Sustainable growth in the UK

Seizing opportunities from technological change and the transition to a low-carbon economy

Special report for the

LSE Growth Commission

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Foreword

Improving productivity and achieving sustainable, inclusive growth are priorities for the UK government. At the same time, the UK is being reminded of the immense risks from unmanaged climate change. The authoritative new report by the Intergovernmental Panel on Climate Change sets the world a clear target: reduce emissions of greenhouse gases to net zero by the middle of this century to have a reasonable chance of limiting global warming to 1.5 degrees Celsius. It makes it clear that the difference between 1.5 and 2 degrees Celsius in terms of impacts is very powerful, showing that the Paris Agreement was wise to strive to go well below 2. Every government is encouraged to read that report and recognise the clear choice we now have: accelerate the transition to clean and sustainable growth or suffer the mounting damage from sea level rise, floods and droughts, which will severely hinder efforts to tackle poverty, raise living standards and improve prosperity.

We have to achieve these emissions reductions over a period during which the world's economy will experience a radical transformation. Global infrastructure will more than double between 2015 and 2030. The global economy will double within two decades or so if it continues to grow at about 3 per cent each year on average. And the population living in cities, where most emissions occur, will likely double in the next four decades.

The UK has a responsibility to set a strong example for the world: as a global leader on climate change action in the past, and as a country at the forefront of developing innovative plans to improve productivity and sustainable growth for the future.

The UK Government's *Industrial Strategy* and *Clean Growth Strategy* amount to a promising start but future strategy needs greater coherence and ambition if economic growth is to be sustainable over the long term. It is not sensible to promote a narrowly defined 'low-carbon sector' that contributes around 1 per cent to UK GDP while the rest of the economy gets on with a business-as-usual high-carbon path. Technical advances and policy innovations are opening up opportunities for improvements to labour and resource productivity, and sustainable growth, everywhere across the economy. This is a far more attractive way to manage the growth and environmental challenges the UK is facing.

Strong institutions and sound policies can unlock investments in infrastructure, innovation, skills and cities, driving productivity improvements and sustainable growth across the nation. Well-designed policies can foster entrepreneurship for all, deliver coherent incentives, enable greater access to opportunities and empower local communities, which are the foundation of prosperity in the UK.

The 2013 and 2017 LSE Growth Commission reports set out the institutional and policy frameworks required to stimulate investments in innovation, infrastructure and skills and to return the UK to long-run and inclusive growth. This report is a very valuable illustration of how the Growth Commission is still contributing to these central themes and, in so doing, considering how to build sustainable, stronger communities, and a new role for the UK in the world.

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Summary of recommendations for policymakers

The recommendations in this report provide a framework and strategy for sustainable growth in the UK. They are built around four policy priority areas: innovation, infrastructure, skills and cities. The UK has existing advantages and strengths across these areas, in particular in the development of advanced technologies such as robotics, and finance for low-carbon investments. We draw attention to these throughout the analysis.

Innovation

- ***Bring together existing growth and green innovation strategies***, in particular the innovation priorities in the *Industrial Strategy* and *Clean Growth Strategy*, to ensure low-carbon and resource-efficient innovation is embedded throughout the economy.
- ***Develop UK research priorities based on a range of metrics, including positive technology spillovers***, rather than comparative advantage alone. This approach suggests high productivity benefits from R&D support for areas such as efficient aviation and marine technologies.
- ***Create a clear and credible carbon price across the economy***, both to replace the less efficient and long established patchwork approach to reducing emissions that currently exists, and to increase the coherence of incentives to help shift and align expectations towards low-carbon innovation.
- ***Work together with hard-to-decarbonise sectors to create roadmaps for achieving a circular economy by 2050***, which are designed to deliver substantial increases in resource productivity.

Infrastructure

- ***Bring together the* Industrial Strategy *and* Clean Growth Strategy *to create one coherent strategy for sustainable infrastructure investment across the economy***.
- ***Develop and publish a pipeline of clean and sustainable infrastructure investments***. The pipeline would contribute to meeting the UK's 2050 decarbonisation targets, avoid locking into capital assets that could render the UK uncompetitive or require scrapping/retrofitting, and be consistent with the recommendations of the National Infrastructure Commission and other relevant statutory bodies.
- ***Establish a National Infrastructure Bank, with an explicit sustainability mandate***, which can both signal the scale and type of sustainable finance needed from the private sector and use a range of financial instruments to 'crowd in' private finance.
- ***Develop a governance structure for infrastructure that joins up and empowers local authorities***, enabling coordination of infrastructure investments across regions and cities, in particular across housing and related infrastructure investments. ***Prioritise regions where productivity would be most responsive to higher capital intensity***.

Skills

- ***Bring together the* Industrial Strategy *and* Clean Growth Strategy *to create a single forward-looking and coherent plan for strengthening the UK's human capital for the low-carbon transition***. There should be a particular focus on improving outcomes and opportunities for disadvantaged students.

- ***Devise targeted employment transition policies in areas at high risk of disruption*** from the forces of change, such as Northeast England and South Wales, to improve the resilience of local communities.
- ***Ensure education institutions are responsive and flexible as the low-carbon transition accelerates and the demand for skills shifts***, by working closely with other economic, environmental, technological and social institutions. This will require ***better data and metrics for assessing employment changes and shifting demand for skills***.
- ***Help firms overcome barriers to in-house*** training through tax credits and partnerships with education providers.

Cities

- ***Commit to investment in smart cities across all UK regions. This commitment could be supported by a national smart city strategy***, which sits at the heart of government and is overseen by a high-level cross-ministerial committee.
- ***Foster deeper partnerships between universities, business and local policymakers***, to help build on local strengths or address local weaknesses.
- ***Devolve greater policy and fiscal autonomy to cities and regions, while concurrently building their fiscal capabilities***, building on the Cities and Local Government Devolution Act 2016, and other recent moves to empower cities.
- ***Encourage creativity and experimentation*** around policies for productivity and sustainable growth and ***improve evidence, evaluation and data collection*** to gain a better understanding of what works.

The recommendations have strong relevance for a number of areas of government. For example, all are relevant for Her Majesty's Treasury and the Department for Business, Energy & Industrial Strategy (BEIS), as they relate to growth. Recommendations at the local level apply to the Ministry of Housing, Communities & Local Government, and recommendations around education policy apply to the Department for Education. The recommendations also apply to the Department for International Development (DfID), which can export the UK's sustainable growth model through its international private and public sector development activities.

Executive summary

Sustainable and inclusive growth is a priority

Promoting strong, sustainable, balanced and inclusive growth is a priority for G20 governments, including the United Kingdom's, reflecting the need to drive improvements in labour and resource productivity through more and better investments in innovation, infrastructure and skills. This report shows why it is sensible for environmental sustainability to be at the heart of the UK's growth strategy and how this can be achieved.

This report builds on the reports of the LSE Growth Commission (2013, 2017), which laid out a blueprint for boosting growth in the UK and its inclusiveness via institutional and policy reforms to drive investment in these complementary areas. It embraces, deepens and strengthens the previous reports in light of technical advances, a stronger understanding of environmental issues, and the changing politics and economy of a UK that is building a new role in the world. It recognises the challenge of managing global trends, powerful forces that are transforming the UK economy, including the impacts of technological progress, including artificial intelligence and robotics, and globalisation. Such forces are impacting regions and communities in different ways, with the North of England facing particularly challenging adjustments.

The pursuit of sustainable growth and the low-carbon transition provides opportunities for investment that are likely to improve labour and resource productivity across the UK's communities and regions. At its essence, this report is about managing change and shifting resources from low-productivity, slow-growing sectors to high-productivity sectors with strong prospects for future growth. It is not about costs and burdens, but investments with attractive returns. The report does not attempt to predict whether the future will be high- or low-carbon, nor how much the various pathways will cost: it is about setting out a strategy that minimises the risks associated with a low-carbon transition and puts the UK in the best position to capitalise on its existing strengths and seize the opportunities.

The transition to a low-carbon economy and sustainable growth is highly likely. Action is urgently needed to avoid lock-in to high-carbon investments, institutions and behaviours, and future climate impacts: the longer we wait, the costlier the transition will be, due to both higher economic costs and climate change. The rapid pace of technological change today, for example the falling cost of renewable energy, and lessons from the history of past technological transformations, make it clear that achieving a net-zero-carbon economy is entirely consistent with continued strong growth in gross domestic product (GDP).

This does not mean action on climate change will all be win-win. Achieving net-zero and a full decoupling of scarce environmental resources from output will require some tough decisions and trade-offs involving material consumption. The extent and cost of these trade-offs will depend, in part, on how well the Government manages the transition. While important discussion of these trade-offs continues, the UK can and should get on with the up to 90 per cent or so reductions in levels of greenhouse gases that the New Climate Economy work argues can be achieved at net zero cost (or even positive gains) to GDP, relative to achieving a target of limiting global warming to 2°C. The case for early and strong growth-enhancing action is strong.

The UK government recognises the economic opportunities from 'clean growth' and a net zero-carbon economy, as evidenced by its *Industrial Strategy* and *Clean Growth Strategy*. However, it is essential that these are integrated into one coherent strategy that considers *sustainable growth everywhere*. Policies need to go beyond a static focus on a single,

narrowly-defined 'low-carbon' sector that contributes around 1 per cent of UK GDP today, while the other 99 per cent of the economy gets on with the real business of growth. Future growth is about sustainable growth and a net-zero-carbon economy that is resilient to the changes that are likely to characterise the 21st century. It will involve all economic sectors and regions, and has the potential to empower local communities, foster entrepreneurship and improve living standards across society.

Challenges for UK policymakers

Recent developments have increased policy uncertainty and called into question the extent of government's overarching commitment to sustainable growth and a net-zero-carbon economy. Examples include the possible relaxation of fracking rules, the continued freeze on fuel duty, uncertainty around the future of carbon pricing, and the end of hybrid vehicle subsidies, to name just a few.

