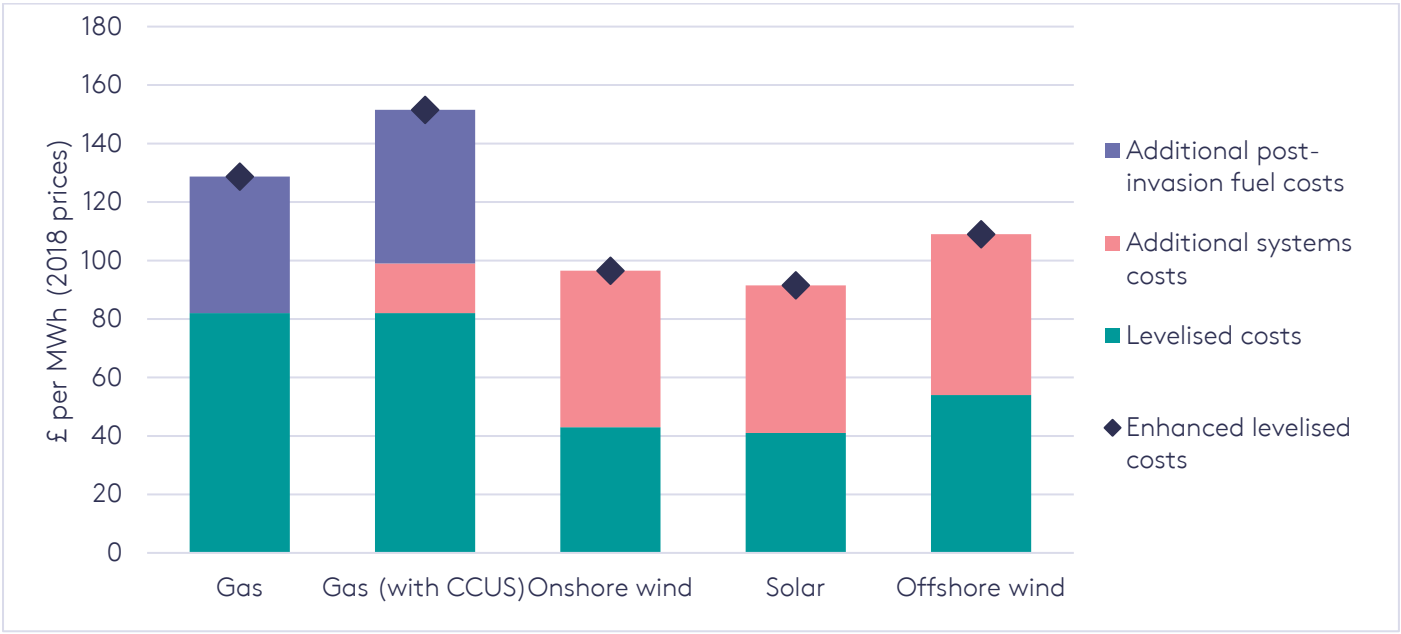
Figure 3.1. Evolution of installed capacity and cost of solar PV and wind energy, 2010–2020



Note: Fossil fuel levelised cost of electricity (LCOE) indicated as shaded blue range at US$50–177/MWh.
Source: Grubb et al. (2021a): analysis of Renewable Power Generation Costs in 2020, IRENA (2021).

Turning specifically to the UK context, analysis by the Office for Budget Responsibility demonstrates that even before the large spike in fuel prices that followed Russia's invasion of Ukraine, renewable electricity generation costs were comparable to the cost of gas-based generation, despite the higher systems costs associated with renewables (Figure 3.2; OBR, 2023b). Rising prices rendered generation from renewables considerably cheaper than generation from gas (ibid.).

Figure 3.2. Illustrative enhanced levelised cost of energy

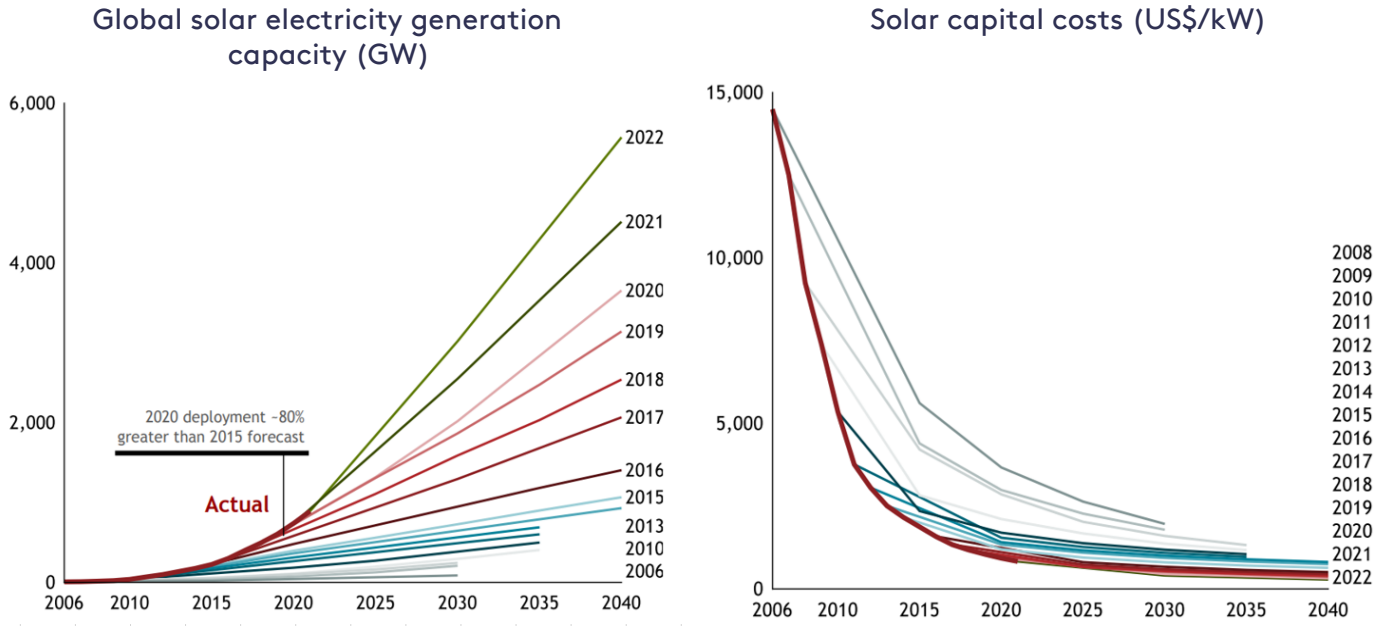


Note: Additional systems costs are the mid-point of high and low scenarios used by the Department for Energy Security and Net Zero (DESNZ) (formerly the Department for Business, Energy and Industrial Strategy [BEIS]). Under OBR analysis, these are rebased to be relative to a reference technology, i.e. the additional systems costs of gas, in line with the literature. Additional fuel costs are calculated by scaling up BEIS estimates of fuel costs in 2025 to account for the gas price in OBR's Economic and Fiscal Outlook forecast of March 2023.
Source: Reproduced based on Office for Budget Responsibility (OBR, 2023b) analysis of DESNZ data.

Forecasts of technology costs now suggest that the world will have cheaper energy (and in time cheaper, more efficient and better performing cars [see BloombergNEF, 2021]), largely as a result of policy initiatives to steer investment in clean technologies. Most economists failed to predict this and the markets alone would not have delivered it, as the technologies were initially too expensive to be viable.

Most analysts, including the International Energy Agency (IEA; see Figure 3.3),[11] have long underestimated both how fast the costs of renewables would fall, and (largely as a consequence) the scale of their deployment (Roberts, 2015; We Mean Business Coalition, 2023; Way et al., 2022). They have been routinely caught by surprise by the speed with which reinforcing feedback changes the energy landscape, which means they have systematically underestimated the pace of innovation and deployment in renewables. A striking example lies in solar PV costs: in 2014, *The Economist* described solar PV as "the most expensive way to reduce carbon emissions". By 2020, the IEA argued that it was generating "the cheapest electricity in history".

Figure 3.3. The faster-than-predicted rise in capacity and fall in cost of solar power



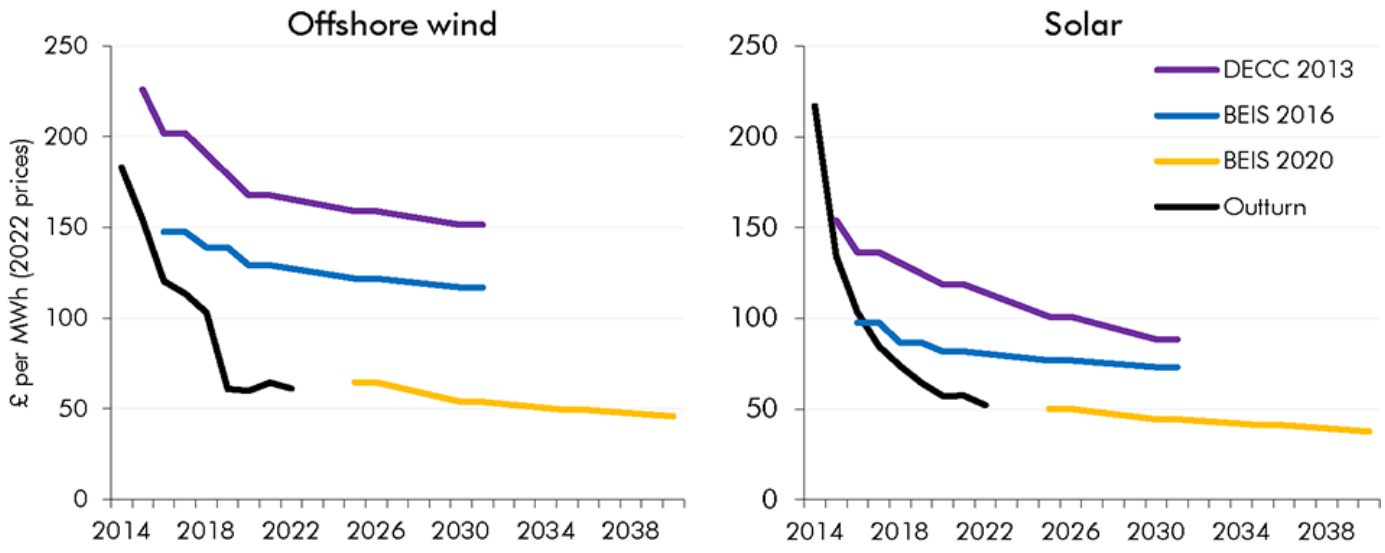
Notes: Forecasts by year vs. outturn. Left-hand figure uses 'new policies scenarios' from the World Energy Outlooks of 2010–18 and the 'stated policies scenarios' from the World Energy Outlooks of 2019–22. Right-hand figure calculates capital costs using the experience curves from the IEA and IRENA datasets. Years on the x-axis indicate when the forecasts were made and colours are consistent across both charts.

Source: We Mean Business Coalition (2023) analysis of IEA's World Energy Outlooks, 2006–22 and IRENA (2019).

A similar story is also true for the UK government's own analyses, with renewable costs in the country repeatedly falling faster than predicted over the years (Figure 3.4; OBR, 2023b). Simon Sharpe, who was a government advisor in the early 2010s, wrote "Subsidising offshore wind when it costs three times the market price must have required guts from ministers." Few guessed that within a decade costs would fall by 70%, outcompeting coal and gas (Grubb et al., 2021a). Technology-neutral market design at the time would instead have chosen cheaper biomass to subsidise. As Sharpe contended recently, "it is hard to argue that burning wood pellets, once the cheaper option, would have been a better bet" (Sharpe, 2023).

[11] This chart is not intended to form a criticism of the IEA's forecasting record. The IEA is arguably the most authoritative body to make such projections, and all major analysts underestimated the scale of the transformation in the electricity sector. Rather, we are drawing attention to the Dornbusch phenomenon that dictates, in economics and markets, "Things take longer to happen than you expect; and then happen faster than you thought possible."

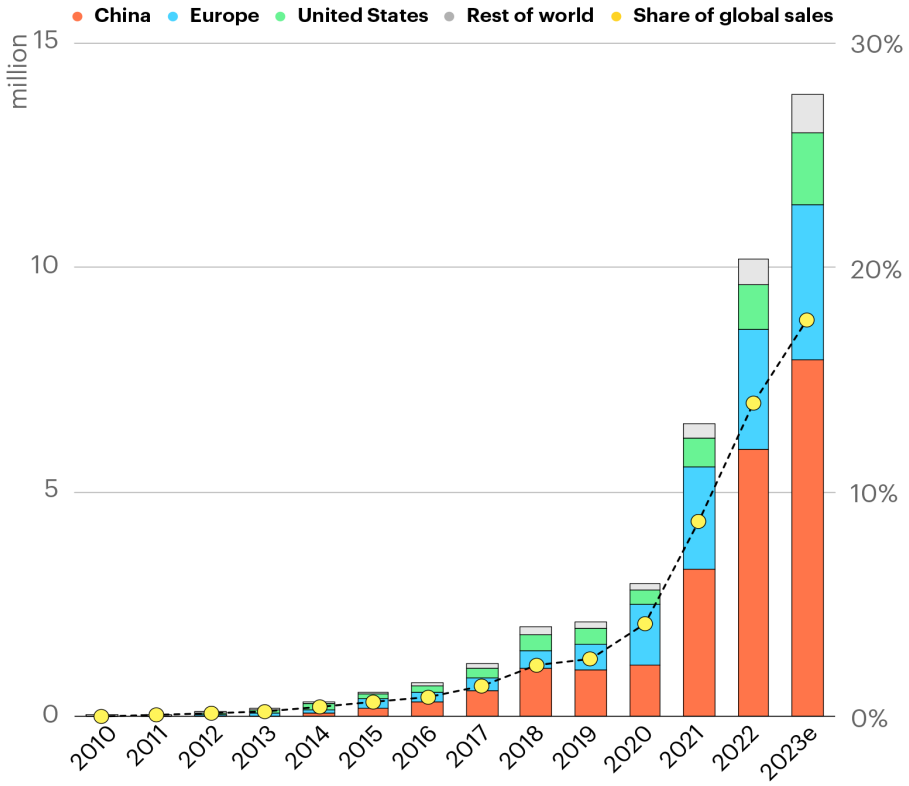
Figure 3.4. Successive UK government forecasts of renewable generation costs versus outturns



Note: Renewable generation costs are expressed as the levelised cost of electricity (LCOE). A moving average trendline was fitted around the historical projections, as these were forecast at five-year intervals.
Source: Office for Budget Responsibility (OBR, 2023b) analysis of DESNZ data.

Until a few years ago, electric vehicles (EVs) were widely seen as expensive playthings for rich people. Yet no serious auto manufacturer is now investing meaningful sums of scarce R&D in the combustion engine. The aim is to dominate the mass-market in EVs (see Figure 3.5).[12]

Figure 3.5. Global electric car sales and share of global car sales, 2010–2023



Note: 2023 figures are estimated.
Source: International Energy Agency (2023a).

[12] Until recently, Toyota was pushing hydrogen vehicles but it too has now aligned with the pack in developing EVs, not least in recognition of the network effects from the corresponding expansion of charging infrastructure.

Based on policies already in place and under development, there will be nearly 10 times more EVs on the road by 2030 than today (IEA, 2023a), by which time renewable energy sources are expected to supply nearly half of all power (IEA, 2023c). Transformative cost reductions are also occurring in other key technologies, such as fuel cells and even electric and synthetic fuel aviation. One study estimates that by the end of this decade, tipping points for crucial low-carbon solutions will have been triggered in sectors representing 90% of emissions, making them cheaper than conventional fossil fuel technologies in key markets (Systemiq, 2021).

New manufacturing supply chains and supporting services will be at the core of this transition. Important spillovers will occur from clean technologies into other sectors, including health, defence and housing. Sometimes, innovations involve new technologies and new products, but they may also be embedded in conventional products such as housing and glass (Llewellyn et al., 2020).

The importance of innovation in a technological transition

Overcoming dynamic market failures, in order to generate dynamic rather than static efficiency, has the potential to change the world economy. This understanding was first outlined by Nobel laureate Paul Romer, and Philippe Aghion and Peter Howitt, when they formalised the theory of endogenous technological change (see Romer, 1990 and Aghion and Howitt, 1993). It is central to the task of efficiently managing the transition to a sustainable, inclusive and resilient economy.

As costs have become increasingly competitive, global investment in clean technologies – including renewables, EVs, nuclear power, grids, storage, low-emission fuels, efficiency improvements and heat pumps – is already outstripping investment in coal, gas and oil (IEA, 2023b). With the flow of investment in global electricity generation now predominantly in renewables, the IEA recently estimated that they will overtake coal to become the largest source of electricity worldwide by 2025 (IEA, 2022). In fact, renewables are now on track to generate most of the world's electricity by 2040 (BloombergNEF, 2022).

Innovation is thus essential in determining economies' ability to decouple growth and consumption from environmental degradation and use of resources. Yet innovation does not just 'happen' in a vacuum. It is induced and relies on path dependencies of three kinds (Aghion et al., 2014):

- First, discovery and invention, with scientists working in areas that are well-funded, where other good scientists work, leading to geographical clustering of research and knowledge production.
- Second, deployment, whereby innovations leverage existing infrastructure and ideas rather than risk investment in potential new sectors.[13]
- Third, incentives for technology adoption, whereby the net benefits of unilaterally switching to an alternative network rise with the number of others using it.