While government wavering increases policy uncertainty and hinders investment, technological progress and other advances are accelerating, presenting new opportunities for enhanced labour and resource productivity and sustainable growth. Few anticipated the rapid technological transformations and other changes we have seen over the past decade. For example, innovations like the iPhone have enabled new disruptive business models such as Uber's. The latest wave of innovations, including artificial intelligence, automation/robotics and other emerging technologies, where the UK has many strengths, as they integrate with the information and communications technology (ICT) revolution and the low-carbon transition, could lead to further unanticipated productivity surprises. Technological, economic and social tipping points could be reached sooner than anticipated as old networks and technologies are replaced by new.

There is great potential in the UK, for example, for electric vehicles to integrate self-driving technologies and car-sharing ownership models, cutting congestion and vehicle emissions. The UK is looking to lead on electric and autonomous vehicles, and is particularly strong here, but for it to do so cities and transport systems have to be recast and its strengths in finance used to ensure that the necessary investments are made. The work of bodies like the Green Finance Initiative, and the work on green finance that has come before, including from the United Nations Environment Programme (UNEP) Inquiry into the Design of a Sustainable Financial System and the New Climate Economy, can ensure the UK strengthens its leadership in green finance.

If the transition is managed poorly it is likely to generate social disruption, powerful resistance to change and lead to erosion of the UK's technology and finance leadership. Investing in institutional capital to help take advantage of change and insure against its worst effects will be vital to ensuring a successful and 'just' transition.

The challenge for UK policymakers is to design effective, clear and supportive institutional and policy frameworks, with coherent incentives that drive improvements in labour and resource productivity and sustainable growth across the economy, while also limiting the risks of disruption and dislocation from the low-carbon transition. These institutions and policies should encourage investment across a diverse set of complementary assets; for example, investment in educational or research institutions located next to transport hubs (think of science hubs locating next to Cambridge rail station or the Crick Institute locating near St Pancras International). They should also promote economic flexibility and the capacity to diffuse and absorb knowledge and innovation.

A well-managed transition to a low-carbon economy, which includes clear and credible institutional and policy reforms, can take advantage of the opportunities for investments in innovation, infrastructure, skills and cities. These investments have attractive returns which can help to reduce or eliminate economic costs and drive productivity improvements and

sustainable growth across the economy. The report provides evidence that shows, with well-designed, coherent policy frameworks, there is greater potential for a sustainable growth path to deliver higher productivity and GDP than a high-carbon counterfactual scenario, while making the UK's cities and regions better places to live in.

The UK is likely to face risks and powerful forces of change over the coming decades. No future growth path can be guaranteed with certainty. However, it is possible to develop a resilient, diverse and flexible asset base with which to manage that change and improve prospects for achieving a prosperous UK in the 21st century.

There is no existing empirical database to use in an assessment of how best to manage a coordinated, global low-carbon transition. Nevertheless, this report develops a range of specific recommendations, which are based on similar periods of change in the UK's past, during which innovative institutions and policies were developed in response to the challenges of those times. It also draws conclusions based on an understanding of the dynamic interaction of key social, economic and technological drivers of change.

Four policy priority areas

Consistent with the focus of the reports of the LSE Growth Commission (2013, 2017), this report examines institutional and policy priorities in four key mutually-supportive areas. The right investments in these areas can drive labour and resource productivity, resulting in a growth path that is both sustainable and inclusive. They are: innovation, infrastructure, skills, and smart cities – all areas that are home to the UK's key assets, are recognised as crucial drivers of productivity growth, and are also likely to be determinants of the UK's success at managing the low-carbon transition. Moreover, they are areas where many of the UK's strengths apply and can be leveraged, including the development of cutting-edge technologies and financial services, but where the UK can also do better than it has in the past.

Below we summarise our core recommendations in each area.

1. Innovation

Innovation is fundamental for productivity and growth, and for getting the most out of the resources we have. However, innovation is in general underprovided by the private sector because of knowledge spillovers: innovations by one firm 'spill over' and provide valuable information that leads to new inventions in other firms. This market failure justifies government intervention to increase the rate of innovation, via direct investment and policies to incentivise private sector investment. Moreover, government can influence the direction of new innovations, such that they are consistent with sustainable growth.

UK spending (public and private) on research and development (R&D) as a share of GDP is consistently lower than its major peers'. R&D on energy technologies is particularly low by historical standards, at under 0.02 per cent of GDP today, compared with around 0.1 per cent in the early 1990s. Recent evidence suggests that spillovers generated by low-carbon innovation may be significantly higher than for high-carbon technologies, increasing the potential for low-carbon R&D to raise productivity and growth relative to a high-carbon counterfactual scenario. For example, evidence suggests that spillovers from low-carbon innovation in the energy production and transport sectors are over 40 per cent greater than from conventional technologies. Innovation spillovers are therefore a useful metric for assessing where government R&D support should be targeted, and could be more effective and forward-looking than metrics based on comparative advantage alone.

The analysis of innovation in this report, based on patent data, seeks to assess which sectors have a comparative advantage in the UK and which are prone to productivity-boosting domestic technology spillovers. It finds that some sectors, such as marine energy, fulfil both criteria and yet are subject to diminishing support by the UK government. Others, such as

support for clean vehicles, must be carefully considered as they are unlikely to have as many benefits for UK productivity.

Beyond innovation, promoting the diffusion and uptake of low-carbon technologies requires carefully designed policies to tackle the market failures that hold them back, including unpriced greenhouse gases, finance constraints and incomplete information. A priority area for reform is carbon pricing. As the UK redefines its relationship with the EU and the rest of the world, it would be sensible to revisit carbon pricing and adopt a broader and more effective domestic policy. Innovations are also increasing the potential for circular economy business models that radically improve resource productivity. Extensive expansion of circular economy activities in the UK could create around half a million jobs (gross), reduce unemployment by over 100,000, and potentially offset close to 20 per cent of the expected loss in skilled employment over the next decade from globalisation and industrial change in the UK.

Innovation – summary of recommendations for policymakers:

- Bring together existing growth and green innovation strategies, in particular the innovation priorities in the *Industrial Strategy* and *Clean Growth Strategy*, to ensure low-carbon and resource-efficient innovation is embedded throughout the economy.
- Develop UK research priorities based on a range of metrics, including positive technology spillovers, rather than comparative advantage alone. This approach suggests high productivity benefits from R&D support for areas such as efficient aviation and marine technologies.
- Create a clear and credible carbon price across the economy, both to replace the less efficient and long-established patchwork approach to reducing emissions that currently exists, and to increase the coherence of incentives to help shift and align expectations towards low-carbon innovation.
- Work together with hard-to-decarbonise sectors to create roadmaps for achieving a circular economy by 2050, which include measures such as lower taxes on reused materials, and which are designed to deliver substantial increases in resource productivity.

2. Infrastructure

Infrastructure creates networks that spur creativity, innovation and productivity across key economic assets and systems, thereby linking cities and regions. It is an essential input for sustainable and inclusive growth. For example, evidence suggests that a 10 per cent increase in the broadband penetration rate in OECD countries from 1996 to 2007 resulted in a 0.9 to 1.5 per cent increase in annual per capita growth.

Infrastructure is long-lived and locks in emissions and resilience patterns for decades. Infrastructure is also likely to be underprovided by the private sector due to market failures around finance and coordination, in particular due to the long-term, large-scale and high-risk nature of infrastructure projects.

The UK's infrastructure is not fit for the 21st century due to years of underinvestment. Public investment in infrastructure, as a share of GDP, is lower than in the United States, France, Canada and Switzerland and has been since the late 1970s, and the perceived quality of UK infrastructure assets is below that of other G7 nations. This is constraining aggregate growth and regional development.

Government action to strengthen the relevant institutions and policies would crowd in investment in sustainable infrastructure. Investing in the right institutions is key; investing in the wrong institutions or underinvesting in the right ones can leave institutional assets stranded. Scaling and shifting private finance for sustainable infrastructure investments is also needed and is likely to require systemic transformation of the finance sector. The work of bodies like the

Green Finance Initiative is crucial here. Now is the time to invest. With positive social returns on these investments and historically low real interest rates, there is strong evidence that such investments will pay for themselves in the long run.

While sustainable infrastructure may require higher upfront capital – these investments will not be costless and not all will pay off quickly – in most cases the social payback period will be fast and the dynamic benefits to the UK economy significant. By contrast, the risks associated with delaying such investment, including lock-in to high-carbon assets and institutions, are high.

Infrastructure – summary of recommendations for policymakers:

- Bring together the *Industrial Strategy* and *Clean Growth Strategy* to create one coherent strategy for sustainable infrastructure investment across the economy.
- Develop and publish a pipeline of clean and sustainable infrastructure investments. The pipeline would contribute to meeting the UK's 2050 decarbonisation targets, avoid locking into capital assets that could render the UK uncompetitive or require scrapping/retrofitting, and be consistent with the recommendations of the National Infrastructure Commission and other relevant statutory bodies.
- Establish a National Infrastructure Bank, with an explicit sustainability mandate, which can both signal the scale and type of sustainable finance needed from the private sector and use a range of financial instruments to 'crowd in' private finance.
- Develop a governance structure for infrastructure that joins up and empowers local authorities, enabling coordination of infrastructure investments across regions and cities, in particular across housing and related infrastructure investments. Prioritise regions where productivity would be most responsive to higher capital intensity, and where network and agglomeration effects can be exploited to support low-carbon innovation hubs.

3. Skills

Workforce skills, or more broadly, 'human capital', are a key driver of labour productivity and crucial for improving economic opportunities and social mobility. As the low-carbon transition intertwines with emerging technologies such as artificial intelligence (AI), the nature of work and skills needed could change radically and rapidly. If the transition is managed badly, there is potential for disruption and hardship for workers, and constraints on growth. Poor policy decisions will mean locking individuals and communities into outdated skills and human capital, which can be left stranded or devalued as the world moves on.