Economies of scale are derived from a number of powerful factors, including learning by doing, combinatorial technologies, and behavioural feedback.[14] Moreover, the spillovers and impacts from one sector to another and more broadly to institutions and consumer behaviour are large. When additional deployment reduces the costs and raises the productivity of systems, they become more attractive, and more extensively deployed. This then drives further cost reductions. Such a reinforcing system of feedback is unstable and hard to predict, but it heightens the importance of early policy decisions. See Box 3.1 for a full discussion of the inter-related forms of feedback.

[13] For example, conventional cars with internal combustion engines have historically been easier to sell than EVs because the existing network of petrol stations is far larger than that of charging stations.

[14] Combinatorial policies and network effects can be extremely important. Without any one of the technologies in question individually being new necessarily, they may be combined in new or novel ways.

Box 3.1. Inter-related forms of feedback

- **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 policies and network and coordination 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. (2014) 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).
- **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.

Without direct policy intervention, strong inertia and high switching costs often make it difficult at first to shift the innovation system from dirty to clean technologies.[15] But once expectations change rapidly, and technologies switch from one network to another, these effects frequently go the other way, as a result of positive and reinforcing feedback effects (Krugman, 1991).

All innovation has the potential to boost output, but there is mounting evidence that low-carbon innovations have a much broader application in other sectors of the economy than the dirty technologies they replace, with greater productivity-boosting knowledge spillovers (Dechezleprêtre et al., 2017). The size of knowledge spillovers associated with clean technologies is also comparable to those associated with information and communication technologies (ICT).

Furthermore, government support for innovation in clean technologies is estimated to generate higher average returns[16] than that produced by innovation in other technology categories, including the 'trending' category containing the likes of AI, 3D printing and robotics (Martin and Verhoeven, 2022; Curran et al., 2022). These returns also carry geographical patterns that have the potential to support regionally balanced growth in the UK. For example, investments in clean technologies such as tidal stream and offshore wind in less innovation-intense regions generate strong returns for those regions

[15] This is consistent with early slow progress in deployment of decarbonisation technologies.

[16] Including private returns for the innovator as well as direct and indirect knowledge spillovers for other UK innovators.

(and little leakage), while such investments in more innovation-intense regions generate strong returns in these regions themselves and spillovers for the rest of the country (Curran et al., 2022).

These findings suggest that induced investment in low-carbon innovation can 'crowd in' rather than 'crowd out' productive investment, help to offset the costs of climate change regulations and even encourage economic growth.

One evaluation suggests that the majority of economic activities the UK is expected to see as a result of moving towards net zero have the potential to be positive for productivity – activities such as investing in renewable energy, constructing higher efficiency buildings, promoting public transport and restoring natural ecosystems (Alvis and Sissons, 2022).

Even looking backwards, over the period when renewable and energy efficiency technologies were more expensive, there has been no detectable difference in economic growth rates between those countries that adopted emissions-reducing technologies early and those that did not. Yet the early-adopter countries are in a stronger position to benefit in years to come from a global transition to a net zero economy.

Behaviours, norms and institutions are also changing

Additional feedback effects, beyond the technology sphere, are likely to accelerate the pace of the transition to a sustainable, inclusive and resilient economy. As better ways of consuming, producing and living are found, complementary changes in behaviour, institutions and social norms will evolve (Boyd et al., 2015). The presence of low-cost alternatives to emitting greenhouse gases has enabled anti-fossil-fuel campaigners to point to superior energy alternatives (Bradshaw, 2015; Collier and Venables, 2014).

Anti-fossil-fuel norms are already concentrating moral pressure on the largest culprits of climate change (Green, 2018). A spate of lawsuits have been filed against fossil fuel companies and governments for deceiving shareholders and citizens by knowingly undertaking or supporting unsustainable and damaging activities.[17] At the same time, new business lobbies in fast-growing sectors have over the last decade begun to challenge the influence of incumbents on policymakers (Lockwood, 2013).

For all the justified concerns about the slow speed of global action, these factors are driving global climate policies at an accelerating pace: as of June 2023, there were more than 3,100 climate change legislation and policies in place around the world.[18]

Changing expectations accelerate the deployment of new technologies (Zenghelis, 2019), which in turn accelerates cost reductions and policy support (Aghion et al., 2014). Strategic complementarities[19] occur as the payoff to investing in low-carbon technologies rises (and the costs fall) when others are expected to invest in low-carbon technologies.

Sustainable investment must also be climate-resilient

While there is an understandable and justified focus on the challenge of creating an economy that is zero-emissions, it must also be climate-resilient. The global impacts of climate change will continue to increase until the world achieves net zero emissions of greenhouse gases, with some effects, such as sea level rise, continuing for many decades afterwards. These impacts can cause loss and damage that will harm the economy and could hinder the transition to zero emissions. For instance, as well as increasing heat-related morbidity and mortality, the increase in the intensity of heatwaves is damaging the economy by reducing productivity through failing infrastructure and overheating workplaces.

The UK is exposed and vulnerable to the direct and indirect impacts of climate change, including sea level rise and the increasing frequency and intensity of extreme weather events such as heavy rainfall and heatwaves. The impacts of climate change on other parts of the world could have significant

[17] At least 2,341 climate-related lawsuits have been recorded to date globally, 190 of which were filed in a single year to the end of May 2023 (Setzer and Higham, 2023). Around 60 of these were against the so-called 'carbon majors' (such as oil and gas companies), and 20 of the 29 cases in the US were filed by cities and states (ibid.).

[18] According to the Climate Change Laws of the World database: https://climate-laws.org

[19] In game theory, strategic complementarities occur when the actions of one player increase the returns to another player taking the same action, such that the decisions of two or more players mutually reinforce one another.

consequences for the UK through, for instance, disruption of supply chains, and increases in the flow of migrants and refugees from affected parts of the world.

Without adaptation and increasing resilience to these impacts, the UK economy will suffer growing loss and damage. It is essential, therefore, that investments are climate-resilient. In many cases this will just mean redirecting investment so that it takes the growing impacts of climate change into account. Additional investment will be needed, but this will be far less than the costs of dealing with loss and damage.

Investments in new zero-emissions infrastructure and technologies will also need to be climate-resilient. For instance, investments in improving the energy efficiency of homes alongside the installation of zero-emissions heating systems to deal with cold weather should also include improvements in ventilation and passive cooling to cope with hot weather. An increased reliance on air conditioning would be more costly and increase pressures on the electricity network.

There are no detailed assessments of the level of investment required by the UK to adapt (Watkiss, 2020), which will depend significantly on the magnitude of climate change. Some studies have suggested that the aggregate costs of adaptation could be equivalent to 1–2% of GDP by 2050.

Protecting biodiversity and enhancing natural capital

The UK continues to suffer from significant loss of its natural capital. The 2023 *State of Nature* report found that across the UK 19% of studied species have declined since 1970, and nearly one in six species in Great Britain are threatened with extinction (State of Nature Partnership, 2023). Unsustainable agricultural and fishing practices, as well as the impacts of climate change, are the main drivers of loss of terrestrial, freshwater and marine habitats and species.

About three-quarters of the UK's land is used for agriculture. The *State of Nature* report concluded that while one-fifth of farmland in the UK is covered by agri-environment schemes, many of these could not be considered as 'nature-friendly' farming. Furthermore, despite recent improvements, only 44% of woodland is certified as sustainably managed and only half of marine fish stocks are sustainably harvested.

The Government has committed to achieve by 2030 a target of 30% of land and sea under effectively managed protected areas or other areas that are well-managed for nature. At present, 38% of UK waters are protected but just 11% of UK land is protected by a legal designation for nature conservation.

Restoration projects are being undertaken across a wide range of ecosystems in the UK. For example, more than 5,000 hectares of degraded peatland are being restored each year, but only 25% of peatlands are assessed as being in good condition. Similarly, only 14% of priority habitats, including 7% of woodland, is in a good condition. Large areas of the UK seafloor do not meet 'good environmental status' (the goal for which is set out in the UK Marine Strategy) because of habitat disturbance from fishing.

A 2021 study found a gap of £44–97 billion between current planned expenditure and the investment from all sources required for a range of nature-related outcomes across the UK between 2022 and 2032, including £13–32 billion for protecting and restoring biodiversity (Green Finance Institute [GFI] et al., 2021).

Tackling environmental pollution and degradation

While pollution of the UK's air and water have reduced markedly from the levels of a few decades ago, there is still a significant demand for investment to reduce it further. The contamination of streams, rivers and beaches with sewage has highlighted chronic underinvestment in the water industry. And while specific policies to tackle air pollution in the UK's cities are currently contentious, the desire for clean air is not.

A recent analysis by the Wildlife Trusts (Morse, 2023) of data from the Environment Agency concluded that less than 15% of surface waters (e.g. rivers, lakes) in England are rated as having a good or high ecological status. The Agency last tested rivers for chemicals in 2019, and every site in England failed,

with contamination expected to last for at least the next 40 years. In more than half of sites, levels of phosphate exceeded limits due to pollution from sewage and farming.

The most recent assessment of air pollution in the UK, published by the Department for Environment, Food and Rural Affairs (Defra) in September 2023, found that nine of 43 zones exceeded annual average limits for nitrogen dioxide in 2022. Six zones failed to meet the long-term 2040 limit for particulate matter, and no zones were compliant with long-term limits for ozone.

A 2021 study concluded that there was a finance gap of £5–15 billion between 2022 and 2032 between planned expenditure and the investment required to ensure clean water in the UK (GFI et al., 2021). The National Infrastructure Commission (NIC) estimated in 2023 that to increase water supply, reduce demand and tackle pollution will require private investment in the water sector of about £12 billion per year from 2025 to 2030, falling to £8 billion per year from 2030 to 2050 (NIC, 2023).

A report by the Clean Air Fund and Imperial College London (2022) called for £3.3 billion per year (in 2018 prices) to be spent on policies to tackle air pollution across the UK, particularly in urban areas.

Investing in an intelligent economy

The potential to integrate AI and digitisation with the transition to a sustainable, inclusive and resilient economy will define the growth story of the 21st century. Digitisation and AI can contribute massively to the speed, efficiency and effectiveness with which net zero technologies are discovered, applied and upscaled. AI and machine learning (ML) can be thought of as general purpose, economy-wide technologies that accelerate our ability to get more out of the resources we have – the core definition of productivity.

Data, information and AI/ML firms are already the world's largest by market capitalisation and are constantly investing and innovating. Fundamental systemic and structural change will involve complex systems optimisation for cities, energy, transport, agriculture, water and supply and distribution networks worldwide. The transition to a sustainable, inclusive and resilient economy and AI/ML will drive productivity growth across all sectors. It will facilitate the move to more sustainable behaviours and forms of consumption as well as the discovery of new technologies, inducing and accelerating innovation tipping points and diffusion cascades.

Waste will be limited by streamlining production. For example, it is estimated that around 70% of the world's primary energy is wasted in the form of heat. Efforts to recycle and store wasted heat in electricity generation and industry can result in substantial cost savings (Forman et al., 2016).[20] The Government should urgently seek to reinstate or replace the UK's now disbanded Energy Efficiency Taskforce with a coherent strategy to reduce and eliminate waste. Decentralised energy and energy close to the point of use have a role to play, with cogeneration and Combined Heat and Power (CHP) markets having been deployed with great success across the UK.[21]

By promoting sustainable practices and lean efficient production, and reducing the demand for new raw materials, a circular economy can shrink resource extraction, limit environmental degradation and contribute to mitigating climate change. In a circular economy, the goal is to minimise resource extraction and waste generation by keeping products, materials and resources in use for as long as possible. Here too there can be scale economies and boosted efficiency. For example, once a critical number of electric vehicles are in circulation, it becomes cheaper to recycle batteries than to mine lithium and cobalt for new ones. A new structural equilibrium can be created.

However, investment in the new economy will require an increase in the use of critical minerals such as lithium, cobalt and rare earths. Commodities such as copper and bauxite will be in strong demand as electricity grids are rolled out and it is important that accessing these resources is monitored, to minimise environmental impact. Real time monitoring and management through connected sensory systems will be at the heart of this. Critically, once the capital is rolled out and installed, the resource intensity of the

[20] The Lawrance Livermore National Laboratory in the US has a graphical representation in its energy flow chart: https://flowcharts.llnl.gov/sites/flowcharts/files/2023-10/US%20Energy%202022.pdf

[21] See the UK CHP tools map: https://chptools.decc.gov.uk/developmentmap and also the portfolio of companies such as SEEIT: https://www.seeitplc.com/portfolio/.

new renewable and circular system will be much lower than in the fossil based, wasteful linear economy. Extensive fossil fuel and resource use will be substituted with long-lived capital.

Increasingly, 'green' will be about intelligent circularity, innovation and lower cost. It is an area of intense human creativity and central to productivity growth. There will be powerful health and resilience benefits from reduced pollution and minimised ecological degradation associated with biodiversity destruction from mining and transportation.

Decarbonisation can yield co-benefits, many immediately

Contrary to the assertion of some politicians, most – or at least many – of the policies required to decarbonise the global economy will boost economic growth, not reduce it. Much of this comes from addressing multiple market failures – situations where a pure market outcome misallocates resources, for example because polluters escape paying for the damage they cause. That these policies provide a boost has been demonstrated by a number of authoritative studies. For example:

- A World Bank study found that, compared with business-as-usual, green growth would produce immediate positive effects on the economy, when taking proper account of co-benefits (e.g. reduced local pollution); growth in new 'green' sectors; and reduced energy price volatility via reduced dependence on fossil fuel imports (Hallegatte et al., 2012).
- The Global Commission on the Economy and Climate (2014) found that more than half, and perhaps as much as 90%, of the global emission reductions required to meet an ambitious climate target could generate net benefits to the economy. These include health benefits from reductions in urban pollution; declining traffic congestion; increased efficiency; and improvements in energy security and supply.
- A study by the University of Oxford estimates that transitioning to a decarbonised energy system by around 2050 could save the world at least $12 trillion compared with 'business as usual' fossil fuel use (Way et al., 2022).
- Turning specifically to the UK, analysis by Cambridge Econometrics has indicated a boost to GDP of around 2% by 2030 under a pathway consistent with the Sixth Carbon Budget, which would continue to grow after 2030 before levelling off at around a 3% boost by 2050, in part reflecting an increase in economic multipliers as less UK spending goes on imported oil and gas (Cambridge Econometrics, 2020).
- A particular advantage of renewables investment is that in the near-term, investment creates new jobs in manufacturing, construction and maintenance – and many of these have so far been high-wage jobs. The CCC considers net zero is overall a net creator of jobs in the UK, although this will of course depend on tightness in the labour market (CCC, 2023b). The shift to a sustainable, inclusive and resilient economy is a story of change in the labour market, requiring new tasks and skills and some moving to new jobs (Valero et al., 2021).
- Congested, polluted cities, with poorly-insulated buildings, using outmoded energy technologies, and ill-served by public transport, are inefficient and wasteful. 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.[22] Global welfare losses due to pollution are estimated by one study to amount to 6.2% of global economic output (Landrigan et al., 2018).
- A recent study by the London School of Economics and Political Science even draws a link between London's growing air pollution and increases in crime (Bondy et al., 2020). Another study, from the United States, links air pollution with increased vulnerability to COVID-19 (Wu et al., 2020).

[22] The European Environment Agency (2022), using data from its Air Quality e-reporting database, puts the figure at approximately 37,800 premature deaths a year in the UK and 432,000 in 2012 in Europe, with an additional 75,000 people dying each year from exposure to atmospheric NO_2.

- Valuing ecosystems and biodiversity, monitoring natural capital and recognising non-market impacts such as benefits for physical and mental health are prerequisites to securing a positive impact on social wellbeing (Agarwala and Zenghelis, 2020).

There will also be costs, which must be distributed fairly

The transition to sustainable, inclusive and resilient growth will be largely beneficial to society, but if not managed carefully, structural change at this scale and pace could leave certain parts of society behind.

Some jobs will disappear in the transition; others will change radically. While the aggregate number of jobs expected to be phased out entirely is thought to be small, some locations may be particularly affected: for instance, coastal communities relying on the oil and gas industry (Broome et al., 2022). If managed badly, these changes could harm crucial public support for the transition as a whole. The challenge is to manage change so that all have a chance of benefitting, with a pivotal role for government (for a more detailed discussion, see Section 8).

Especially when the cost-of-living is high, some households will struggle to afford the upfront costs of the technologies that need to be adopted at scale to deliver net zero. This is a particular consideration for the installation of energy efficiency upgrades and heat pumps in homes and the uptake of electric vehicles in personal transport (Anis-Alavi et al., 2022; Corlett and Marshall, 2022). Even though most of these changes have the potential to deliver operational savings once initial investments are made, currently high upfront costs mean that the savings will only accrue to households that can afford them.

However, there are also low-carbon technologies that do not yet offer a clear operational cost advantage to consumers. For example, the CCC (2022) estimated that the average heating bill for a heat pump was around 10% higher than for a gas boiler even under the record high gas prices at the time of its analysis. The Government will therefore have a role not just to provide targeted support for households with the upfront costs of low-carbon technologies but also to address price distortions that often penalise these technologies, while making sure policy costs are passed on fairly (Owen and Barrett, 2020).

To secure the support of citizens, consumers and workers as the transition progresses, it will be crucial to ensure the costs and benefits are distributed fairly and are perceived to be done so.

4. Competitiveness

The race to develop knowledge clusters is on

Our analysis in the preceding sections suggests that, to the extent that the UK can shift its energy and production systems from one network to another, this will likely generate large spillovers across the economy. Yet there is a growing risk that the UK loses any potential comparative advantage in low-carbon markets due to delayed policy action.

Economies of scale that drive cost reduction in fast-growing clean sectors drive up productivity and wages, attracting high-skilled employees. This implies a tendency towards clustering and agglomeration of new industries (see Section 3). The presence of a diverse and specialised skilled workforce then expands productivity further. Once established, such clusters become hard to dislodge, as they develop competitive leads in boosting productivity and wages and driving product costs down (Porter, 1990; Krugman, 1979). Late entrants will then find it hard to build production capabilities in these sectors. Examples include integrated semiconductor fabrication in Taiwan and financial services in the City of London.

Building on the UK's strengths requires a clear strategy

Building competitiveness in explicit 'green' sectors where the UK has current or latent comparative advantage can present an opportunity for the UK, but an economic strategy for sustainable, resilient and inclusive growth must recognise the country's broader strengths across finance and professional services, the creative sectors, life sciences and areas of high value manufacturing (De Lyon et al., 2022). As such, green industrial policy must be embedded in a wider growth strategy (Valero and Van Reenen, 2023).

To an extent, it is easier for countries to become competitive in new green products that require production capabilities and know-how that are similar to their existing domestic capabilities (Hidalgo et al., 2007; Mealy and Hepburn, 2020). As a result, green transitions are highly path-dependent: countries that successfully invest early in green capabilities have greater success in diversifying into future green product markets. A firm's choice over whether to innovate 'clean' or 'dirty' products is influenced by the practice of the countries in which its researchers/inventors are located. Moreover, firms tend to direct innovation towards what they are already good at (Aghion et al., 2016).

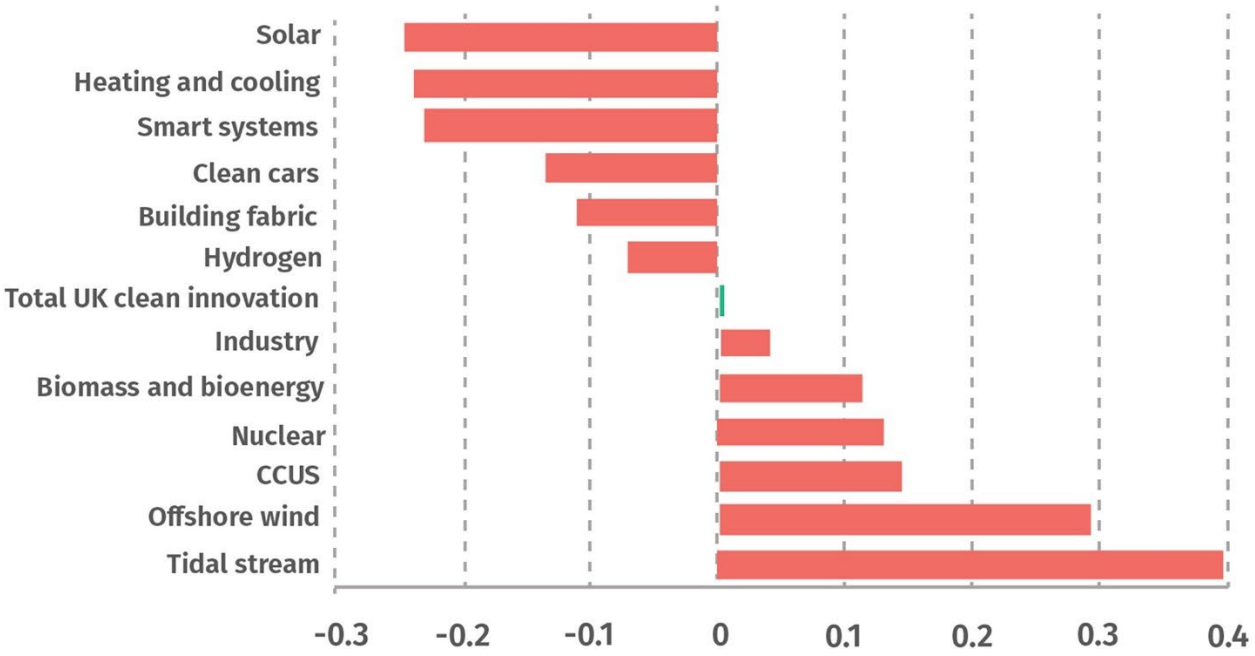
The pace of international decarbonisation policy developments has stepped up. Strong policy strategies include the US Inflation Reduction Act; the EU's Green Deal, hydrogen strategy and Carbon Border Adjustment Mechanism; China's 14th Five Year Plan; and India's Union budget and Energy Access strategy. The sharp cost reductions in renewables, allied with unexpectedly rapid deployment, are increasingly well-known. Notwithstanding the risk of some instances of early lock-in to fossil fuel infrastructure, the war in Ukraine is on balance set to accelerate this process (Zenghelis et al., 2022).

Green industrial policies and support must be informed by the areas of comparative advantage, proximate skills and intangible capital the country can build on to drive a leading position in clean manufacturing (see e.g. Andres and Mealy, 2023; Valero and Van Reenen, 2023). In fact, the UK is already specialised in the innovation of a number of clean technologies that are seeing rapid growth globally, including offshore wind, carbon capture, usage and storage (CCUS) and tidal stream energy (see Figure 4.1 below and Serin et al., 2021; Curran et al., 2022; Serin et al., 2023).[23] The UK can also benefit from its competitiveness as a centre of green finance and expertise in other key services such as consultancy and design (Curran et al., 2022).

Moreover, the UK's innovative strengths in clean technologies, products and services tend to be concentrated in less productive parts of the country (Curran et al., 2022). Hence, on top of their environmental benefits, investing in net zero innovation and capabilities could also support local prosperity and help address longstanding regional inequalities.

[23] Also see Renewable UK's map of renewable technology supply chain companies: https://www.renewableuk.com/Page/SupplyChainMap

Figure 4.1. UK revealed technological advantage (RTA) by selected clean technologies, 2015-2018



Notes: Revealed Technological Advantage (RTA) compares a country's share of total innovation in a particular technology area with the global share for the categories. Positive values suggest that the UK is specialised in a particular area. Patent codes underpinning the clean technology categories on the y-axis are based on Martin and Verhoeven (2022), with the 'clean cars' category added. 'Total UK clean innovation' refers to all UK innovations under the 'Y02' class from the Cooperative Patent Classification system, which corresponds to technologies or applications for mitigation or adaptation against climate change.
Source: Valero and Van Reenen (2023), reproduced from Curran et al. (2022)

For a range of other clean technologies and products, such as solar photovoltaics, building fabric and batteries, the global markets have already reached a level of maturity, but the UK does not currently demonstrate competitiveness (Curran et al., 2022). Yet they need to be deployed at scale regardless to bring UK emissions to net zero. While manufacturing opportunities available to the UK from these technologies may be limited, investing to scale them up rapidly will make the overall economy more resilient, efficient and productive. Building some level of domestic productive capability for strategic products like batteries might also be justified for national resilience and security purposes across supply chains, regardless of potential opportunities from international trade.

Adjustment costs to business are over-stated and can be ameliorated

Incumbent industries directly or indirectly reliant on fossil fuels are inclined to claim that stronger climate policy will put them at a competitive disadvantage relative to those in other countries, or even cause them to relocate. The evidence suggests that such risks of 'carbon leakage' are overplayed (Grover et al., 2016). Indeed, the future commercial viability of tradable carbon-intensive sectors is likely to depend on them becoming best-in-class in terms of emissions and resource use (Bassi and Zenghelis, 2014). The scale of potential opportunity, but also of loss of competitiveness and asset devaluation, demonstrates this. Heightened regulatory and policy risk means investors and individuals need a clear policy steer to guide investment (see Section 8).

Working with the UK's existing comparative advantages is pragmatic. At times, however, a more disruptive strategy and change in direction is required to make a success of new economic sectors. Had South Korean policymakers pursued only the country's comparative advantage through the 20th century, rather than taking strategic decisions, the country might today be a global leader in the production of rice rather than smartphones.

5. Energy security

Fossil fuels have historically generated revenues for the UK...

The UK has previously been a significant producer of coal, oil and natural gas. However, coal production has been in decline since 1913, petroleum production peaked in 1998, and natural gas production has been in decline since 2000. The UK has been a net importer of natural gas since 2004, and in 2022, domestic production of natural gas was equivalent to 54% of UK demand (Department for Energy Security and Net Zero [DESNZ], 2023a). The UK has been a net importer of petroleum products since 2013 (ibid.).

While production of oil and natural gas has in the past created significant tax revenue for the UK, between 2015–16 and 2020–21 relatively low wholesale market prices and declining production meant that total receipts were well below £2 billion per annum, equivalent to much less than 0.1% of UK GDP. According to the Office for Budget Responsibility (2023d), tax receipts surged after the large rises in oil and gas prices in late 2021 and 2022, and the introduction of the energy profits levy in May 2022, and are expected to have reached a peak of £11 billion in 2022–23. However, a significant decline is predicted for subsequent years, in line with falls in both oil and gas prices and production.

...but dependence on fossil fuels comes with growing costs

The UK's heavy dependence on natural gas for electricity and heating meant it was exposed and vulnerable to a huge spike in costs after Russia's invasion of Ukraine. This, combined with the country's old housing stock, played a large part in household budgets being hit harder in the UK than in any other country in Western Europe during the energy crisis that followed (Ari et al., 2022; Kranz et al., 2022). The Government was forced to shield consumers from rising energy bills and cost of living through various support schemes at an estimated total cost of £78 billion across 2022–23 and 2023–24 (OBR, 2023a). This significant public subsidy contributed to record profits for energy producers in the UK and abroad. The lack of previous investment in cost-effective domestic energy security, including investment in energy efficiency and, more recently, renewable energy, made the UK more susceptible to a global price shock, with the resulting last-minute support that was required worsening the country's fiscal position.

The UK is also exposed to the volatility of prices for diesel and petrol resulting from the international oil market. International oil prices are strongly influenced by the actions of a small number of large producers, including the Organisation of Petroleum Exporting Countries (OPEC), which adjusts supplies to attempt to maintain the global price at desired levels. Action by the OPEC countries and Russia in 2023 led to rises in the prices of petrol and diesel in the UK, which slowed down the speed of reduction in the rate of inflation (Bank of England, 2023). The major shocks to the global oil supply also led to large windfall rents to low marginal cost oil-extracting regions (which does not include reserves under the North Sea). New domestic oil and gas licences will do little to enhance UK energy security.

Continued dependence on fossil fuels would constitute an unsustainable economy, undermining the UK's energy security, future living standards and economic competitiveness. The sustainable economy, on the other hand, would include a rapid transition to domestic clean energy and electrification of the economy, and thus 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 (Evans, 2022). Savings could have been even larger had the UK pursued a faster transition to renewables and energy efficiency.

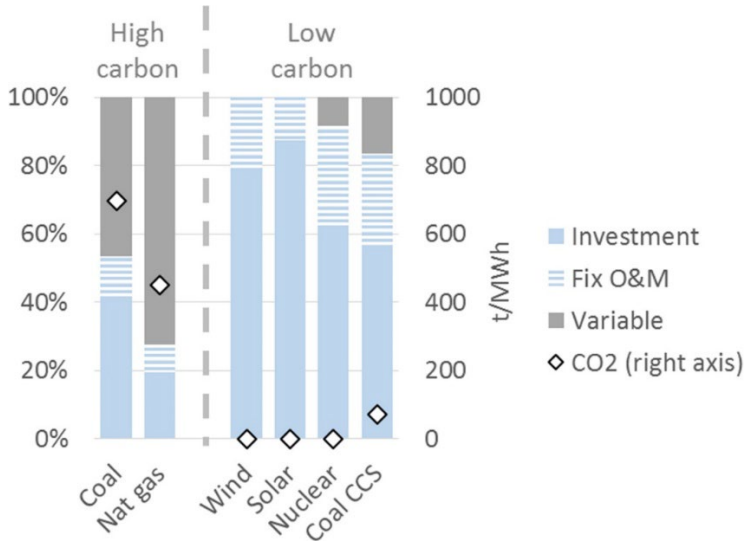
Looking ahead, while it will be capital-intensive upfront to scale up the low-carbon technologies necessary for the UK's net zero transition, these costs will likely be offset over time by the operational cost savings they unlock, particularly from the avoided purchase of fossil fuels (CCC, 2020). Furthermore, a notable amount of energy consumption that currently lies in the UK's buildings sector is avoidable, with the CCC *conservatively* estimating that energy efficiency and behavioural measures could deliver a 12% reduction in primary energy for heat to 2050 in its balanced net zero pathway (ibid.). Decarbonising buildings through a rapid roll-out of energy efficiency upgrades alongside low-carbon heating will be central to the UK's energy security and economic sustainability.

6. Impact of high interest rates

Higher interest rates are affecting capital costs

The clean transition relies on substituting capital for fossil fuels. It is becoming evident that the UK missed an opportunity to increase investment over the decades in which interest rates were historically low. The recent increase in interest rates has sharply raised the cost of capital for clean energy sectors including solar and wind, which are in general more capital-intensive than fossil fuel-based sectors (see Figure 6.1).

Figure 6.1. Cost composition of different power generation technologies



Note: The figure assumes 7% weighted average cost of capital (WACC) and capacity factors of 60% for fossil fuelled plants, 35% for wind power, 20% for solar power, and 90% for nuclear, and a carbon price of US$30/tonne CO_2. Under these assumptions, the levelised electricity costs of all technologies are comparable in level (US$58–84/MWh). O&M = operations and maintenance.

Source: Hirth and Steckel (2016) (reproduced under CC BY 3.0 DEED licence)

The failure of the 2023 Contracts for Difference auction to attract any bids in offshore wind is testament to the pressure higher capital costs are putting on the industry in the UK (DESNZ, 2023b). Shares in wind companies such as Siemens Energy and Orsted have suffered, with the latter having to abandon projects in the US (Lex, 2023; Millard, 2023).

Yet, after rising capital costs pushed prices up in 2022, clean technology prices globally renewed their sharp downward trend during 2023. The levelised cost of solar photovoltaics fell by 9% over the year to the first half of 2023 while that of onshore wind fell 13% (Butler-Sloss et al., 2023 based on BloombergNEF). Battery cell costs fell by 16% over the same period (ibid.). Investment in clean energy exceeded $1 trillion in 2022, for the first time matching the total investment in fossil fuels (BloombergNEF, 2023). Around 90% of this went to just two sectors: renewable energy and electric vehicles (ibid.). Capital expenditure for clean energy was almost twice that for fossil fuels in 2023, and is set to be more than 10 times that for fossil fuels by 2030 under a scenario that brings emissions from the global energy system to net zero by 2050 (IEA, 2023c).

The net zero energy system in the UK will be a largely electrified one, with demand across buildings and transport almost entirely met from clean electricity (CCC, 2020). The UK's electricity output will need to more than double current levels by 2050 (ibid.), which will need to be matched with an expansion of the transmission network at an unprecedented scale and pace, alongside development of storage and flexibility services (Winser, 2023). Meeting the current government's target of 50 GW of installed capacity of offshore wind by 2030 alone will require in the next seven years building more than five times the total amount of transmission infrastructure built in the last three decades (National Grid, 2023). Recent commitments in the 2023 Autumn Statement to expand and speed up access to the UK

electricity grid were positive steps in that regard (HM Treasury, 2023), and were welcomed by the energy industry itself (Energy UK, 2023). In addition, the permanent full expensing of capital outlays announced in the Autumn Statement also reduces costs for capital-intensive projects such as renewable infrastructure.

Interest rates are likely to fall, reflecting plentiful desired saving

The near-term cost of the transition very much depends on the pathway for global interest rates. The global real neutral interest rate finds a level which clears the market for global saving and investment, such that desired saving equals desired investment.[24] It affects all other global market interest rates. An excess of desired saving over desired investment pushes the global rate down (the term 'desired' is key, as once rates have adjusted, actual global investment will always equal actual global saving). As we have argued before, there is no shortage of available finance and an abundant supply of savings is likely to continue (Stern and Zenghelis, 2021). 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 et al., 2023; Zenghelis, 2023). However, the UK may need to increase its domestic supply of savings to avoid reliance on global sources of investment and a widening current account disparity (see Section 2).

The evidence suggests that once the present inflationary pressures and supply constraints abate, the real neutral rate of interest will settle at a low rate. It is far from clear that the era of secular stagnation and insufficient planned investment relative to planned saving is entirely behind us. Rates may settle at a somewhat higher value than in recent decades, perhaps 1% or more, reflecting in part a political shift towards active industrial policy to drive investment (Blanchard and Summers, 2023), but by historical standards the opportunity to absorb saving for productive investment looks likely to remain high.

This matters, because capital-intensive investment in infrastructure networks to support the integration of new technologies in electricity grids and public transport, broadband and recycling, as well as the planning of compact and connected liveable cities, will be central to the success of the transition to a sustainable, inclusive and resilient economy.

[24] The neutral (or natural, or 'equilibrium') real rate is taken to be the rate at which an economy is neither overheating nor being reined back. While it is empirically unobservable, important attempts have been made to estimate it (see Zenghelis, 2023).

7. Fiscal space

Most of the necessary finance will be private, but public capital plays a key role

For all the problems in the financial sector since 2008, the market remains the most efficient way to distribute scarce resources in any economy and drive innovation in their use. It effectively coordinates the vast amount of information needed to match supplies and materials with the things consumers want to buy. It also matches personal savings with investment opportunities that deliver the best risk-adjusted return.

This means recognising that a key task for business and innovation policy is to promote competition and enhance market efficiency, and also recognising the role of financial markets in effectively funding investment. Delivering the UK's net zero transition will require a large investment programme, worth around £50 billion each year on average until 2050, the majority of which will be privately funded (CCC, 2020). Yet the presence of static and dynamic market failures, as outlined in previous sections, suggest government will have to play a critical role in strategically guiding private sector activity. Some of this will be direct public investment, and the policy environment should be designed to maximise the extent to which this can mobilise private sector investment (policies are discussed in Section 8).