A key role for government is to create a strong institutional framework and sound policies for flexible labour markets and a 'just transition' for workers. This will be necessary during a process of creative destruction whereby the demand for some existing occupations or skills might disappear and demand for new low-carbon jobs will emerge. Universities, colleges, schools and employers have key roles to play in equipping workers to deal with and embrace inevitable change throughout their lives. Equipping people with the right skills and resilience to changing labour markets can limit the harm to people's lives and livelihoods from potential and actual job displacement. Investors and financial markets, as stewards of assets and allocators of capital, can also make a valuable contribution to achieving a 'just transition'. This can help to maximise productivity gains from the low-carbon transition.

Skills – summary of recommendations for policymakers:

- Bring together the *Industrial Strategy* and *Clean Growth Strategy* to create a single forward-looking and coherent plan for strengthening the UK's human capital for the low-carbon transition. This would coordinate investments across all levels of government and institutions, including across all education levels, with the aim of maximising adaptability

to technological change, fostering entrepreneurship, and increasing the ability of workers to re-skill or up-skill through lifelong learning. There should be a particular focus on improving outcomes and opportunities for disadvantaged students.

- Devise targeted employment transition policies in areas at high risk of disruption from the forces of change, such as Northeast England and South Wales, to improve the resilience of local communities.
- Ensure education institutions are responsive and flexible as the low-carbon transition accelerates and the demand for skills shifts, by working closely with other economic, environmental, technological and social institutions. This will require better data and metrics for assessing employment changes and shifting demand for skills.
- Help firms overcome barriers to in-house training through tax credits and partnerships with education providers.

4. Cities

Cities are central to the UK's economic and social success. Around 55 per cent of UK residents, around 35 million people, live in cities and the four largest UK cities (London, Birmingham, Manchester and Glasgow) are home to almost a quarter of the total UK population. London alone accounts for around 23 per cent of total UK gross value added (GVA). Cities are areas where physical and human capital combine to spur creativity and innovation, which is particularly important in the UK's service-driven 'knowledge economy'. As hubs of productivity and economic growth the Government has rightly positioned them at the centre of UK growth strategy.

The UK's cities face considerable sustainability challenges, including congestion, air pollution, urban sprawl and climate change impacts such as flooding. The nature of these challenges implies a crucial role for local and national government in tackling them. Well-planned and governed cities that are compact, efficient, interconnected and make appropriate use of technology – so-called 'smart cities' – can maximise agglomeration economies, benefitting the flow of people, ideas, creativity and low-carbon innovation.

Developing smart cities across the UK is crucial for improving the performance of the regions. Progress on development in the North, for example, can be accelerated through further devolution of political and fiscal powers. This would enable local residents to have a greater say in investment plans for the smart cities where they will live. There is no trade-off between sustainability and growth at the urban level: polluted, congested, unattractive cities create alienation and fail to attract skilled labour and capital.

Cities – summary of recommendations for policymakers:

- Commit to investment in smart cities across all UK regions. This commitment could be supported by a national smart city strategy, which sits at the heart of government and is overseen by a high-level cross-ministerial committee. This should be coordinated and aligned with local industrial strategies, local city development and decarbonisation plans, and aligned with national emissions reduction commitments.
- Foster deeper partnerships between universities, business and local policymakers, to help build on local strengths or address local weaknesses.
- Devolve greater policy and fiscal autonomy to cities and regions, while concurrently building their fiscal capabilities, building on the Cities and Local Government Devolution Act 2016, and other recent moves to empower cities. This will enable local communities to have a greater say in future investment plans for the smart cities where they will live.

- Encourage creativity and experimentation around policies for productivity and sustainable growth and improve evidence, evaluation and data collection to gain a better understanding of what works.

There are no guarantees that investing in a coordinated set of policies to manage a low-carbon future will boost the UK's productivity performance. And economic models are of limited help as they were never designed to estimate the costs and benefits of long-run policies for large non-marginal transformations. However, the evidence suggests that a more sustainable and inclusive growth path will bring great opportunities, and that the alternative of investing in high-carbon, resource-intensive infrastructure, behaviours and institutions will be an economically and socially risky proposition, potentially to the detriment of the economy and UK citizens. The risks of inaction go well beyond climate change, and could see the UK left behind in a rapidly changing world.

This report finds that although there are uncertainties with every option, a rigorous risk management and hedging strategy should acknowledge the likelihood that the future will be resource-efficient and low-carbon, and therefore the UK should capitalise on its strengths in the development of cutting-edge technologies and financial services, and grasp the opportunities from sustainable growth.

1. Introduction

1.1. The sustainable growth challenge

Promoting strong, sustainable, balanced and inclusive growth is a priority for G20 governments, as reaffirmed at their meeting in Hamburg in 2017.[4] This priority reflects the need to drive labour and resource productivity and economic growth through increased and better investments in innovation, infrastructure and human capital. The UK can lead these efforts as it redefines its role in a changing world.

The LSE Growth Commission (2013, 2017) set out key elements of this growth story. The Commission's 2013 report[5] outlined an institutional and policy framework for investment that would sustain UK economic growth in the dynamic world economy of the 21st century. This framework would see the UK repurpose its institutional and policy architecture to address longstanding structural weaknesses that have led to under-investment in the key drivers of productivity growth: innovation, infrastructure and skills. The 2017 report[6] highlighted the importance of achieving growth that is inclusive, and focused also on maintaining openness, developing an industrial strategy for the long term, and the role of the financial sector in driving prosperity in the UK.

This report builds on those earlier publications, placing additional focus on sustainability (see Box 1.1 for definitions). The report embraces, deepens and strengthens the narrative of its predecessors in light of technical advances, a stronger understanding of environmental issues, and the politics and economy of a UK that is building a new role in the world.[7] The report recognises that the UK is redefining its relationship with Europe and is tapping growing global markets. It also recognises the challenge of managing global trends – powerful forces that are transforming the UK economy, including the shift from manufacturing to services, the impact of technological progress on labour, and globalisation.

These forces are affecting the UK's regions and communities in different ways, with the North of England facing a particularly challenging adjustment. The shift to a sustainable growth path and the low-carbon transition present opportunities to embrace change and raise living standards across regions and communities. This change, if managed well, represents an opportunity for investment that is likely to drive productivity and growth across all UK regions and communities by enhancing competitiveness in global markets; it is not another burden that the regions must endure.

The transition is already driving change across the world and its pace is accelerating. The UK has seen large-scale investments in low-carbon power and transport, notwithstanding a lack of policy clarity and consistency. With sound policy, low-carbon investment could be many times stronger and less volatile, delivering important opportunities for sustainable and more inclusive productivity growth that is likely to benefit the UK's citizens, businesses, cities and regions in the short, medium and long term.

[4] G20 Germany, 2017, G20 Leaders' Declaration: Shaping an interconnected world, Hamburg, July. http://www.g20.utoronto.ca/2017/2017-G20-leaders-declaration.pdf

[5] LSE Growth Commission (2013) Investing in Prosperity: Skills, Infrastructure and Innovation. London School of Economics and Political Science. http://www.lse.ac.uk/researchAndExpertise/units/growthCommission/documents/pdf/LSEGC-Report.pdf

[6] LSE Growth Commission (2017) UK Growth: A New Chapter. London School of Economics and Political Science. http://www.lse.ac.uk/researchAndExpertise/units/growthCommission/documents/pdf/2017LSEGCReport.pdf

[7] LSE Growth Commission (2017) outlines the risks and likely negative impacts from Brexit, but also suggests it may open up some new options for UK policy. For example, the UK will be able to formulate its own state aid rules, rather than having to obtain approval from the European Commission, which could assist in establishing a national infrastructure bank or designing more innovative industrial strategies. See also http://blogs.lse.ac.uk/brexit/2018/07/16/the-brexit-dividend-expect-a-lost-decade-of-economic-underperformance-and-political-crisis/

1.2. Sustainable growth everywhere

The Government has shown through its *Industrial Strategy White Paper*[8] and *Clean Growth Strategy*[9] that it recognises the essential contribution the low-carbon transition can make to the economy. As a leader in the creation of the Paris Agreement on climate change, which has invited countries to submit their 'mid-century' strategies by 2020, the UK needs to identify a credible institutional and policy framework that can drive the right investments for achieving a sustainable growth path.

The framework must consider sustainable growth *everywhere across the economy*, recognising the global trend in this direction. This will require a fundamental shift in how government considers low-carbon activities and sustainable or clean growth. 'Traditional' low-carbon activities are already contributing to the UK economy – around 1 per cent of UK GDP in 2016, and are growing strongly – at 5 per cent from 2015 to 2016.[10] However, a static and narrow focus on low-carbon activities does not get to the heart of the growth challenge facing the UK economy, nor does it reflect the profound processes of change and transformation that are accelerating across the world. In other words, it is not sensible to focus on an individual, stand-alone and narrowly defined low-carbon sector, while the rest of the economy gets on with the 'real business of growth'.

Low-carbon activity data also has serious shortcomings and can be misleading, in part due to a lack of appropriately-defined classifications and measurement tools. For example, traditional definitions only include those low-carbon activities that directly reduce emissions, whereas a common-sense meaning of the term would also include activities such as teaching, social work, research, design and other economic activities with a small carbon footprint. Low-carbon activity also includes improving resource productivity in high-carbon sectors such as steel and cement. These firms will need to innovate and improve production processes in order to enhance competitiveness as they fight to supply products in an increasingly carbon- and resource-constrained world.

The UK will do better if it adopts a broad definition of low-carbon activity and places sustainability at the heart of its growth strategies and policies across all economic sectors, regions and communities, including carbon-intensive sectors.[11,12] This is about a coherence of incentives across the whole economy, fostering entrepreneurship and opportunities for all and empowering local communities. This report adopts this broader perspective, consistent with sustainable growth everywhere – see Box 1.1.