In August 2022, the US Inflation Reduction Act committed at least $369 billion of public spending over a decade to support sustainable growth. Early evidence illustrates how this has been mobilising (or 'crowding in') private sector investment into clean energy, infrastructure and the manufacture of clean technologies across the country (Boushey, 2023). Over the first year after the Act was signed (along with the CHIPS Act), at least $224 billion worth of new projects were announced in clean technology and semiconductor manufacturing (Chu et al., 2023). This provides a stark example of how a clear and ambitious commitment can drive private investment.

Can sustainable investment co-exist with fiscal sustainability?

Section 2 outlined the extent to which the UK's overall investment rate has been low compared with other advanced economies, and the impact this is likely to have had on economic performance. This shortfall is evident when considering business investment (Brandily et al., 2023) and public sector investment (Odamtten and Smith, 2023) separately.

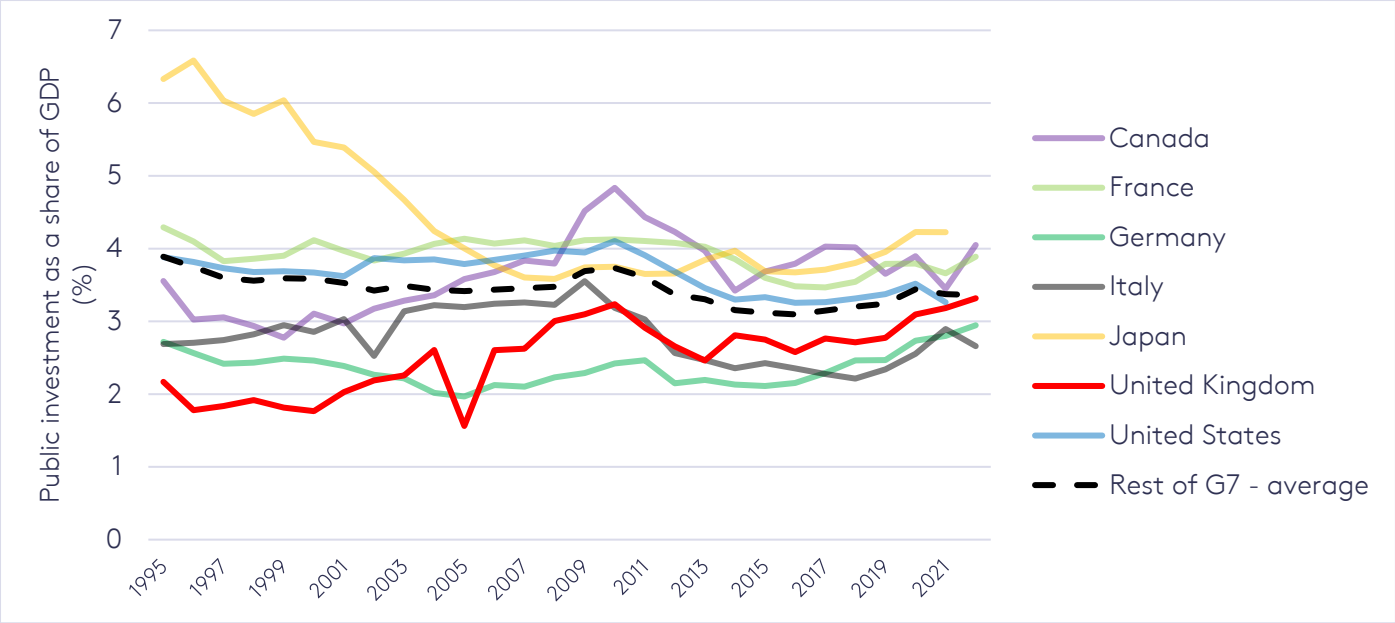
Public sector investment in the UK has consistently lagged behind some other major advanced economies, including Canada, France and the US (see Figure 7.1). From the mid-1990s until very recently, the UK's annual public investment stood at 2.5% of GDP on average, which is 0.9 percentage points less than the average for the rest of the G7 economies (ibid.).[25]

Private sector investment in the UK has also consistently lagged behind the rest of the G7 since the global financial crisis, with only Canada and Italy performing worse in some years (see Figure 7.2). The UK's annual private investment since 2010 has stood at around 10% of GDP on average, over 2 percentage points below the average for the rest of the G7 (ibid.). The combined impact of public policy and public investment has not generated sufficient investment to support higher UK productivity growth.

Some progress has been made in recent years, and UK public sector investment is expected to rise to 3.6% of GDP in 2024. However, it will then fall to 3.1% in 2028–29 as a result of the decision announced by the Chancellor in the Autumn Statement in November 2023 to continue to hold capital departmental spending flat in cash terms (OBR, 2023c). In contrast, previous cross-country analyses lead to the argument that governments should be investing the equivalent of about 4.5% of GDP annually (Odamtten and Smith, 2023).

[25] While the UK's public sector investment has been on a par with Germany's, Germany has recorded much higher business investment. See Figure 7.2.

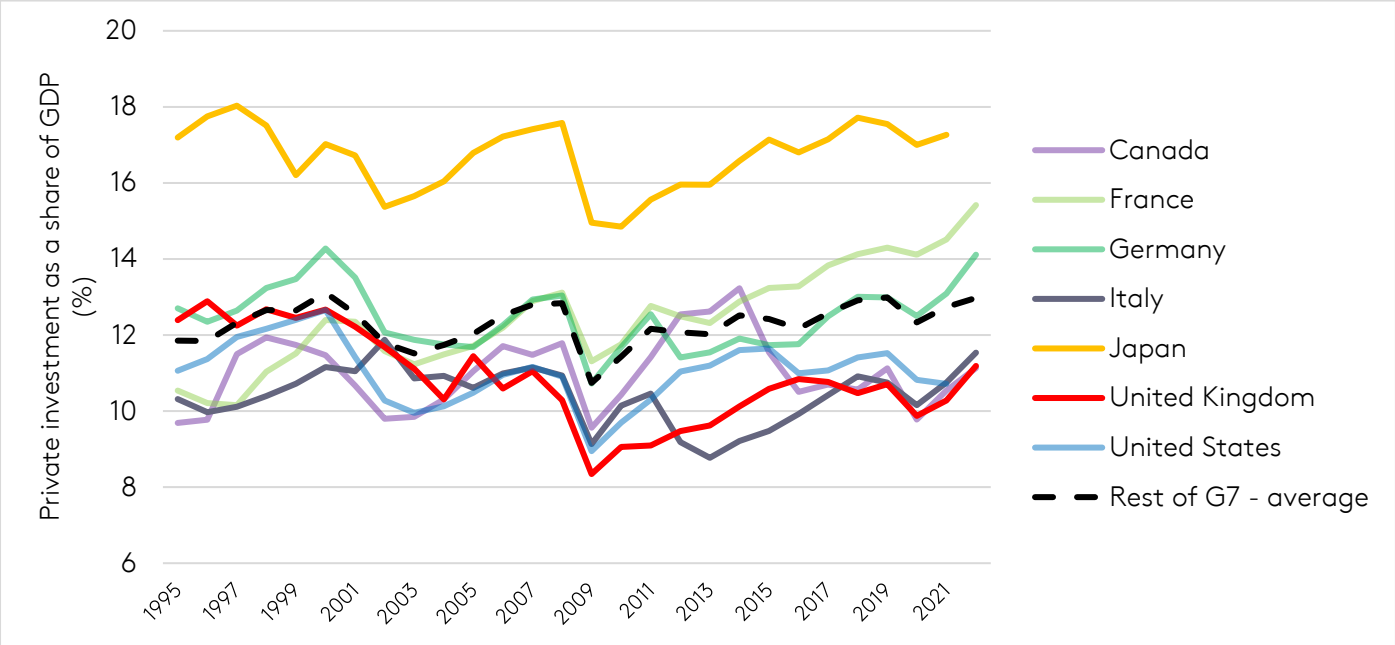
Figure 7.1. Public investment rates for G7 countries, 1995–2022



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 of International Monetary Fund, World Economic Outlook Database, October 2023 (IMF, 2023b) and OECD, Investment by sector, 2023 (OECD, 2023)

Figure 7.2. 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.

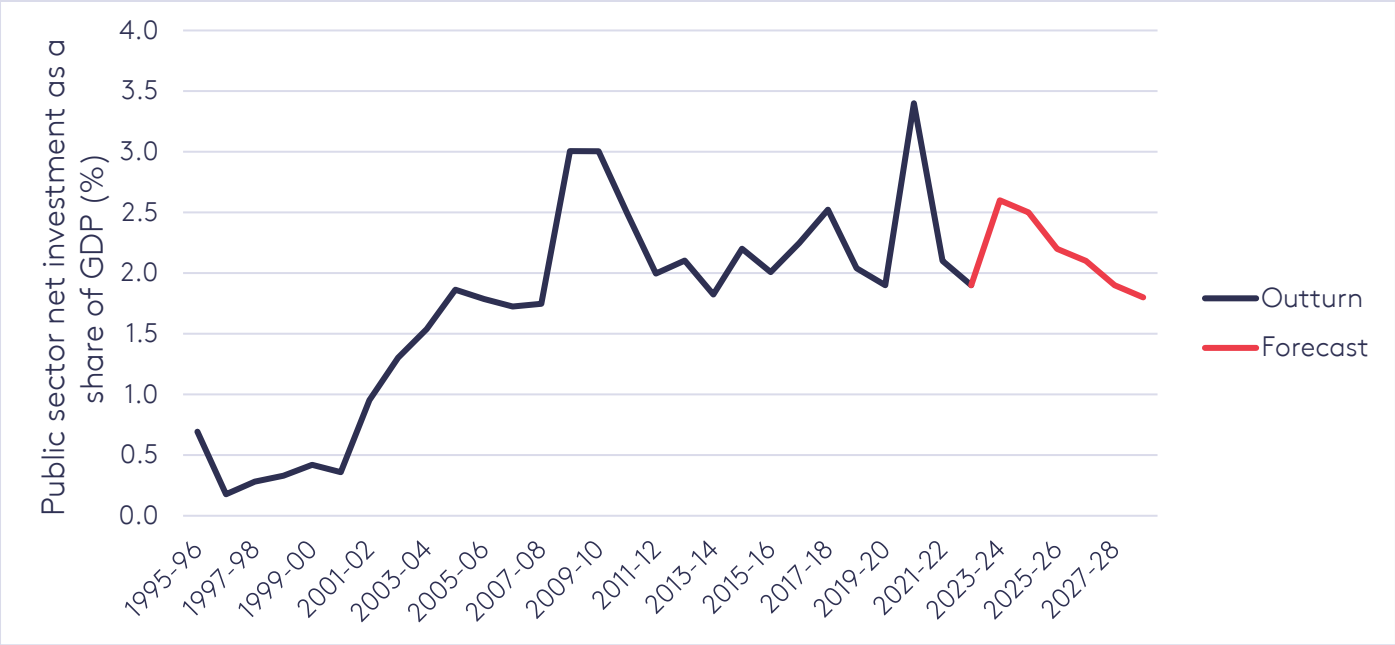
Source: Authors' analysis of International Monetary Fund, World Economic Outlook Database, October 2023 (IMF, 2023b) and OECD, Investment by sector, 2023 (OECD, 2023)

As well as being relatively low, UK public sector investment has also been too volatile, with the coefficient of variation (a scaled measure of variation to allow comparability) for annual growth in UK public investment between 1960 and 2019 being the second highest among advanced economies (Odamtten and Smith, 2023). Public investment commitments are prone to 'feast and famine' and are often the soft target when bad news comes along: investment has been cut by an average of nearly 20% in each of the post-recession fiscal consolidations that have taken place since the 1970s (ibid.). In response, the

final report of the Economy 2030 Inquiry recommended that the UK's public sector net investment (PSNI)[26] should be sustained at 3% annually (RF and CEP, 2023). This compares with the announcements in the Chancellor's Autumn Statement in November 2023 which would mean PSNI will rise from 1.9% of GDP in 2022–23 to 2.6% in 2023–24 before declining gradually to 1.8% by 2028–29 (see Figure 7.3).

The National Infrastructure Commission underlines the importance of public investment in economic infrastructure being sustained at high levels in the long term, recommending in its Second National Infrastructure Assessment that the Government invest over 1% of GDP annually up to 2055 towards developing sustainable, inclusive and resilient infrastructure that supports the country's economic growth and protects its environment (NIC, 2023). Given that the investment that falls within the Commission's remit is specific to certain types of economic infrastructure, the recommended figures represent a lower bound for the UK's public investment requirements overall.

Figure 7.3. UK public sector net investment, 1995–2023 outturn and 2023–29 forecast



Source: Authors' analysis of Office for Budget Responsibility's Economic and Fiscal Outlook reports (various years). Forecasts based on the November 2023 issue (OBR, 2023c).

The toll of years of underinvestment is beginning to show on the UK's public infrastructure and services. A lack of enabling assets risks curtailing individual capabilities and the ability of the economy to prosper. It appears, therefore, that there are strong grounds for increasing overall public sector investment by at least 1% of GDP, or £26 billion at current prices, annually. This investment and the resulting infrastructure need to be in the sustainable economy in its entirety and will look very different from the past, adopting the widespread use of AI and digitisation. Investments in adaptation and resilience also afford high returns (see Section 3).

One explanation for the UK's poor record on public investment is excessive focus by HM Treasury on the debt side of the public sector balance sheet, to the neglect of an assessment of the value of assets that result from cumulative public investment. Assets are harder to define and measure than debt, but their value should not be ignored in any strategy to enable productivity growth. The net worth of the UK's public sector has been falling and turned negative in 2010, standing at -£614 billion in the fiscal year 2022/23 (ONS, 2023b). This reflects low and volatile investment (Ebdon and Khatun, 2021). Among rich countries, only Portugal has performed worse (Odamtten and Smith, 2023).

[26] PSNI consists of public sector gross fixed capital formation, with depreciation deducted, and accounting for capital grants between the public and private sectors. By contrast, the national accounts component of GDP by expenditure is measured gross – that is, it includes investment to replace worn out or depreciated capital.

Nevertheless, budgetary pressures continue to have implications for global imperatives like the net zero transition as governments struggle to tackle fiscal overhangs. The UK's ageing population means increased spending on health, social care and state pensions, and a smaller population working and paying taxes (OBR, 2023b). Meanwhile, the invasion of Ukraine, renewed conflict in the Middle East and the increased tension between the US and China have prompted policymakers to increase defence spending. This is set against the fact that budget deficits ballooned during the COVID-19 pandemic, as governments acted as 'insurers of last resort' to keep economies ticking over. Public deficits in 2020 averaged more than 20% of GDP in advanced economies, sending public debt as a percentage of output to highs of over 100% of GDP in many advanced economies (Gaspar et al., 2022; IMF, 2023a).[27]

More recently, rising interest rates across the world have pushed debt servicing costs higher, requiring additional borrowing to pay off the interest. The Bank of England's official policy rate has risen to 5.25% from around 0.1% at the end of 2021. The era of 'lower for longer' interest rates (see Adrian, 2020) seems to be behind us at least for now (Zenghelis et al., 2023).

In this context, can the UK government keep its public debt ratio at sustainable levels while delivering the multi-billion-pound clean transition required to meet its climate targets? There are only four ways to improve debt sustainability as a proportion of GDP. The options, set out in Table 7.1, involve either a nominal restructuring through debt default, higher inflation, a real restructuring through tightening the fiscal screws, or boosting growth in GDP. Of these, only the latter two 'real' options are sustainable.

Table 7.1. 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

The austerity dilemma

It has been demonstrated that the collective drive towards fiscal austerity in large economies since the great financial crash of 2008 throttled productivity-enhancing government investment (Jordà and Taylor, 2016), thereby ultimately making debt/GDP ratios higher (Auerbach and Gorodnichenko, 2017). Furthermore, after years of underinvestment in public services, these countries have little appetite for a further bout of fiscal austerity.

[27] Higher inflation has, however, recently eroded the real value of public liabilities (pushing them on to bondholders), allowing global public debt/GDP to fall from its 2020 peak by around 10 percentage points in most advanced economies, generating unexpected fiscal space. Fiscal drag, as tax bands have not risen in line with inflation, has also served to boost revenues in many countries. See IMF (2023).

Whether to focus on austerity or borrow to boost growth will depend on the scope for expansionary fiscal policy to generate so-called growth multipliers (Lenoël, 2020). These occur when government outlays directly stimulate demand (rather than being saved by consumers) in the short run, and boost the productivity of the economy in the long run. As a result, the economy can expand by more than the additional borrowing, with the policy thereby potentially paying for itself.

In many countries, labour markets are tight, capacity is constrained and inflation, though falling, remains stubbornly high. In such circumstances, fiscal multipliers are likely to be low. Additional public borrowing is likely to crowd out scarce private investment. Central banks can be expected to respond by pushing policy rates higher to offset any additional demand in order to control inflation, thereby obviating any GDP boost and aggravating the cost of interest on public debt.

But the evidence increasingly suggests that long-run multipliers from targeting public investment in clean growth sectors are likely to be strongly positive (Hepburn et al., 2020b). Both the risks associated with locking into unsustainable high-carbon infrastructure (see e.g. Barbrook-Johnson et al., 2023), and the opportunities associated with markets in sustainable, inclusive and resilient goods and services (see Peñasco et al., 2021), have been shown to be much higher than economists hitherto understood.

A recent study compared two scenarios (Kharas and Rivard, 2022). In the first, debt sustainability is restored through fiscal consolidation based on building up primary budget surpluses. In the second, countries undertake a 'big investment push', generating larger primary deficits but also faster growth. The study concluded that both scenarios improve public creditworthiness, but the 'big investment push' improves it more. Of course, this finding depends critically on the micro-level relationship between investment and growth, but the study utilises a growing body of literature on project returns from climate change mitigation, adaptation, resilience, human capital and biodiversity conservation, which suggests considerable scope for investments with high economic returns in most countries. Even fractionally higher productivity growth will compound over a period of years to make the economy significantly larger, swamping other drivers of debt/GDP ratios (Grubb et al., 2021a).

Modelling sustained UK public investment at an OECD average rate of 3% of GDP from 2023–24, Odamtten and Smith (2023) note that this would increase UK public sector net debt by around £70 billion by 2027–28. However, by then they expect a permanent upward shift in GDP of 0.8%. The boost to receipts would shortly thereafter lead to a declining profile for public debt. It would also put net public worth on an upward trajectory for the first time since the 1970s. This is in contrast to the decline in public investment as a proportion of GDP that was outlined by the current Chancellor in his Autumn Statement of November 2023.

It is, of course, impossible to pin down a precise productivity impact from the combination of these sustainable investments. Nor can one deterministically assess the impact on meeting current fiscal rules of decreasing the debt/GDP ratio within five years. This suggests the OBR's model, like most economic models, needs to be amended to better reflect dynamics and the changing landscape of risk and opportunity extending over a longer time horizon.

All this is an inevitable feature of a path-dependent world, where decisions build on (and often reinforce) other decisions, and the range of potential outcomes expands. Much of the dynamics flow through fundamental structural and systemic change – the cumulative impact of a multitude of policy choices. These key systems include cities, land use, energy, transport and water. They are the core enabling assets that determine an economy's social and productive potential. How these assets change and interact over the next two decades will be crucial to shaping the economy, and of course to productivity and growth.

There is no optimal investment path, and the return to any one policy or investment cannot be assessed in isolation from the system of choices. But there are clearly better and worse ex-ante choices, depending on changing risks and opportunities. The risk of locking into the wrong systems at a time of rapid change are grave, with a potentially enduring impact on productivity, growth and debt sustainability.

There is a clear role for the public sector to stimulate investment in new technologies and behaviours that improve the efficiency of the economy and drive productivity.[28] But unlike policies seeking to stimulate demand in the short run, fiscal policies to restore long-term growth must be targeted towards specific investment in properly measured assets that generate economies of scale in production and discovery (Hepburn et al., 2020a; Zenghelis et al., 2022; Agarwala et al., 2023).

Governments must step in with sufficient ambition to provide enabling assets and an environment to foster private investment, by investing in infrastructure, skills and intangible knowledge-generating assets. These investments must support the transition to sustainable, inclusive and resilient growth. Complementary public investment in human capital is necessary to provide an appropriately educated and skilled workface capable of utilising the latest ideas and technologies. Building resilience is also crucial, whether it be against floods, storms or fires; there is a need to adapt to climate change worldwide.

The Treasury's current fiscal rules should be changed to stop 'feast and famine' in public investment. This requires greater transparency over the business case for particular projects, and explicitly accounting for the difference between public investment and current consumption. Consideration should be given to developing more comprehensive measures of public sector net worth (IFS, 2023). The aim is not to justify further borrowing by virtue of unreliable estimates of public assets the government mostly cannot sell: it is to track the degree to which government borrowing is boosting the country's asset stock, and thereby support future direct and indirect tax revenues, relative to borrowing to fund consumption. With this aim in mind, and noting the public sector's influence on private activity, measures of net worth should be developed to cover the whole economy.

Institutional change might include public investment targets being set by Parliament, with the Government held to account for meeting these targets with independent review and oversight from the OBR (the process enshrined through a Parliamentary Act). More investment decisions should also be devolved outside of Whitehall to centres of power that better reflect local investment needs (Odamtten and Smith, 2023; Newman and Kenny, 2023).

Although debt is the appropriate way to finance productive investment, some of the investment will take the form of capital maintenance rather than net expansion of the capital stock. Together with the likelihood that some productive investment is crowded out in the short run, this suggests a temporary increase in aggregate tax and social security contributions will likely be required in order to finance some of the transition to sustainable, inclusive and resilient growth (Pisani-Ferry and Mahfouz, 2023).

Finally, imperfect information and assessment of risks (especially policy risk) in capital markets, requires risk sharing/reduction through guarantees, long-term contracts and public convening power for co-financing (Gordon, 2023). But policy is about more than correcting static market failures: it is about the Government's ability to shape markets and generate new ones for the future, inducing clean, digital investment in 21st century technologies (as opposed to fossil fuel technologies of past centuries), and setting up complementary institutions and policies that resist influence from incumbent vested interests. These new markets cannot be forecast with precision. Market shaping involves policy action that can be justified because it likely brings about change that is desirable, and/or avoids a change that is undesirable (Sharpe et al., 2021). Many of the policy requirements are costless; we turn to these in the next section.

[28] A thought experiment can help reinforce the notion of debt affordability. Assume a macroeconomic policymaker does not know the level of public debt. They have to decide on an appropriate fiscal stance for an economy on the brink of recession and include that a fiscal contraction would be economically ruinous. They are then told public debt is relatively high. To what extent would that materially change their view on the appropriate fiscal stance? The answer is it should not, except in so far as higher debt impacts affordability by pushing up risk premiums on public borrowing rates. A similar rationale underlies decisions to invest in long-term structural change – value to the economy is independent of the past stock of debt. There is scant evidence for this thus far: financial markets were intolerant of the Truss/Kwarteng measures of Autumn 2022, 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.

8. Implications for policy

The surest way to drive improvements in living standards is through improving productivity and economic growth. The core enabling assets (physical, human, intangible and natural) are prerequisites for generating a sustained flow of productive activity. The question of allocation, how to divide up the pie, derives from how best to grow the pie in the first place. Far from being more costly, a transition to sustainable, inclusive and resilient growth can be economically essential in expanding wealth and growing the size of the pie (Geels et al., 2021).

As outlined in Section 3, there is clear evidence for why the structure of the economy is highly path-dependent. The costs of transitioning the UK economy to sustainable, innovative and efficient forms of production will be a function of the choices and decisions made between now and 2050. The more coordinated the UK's response to managing the transition, the more cost-effective it will be.[29] The best we can do in a path-dependent economy is to choose a direction that seems to fit our interests (Aghion et al., 2014). If the UK wishes to be competitive in the economy of the future, it will have to steer and anticipate the choices made by others.

Paul Romer once remarked: "instead of suggesting that we can relax because policy choices don't matter, it suggests to the contrary that policy choices are even more important than traditional theory suggests." There is strong evidence that public policies are the most important driver of deployment of, and innovation in, sustainable, inclusive and resilient technologies. Moreover, this impact appears both large and rapid: evidence suggests that much of the innovative response to climate change policy measures occurs within five years or less (Dechezleprêtre et al., 2016). Taking the lead in a competitive playing field therefore requires early supportive and 'enabling' government intervention.

Economics must better inform policy choice

The standard approach to assessing the costs and benefits of climate action has been to run models that assume a static and pre-determined economic structure. In essence, when asked to assess what it will cost to cut emissions to zero by 2050, many economists run models that assume we know the technologies, tastes and preferences, and institutions that will prevail from now to 2050 (Nordhaus, 1992).

Such models can generate deterministic forecasts and will automatically tell you the more we cut carbon emissions, the greater the costs will be, because so much is hard-baked into the model that any adjustment is very costly. However, non-marginal structural change is very different. As outlined in Section 3, innovation can be induced to make the system more efficient. New markets and behaviours evolve such that the more we try to cut carbon emissions, the better we become at cutting carbon emissions. Unlike material resources, knowledge builds on knowledge and does not deplete. The assumption of a pre-existing equilibrium is therefore just an assumption.

Standard cost–benefit, static optimisation and Integrated Assessment Models, used widely across the economics profession, grossly misrepresent risk and are silent, by construction, on the big issues of policy, opportunities from structural and technological change, multiple market failures and distribution and justice. These models divert from the crucial issues. There is a need to look elsewhere for analytical foundation, recognising that all models are wrong (they omit important issues) but that some are useful (Ekins and Zenghelis, 2021).

Identifying the limitations in modelling 'optimal' pathways to net zero is important, because the economy creates possibilities faster than models can explore them, so options can only shape the balance of risks and opportunities. Rather than outlining 'optimal' pathways, economists can provide information about better or worse choices in relation to risks.

[29] For example, policy can generate cost reductions and new economic benefits by avoiding locking into unsustainable high-carbon infrastructure, behaviours and institutions which will be expensive to subsequently retrofit or scrap, while at the same time inducing resource-efficient innovation.

Policy credibility and an enabling environment

We have seen how policy intervention is the opposite of distorting when applied to sectors where market failures are corrected or necessary new market signals created. The need to steer a rapidly changing global economy suggests more, not less, strategic intervention will be required. But the intervention needs to be well-designed in order to avoid replacing market failure with policy failure (Hepburn, 2010).

To be credible, the pace and scale of economic change embedded in government policy should be informed by evidence and scientific understanding. For the specific objective of reducing emissions, in the UK that should mean working with the Climate Change Committee to develop credible timelines and legislate targets for key sectors, including sector-by-sector transition plans (for example, in low-carbon hydrogen, heat and buildings, grid infrastructure, low-emission vehicles and CCUS).

It is widely recognised that stable and credible economic institutions, rules-based property rights, macroeconomic stability and policy certainty are preconditions for business investment and innovation. Carefully targeted and time-bound fiscal policies to address market failures and invest in new markets will need to be complemented by transparent regulations to prevent rent-seeking by vested interests and natural monopolies and ensure an open, level playing field for competition.

But during potentially disruptive structural transitions, guiding expectations is central to keeping costs low, while securing institutional flexibility to respond to rapid technological change. This is the most effective way to generate investor confidence (Aghion et al., 2009). By contrast, mixed and muddled signals, or backtracking on stated policies, exacerbate uncertainty and lack of trust in government sticking to its commitments. This delays action and raises the policy risk premium attached to sustainable investments.

For example, UK carmakers are, like auto manufacturers across the world, preparing for the shift to electric vehicles. By delaying the ban on new petrol and diesel car sales from 2030 to 2035, announced by the Prime Minister in September 2023, the Government introduced new uncertainty and a setback for UK carmakers looking for a stable environment in which to invest with confidence. Assessing the impact of Rishi Sunak's announcement, the Climate Change Committee concluded that this kind of loosening of near-term ambition "risks undermining consumer confidence and the development of UK supply chains" (CCC, 2023). Ford's UK chair said the Government had undermined its own "ambition, commitment and consistency". Meanwhile, China and the US are pouring billions of dollars into grants, purchase incentives and EV charging infrastructure roll-out schemes (IEA, 2023a).

The private sector can handle risk that it owns, such as technology or construction risk. What it cannot handle is policy risk because it cannot directly control it. More policy risk, especially in highly-regulated sectors like energy, transport and buildings, means the private sector demands a risk premium on investment.

Of course, policy must be set in the context of uncertainty. It must therefore be sufficiently stringent to change behaviour and predictable in order to contain policy risk, yet simple and flexible in evolving to changing circumstances while limiting compliance costs (Helm, 2010). This requires that it be based on clear rules for review and revision, where the public sector responds to surprises in a predictable manner.

Government must convince business that it will not renege on its commitments once investment costs are sunk. It can do this by sending clear signals and setting credible long-term policies while underwriting elements of the policy risk and avoiding retrospective change. Consistency is among the most important and costless elements of sustainable policy.

A stronger institutional framework would help to ensure that targeted industrial policies are embedded in a lasting and coordinated UK growth strategy, along with policies to ensure that risks and opportunities are shared. But at a time of global structural change, and in contrast with several other advanced economies, the UK lacks a dedicated growth institution (Valero and van Ark, 2023). A new, statutory growth and productivity institution is needed to provide independent expertise and credibility to shape effective, coordinated and lasting pro-productivity policy. Such a body should also explicitly consider where there are synergies and trade-offs between sustainability and productivity objectives over different timescales, and what this means for policy (ibid.).

The speed of economic and structural change is accelerating as new technologies associated with the clean economy combine with digitisation and AI. Economic and social flexibility to respond to changing markets is more important than ever. The UK has in the past prided itself on its economic flexibility and institutional capacity to adapt to change.[30] However, the evidence is less encouraging. Recent analysis shows that reallocation of labour between sectors is at its lowest rate in over 90 years (RF and CEP, 2023a). This testifies to the importance of making inclusive investments in enabling assets, especially in low productivity regions, so that all sections of society can have better access to economic opportunities (see below on the need for a UK skills strategy).

Blended finance constitutes another way for the Government to crowd in private capital towards public policy objectives, potentially multiplying every £1 contributed by the taxpayer (Gordon, 2023; Gordon and Valero, 2023). For example, the UK could channel far greater institutional capital from pensions and insurance assets towards productive investments in the next five to 10 years (ibid.). There are already successful examples in and outside the UK of blended finance mechanisms that enable private and public investors to work together, despite their different outcome, risk and return expectations, to deliver productive investment consistent with positive social and environmental objectives (ibid.).

However, the ultimate problem lies not with the supply of money to invest, but with a perceived lack of bankable projects. Risks and opportunities are enhanced at a time of systemic and structural change. The importance of strategic coordination and credible policy is increased by reliance on core primary assets such as access to healthcare, basic education, digital connectivity, communications, water and transport to drive economic activity. These increasingly important markets often exhibit some combination of non-rival market properties (i.e. one person's consumption does not diminish another's, as with broadband) or non-excludable properties (e.g. public roads). Similarly, knowledge spillovers mean the full returns to research and innovation do not accrue to the private innovator. Markets based on marginal cost pricing result in under-provision of core goods and services, requiring public intervention or regulation. The perception of enhanced policy risk in heavily regulated and policy-driven sectors such as transport, buildings and energy puts off private investors who cannot own or control policy risk. This raises the cost of capital and deters investment. Decision-makers in public institutions therefore have an enhanced responsibility to anticipate, manage and shape the rapidly shifting landscape of risk and opportunity.

Targeting sensitive intervention points

Targeting policy is another way of limiting costs to the public purse. Researchers at the University of Oxford have shown how policymakers should seek points of leverage, where a small policy intervention can have an outsized effect by generating reinforcing feedback effects (Farmer et al., 2019; Hepburn et al., 2020a).

A good example is tipping coal out of the UK power system as a result of a relatively minor carbon support price of around £18 per tonne, which led to a structural change in the system and coal's share of electricity falling from around 40% of the total to close to zero in less than a decade (Sharpe and Lenton, 2021). Global examples extend to Norway's coordinated policies to support growth in electric vehicles, including carbon pricing, subsidies, free parking and ability to drive in bus lanes. The Brazilian market for onshore wind, German and Chinese efforts to expand solar power, and India's spectacular success in transitioning to LED lighting (cutting the costs of light bulbs by over 90% in less than a decade) provide other examples.

Support for technology deployment

Policies should be as neutral as possible, to enable a broad range of technologies to emerge and compete. However, there is no such thing as a truly technology-neutral choice. Every decision will, unavoidably, advantage some technologies over others (Sharpe, 2023). Inaction normally favours incumbents with deep pockets and hefty lobbying power. Policymakers will inevitably 'pick winners', even if they do not always get it right (Grubb et al., 2021b). Where they do get it right, the results are

[30] For example, see government policy set out in 1997 on the five economic tests on which any decision about UK membership of the Economic and Monetary Union should be based – Test 2: "If problems emerge is there sufficient flexibility to deal with them?" (HM Treasury, 1997).

dramatic: as a prime example, the UK has developed a thriving and globally competitive offshore wind industry, which is creating high-skilled jobs and is set to deliver even cheaper energy.

Governments cannot avoid making some choices, given that there are a range of technological options that will be available over the coming decades, and some technologies have specific barriers and opportunities that may require targeted assistance. The process of making choices should therefore be well-informed, open and transparent, and carried out in collaboration with civil society and the private sector.

Policy choices made today will determine the institutions, technologies and infrastructure that drive our economies for decades to come. This adjustment will be disruptive and will require bold leadership and substantial early investment. But in the world of innovation, it is often the high hanging fruit that proves the ripest. This is why Acemoglu et al. (2012) make a powerful theoretical case to suggest that policy to support clean innovation can be temporary, because once the "clean innovation machine" has been "switched on and is running", it can be more innovative and productive than the conventional alternative, which has a positive impact on both GDP levels and growth. Aghion et al. (2016) argue that clear, credible and enduring policy signals are the most effective way to generate investor confidence to kick-start that clean innovation machine. The policy intervention can be removed once the new networks outcompete established market participants.

Just as in defence innovation in wartime, the race to the moon, and the need to find a COVID-19 vaccine induced innovation, so the setting of mission-led green innovation or digital connectivity challenges can be expected to create substantial knowledge-spillovers, boosting Schumpeterian innovation and productivity across a broad number of sectors (see Mazzucato, 2013 and Perez, 2009).

Government can provide clarity on the vision for the future and how to get there. This means regulations and standards at the product level, defining outcomes and letting entrepreneurs figure out how to get there. China has understood the logic of this approach and has moved decisively to embrace high-tech, low-carbon growth. In 2022 alone it invested over $500 billion in clean energy, more than any other nation or region (IEA, 2023b). China accounts for more than half the electric vehicles on the world's roads (IEA, 2023a) and has more solar generation capacity than the rest of the world put together. China and other countries recognise that investment flows to the pioneers of industrial revolutions (Perez, 2002, 2012).