[8] HM Government (2017) Industrial Strategy: Building a Britain fit for the future. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664563/industrial-strategy-white-paper-web-ready-version.pdf

[9] HM Government (2017) The Clean Growth Strategy: Leading the way to a low carbon future. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf

[10] Office for National Statistics (2018) Low Carbon and Renewable Energy Economy Survey, 2018. https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/finalestimates/2016#main-points

[11] Fankhauser S, Bowen A, Calel R, Dechezleprêtre A, Grover D, Rydge J, Sato M (2013) Who will win the green race? In search of environmental competitiveness and innovation. Global Environmental Change 23 (2013) 902–913; New Climate Economy (2014) Better Growth, Better Climate. https://newclimateeconomy.net/publications

[12] This is consistent with the recommendation for a green industrial strategy from the recent Commission on Economic Justice report. The Commission argues that industrial strategy should be organised in part around 'missions', in which government directs innovation and supply chain policy to meet some of the great societal challenges of the 21st century; and that sustainable growth should be one of these. It proposes the adoption of a 'green industrial strategy', with the aim of reducing the UK's environmental footprint to levels consistent with global sustainability by 2040. See Institute for Public Policy Research (IPPR) (2018) Prosperity and Justice. A Plan for the New Economy. The Final Report of the IPPR Commission on Economic Justice. Polity Press, Cambridge. https://www.ippr.org/files/2018-08/1535639099_prosperity-and-justice-ippr-2018.pdf

Box 1.1. Defining sustainable and inclusive growth and the central contribution of the low-carbon transition

In this report we examine policy priorities that can drive sustainable and inclusive growth. By 'sustainable' we mean growth that is environmentally sustainable, driven by a low-carbon transition that increases underlying strength and productivity across the UK's physical, human, knowledge and natural capital assets – and therefore can be sustained in the long run. Addressing the UK's persistently poor productivity performance is a major challenge for our time, along with new economic risks as the UK redefines its position in the global economy, experiences rapid technological change and faces a global transition to a low-carbon and low-waste future.

The general rise of populism and anti-globalisation sentiment in the Western world has highlighted the importance of ensuring that the benefits of economic growth are distributed widely across society. A low-carbon transition is desirable as it can boost productivity and growth and avoid predicted climate change impacts that will hit the poorest and most vulnerable hardest. However, lessons from history suggest that the low-carbon transition – as it combines with emerging technologies such as artificial intelligence (AI), Big Data, automation, robotics, 3D-printing and nanotechnology (in sum often referred to as the 'Fourth Industrial Revolution' – see below) – will not automatically deliver inclusive growth unless the appropriate, forward-looking institutional frameworks and policy mechanisms are in place.

With strong institutions and sound policies across the key areas of innovation, infrastructure, skills and cities, there is potential for the low-carbon transition to deliver not only sustainable and more inclusive growth, but also higher rates of growth compared with a high-carbon counterfactual scenario.

This report discusses sustainable and inclusive growth, and the low-carbon transition, in this context. 'Sustainable and inclusive growth', 'sustainability', 'clean growth', and 'low-carbon growth' are used interchangeably.

1.3. Policymaking in the context of anticipated but unpredictable change

The scale of the low-carbon transformation and associated structural change over the coming decades is likely to be immense. Fortunately, we have the advantage of learning about change from several economic transformations since the initial Industrial Revolution of the 18th and 19th centuries. A crucial lesson from history, and a premise underlying the analysis in this report, is that economies are constantly changing, often in ways that are hard to predict and that can be surprising. In the 1800s, few could have predicted the great advances in lighting that transformed economies in the late part of that century; today LED lighting is around 800 times more efficient than 19th century tallow candles. And in the 1970s, the huge transformative impacts of the information and communications technology (ICT) revolution on economies and societies were as yet unforeseen, including the effects on the ways in which we live and work.[13]

Indeed, few anticipated the technological transformations and other changes we have seen over the past decade. For example, the price of solar PV modules has fallen by at least 80 per cent since 2006 and UK offshore wind installation costs have declined by more than 50 per cent in the past three years. These declines have been far more rapid than predicted, transforming the cost of energy infrastructure and the economics of the energy industry.[14] In parallel, battery prices have fallen by 80 per cent since 2010.[15] In part due to these cost reductions, vehicle manufacturer Volvo has announced it will end the production of combustion-engine-only vehicles from 2019.

[13] The ICT revolution is visible everywhere, except in the productivity statistics. For a discussion on this 'productivity puzzle' and the complex interaction of factors that explain it see: https://www.project-syndicate.org/bigpicture/in-search-of-productivity

[14] In the year 2000 the International Energy Agency estimated the total global installed capacity of solar PV and wind to 2014. It underestimated actual solar PV and wind capacity in 2014 by a factor of 18 and 15, respectively, and has continued to underestimate in more recent reports. IEA, World Energy Outlook (2000, 2002, 2005, 2007). https://www.iea.org/weo/

[15] Bloomberg New Energy Finance (2018) Batteries boom enables world to get half of electricity from wind and solar by 2050. June. https://about.bnef.com/blog/batteries-boom-enables-world-get-half-electricity-wind-solar-2050/

Elsewhere, judicial action on air pollution has progressed faster than expected, with the UK high court ruling the Government's current air pollution policies are unlawful, triggering an unprecedented level of judicial control and oversight of these policies.[16] The Dutch court of appeals in The Hague recently upheld a legal order from 2015 that the Dutch government must increase its emissions reduction target to a 25 per cent cut on 1990 levels. Moreover, new designs have emerged for more compact and connected cities and urban areas that can foster long-term urban productivity and deliver environmental and social benefits, including being better places to live.

Technological change is likely to surprise us again as the next emerging wave of innovation, often referred to as the Fourth Industrial Revolution,[17] blends with the tail-end of the ICT revolution and the emerging low-carbon transition.[18] These innovations include technologies such as artificial intelligence (AI), Big Data, automation, robotics, 3D-printing and nanotechnology – so-called 'disruptive' technologies that could have profound implications for managing environmental footprints.[19]

AI and machine learning have huge potential to accelerate human learning, low-carbon innovation and the transformation of labour markets and business models. It is perhaps unsurprising, therefore, that investment in these technologies is growing rapidly. Recent and ongoing advances in materials science and digitisation are transforming the prospects for resource productivity in hard-to-decarbonise sectors like steel, cement and plastics. The challenge of sustainable growth has already been transformed to one of economic opportunity, with great potential for better productivity, innovation, investment and growth, and it will keep being transformed in exciting ways by new ideas and technical advances.

History also informs us that technological and policy tipping points can arrive more quickly than anyone currently anticipates.[20] These points of inflection could be triggered by a constellation of external events, including ambitious climate and trade policies in leading economies, associated rapid clean technology breakthroughs, changes in social norms and behavioural shifts of consumers and investors. Each of these events makes the others more likely, aligning expectations and reinforcing the dynamics of transition, potentially leading to rapid and permanent structural market shifts.[21] However, in the short run, such transitions face inertia and political economy barriers that can slow down the pace of change. They can create powerful (typically incumbent) losers, often with political influence, while winners are often more diffuse.

The task for policymakers, having to make plans today under uncertainty, is to create effective and supportive institutional frameworks and governance structures that can help shape expectations, strengthen policy alignment and manage and resolve political economy challenges as they arise. These frameworks and structures are crucial if governments are to design, implement and maintain clear, credible and well-aligned policies that direct and

[16] It has also been referred to the European Court of Justice for failing to tackle illegal levels of air pollution.

[17] The Fourth Industrial Revolution involves emerging technology breakthroughs in fields such as artificial intelligence, robotics, the Internet of Things, autonomous vehicles, 3D-printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing. It is characterised by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres, with huge potential for transformation of entire systems of production, management and governance. The First Industrial Revolution used water and steam power to mechanise production. The Second used electric power to create mass production. The Third used electronics and information technology to automate production. See: World Economic Forum, https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/

[18] Henceforth, when discussing the low-carbon transition, we assume this incorporates these other transitions that are happening concurrently and are inextricably intertwined.

[19] World Economic Forum (2017) Harnessing the Fourth Industrial Revolution for the Earth. Fourth Industrial Revolution for the Earth Series. In collaboration with PwC and Stanford Woods Institute for the Environment. November. http://www3.weforum.org/docs/WEF_Harnessing_the_4IR_for_the_Earth.pdf. PwC (2018) Building block(chain)s for a better planet. Fourth Industrial Revolution for the Earth Series, September. https://www.pwc.com/gx/en/sustainability/assets/blockchain-for-a-better-planet.pdf

[20] However, this is not guaranteed. Atomic power, supersonic travel, exploiting outer space, for example, have not been able to exploit their full potential due to a range of technological, regulatory, safety, funding and other barriers.

[21] Peszko G, van der Mensbrugghe D, Golub A, et al. (2018) Crossroads: Climate strategies of fossil fuel-dependent countries, managing risks and harnessing opportunities of global low-carbon transition through diversification and cooperation. The World Bank, May 21.

manage change, including ones that maximise the opportunities and sustainable growth benefits from the low-carbon transition.[22]

While innovation will always surprise and open up opportunities that are impossible to anticipate, this will not always mean positive impacts on productivity growth. To maximise the potential for productivity gains we need a flexible economy that can respond to and grasp the best innovations and tackle barriers to their diffusion. Policies should avoid directing investment towards technologies, infrastructure and institutions that lock in unsustainable patterns of behaviour, while being flexible enough to adjust as technologies, preferences and politics change.[23]

This policy challenge can be considered in terms of investment in a diverse range of complementary capital assets, in the face of an uncertain, but endogenously determined future. In the long term, a low-carbon transition in the UK is highly likely – the country either manages it or it will be imposed by a hostile climate and/or global change. In the short term, the speed of that transition is hard to predict, as is the scale of inertia and resistance to change. Policymakers need to design the best economic strategy for transition that allows them to steer, lead and benefit from opportunities of change.[24] A strategy that stresses investment in assets across different forms of 'capital', including natural,[25] built, human, and intellectual, will maximise expected productivity, economic flexibility and the capacity to diffuse and absorb knowledge and innovation.[26]

1.4. The importance of getting it right

Failure to get the institutional and policy structures right, including the new *Industrial Strategy*,[27] risks continued under-investment across national assets that are the UK's foundations for sustainable and more inclusive growth. This would leave the UK with ongoing structural weaknesses, muddled expectations on the direction of change, including policy uncertainty, and less flexibility to adapt to external shocks. The UK would be less well prepared for the transition ahead, diffusion of new productivity-enhancing technologies would be slow, and growth and living standards would suffer.