Specific support is required to promote the digital economy. Regulation must be updated to support changing market dynamics, sector competition and the power of consumers in an intelligent electricity system. New frameworks will be required for open collaboration, interoperability and data-sharing across the energy system in the UK, and to address safeguarding concerns about cyber security, privacy and consumer trust.

Policy must also focus on the practicalities of effectively integrating new technologies and digital assets across the energy system, coordinating the further rollout of smart meters and other appliances. This will require careful strategic planning for integrating digitisation and net zero plans, for example. Managing investment in the new economy will be at the core of building and sustaining productivity growth.

Carbon pricing

Carbon pricing is an important part of any transition to sustainable, inclusive and resilient growth. It provides a clear and non-discriminatory price signal to induce consumers and producers to change behaviour, without predetermining or favouring a particular technology or action. It also generates revenues that can be recycled to improve economic efficiency (through public investment, tax cuts or reducing borrowing).

However, a tax for the purpose of revenue-raising (a so-called Ramsey tax[31]) is different from a tax whose purpose is to change behaviour (a so-called Pigouvian tax[32]). The tax that aims to change

[31] For a given amount of revenue to be extracted from a consumer, the tax system that makes the consumer happiest is that which is least distortionary in the allocation of goods and services. The tax should aim to minimise the change in behaviour. This means taxes should be spread thinly across the economy and goods with higher demand elasticities should be taxed less. See Stiglitz (2015).

[32] In contrast to a Ramsey tax, a Pigouvian tax is *intended* to change behaviour, by taxing the producer of goods or services that create adverse side effects for society.

behaviour, if it succeeds, will not in the end generate revenue (this would be the case with a carbon price in a zero-emissions economy). If a tax is created with both these purposes in mind, the risk is that it fulfils neither purpose well. A successful carbon price will eliminate its revenue base. Raising revenue to replace displaced fuel duty and carbon pricing might instead take the form of road or congestion pricing as the world rapidly decarbonises.

In a recent cross-country analysis, the IMF found that any form of carbon pricing in the UK is unlikely to be enough to offset the erosion of fuel tax bases and costs of public investment spending required to reach net zero, so the impact on the primary balance from decarbonisation would grow to a deficit of 0.5% of GDP by 2040 (de Mooij et al., 2023[33]). The OBR believes this figure could reach as much as 1.2% of GDP in 2040 (OBR, 2023b). These studies make no assumptions about the returns to innovation and productivity from investment in clean energy technologies. Even a fractional increase in growth relative to a high-carbon pathway would be enough to offset any increase in public debt to GDP (see below).

It is important to think carefully about how carbon pricing (through a tax or a trading mechanism for emissions permits) is applied to accelerate the technology transition and create future new markets in any given sector. The conventional policy response suggested by economists has been to internalise the damages caused by global warming by imposing a uniform global carbon price. This price is then ramped up through time as more and more costly abatement options are picked off (Nordhaus, 1992) to meet carbon emission targets. But in fact, differential carbon pricing may be more effective at delivering efficient emission reductions, by specifically targeting expensive technologies with large potential for induced innovation with a higher price to trigger a tipping point.

Finally, the role of carbon pricing must be considered in combination with other policies. In a complex system (such as an economic sector undergoing structural change) the combined effect of different actions will often be different from, and more effective at, achieving the desired outcome than the sum of their parts. The net present value of an individual policy that is intended to contribute to a system transition will depend on which other policies it is combined with.

Standards and regulations

It turns out that regulation, often associated with inefficiency and 'red tape', can be the most effective driver of innovation (Mercure et al., 2021). Data shows that energy efficiency standards drive cost reductions across numerous sectors (Drolette, 2016), as entrepreneurial firms seek to meet or bypass the regulation (Ekins and Zenghelis, 2021). If the constraints are credible, necessity will prove the mother of invention.

Also important will be the role of utility regulators in coordinating multiple supporting networks and systems to ensure long-term investment in the sustainable provision of utilities such as electricity, water, transport and broadband. Many such authorities were set in place following or accompanying privatisation in the 1980s–90s, with a primary focus on regulating prices, but the protection of consumers and society increasingly requires an additional focus on helping to navigate the UK's transition to a sustainable economy (Stern and Valero, 2021). The increasingly demanding need to integrate intelligent and responsive systems to deliver core utilities, like energy, which cannot be priced at the margin indicates an enhanced coordination role for a system operator (Starks, 2023).

Clear and consistent regulation alongside an improved planning system will be key to getting infrastructure projects from renewable generators to transmission lines built on time, while maximising support and investment from the private sector. It is widely recognised that the planning system is slowing down the roll-out of low-carbon houses and infrastructure, with excessive power in the hands of those who own land. Addressing process bottlenecks, improving the use of data, enabling meaningful engagement with local communities and improving coordination between national- and local-level decision-making will be important for achieving a more effective planning system that properly supports the UK's transition to net zero (NIC, 2023; Skidmore, 2023). The Government's commitment in the

[33] This uses a tool developed jointly with the World Bank and outlined in a working paper to generate the fiscal impacts on different countries of different climate change scenarios. See the IMF-World Bank Climate Policy Assessment Tool (CPAT): A Model to Help Countries Mitigate Climate Change, 23 June 2023.

Autumn Statement to reforming the planning system towards that goal was a positive step (HM Treasury, 2023).

A greater role for public policy comes with the need for robust and transparent regulatory authorities designed to protect consumer interests against monopolistic pricing and rent-seeking activities among the providers of core services such as electricity, transport, digital communications and water.

Public procurement is another tool available to government for encouraging the private sector to move towards sustainable practices. By aligning its own purchasing power with sustainability principles, government can promote resource efficiency, innovation and development of new technologies, social value and increased resilience in the economy (OECD, 2015; European Commission, 2016; Salazar Cota et al., 2018). Sustainable procurement can be particularly influential in sectors where public procurement represents a significant percentage of the market, such as buildings and construction, public transport, and health services (OECD, 2015).[34]

Research and development (R&D)

Price-based instruments such as carbon markets, and quantity-based instruments such as renewable energy mandates, have a large effect on low-carbon innovation, but they tend to favour innovation in technologies that are closest to the market. Thus, they need to be complemented by direct public funding of and tax breaks for R&D in order to support the development of technologies that are further from market but nonetheless have long-term potential. This will complement support for demonstration, dissemination and deployment.

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 research base and innovative strengths in sustainable technologies. The UK may have 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 (National Academies, 2015), and the country ranks fourth overall in the Global Innovation Index, largely due to the strengths of its university research and innovation system.[35]

The links between research and innovation and comparative advantage in high-skill, high-wage manufacturing are clear, yet the UK has not made the most of this opportunity. The IEA estimates that public R&D spending needs to at least double to achieve significant reductions in greenhouse gas emissions. Innovation policy must be woven into the broader growth strategy for the UK (Valero and Van Reenen, 2023) and based on the evidence of what works (Bloom et al., 2019). There is a key role for R&D support, including via tax incentives. And when it comes to the invention, development and deployment of net zero technologies, these might be 'horizontal', e.g. full expensing of capital investment or R&D tax credits, or more targeted, e.g. the US Inflation Reduction Act tax credits for clean technologies. There is scope for considering where tax incentives for sustainable investments can be enhanced in the UK.

It is important to shore up, extend and integrate the focus of any UK 'industrial' strategy on securing strong domestic supply chains, in order to support the full spectrum of activities to promote a sustainable, inclusive and resilient economy (BEIS, 2017).

Global leadership

The UK cannot materially affect global climate change by itself: today, it is directly responsible for just 1% of global greenhouse gas emissions. Even when indirect effects (arising from net imports of greenhouse-gas-intensive goods) are taken into account, its responsibility amounts to less than 2%. Similarly, the UK alone cannot stop biodiversity loss and environmental degradation, including global air and water pollution. However, there are likely returns to leadership and early action in effecting structural transition to a sustainable, inclusive and resilient economy.

As a medium-sized open economy, the UK is likely to require a joint strategy of helping to drive a global transition where it can, illustrating how profitable it can be, while reacting to developments across the

[34] The Independent Review of Net Zero recommended the more effective use of public procurement to drive low-carbon construction and the creation of sustainable material supply chains in the UK (Skidmore, 2023).

[35] See www.wipo.int/global_innovation_index/en/

world. Its ability to change global attitudes has already been demonstrated by the influence of the UK Climate Change Act and the diplomatic awareness-raising activities undertaken by the Government in this area. Innovative and successful policies like the Contracts for Difference in the electricity generation market are seeing global uptake. The UK will continue to have influence, even if that influence is lessening now that it is no longer speaking as a member of the EU. Credibility on the world stage, including so-called 'soft power' as an influential thought leader, is important in trade negotiations and international agreements.

Anticipating and managing change and disruption

Harnessing the transition to sustainable, inclusive and resilient growth will be largely beneficial to society. However, structural and technological change at this scale and speed will involve dislocations and difficulties, particularly for those on lower incomes and those working in high-carbon, resource-intensive sectors. Strong policy and significant expenditure are required to ensure a 'just transition'. If managed badly, this could delay or derail the transition by harming crucial public support.

Government support will be crucial for enabling households, especially those on low incomes, to make the initial investments in low-carbon technologies, in turn helping all of society to capture the benefits of the transition. Targeted support will be highly relevant for driving the rapid uptake of energy efficiency upgrades, heat pumps and EVs.

There will also be a pivotal role for government in managing the workforce transition as some sectors decline, some transform and others grow under net zero. Workers will need to be re-skilled and retooled to take advantage of the opportunities presented by the sustainable, inclusive and resilient economy. Much of this will involve investment in people and places and in some cases compensation and direct income support.

Support for workers, including retraining when temporarily unemployed, should take precedence over support for existing jobs (RF and CEP, 2023a). The UK requires a skills strategy aligned with its growth strategy, based on strategic sectors and technologies including clean technologies and AI (Costa et al., 2023).

Environmental policies have become an axis of identity politics and a source of political fracture in many countries. The Prime Minister Rishi Sunak was right to note that with current net zero policies "we risk losing the consent of the people". The most effective way to address this, however, is not through rolling back commitments and delaying well-established milestones which businesses were planning against, but through urgent application of policies and targeted assistance to the vulnerable and those likely to be left worse off.

9. Conclusion and recommendations

The growth story of the 21st century

While short-term challenges loom, the evidence suggests that a focus on sustainable growth is the key to long-term economic and fiscal resilience. The UK Government has an opportunity to direct technological, institutional and behavioural innovation at a time of global structural change.

The Government should seize on the transition to a sustainable, inclusive and resilient economy to rekindle productivity growth and induce innovation through a coherent, credible and targeted set of policies. The intersection between environmental targets and fiscal sustainability requires strategic, targeted investments, regulatory innovations and an intelligent approach to debt management, with augmented fiscal rules.

This is an opportunity to unlock new, intelligent, sustainable forms of growth. The growth story of the 21st century is one of efficiency, innovation and high wages. Creating it, and ensuring it is inclusive, will involve fundamental structural transformations. This must be carefully managed, but the opportunities are too great to miss.

We recommend that the Government:

Drive a sustained increase in UK public and private investment and support innovation to boost productivity

- **Increase annual public investment** by the equivalent of at least 1% of GDP, or £26 billion (at current prices), driving investment in key sectors such as energy, transport and housing.
- **Use the policy toolbox to support and steer private investment in the opportunities afforded by the global transition to an efficient, resilient and inclusive economy.**
- **Explicitly support the knowledge sector, digitisation and AI to drive resource and energy efficiency.**
- **Curtail the development of new oil and gas fields** in the North Sea and invest in energy-efficient buildings and grid infrastructure to support renewable energy.

Promote new methodologies to better reflect the nature of structural change

- **Utilise economic approaches that inform on risk and opportunity** rather than attempt to forecast structural change.
- **Recognise that conventional cost–benefit approaches are inappropriate tools for assessing non-marginal structural change.** Adopt risk–opportunity analysis to assess policies designed to drive systemic transformations and adopt the advice in Annex 7 of the Government's Green Book.
- **Commit the Office for Budget Responsibility and the Treasury to undertake a thoroughgoing review of their forecasting methodologies to assess dynamic change**, clearly setting out their approach to the modelling of large-scale risks and opportunities in line with Annex 7 of the Government's Green Book.

Promote fiscal sustainability through temporary and targeted borrowing to invest

- **Adjust fiscal rules** to recognise that borrowing for good public net investment reduces the debt-to-GDP ratio over time and is fiscally responsible, and to account for the net worth of the public and private sector.
- **Ensure scarce public resources are targeted** at sectors close to a technology or behavioural tipping point, and at growing areas where the UK has current or potential comparative strength.

Leverage private sector investment through a clear and predictable policy framework

- **Develop a lasting, consistent and predictable policy framework, based on a national growth, innovation and skills strategy,** to provide investors with greater clarity and confidence that

investment in heavily policy-driven and regulated sectors like energy, housing and transport will be profitable.

- **Commit to an integrated and coordinated set of policies** that addresses numerous market failures and barriers to investment, including resource and carbon pricing, ambitious standards or regulations, planning reform, support for R&D and deployment, and further mechanisms to catalyse private capital towards sustainable and productive investments.
- **Create a dedicated, independent policy institution, focused on finding solutions to the country's productivity problem** and analysing its interaction with sustainability imperatives – this can hold policymakers accountable for inadequate policies for long-term prosperity.

Manage change and disruption

- **Recognise that strategic choices need to be made,** and that there is no de facto 'technology-neutral' option.
- **Provide institutional capacity to increase understanding of the nature of structural change** and incentives to procure change rather than only setting targets.
- **Manage disruption and dislocation, responding to distributional impacts** of all policies as a part of a coherent skills and growth strategy to ensure that the risks and opportunities of the new economy are shared.

References

Acemoglu D, Aghion P, Bursztyn L, Hemous D (2012) The Environment and Directed Technical Change. *American Economic Review*, *102*(1): 131–166. https://doi.org/10.1257/aer.102.1.131

Adrian T (2020) *What to do When Low-for-Long Interest Rates are Lower and for Longer*. IMF Blog. https://www.imf.org/en/Blogs/Articles/2020/12/14/what-to-do-when-low-for-long-interest-rates-are-lower-and-for-longer

Agarwala M, Burke M, Klusak P, Kraemer M, Volz U (2022) *Nature Loss and Sovereign Credit Ratings*. Bennett Institute for Public Policy. https://www.bennettinstitute.cam.ac.uk/publications/biodiversity-loss-sovereign-credit-ratings/

Agarwala M K, Coyle D, Peñasco C, Zenghelis D (2023) *Measuring for the Future, Not the Past*. 4th Annual NBER Conference/Publication on Measurement and Accounting for Environmental Public Goods. https://www.nber.org/books-and-chapters/measuring-and-accounting-environmental-public-goods-national-accounts-perspective/measuring-future-not-past

Agarwala M, Zenghelis D (2020) *Natural Capital Accounting for Sustainable Macroeconomic Strategies*. United Nations Department of Economic and Social Affairs. https://seea.un.org/content/natural-capital-accounting-sustainable-macroeconomic-strategies

Aghion, P and Howitt, P (1992) A Model of Growth through Creative Destruction. *Econometrica* 60(2): 323-351

Aghion P, Dechezleprêtre A, Hémous D, Martin R, Van Reenen J (2016) Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence from the Auto Industry. *Journal of Political Economy*, *124*(1), 1–51. https://doi.org/10.1086/684581

Aghion P, Hemous D, Veugelers R (2009) *Kick-Starting the Green Innovation Machine*. Bruegel. https://www.bruegel.org/blog-post/kick-starting-green-innovation-machine

Aghion P, Hepburn C, Teytelboym A, Zenghelis D (2014) *Path dependence, innovation and the economics of climate change*. Centre for Climate Change Economics and Policy and the Grantham Research Institute on Climate Change and the Environment, Contributing Paper to the New Climate Economy. https://doi.org/https://www.lse.ac.uk/granthaminstitute/publication/path-dependence-innovation-and-the-economics-of-climate-change/

Alvis S, Sissons A (2022) *Climate for growth: productivity, net zero and the cost of living*. Green Alliance and Nesta. https://green-alliance.org.uk/publication/climate-for-growth/

Andres P, Mealy P (2023) *Green Transition Navigator*. www.green-transition-navigator.org

Anis-Alavi A, Judge L, Marshall J, McCurdy C, Tomlinson D (2022) *Hitting a brick wall: How the UK can upgrade its housing stock to reduce energy bills and cut carbon*. Resolution Foundation and Centre for Economic Performance, London School of Economics and Political Science. https://economy2030.resolutionfoundation.org/reports/hitting-a-brick-wall/

Ari A, Arregui N, Black S, Celasun O, Iakova D, et al. (2022) *Surging Energy Prices in Europe in the Aftermath of the War: How to Support the Vulnerable and Speed up the Transition Away from Fossil Fuels*. IMF Working Papers, 2022/152. https://www.imf.org/en/Publications/WP/Issues/2022/07/28/Surging-Energy-Prices-in-Europe-in-the-Aftermath-of-the-War-How-to-Support-the-Vulnerable-521457

Auerbach A, Gorodnichenko Y (2017) Fiscal Stimulus and Fiscal Sustainability. *National Bureau of Economic Research*. https://doi.org/10.3386/w23789

Barbrook-Johnson P, Sharpe S, Pasqualino R, de Moura F S, Nijsee F, et al. (2023) *New economic models of energy innovation and transition*. The Economics of Energy Innovation and System Transition (EEIST) Consortium. https://eeist.co.uk/eeist-reports/new-economic-models-of-energy-innovation-and-transition/

Bassi S, Zenghelis D (2014) *Burden or opportunity? How UK emissions reductions policies affect the competitiveness of businesses*. Centre for Climate Change Economics and Policy and Grantham Research Institute on Climate Change and the Environment.

https://www.lse.ac.uk/granthaminstitute/publication/burden-or-opportunity-how-uk-emissions-reductions-policies-affect-the-competitiveness-of-businesses/

Blanchard O, Summers L H (2023) *Summers and Blanchard debate the future of interest rates*. Peterson Institute for International Economics. https://www.piie.com/events/summers-and-blanchard-debate-future-interest-rates

Bloom N, Van Reenen J, Williams H (2019) A Toolkit of Policies to promote Innovation. *Journal of Economic Perspectives* 33(3): 163–184. https://www.aeaweb.org/articles?id=10.1257/jep.33.3.163

BloombergNEF (2023) *Energy Transition Investment Trends*. https://about.bnef.com/energy-transition-investment/

BloombergNEF (2022) *New Energy Outlook 2022*. https://about.bnef.com/new-energy-outlook/

BloombergNEF (2021) Hitting the EV inflection point. Transport & Environment. https://www.transportenvironment.org/discover/hitting-the-ev-inflection-point/

Bondy M, Roth S, Sager L (2020) Crime Is in the Air: The Contemporaneous Relationship between Air Pollution and Crime. *Journal of the Association of Environmental and Resource Economists*, *7*(3), 555–585. https://doi.org/10.1086/707127

Boushey H (2023) *The Economics of Public Investment Crowding in Private Investment*. The White House. https://www.whitehouse.gov/briefing-room/blog/2023/08/16/the-economics-of-public-investment-crowding-in-private-investment/

Boyd R, Green F, Stern N (2015) *The road to Paris and beyond*. Centre for Climate Change Economics and Policy and Grantham Research Institute on Climate Change and the Environment. https://www.lse.ac.uk/granthaminstitute/publication/the-road-to-paris-and-beyond/

Bradshaw E A (2015) Blockadia Rising: Rowdy Greens, Direct Action and the Keystone XL Pipeline. *Critical Criminology*, *23*(4), 433–448. https://doi.org/10.1007/s10612-015-9289-0

Brandily P, Distefano M, Donnat H, Overman H G, Shah K (2022) *Bridging the gap: What would it take to narrow the UK's productivity disparities?* Resolution Foundation and Centre for Economic Performance, London School of Economics and Political Science. https://economy2030.resolutionfoundation.org/reports/bridging-the-gap/

Brandily P, Distefano M, Shah K, Thwaites G, Valero A (2023) *Beyond Boosterism: Realigning the policy ecosystem to unleash private investment for sustainable growth*. Resolution Foundation and Centre for Economic Performance, London School of Economics and Political Science. https://economy2030.resolutionfoundation.org/reports/beyond-boosterism/

Broome M, Cellini S, Henehan K, McCurdy C, Riom C, Valero A, Ventura G (2022) *Net zero jobs: The impact of the transition to net zero on the UK labour market*. Resolution Foundation and Centre for Economic Performance, London School of Economics and Political Science. https://economy2030.resolutionfoundation.org/reports/net-zero-jobs/

Butler-Sloss S, Bond K, Walter D, Speelman L (2023) *The Renewable Revolution Continues*. Rocky Mountain Institute, December. https://rmi.org/the-renewable-revolution-continues

Cambridge Econometrics (2020) *Economic Impact of the Sixth Carbon Budget*. https://www.theccc.org.uk/publication/economic-impact-of-the-sixth-carbon-budget-cambridge-econometrics/

Chu A, Roeder O, Irwin-Hunt A (2023) Inside the $220bn American cleantech project boom. *Financial Times*, 16 August. https://www.ft.com/content/3b19c51d-462b-43fa-9e0e-3445640aabb5

Clark P (2023) China may be close to a climate tipping point. *Financial Times*, 30 November. https://www.ft.com/content/8085ba27-3e55-4f41-8917-dc3ae50934a3

Clean Air Fund and Imperial College London (2022) *The Pathway to Healthy Air in the UK*. https://www.cleanairfund.org/resource/the-pathway-to-healthy-air-in-the-uk/

Climate Change Committee [CCC] (2020) *The Sixth Carbon Budget: The UK's path to Net Zero*. https://www.theccc.org.uk/publication/sixth-carbon-budget/

Climate Change Committee [CCC] (2022) *Progress in Reducing Emissions: 2022 Report to UK Parliament*. https://www.theccc.org.uk/publication/2022-progress-report-to-parliament/

Climate Change Committee [CCC] (2023a) *CCC assessment of recent announcements and developments on Net Zero*. https://www.theccc.org.uk/2023/10/12/ccc-assessment-of-recent-announcements-and-developments-on-net-zero/

Climate Change Committee [CCC] (2023b) *A Net Zero workforce*. May. https://policycommons.net/artifacts/3857139/a-net-zero-workforce/4663094/

Collier P, Venables A J (2014) *Closing coal: economic and moral incentives*. Centre for Climate Change Economics and Policy Working Paper No. 176/Grantham Research Institute on Climate Change and the Environment Working Paper No. 157. https://www.lse.ac.uk/granthaminstitute/publication/closing-coal-economic-and-moral-incentives/

Committee on the Medical Effects of Air Pollutants [COMEAP] (2010) *Mortality effects of long-term exposure to air pollution in the UK*. Public Health England. https://www.gov.uk/government/publications/comeap-mortality-effects-of-long-term-exposure-to-particulate-air-pollution-in-the-uk

Congressional Budget Office (2023) *The Budget and Economic Outlook: 2023 to 2033*. https://www.cbo.gov/publication/58946

Corlett A, Marshall J (2022) *Shrinking footprints: The impacts of the net zero transition on households and consumption*. Resolution Foundation and Centre for Economic Performance, London School of Economics and Political Science. https://economy2030.resolutionfoundation.org/reports/shrinking-footprints/

Costa R, Liu Z, McNally S, Murphy L, Pissarides C, et al. (2023) *Learning to grow: How to situate a skills strategy in an economic strategy*. Resolution Foundation and Centre for Economic Performance, London School of Economics and Political Science. https://economy2030.resolutionfoundation.org/reports/learning-to-grow/

Curran B, Martin R, Muller S, Nguyen-Tien V, Oliveira-Cunha J, et al. (2022) *Growing Clean: Identifying and investing in sustainable growth opportunities across the UK*. Resolution Foundation and London School of Economics and Political Science. https://economy2030.resolutionfoundation.org/reports/growing-clean/

De Lyon J, Martin R, Oliveira-Cunha J, Shah A, Shah K, et al. (2022) *Enduring strengths: Analysing the UK's current and potential economic strengths, and what they mean for its economic strategy, at the start of the decisive decade*. The Economy 2030 Inquiry. https://economy2030.resolutionfoundation.org/reports/enduring-strengths/

Dechezleprêtre A, Martin R, Bassi S (2016) *Climate change policy, innovation and growth*. Grantham Research Institute on Climate Change and the Environment and Global Green Growth Institute. https://www.lse.ac.uk/granthaminstitute/publication/climate-change-policy-innovation-and-growth/

Dechezleprêtre A, Martin R, Mohnen M (2017) *Knowledge spillovers from clean and dirty technologies*. Centre for Climate Change Economics and Policy Working Paper 151/Grantham Research Institute on Climate Change and the Environment Working Paper 135. https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2013/10/Working-Paper-135-Dechezlepretre-et-al_updateOct2017.pdf

de Mooij R with Black S, Gaspar V, Parry I, Zhunussova K (2023) *How does Decarbonisation Change the Fiscal Equation?* Peterson Institute for International Economics. https://www.piie.com/sites/default/files/2023-06/2023-06-05-03demooj-ppt.pdf

Department for Business, Energy and Industrial Strategy [BEIS] (2017) *Industrial Strategy: building a Britain fit for the future*. https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future

Department for Energy Security and Net Zero [DESNZ] (2023b) Contracts for Difference (CfD) Allocation Round 5: results. https://www.gov.uk/government/publications/contracts-for-difference-cfd-allocation-round-5-results

Department for Energy Security and Net Zero [DESNZ] (2023a) Digest of UK Energy Statistics (DUKES) 2023. https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes#2023

Drollette D (2016) Taking stock: Steven Chu, former secretary of the Energy Department, on fracking, renewables, nuclear weapons, and his work, post-Nobel Prize. *Bulletin of the Atomic Scientists*, *72*(6): 351–358. https://doi.org/10.1080/00963402.2016.1240398

Ebdon J and Khatun F (2021), *Forecasting the balance sheet: Public sector net worth*, Office for Budget Responsibility Working Paper No. 16, October.

Economist, The (2014) Sun, wind and drain, *The Economist*, 29 July. https://www.economist.com/finance-and-economics/2014/07/29/sun-wind-and-drain

Ekins P, Zenghelis D (2021) The costs and benefits of environmental sustainability. *Sustainability Science*, *16*(3): 949–965. https://doi.org/10.1007/s11625-021-00910-5

Energy & Climate Intelligence Unit [ECIU] (2023) *Cost of NOT zero in 2022*. https://eciu.net/analysis/reports/2022/cost-of-not-zero-in-2022

Energy UK (2023) *Energy UK responds to the Autumn Statement*. Press release, 22 November. https://www.energy-uk.org.uk/news/energy-uk-responds-to-the-autumn-statement/

European Commission (2016) *Buying green! A handbook on green public procurement*. Brussels: European Commission. https://op.europa.eu/en/publication-detail/-/publication/8c2da441-f63c-11e5-8529-01aa75ed71a1/language-en

European Environment Agency (2022) *Premature deaths attributable to air pollution*. Press release, 25 November. https://www.eea.europa.eu/media/newsreleases/many-europeans-still-exposed-to-air-pollution-2015/premature-deaths-attributable-to-air-pollution

Evans S (2022) Analysis: Why UK energy bills are soaring to record highs – and how to cut them. *Carbon Brief*, 12 August. https://www.carbonbrief.org/analysis-why-uk-energy-bills-are-soaring-to-record-highs-and-how-to-cut-them/

Farmer J D, Hepburn C, Ives M C, Hale T, Wetzer T, et al. (2019) Sensitive intervention points in the post-carbon transition. *Science*, *364*(6436): 132–134. https://doi.org/10.1126/science.aaw7287

Fetzer T, Gazze L, Bishop M (2022) How large is the energy savings potential in the UK? CAGE working paper no. 644. https://warwick.ac.uk/fac/soc/economics/research/centres/cage/publications/workingpapers/2022/how_large_is_the_energy_savings_potential_in_the_uk/

Forman C, Muritala IK, Pardemann R, Meyer B (2016) Estimating the global waste heat potential. *Renewable and Sustainable Energy Reviews* 57: 1568–1579. https://doi.org/10.1016/j.rser.2015.12.192

Gaspar V, Medas P, Perrelli R (2022) *Riding the Global Debt Rollercoaster*. IMF Blog. https://www.imf.org/en/Blogs/Articles/2022/12/12/riding-the-global-debt-rollercoaster

Geels F W, Pinkse J, Zenghelis D (2021) *Productivity opportunities and risks in a transformative, low-carbon and digital age*. The Productivity Institute Working Paper No. 009. https://www.productivity.ac.uk/research/productivity-opportunities-and-risks-in-a-transformative-low-carbon-and-digital-age/

Global Commission on the Economy and Climate (2014) *Better Growth, Better Climate*. The New Climate Economy. https://newclimateeconomy.report/2014/

Gordon S (2023) *Investing in our future: practical solutions for the UK government to mobilise private investment for economic, environmental and social policy priorities*. Grantham Research Institute on Climate Change and the Environment. https://www.lse.ac.uk/granthaminstitute/publication/investing-in-our-future-practical-solutions-for-the-uk-government-to-mobilise-private-investment-for-economic-environmental-and-social-policy-priorities/

Gordon S, Valero A (2023) *Finance for the future: Practical solutions for the UK Government to mobilise private investment for economic, environmental and social priorities*. Resolution Foundation and London School of Economics and Political Science. https://economy2030.resolutionfoundation.org/reports/finance-for-the-future/

Grantham Research Institute at the London School of Economics, Climate Policy Radar (2023) *Climate Change Laws of the World* database and website: https://climate-laws.org

Green F (2018) Anti-fossil fuel norms. *Climatic Change*, *150*(1–2): 103–116. https://doi.org/10.1007/s10584-017-2134-6

Green Finance Institute, eftec, Rayment Consulting (2021) *The Finance Gap for UK Nature*. https://www.greenfinanceinstitute.com/news-and-insights/finance-gap-for-uk-nature-report/

Grover D, Shreedhar G, Zenghelis D (2016) *The competitiveness impact of a UK carbon price: what do the data say?* Centre for Climate Change Economics and Policy and Grantham Research Institute on Climate Change and the Environment. https://www.lse.ac.uk/granthaminstitute/publication/competitiveness-impact-of-a-uk-carbon-price/

Grubb M, Drummond P, Mercure J-F, Hepburn C, Barbrook-Johnson P, et al. (2021a) *The New Economics of Innovation and Transition: Evaluating Opportunities and Risks*. The Economics of Energy Innovation and System Transition (EEIST) Consortium. https://eeist.co.uk/eeist-reports/the-new-economics-of-innovation-and-transition-evaluating-opportunities-and-risks/

Grubb M, Drummond P, Poncia A, McDowall W, Popp D, et al. (2021b) Induced innovation in energy technologies and systems: a review of evidence and potential implications for CO_2 mitigation. *Environmental Research Letters*, *16*(4): 043007. https://doi.org/10.1088/1748-9326/abde07

Hallegatte S, Heal G, Fay M, Treguer D (2012) *From Growth to Green Growth – a Framework*. National Bureau of Economic Research Working Paper 17841. https://doi.org/10.3386/w17841

Helm D (2010) Government failure, rent-seeking, and capture: the design of climate change policy. *Oxford Review of Economic Policy*, *26*(2): 182–196. https://doi.org/10.1093/oxrep/grq006

Hepburn C (2010) Environmental policy, government, and the market. *Oxford Review of Economic Policy*, *26*(2): 117–136. https://doi.org/10.1093/oxrep/grq016

Hepburn C, Allas T, Cozzi L, Liebreich M, Skea J, et al. (2020a) *Sensitive intervention points to achieve net-zero emissions*. Report of the Policy Advisory Group of the Committee on Climate Change. https://www.theccc.org.uk/publication/sensitive-intervention-points-to-achieve-net-zero-emissions-sixth-carbon-budget-policy-advisory-group/

Hepburn C, O'Callaghan B, Stern N, Stiglitz J, Zenghelis D (2020b) Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change? *Oxford Review of Economic Policy*, *36*(Supplement_1): S359–S381. https://doi.org/10.1093/oxrep/graa015

Hidalgo C A, Klinger B, Barabási A-L, Hausmann R (2007) The Product Space Conditions the Development of Nations. *Science*, *317*(5837): 482–487. https://doi.org/10.1126/science.1144581

Hirth L, Steckel J C (2016) The role of capital costs in decarbonizing the electricity sector. *Environmental Research Letters*, *11*(11): 114010. https://doi.org/10.1088/1748-9326/11/11/114010

HM Treasury (1997) *UK Membership of the Single Currency: an Assessment of the Five Economic Tests*. The National Archives. https://webarchive.nationalarchives.gov.uk/ukgwa/20100407164922mp_/http://www.hm-treasury.gov.uk/d/single.pdf

HM Treasury (2022) *The Green Book: appraisal and evaluation in central government*. https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-government

HM Treasury (2023) *Autumn Statement 2023*. https://www.gov.uk/government/publications/autumn-statement-2023

Holder M (2019) Cheaper than fossil fuels: Global renewables costs hit record low. *BusinessGreen*, 30 May. https://www.businessgreen.com/news/3076511/cheaper-than-fossil-fuels-global-renewables-costs-hit-record-low

Institute for Fiscal Studies [IFS] (2023) *IFS Green Budget* - Chapter 6: Public sector net worth as a fiscal target. https://ifs.org.uk/sites/default/files/2023-10/Public-sector-net-worth-as-a-fiscal-target-1.pdf

International Energy Agency [IEA] (2022) *Renewables 2022*. https://www.iea.org/reports/renewables-2022

International Energy Agency [IEA] (2023a) *Global EV Outlook 2023*. https://www.iea.org/reports/global-ev-outlook-2023

International Energy Agency [IEA] (2023b) *World Energy Investment 2023*. https://www.iea.org/reports/world-energy-investment-2023

International Energy Agency [IEA] (2023c) *World Energy Outlook 2023*. https://www.iea.org/reports/world-energy-outlook-2023

International Monetary Fund [IMF] (2023a) *World Economic Outlook - October 2023*. https://www.imf.org/external/datamapper/datasets/WEO

International Monetary Fund [IMF] (2023b) *World Economic Outlook Database: October 2023 Edition*. https://www.imf.org/en/Publications/WEO/weo-database/2023/October

Jordà Ò, Taylor A M (2016) The Time for Austerity: Estimating the Average Treatment Effect of Fiscal Policy. *The Economic Journal*, *126*(590): 219–255. https://doi.org/10.1111/ecoj.12332

Kharas H, Rivard C (2022) *Debt, creditworthiness, and climate: A new development dilemma*. Brookings Institution. December. https://www.brookings.edu/articles/debt-creditworthiness-and-climate-a-new-development-dilemma/

Kranzl L, Fallahnejad M, Büchele R (2022) *Renewable space heating under the revised Renewable Energy Directive*. European Commission, Directorate-General for Energy. *ENER/C1/2018-494: final report*, Publications Office of the European Union. https://data.europa.eu/doi/10.2833/525486

Krugman P (1991) History Versus Expectations. *The Quarterly Journal of Economics*, *106*(2): 651. https://doi.org/10.2307/2937950

Krugman P R (1979) Increasing returns, monopolistic competition, and international trade. *Journal of International Economics*, *9*(4): 469–479. https://doi.org/10.1016/0022-1996(79)90017-5

Landrigan P J, Fuller R, Acosta N J R, Adeyi O, Arnold R, et al. (2018) The Lancet Commission on pollution and health. *The Lancet*, *391*(10119): 462–512. https://doi.org/10.1016/S0140-6736(17)32345-0

Lenoël C (2020) *What is the size of the fiscal multiplier?* Economics Observatory. https://www.economicsobservatory.com/what-size-fiscal-multiplier

Lex (2023) Siemens Energy: turbine trouble pops the renewables bubble. *Financial Times*, 26 October. https://www.ft.com/content/7dc6baff-ea24-47f5-8a3a-ea5e6ade54f1

Llewellyn P, Llewellyn J, Zenghelis D (2020) *Decarbonisation: Future Growth for Manufacturing*. Manufacturing Technologies Association and Llewellyn Consulting. https://www.mta.org.uk/wp-content/uploads/2023/10/Decarbonisation-Future-Growth-for-Manufacturing.pdf

Lockwood M (2013) The political sustainability of climate policy: The case of the UK Climate Change Act. *Global Environmental Change*, *23*(5): 1339–1348. https://doi.org/10.1016/j.gloenvcha.2013.07.001

Martin R, Verhoeven D (2022) *Knowledge spillovers from clean and emerging technologies in the UK*. CEP Discussion Paper No. 1834. https://cep.lse.ac.uk/_NEW/PUBLICATIONS/abstract.asp?index=9256

Mazzucato M (2013) *The Entrepreneurial State: Debunking Public vs. Private Sector Myths*. Anthem Press.