In particular, failure to deliver appropriate sustainable investments in the UK's assets would expose the UK to the risks from a high-carbon path. For example, the development of the country's shale gas industry is perceived as high-risk, with uncertainty around the extent of the domestic resource, the amount of gas that is technically recoverable, the extent of environmental impacts from fracking, and social resistance.[28] Moreover, alternatives for gas, such as energy storage and smart-grids, are benefitting from technical progress and falling in price, increasing the risk that gas assets will become stranded. A high-carbon path might

[22] The potential benefits from the low-carbon transition are comprehensively examined in the New Climate Economy reports from 2014, 2015 and 2016 and associated working papers. www.newclimateeconomy.net

[23] Governments have faced similar transition challenges in the past. See New Climate Economy, 2014, Chapter 5, section 5.3, for a description of post-war policy frameworks that set up the conditions for the flourishing of the previous mass production, suburban revolution.

[24] This is analogous to what the Task Force on Climate-related Financial Disclosures (TFCD) requires of private companies, though the strategic challenges for government are much greater. The TFCD requests not just carbon disclosure by business, but a public forward-look at the resilience of the business model to a low-carbon transition to safeguard investor value. The authors thank Dimitri Zenghelis for this insight.

[25] Natural capital includes the water, air, soil, geology, and living things that provide us with the basic, and at times quite complex, building blocks of all other forms of capital. Many of our most valuable 'inventions' are discovered in natural capital. Consider antibiotics: penicillin, which is fungus-derived, and streptomycin, chloramphenicol, and tetracycline, which are produced by soil bacteria, enabled the modern 'antibiotic age' and enormous gains in healthcare. See 'The natural history of antibiotics' in Current Biology: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2731226/

[26] Peszko et al. (2018) op. cit.

[27] The challenges of implementing an effective industrial strategy are considerable. The UK should learn from past experience to reduce the risk of policy failure. The LSE Growth Commission (2017) and Mazzucato (2017) discuss principles of industrial strategy, lessons from past successes and failures, and the current UK *Industrial Strategy*. LSE Growth Commission (2017) UK Growth A New Chapter, A Blueprint for Growth in 2017 and Beyond. London School of Economics and Political Science. http://www.lse.ac.uk/researchAndExpertise/units/growthCommission/documents/pdf/2017LSEGCReport.pdf. Mazzucato, M., 2017. Response to the Green Paper "Building our Industrial Strategy" https://marianamazzucato.com/wp-content/uploads/2017/05/BEIS-INDUSTRIAL-STRATEGY-GREEN-PAPER-CONSULTATION-RESPONSE-15-April-2017.pdf

[28] Grantham Research Institute on Climate Change and the Environment (2018) Shale gas and fracking in the UK. http://www.lse.ac.uk/GranthamInstitute/faqs/what-potential-reserves-of-shale-gas-are-there-in-the-uk/

expose the UK to higher dependence on imported oil and gas over the long term – UK net oil and gas imports were around £11.5bn in 2016[29] – with associated price volatility and energy security concerns.[30] Shale gas could mitigate this dependence, but is in itself a high-risk strategy.

UK cities, where more than half of all UK residents live and work today, would be likely to become less productive and innovative in this scenario as they would face rising costs from climate change impacts, air pollution, congestion and urban sprawl. In this context cities would struggle to attract high-skilled, high-value workers. Cities would also risk locking into an infrastructure based on increasingly inefficient and uncompetitive fossil fuels.

UK industry would probably likely remain carbon-intensive for longer, foregoing the productivity benefits from radical technological advances in resource and energy efficiency. Firms would also face the prospect of shrinking markets for high-carbon goods and services, border tariffs, and growing shareholder activism, including financial divestment and potential litigation. The UK would risk being left behind in some of the fastest growing world markets, with its own resources tied up in declining industries, stranded assets and outdated skills and technologies.

Poor management of the low-carbon transition, for example a badly defined and incomplete growth strategy and weak policy, would lock in infrastructure that is not fit for purpose, such as unreliable and poorly planned renewable energy generation with inadequate networks. It would also see underinvestment in adaptation, which would be costly as infrastructure would be less resilient to climate change impacts.

In contrast, if managed well, and especially if other countries also act strongly, there is great potential for sustainable growth and the low-carbon transition to deliver higher labour and resource productivity and GDP than in the high-carbon counterfactual scenario. Evidence indicates that 'spillovers' from green investment and innovation could be large – significantly larger than those from high-carbon spending – offsetting the extra call on resources for low-carbon investment (see Chapter 2). The reduction in cash expenditure on high-carbon fuels, and other savings, for example capital savings from more compact and connected urban development, would with time provide extra resources to invest in the rest of the economy.[31] If the policies are clear and credible, the complex and dynamic interaction between these factors should lock the UK into a more productive low-carbon path.

The UK *can* get the institutional and policy structures right. It has a history of embracing change in challenging social and economic times comparable to those we face today. As stated by the Commission on Economic Justice,[32] fundamental reform has happened twice before, in the last century, following periods of crisis – the Attlee government's Keynesian reforms in the 1940s and the Thatcher government's free market reforms in the 1980s. Ten years after the financial crash some argue that change of this magnitude is now needed again.

In the past the UK has sought out innovative institutional solutions for designing policy more effectively to and support growth.[33] Examples include monetary policy independence for the Bank of England and the establishment of the Office for Budget Responsibility. Both of these

[29] National Statistics (2018) Digest of UK Energy Statistics (DUKES): energy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/642716/Chapter_1.pdf
[30] The Oxford Institute of Energy Studies (2018) UK Dependence on Imported Hydrocarbons: How Important is Russia? https://www.oxfordenergy.org/wpcms/wp-content/uploads/2018/03/UK-Dependence-on-Imported-Hydrocarbons-Insight-32.pdf
[31] New Climate Economy (2014) op. cit.
[32] Institute for Public Policy Research (IPPR) (2018) op. cit.
[33] LSE Growth Commission (2013) op. cit.

devolve responsibility for complex decisions to technocrats who act transparently and are removed from the political arm of government (while still subject to a public mandate).[34]

It is also helpful that the UK has economic strengths crucial for facilitating the low-carbon transition and realising its benefits, including a world-leading financial system, competitive product markets, flexible labour markets, an open economy, a world-class university system, a strong and functional legal system, and internationally competitive and dynamic firms in manufacturing and services.[35] These strengths will help to increase the flexibility with which resources are deployed and redeployed, support the conditions for sustainable growth, and facilitate a more cost-effective and productive low-carbon transition. Recent wavering by policymakers on the openness of the UK economy, and poor investment and productivity growth, even at the UK's best performing firms, are of concern, and are partly attributable to institutional and policy weakness. This highlights the importance of getting policy right.[36]

1.5. Four policy priority areas

Building on the frameworks outlined by the LSE Growth Commission (2013, 2017), this report examines *policy priorities* in four key mutually-supportive areas:

- Innovation
- Infrastructure
- Skills
- Cities

These four areas are home to the UK's most important assets, and are the interlocking building blocks that underpin sustainable growth. They are also characterised by underinvestment over recent decades. Strong institutions and sound policies, in particular in sustainable finance, can ensure that this asset base is strengthened and made more resilient, diverse and low-carbon, increasing the UK's ability to minimise risks and maximise opportunities for sustainable growth in times of change.

Improved performance in these four priority areas can accelerate innovation in low-carbon technologies and their diffusion, deliver sustainable infrastructure that is fit for the 21st century, ensure workers are equipped with the right skills for a fast-changing and technologically-advanced world, and create smart, clean cities that maximise the returns from human capital. Action across these areas can contribute to improving labour and resource productivity, and shifting the UK onto a sustainable, inclusive growth path and a successful transition to a low-carbon economy and society.

[34] Zenghelis D (2016a) Building 21st century sustainable infrastructure (Part 2): institutional reform. Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2016/08/Zenghelis-policy-brief-August-2016b.pdf

[35] LSE Growth Commission (2013) op. cit.

[36] See LSE Growth Commission (2017) op. cit. See also: Giles C (2018) UK's biggest companies are productivity slackers. Financial Times, 24 May. https://www.ft.com/content/cd402548-5e7d-11e8-9334-2218e7146b04

2. Innovation

Summary

- Innovation is a crucial driver of productivity and sustainable growth but it is underprovided by the private sector, in part due to market failures. The Government has a crucial role in tackling the market failure in research and development (R&D) to increase the rate of innovation and ensure its direction drives sustainable growth.
- UK governments have had a mixed record in R&D support. Current R&D spending is below that of the UK's main peers. Recent moves to boost R&D spending are encouraging but it is essential that support is well targeted.
- Analysis of innovation spillovers offers an additional useful metric for assessing government R&D support. This could be more effective and forward-looking than basing support on comparative advantage alone. Spillovers from low-carbon innovation may be significantly higher than for high-carbon technologies, increasing productivity across the economy and boosting sustainable growth, relative to a high-carbon counterfactual.
- Beyond innovation, the diffusion of existing low-carbon technologies requires carefully designed policies to address market failures that hinder their adoption. A priority for reform is carbon pricing. As the UK redefines its place in the world it would be sensible to revisit carbon pricing to ensure a broader and more effective policy that creates a robust carbon price signal throughout the production and consumption chain.
- Coherent policy to stimulate and support both new innovation (including in business models) and the diffusion of existing technologies has the potential to enable rapid advances in resource productivity and emissions reductions, in particular in hard-to-decarbonise industries such as plastics, steel and cement.