Mealy P, Hepburn C (2020) Transformational change: parallels for addressing climate and development goals. *Handbook on the Economics of Climate Change*. https://doi.org/10.4337/9780857939067.00025

Mealy P, Teytelboym A (2022) Economic complexity and the green economy. *Research Policy*, *51*(8): 103948. https://doi.org/10.1016/j.respol.2020.103948

Mercure J-F, Sharpe S, Vinuales J E, Ives M, Grubb M, et al. (2021) Risk-opportunity analysis for transformative policy design and appraisal. *Global Environmental Change*, *70*: 102359. https://doi.org/10.1016/j.gloenvcha.2021.102359

Millard R (2023) Ørsted shakes up management team after shelving US projects. *Financial Times*, 14 November. https://www.ft.com/content/95fcce46-afbc-4482-806b-6d107c410a60

Morse A (2023) *New data shows scant progress on the state of rivers, lakes and coasts*. The Wildlife Trusts. https://www.wildlifetrusts.org/blog/ali-morse/new-data-shows-scant-progress-state-rivers-lakes-and-coasts

National Academies (2015) *Building a stronger future: Research, innovation and growth*. https://www.thebritishacademy.ac.uk/publications/building-stronger-future/

National Grid (2023) *Written evidence submitted by the National Grid*. https://committees.parliament.uk/writtenevidence/121816/pdf/

National Infrastructure Commission [NIC] (2023) *Second National Infrastructure Assessment*. https://nic.org.uk/studies-reports/national-infrastructure-assessment/second-nia/

Newman J, Kenny M (2023) *Devolving English Government*. Bennett Institute, University of Cambridge, Institute for Government. https://www.instituteforgovernment.org.uk/publication/devolving-english-government

Nordhaus W D (1992) An Optimal Transition Path for Controlling Greenhouse Gases. *Science*, *258*(5086): 1315–1319. https://doi.org/10.1126/science.258.5086.1315

Odamtten F, Smith J (2023) *Cutting the cuts. How the public sector can play its part in ending the UK's low-investment rut*. The Economy 2023 Enquiry. https://economy2030.resolutionfoundation.org/reports/cutting-the-cuts/

Organisation for Economic Co-operation and Development [OECD] (2015) *Going Green: Best Practices for Sustainable Procurement*. Paris. https://www.oecd.org/gov/ethics/Going_Green_Best_Practices_for_Sustainable_Procurement.pdf

Organisation for Economic Co-operation and Development [OECD] (2023) *Investment by sector (indicator)*. doi: 10.1787/abd72f11-en. https://data.oecd.org/gdp/investment-by-sector.htm#indicator-chart (Accessed 19 December 2023)

Organisation for Economic Co-operation and Development [OECD] (2024) *Saving rate (indicator)*. doi: 10.1787/ff2e64d4-en. https://data.oecd.org/natincome/saving-rate.htm (Accessed 6 January 2024)

Office for Budget Responsibility [OBR] (2023a) *An international comparison of the cost of energy support packages*. https://obr.uk/box/an-international-comparison-of-the-cost-of-energy-support-packages/

Office for Budget Responsibility [OBR] (2023b) *Fiscal risks and sustainability report – July 2023*. https://obr.uk/frs/fiscal-risks-and-sustainability-july-2023/

Office for Budget Responsibility [OBR] (2023c) *Economic and fiscal outlook – November 2023*. https://obr.uk/efo/economic-and-fiscal-outlook-november-2023/

Office for Budget Responsibility [OBR] (2023d) *Oil and gas revenues*. https://obr.uk/forecasts-in-depth/tax-by-tax-spend-by-spend/oil-and-gas-revenues/

Office for Environmental Protection (2024) *Progress in improving the natural environment in England 2022/2023*. https://www.theoep.org.uk/report/government-remains-largely-track-meet-its-environmental-ambitions-finds-oep-annual-progress

Office for National Statistics [ONS] (2023a) *UK Whole Economy: Output per hour worked % change per annum SA (October 2023 release)*. https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/labourproductivity/timeseries/lzvd/prdy

Office for National Statistics [ONS] (2023b) *Public sector net worth: Appendix O. Series: 'PSNW ex' Public sector net worth excluding public sector banks, UK, not seasonally adjusted*. https://www.beta.ons.gov.uk/economy/governmentpublicsectorandtaxes/publicsectorfinance/datasets/publicsectornetworthappendixo

Oliveira-Cunha J, Kozler J, Shah P, Thwaites G, Valero A (2021) *Business time: How ready are UK firms for the decisive decade?* Resolution Foundation and Centre for Economic Performance, London School of Economics and Political Science. https://economy2030.resolutionfoundation.org/reports/business-time/

Owen A and Barrett J (2020) Reducing inequality resulting from UK low-carbon policy. *Climate Policy*, 20(10): 1193–1208. https://doi.org/10.1080/14693062.2020.1773754

Peñasco C, Kolesnikov S, Diaz Anadon L (2021) *Underestimation of the impacts of decarbonisation policies on innovation to create domestic growth opportunities*. The Economics of Energy Innovation and System Transition (EEIST) Consortium. https://eeist.co.uk/wp-content/uploads/Stage3_C1_EmpiricalInsights_PolicyBrief_final.pdf

Perez C (2002) *Technological Revolutions and Financial Capital*. Edward Elgar Publishing. https://doi.org/10.4337/9781781005323

Perez C (2009) The double bubble at the turn of the century: technological roots and structural implications. *Cambridge Journal of Economics*, *33*(4): 779–805. https://doi.org/10.1093/cje/bep028

Perez C (2012) *Financial bubbles, crises and the role of government in unleashing golden ages*. Finance, Innovation & Growth (FINNOV) (Discussion Paper 2.12). https://www.finnov-fp7.com/publications/finnov-discussion-papers/financial-bubbles-crises-and-the-role-of-government-in-unleash.html

Pisani-Ferry J, Mahfouz S (2023) *Les incidences économiques de l'action pour le climat, Rapport à la Première ministre, France Stratégie*. https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/2023-incidences-economiques-rapport-pisani-5juin.pdf

Porter M E (1990) The Competitive Advantage of Nations. *Harvard Business Review,* March–April. https://hbr.org/1990/03/the-competitive-advantage-of-nations

Ramey V A (2020) The macroeconomic consequences of infrastructure investment. NBER Working Paper 27625. https://www.nber.org/system/files/working_papers/w27625/w27625.pdf

Resolution Foundation, Centre for Economic Performance [RF and CEP] (2023a) *Ending stagnation: A New Economic Strategy for Britain*. Final Report of The Economy 2030 Inquiry. https://economy2030.resolutionfoundation.org/reports/ending-stagnation/

Roberts D (2015) The International Energy Agency consistently underestimates wind and solar power. Why? *Vox*, 12 October. https://www.vox.com/2015/10/12/9510879/iea-underestimate-renewables

Romer P M (1990) Endogenous Technological Change. *Journal of Political Economy*, *98*(5, Part 2): S71–S102. https://doi.org/10.1086/261725

Salazar Cota A, Fernández L, Dalaison W (2018) *Green Procurement. How to encourage green procurement practices in IDB funded projects?* Washington, D.C. https://publications.iadb.org/en/green-procurement-how-encourage-green-procurement-practices-idb-funded-projects

Serin E, Andres P, Martin R, Shah A, Valero A (2023) *Seizing sustainable growth opportunities from tidal stream energy in the UK*. Centre for Climate Change Economics and Policy, Grantham Research Institute on Climate Change and the Environment and Centre for Economic Performance, London School of Economics and Political Science. https://www.lse.ac.uk/granthaminstitute/publication/seizing-sustainable-growth-opportunities-from-tidal-stream-energy-in-the-uk/

Serin E, Valero A, Martin R, Shah A, Andres P, Mealy P (2021) *Seizing sustainable growth opportunities from carbon capture, usage and storage in the UK*. Centre for Climate Change Economics and Policy, Grantham Research Institute on Climate Change and the Environment and Centre for Economic Performance, London School of Economics and Political Science. https://www.lse.ac.uk/granthaminstitute/publication/seizing-sustainable-growth-opportunities-from-carbon-capture-usage-and-storage-in-the-uk/

Setzer J, Higham C (2023) *Global trends in climate change litigation: 2023 snapshot*. Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy, London School of Economics and Political Science. https://www.lse.ac.uk/granthaminstitute/publication/global-trends-in-climate-change-litigation-2023-snapshot/

Sharpe S, Mercure J-F, Vinuales J, Ives M, Grubb M, et al. (2021) *Deciding how to decide: Risk-opportunity analysis as a generalisation of cost-benefit analysis*. UCL Institute for Innovation and Public Purpose, Working Paper Series (IIPP WP 2021/03). https://www.ucl.ac.uk/bartlett/public-purpose/wp2021-03

State of Nature Partnership (2023) *State of Nature 2023*. https://stateofnature.org.uk/wp-content/uploads/2023/09/TP25999-State-of-Nature-main-report_2023_FULL-DOC-v12.pdf

Starks M (2023) *Watt's the plan? Renewing utilities regulation for the net zero era*. Resolution Foundation. https://economy2030.resolutionfoundation.org/reports/watts-the-plan/

Stiglitz J E (2015) In Praise of Frank Ramsey's Contribution to the Theory of Taxation, *The Economic Journal* 125(583): 235–268. https://doi.org/10.1111/ecoj.12187

Sharpe S (2023) *Five Times Faster*. Cambridge University Press. https://doi.org/10.1017/9781009326506

Sharpe S, Lenton T M (2021) Upward-scaling tipping cascades to meet climate goals: plausible grounds for hope. *Climate Policy*, *21*(4): 421–433. https://doi.org/10.1080/14693062.2020.1870097

Skidmore C (2023) *Mission Zero: Independent Review of Net Zero - final report*. Department for Energy Security and Net Zero and Department for Business, Energy & Industrial Strategy. https://www.gov.uk/government/publications/review-of-net-zero

Stern N (2018) Public economics as if time matters: Climate change and the dynamics of policy, *Journal of Public Economics*, 162: 4-17. ISSN 0047-2727. https://doi.org/10.1016/j.jpubeco.2018.03.006

Stern N, Tanaka J, Bhattacharya A, Lankes H P, Pierfederici R, et al. (2021) *G7 leadership for sustainable, resilient and inclusive economic recovery and growth: An independent report requested by the UK Prime Minister for the G7*. London School of Economics and Political Science. https://www.lse.ac.uk/granthaminstitute/publication/g7-leadership-for-sustainable-resilient-and-inclusive-economic-recovery-and-growth/

Stern N, Valero A (2021) Innovation, growth and the transition to net-zero emissions. *Research Policy*, *50*(9): 104293. https://doi.org/10.1016/j.respol.2021.104293

Stern N, Zenghelis D (2021) *Fiscal responsibility in advanced economies through investment for economic recovery from the COVID-19 pandemic*. Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy, London School of Economics and Political Science. https://www.lse.ac.uk/granthaminstitute/publication/fiscal-responsibility-in-advanced-economies-through-investment-for-economic-recovery-from-the-covid-19-pandemic/

Systemiq (2021) *The Paris Effect - COP26 edition: How Tipping Points Can Accelerate and Deliver a Prosperous Net Zero Economy*. https://www.systemiq.earth/the-paris-effect-cop26-edition/

Valero A, van Ark B (2023) *A new UK policy institution for growth and productivity – a blueprint*. Productivity Insights Paper No 027. The Productivity Institute. https://www.productivity.ac.uk/research/a-new-uk-policy-institution-for-growth-and-productivity-a-blueprint/

Valero A, Van Reenen J (2023) Embedding green industrial policy in a growth strategy for the UK. *IPPR Progressive Review*, *30*(3): 175–183. https://doi.org/10.1111/newe.12370

Valero A, Li J, Muller S, Riom C, Nguyen-Tien V, Draca M (2021) *Are 'green' jobs good jobs? How lessons from the experience to-date can inform labour market transitions of the future*. Grantham Research Institute on Climate Change and the Environment and Centre for Economic Performance, London School of Economics and Political Science. https://www.lse.ac.uk/granthaminstitute/publication/are-green-jobs-good-jobs-how-lessons-from-the-experience-to-date-can-inform-labour-market-transitions-of-the-future/

Valero A, Van Reenen J (2023) Embedding green industrial policy in a growth strategy for the UK. *IPPR Progressive Review,* 30: 175-183. https://doi.org/10.1111/newe.12370

van der Meijden G, Smulders S (2017) Carbon lock-in: the role of expectations. *International Economic Review*, *58*(4): 1371–1415. https://doi.org/10.1111/iere.12255

Van Reenen J, Yang X (2023) *Cracking the Productivity Code: An international comparison of UK productivity*. Centre for Economic Performance POID Special Report. https://cep.lse.ac.uk/_NEW/publications/abstract.asp?index=10566

Watkiss P (2022) *The Costs of Adaptation, and the Economic Costs and Benefits of Adaptation in the UK*. Independent report to the Climate Change Committee. https://www.theccc.org.uk/publication/the-costs-of-adaptation-and-the-economic-costs-and-benefits-of-adaptation-in-the-uk-paul-watkiss/

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

We Mean Business Coalition (2023) *Corporate Climate Stocktake 2023*. https://www.wemeanbusinesscoalition.org/corporate-climate-stocktake-2023

Winser N (2023) *Accelerating electricity transmission network deployment: Electricity Networks Commissioner's recommendations*. Department for Energy Security and Net Zero. https://www.gov.uk/government/publications/accelerating-electricity-transmission-network-deployment-electricity-network-commissioners-recommendations

Wolf M (2023) Jeremy Hunt's search for an elusive growth strategy. *Financial Times*, 26 November. https://www.ft.com/content/eafa396a-b0c1-493b-8f0e-92ddf318e923

World Bank (2024) *Global Economic Prospects*. https://www.worldbank.org/en/publication/global-economic-prospects

Wu X, Nethery R C, Sabath M B, Braun D, Dominici F (2020) Air pollution and COVID-19 mortality in the United States: Strengths and limitations of an ecological regression analysis. *Science Advances*, 6(45). https://doi.org/10.1126/sciadv.abd4049

Zenghelis D (2019) *Mind over matter – how expectations generate wealth*. Blog, Bennett Institute for Public Policy, University of Cambridge. https://www.bennettinstitute.cam.ac.uk/blog/mind-over-matter-how-expectations-generate-wealth/

Zenghelis D, Llewellyn J, Sepping S (2023) *Prospects for the neutral real rate of interest*. Independent Economics. https://independent-economics.com/wp-content/uploads/2023/04/Macro-series-Analysis-Prospects-for-the-neutral-real-rate-of-interest-April-2023.pdf

Zenghelis D (2023) *Where's the money? Why the interest rate tells us the clean transition is affordable*. Blog, Bennett Institute for Public Policy, University of Cambridge. https://www.bennettinstitute.cam.ac.uk/blog/wheres-the-money/

Zenghelis D, Llewellyn J, Sepping S, Llewellyn P, Prag A (2022) *Foot on the gas? Maintaining momentum for net-zero while responding to the war in Ukraine*. OECD Background paper prepared for the 43rd Round Table on Sustainable Development. https://www.oecd.org/sd-roundtable/papersandpublications/Foot%20on%20the%20Gas_Maintaining%20momentum%20for%20net-zero%20while%20responding%20to%20the%20war%20in%20Ukraine.pdf

Zenghelis D, Taylor C, Stern N (2022) *Policies for investing in sustainable growth: risks and opportunities in the current macroeconomic environment*. Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy, London School of Economics and Political Science. https://www.lse.ac.uk/granthaminstitute/publication/policies-for-investing-in-sustainable-growth-risks-and-opportunities-in-the-current-macroeconomic-environment/