2.1. Innovation and sustainable growth

Innovation is a crucial driver of productivity and growth. Innovative firms that introduce new products and processes drive growth via the process of 'creative destruction', which propels economic change. The LSE Growth Commission's 2013 report contains a number of recommendations for supporting private investment and innovation in the UK, largely centred on improving the provision of finance for innovative firms.[37]

Government has a central role to play in fostering an environment that is supportive to low-carbon innovation. This is because private companies carrying out research and development (R&D) incur the full costs of their efforts, but they do not capture the full benefits. This market failure results in R&D below the socially optimal level. Even with a perfectly enforced system of intellectual property rights, such as patents, there are tremendous spillover benefits to other firms.[38] Innovations by one firm 'spill over' and provide valuable information that leads to new inventions in other firms. This makes the private payoffs to R&D investment very uncertain and deters private sector investment. Spillovers can be large, with social marginal returns from R&D estimated at between 30 and 50 per cent, which can be more than double private marginal

[37] LSE Growth Commission (2013) op. cit.

[38] Stavins R (2011) Repairing the R&D Market Failure. Environmental Law Institute, Washington, D.C. https://scholar.harvard.edu/files/stavins/files/column_40.pdf

rates of return.[39] With spillovers from low-carbon innovation potentially much higher than those from high-carbon innovation, this market failure will be even more pronounced.

Tackling this R&D market failure will require innovation policies and strategies, and also innovation in those policies themselves. UK strategies in the 1960s and 70s made ill-judged and badly targeted R&D investments, for example in the British car and computer industries, wasting billions of pounds of taxpayer funds.[40] This dented policymakers' appetite for activist industrial strategy for decades. Today, R&D spending (public and private) as a share of GDP in the UK is lower than its main international peers'.[41] R&D spending on energy technologies in particular is low by both historical and international standards: in the early 1980s, after the oil price shocks, R&D spending on energy technologies was around 0.1 per cent of GDP and the share today is below 0.02 per cent. The Government's recent announcement that it will be setting up a venture capital fund to support UK clean technology companies is a step in the right direction.[42]

Lessons from history and recent evidence, including that presented in this chapter, can help guide R&D policy. The LSE Growth Commission (2017) discusses how US government finance for R&D has been the source of many significant post-war innovations. The technologies that have gone into the iPhone are probably the most high profile example. The Internet, GPS, touch-screen display and voice-activation were all initially government-funded. Some of these successes are by-products of a wider research 'mission' – which focused on solving specific societal challenges through the interaction of many different sectors and government. A key example is the Internet, the origins of which trace back to the US government's efforts to build more reliable communication networks in the 1960s.[43]

The concept of research missions is gaining in popularity across the world as a basis for industrial strategies that try to achieve important economic and social objectives, such as low-carbon innovation across all sectors.[44] The UK government has made an important step by adopting clean growth as one of its cross-cutting grand challenges in the *Industrial Strategy*. Rather than public subsidies and guarantees in particular sectors, the Government can focus on ambitious low-carbon missions for sustainable growth that activate low-carbon innovation and enable bottom-up solutions and experimentation across sectors (in manufacturing and services), across actors (universities and business), and across disciplines (beyond science, technology, engineering and maths [STEM]).

Such missions require a more active and coherent policymaking framework in which different actors, including the public sector, actively shape the markets of the future.[45] This may involve, for example, providing patient strategic finance to organisations and projects willing to engage with challenging sustainability or low-carbon problems (or missions); creating the right supporting institutions that accept the risk and uncertainty around sustainable R&D outcomes; and going beyond sustainable R&D to other projects along the innovation curve.[46] In this way missions avoid a strategy of trying to 'pick winners', which has most often failed in the past, partly as the future of technological development is highly uncertain and likely to surprise us in

[39] Hepburn C, Pless J, and Popp D (2018) Review of Environmental Economics and Policy, volume 12, issue 1, Winter 2018, pp. 154–169

[40] Valero A and Davies R (2017) Towards a new UK industrial strategy. CentrePiece, Centre for Economic Performance. http://cep.lse.ac.uk/pubs/download/cp502.pdf

[41] See OECD Main Science and Technology indicators. http://www.oecd.org/sti/msti.htm

[42] Clark G (2018) Now is the time to reap the benefits of a low carbon economy. The Daily Telegraph, Monday 15 October. https://www.telegraph.co.uk/business/2018/10/14/now-time-reap-benefits-low-carbon-economy/

[43] LSE Growth Commission (2017) op. cit.

[44] Mazzucato (2017) op. cit. and Mazzucato M and MacFarlane L (2018) Patient Finance for Innovation Driven Growth. IIPP Policy Brief, June.

[45] Mazzucato M (2018) Missions. Mission-Oriented Research & Innovation in the European Union: A problem-solving approach to fuel innovation-led growth. European Commission. https://www.ucl.ac.uk/bartlett/public-purpose/sites/public-purpose/files/mission-oriented_ri_in_the_eu_mazzucato_2018.pdf

[46] UCL Institute for Innovation and Public Purpose (2018) Industrial strategy. https://www.ucl.ac.uk/bartlett/public-purpose/research/research-streams/mission-oriented-innovation-policy/industrial-strategy

ways few can anticipate. This strategy can tilt the playing field and change both the rate and direction of innovation (towards low-carbon) across many sectors at the same time.[47]

New evidence discussed below can further help government design its R&D policies as part of an industrial strategy that aims for sustainable growth everywhere. We argue that innovation spillovers offer an additional useful metric for assessing government R&D support. This could be more effective and forward-looking than support based on comparative advantage alone. We find a compelling case for increasing publicly-financed R&D in clean technologies and processes, [48] and similarly for policies to incentivise businesses to invest in more low-carbon R&D – for example building on the R&D tax credit system, which has been shown to be effective at generating R&D, patenting and spillovers.[49]

Support for the diffusion of innovative technologies and practices across the economy is also important: it helps raise productivity as firms reorganise their production processes to achieve best practice. Through regulatory structures and incentives, government can tackle market failures such as information or financing constraints, which hold back the adoption or diffusion of innovative and cleaner technologies and practices.

2.2. Innovation and comparative advantage in the UK

In this section we use patent data[50] to explore where the UK has comparative advantage in low-carbon technologies, and the spillovers low-carbon innovation generates.

In a number of areas, UK businesses are already taking the global lead in low-carbon innovation. Overall the share of clean[51] in total innovations is 11%,[52] somewhat higher than in other G7 countries, where the clean share is only 7%. Figure 2.1 illustrates that clean innovations are relevant across a wide range of sectors, particularly in the UK, where around 55% of all clean innovations come from *non*-manufacturing sectors; in the rest of the G7 nearly 80% of clean innovations come from manufacturing. This is a consequence of the fact that a high share of the UK's R&D takes place in the service sector,[53] which includes the research activities of companies such as Dyson, whose research departments but not its manufacturing activities are based in the UK. It also includes the activities of the UK's world leading universities.

We explore the performance of UK-based firms across various technologies and also include a number of cutting-edge technology fields that are not necessarily related to clean technologies: that is, whose main aim is not reducing emissions or saving resources – examples include information technology (IT) and biotechnology. This is important for assessing how clean technologies fit into the wider industrial strategy context. Our categories are not necessarily mutually exclusive as some of these 'non-strictly-clean' technologies can also be beneficial to the environment – for example, IT can reduce demand for travel and therefore transport-related emissions.

47 UCL Institute for Innovation and Public Purpose (2018) Mission-oriented innovation policy. https://www.ucl.ac.uk/bartlett/public-purpose/research/research-streams/mission-oriented-innovation-policy

48 And as benefits to innovation accrue over time, gains to society will be higher if policies to induce innovation start earlier rather than later. Fankhauser S, Sehlleier F, and Stern N (2008) Climate change, innovation and jobs. Climate policy, 8(4), 421-429.

49 Dechezleprêtre A, Einiö E, Martin R, Nguyen KT and Van Reenen J (2016) Do Tax Incentives for Research Increase Firm Innovation? An RD Design for R&D, CEP Discussion Paper No. 1,413

50 Patents only capture a subset of all innovation in the economy. However, there are few good alternatives to patent data for measuring innovation comprehensively. How good patents are as a measure of innovation will also vary between different sectors and technologies. Patenting is more prevalent in manufacturing sectors and related to equipment that will be most relevant to mitigate greenhouse gas emissions.

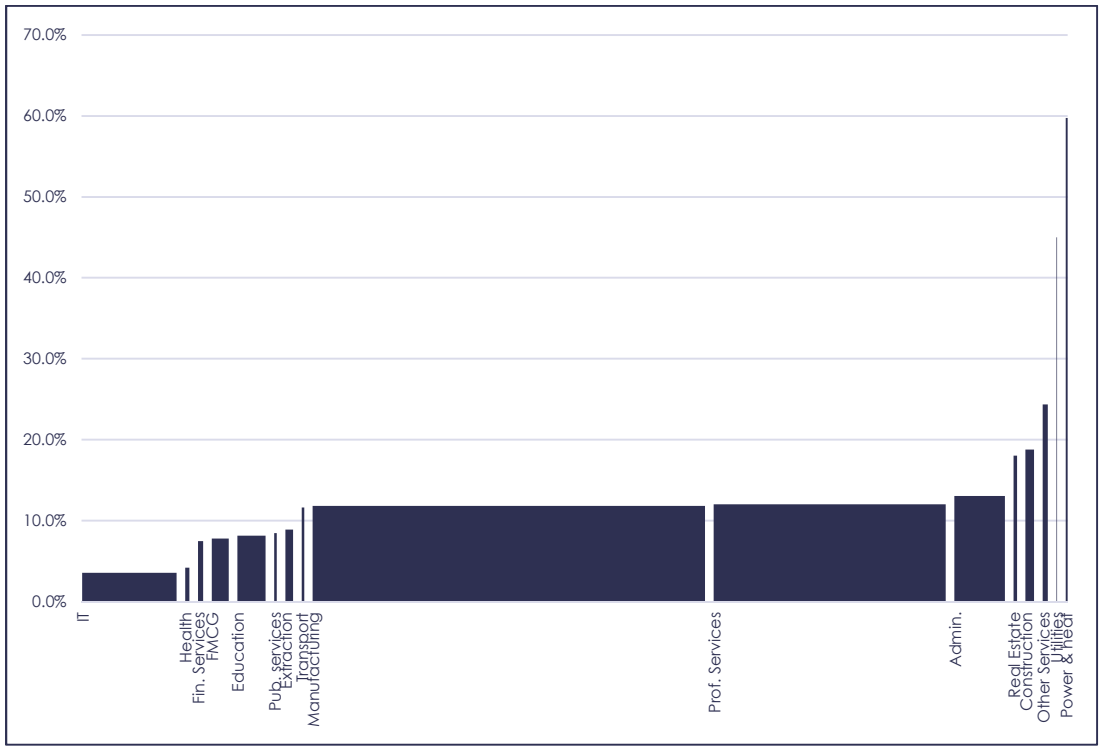
51 We classify innovations as clean and we rely on a patent classification exercise by the European Patent office that developed the Y02 classification specifically to identify innovations that are relevant for greenhouse gas mitigation. For further details see https://www.epo.org/news-issues/issues/classification/classification.html

52 Over the 2000-2014 period.

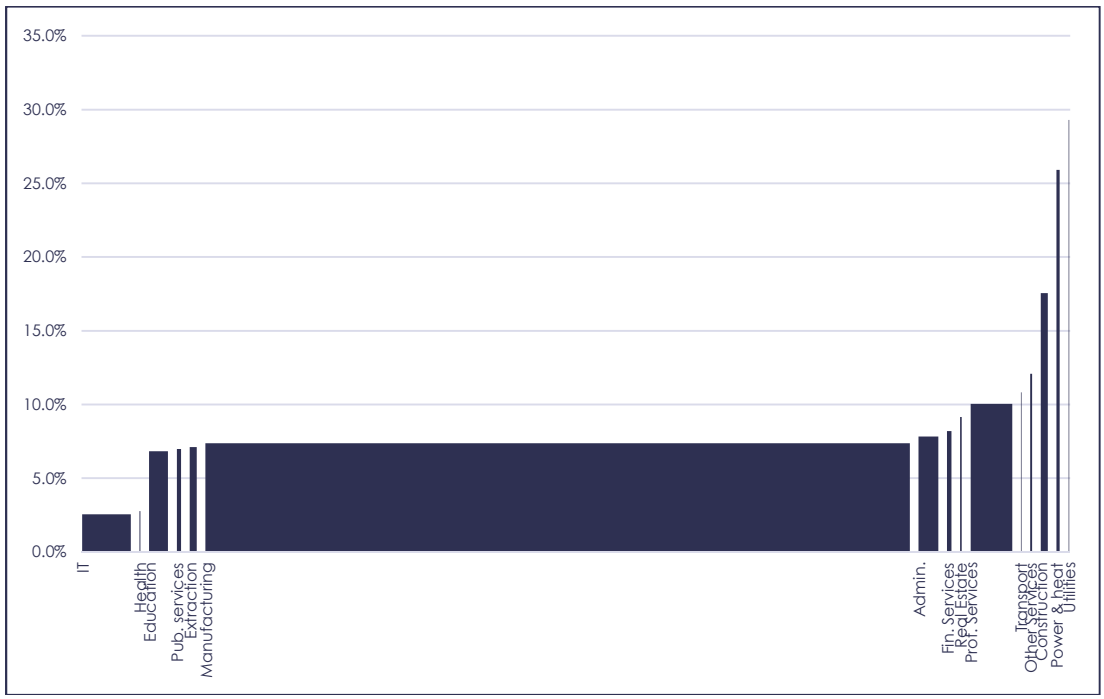
53 UK universities account for around a quarter of gross domestic expenditure on R&D, which is high by international standards. In the US, the equivalent share is 13%, for Germany it is 18%, and the OECD average is 17% (OECD MSTI, Percentage of GERD performed by the Higher Education sector, 2016).

Figure 2.1. Clean innovations across sectors

2.1 A. United Kingdom



2.1 B. G7 + Korea, excluding UK



Notes: The vertical axis reports the share of clean innovations in a sector; the horizontal axis reports the share of a sector in total innovations. So the surface area of a bar corresponds to the share of clean innovations in a particular sector in total clean innovations; therefore the figure shows that most clean innovations come from manufacturing in both the UK and the rest of the G7. However, manufacturing is dramatically much less dominant for the UK, where Professional Services are a more important category than in other G7 countries.
Source: Authors, based on PATSTAT data.

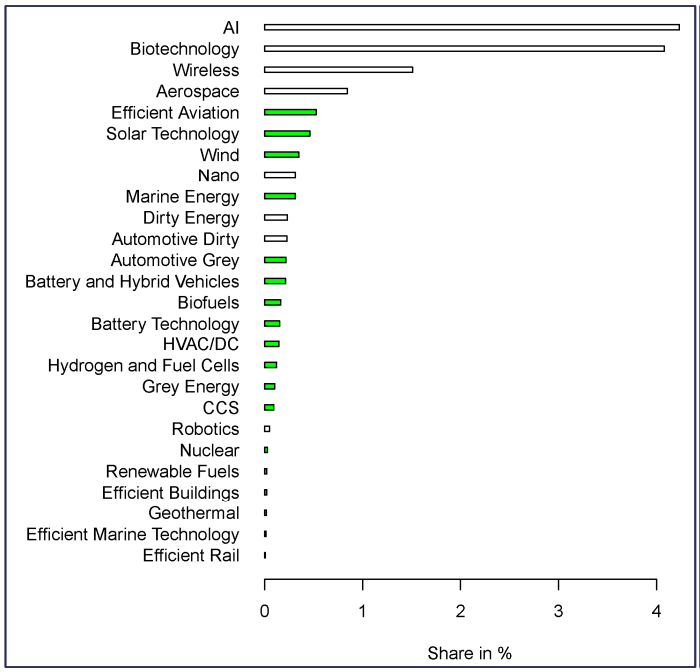
Figure 2.2 shows patents by technology class, as a share of total patents filed in the UK between 2000 and 2014. It is apparent that IT-related patents are by far the most important group (panel A). The largest clean technology group is efficient aviation technologies. The broad picture for 'high value innovations' (those patented in more than one country) is very similar (panel B), although there are some changes in the relative ranking.

To get a better sense of how the UK performs internationally, we compare the size of each of those categories to the size in other leading economies[54] – see Figure 2.3. A positive value in this case means the UK has a larger share in this category than do the other leading economies. We interpret this as a sign of comparative advantage. Similarly, a negative value would indicate a comparative disadvantage.

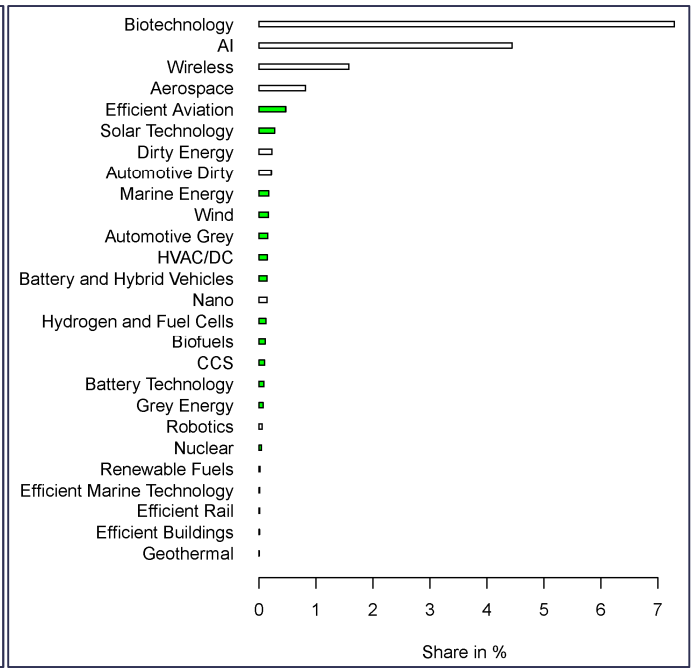
The UK appears to be leading in areas such as biotechnology and also has a comparative advantage in some clean fields such as efficient aviation, marine energy and wind energy. IT and artificial intelligence (AI) are the categories in which the UK seems to have the biggest *dis*advantage in comparison with other advanced economies (panel A). Similar conclusions can be drawn for high value innovation, as shown in panel B.

Figure 2.2. Comparison across technology fields in the UK (2000–14)

2.2 A. Share in total UK innovation



2.2 B. Share in UK high value innovation

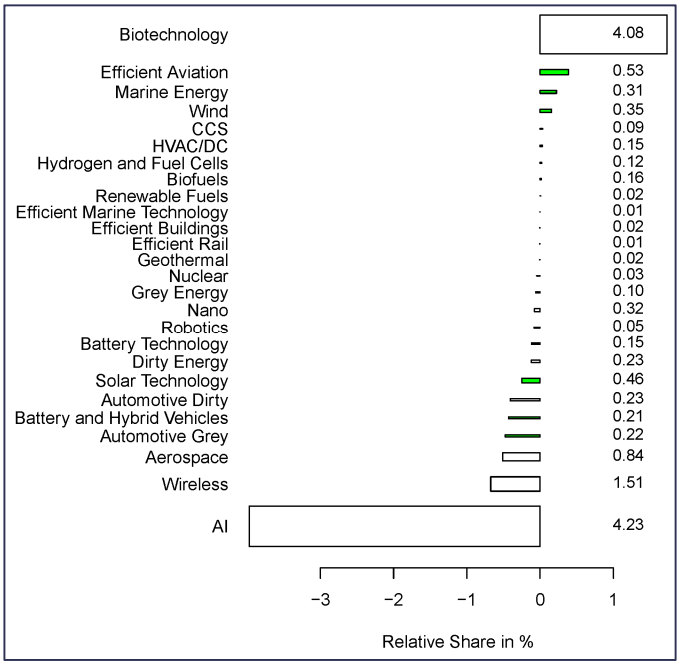


Note: Clean technologies are marked in green. Source: Authors' estimates based on PATSTAT data.

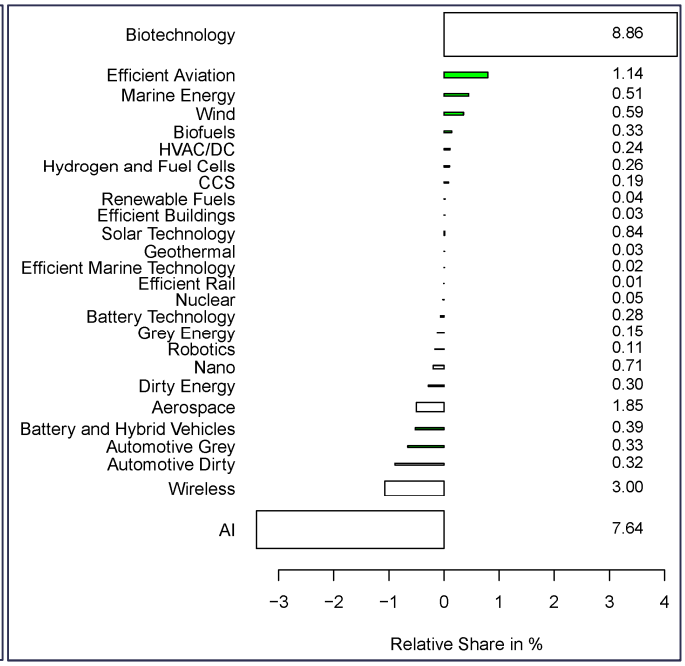
[54] Suppose *UK* is the set of innovations in the UK and C_{-UK} the set of all innovations in G7 countries other than the UK. Moreover let A be the set of all innovations in a particular technology area. Then the figure reports $\frac{Innovations\ in\ UK \cap A}{Innovations\ in\ UK} - \frac{Innovations\ in\ C_{-UK} \cap A}{Innovations\ in\ C_{-UK}}$

Figure 2.3. UK comparative advantage: share of UK innovation relative to other advanced economies (2000–14)

2.3 A. Relative share of all UK innovation



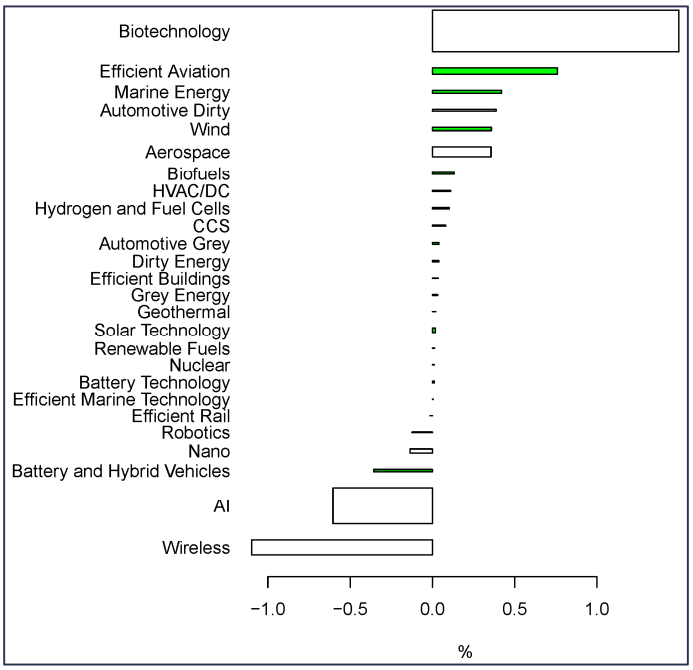
2.3 B. Relative share of high value UK innovation



Notes: UK share in a category relative to the share in rest of G7 plus South Korea combined. The width of the bars indicates the relative size of the various categories. Clean technologies are marked in green. The labels show the share in all UK innovation in %, e.g. biotech has a share of 8.86% of high value innovation from 2000–14. Source: Authors' estimates based on PATSTAT data.

Figure 2.4 shows how the UK's comparative advantage has changed over time, between the periods 1995–2005 and 2005–2014. This reveals a similar picture as the static analysis for 2000–2014: biotechnology is not only the area where the comparative advantage is highest in the post-2000 period, it is also the technology for which the comparative advantage has been growing the fastest. By contrast, the UK has been losing comparative advantage in various ICT technologies, although the ranking of technologies changes somewhat compared with the static picture painted in Figure 2.3.

Figure 2.4. Changes in UK comparative advantage, 2005–2014 vs 1995–2004



Notes: The figure reports changes in the relative shares between the two time periods. The width of the bars indicates the relative size of the various categories. Clean technologies are marked in green. Source: Authors' estimates based on PATSTAT data.

It is interesting to note that clean automotive technologies (battery and hybrid vehicles), an area identified as strategic in the Government's *Industrial Strategy*, and the recipient of recent funding announcements,[55] appear to be losing comparative advantage.

2.3. Spillovers: a new focus for policy intervention

A major aim of the UK's *Industrial Strategy* is to support high-productivity, high-growth sectors or technologies for which the UK has comparative advantage.[56] However, such areas could do well irrespective of government support, and funding could be better spent elsewhere. While it is important not to lose or weaken existing areas of comparative advantage, the rationale for prioritising such areas or making them a special target for policy intervention, for example via special tax credits or subsidies, exists only if there are clear externalities or spillovers leading to under-provision without government intervention.

The existence of innovation spillovers provides a clear market failure that government intervention in the form of innovation incentives can address. Equally, variations in the strength of innovation spillovers between different technologies or sectors can motivate variations in support.

There is evidence that the potential spillovers from low-carbon innovation to other sectors – one of the factors that helps to drive overall growth – may be significantly higher than for high-carbon technologies.[57] This is shown in Figure 2.5. Analysis of more than 1 million innovations using patent data and 3 million citations worldwide suggests that spillovers from low-carbon

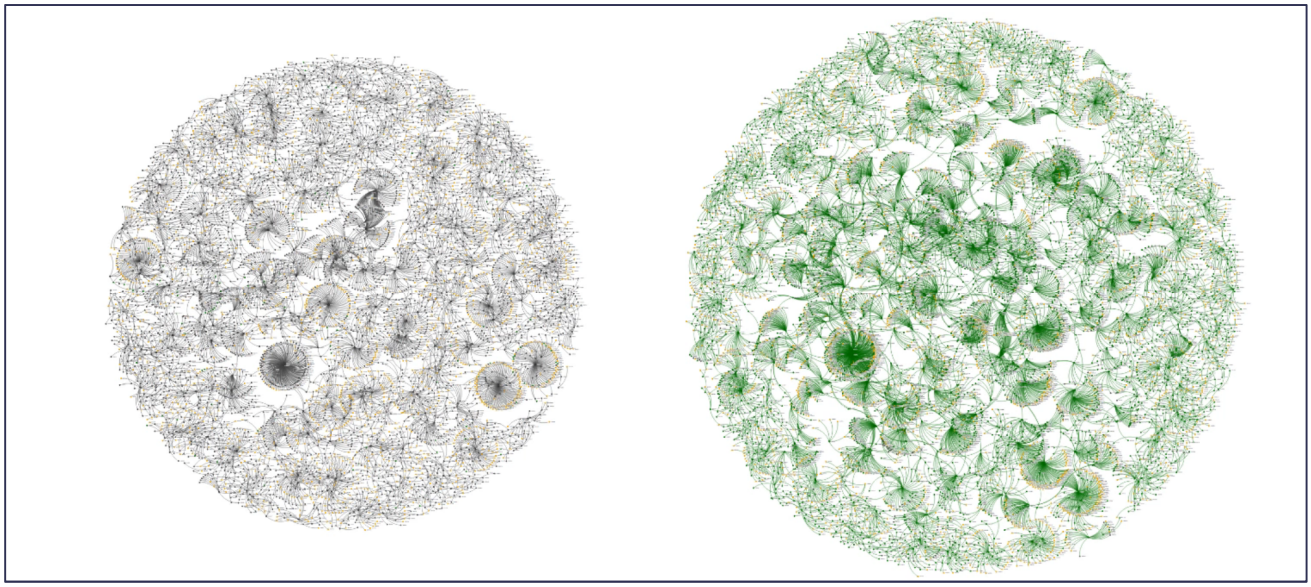
[55] Gov.uk (2018) PM unveils plans for UK to become world leader in low emission tech. Press release, 10 September. https://www.gov.uk/government/news/pm-unveils-plans-for-uk-to-become-world-leader-in-low-emission-tech

[56] The 'Industrial Strategy Challenge Fund' is a core part of the Government's pledge to increase funding in R&D. 'Challenges' are areas where the UK already has world-leading research and businesses that are ready to innovate; and where the global market is large, fast growing and sustainable. See https://www.ukri.org/innovation/industrial-strategy-challenge-fund/

[57] Dechezleprêtre A, Martin R, Mohnen M (2013) Knowledge spillovers from clean and dirty technologies: A patent citation analysis, Centre for Climate Change Economics and Policy Working Paper No. 151 Grantham Research Institute on Climate Change and the Environment Working Paper No. 135. Available at: http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2013/10/WP135-Knowledge-spillovers-from-clean-and-dirty-technologies.pdf

innovation in the energy production and transport sectors are over 40 per cent greater than in conventional technologies.[58] The knowledge spillovers from low-carbon innovations are indeed comparable to those in other leading fields such as IT and biotechnologies.[59]

Figure 2.5. Visualising spillovers from high-carbon (left) and low-carbon (right) technologies



Notes: The figure visualises all citations to a sample of 1,000 high-carbon (left panel) and 1,000 low-carbon (right panel) innovations. Each node represents an innovation (black = high-carbon innovation, green = low-carbon innovation, orange = other innovation); edges represent citations. The samples were drawn among innovations applying for patent protection in 1995. Source: Dechezleprêtre et al. (2016)[60]

While most spillovers typically occur within a given technology area or sector, there is also considerable cross-technology inspiration. Sometimes this leads to very surprising connections. For instance, an innovation from 1981 describing a wave energy system (US Patent 4260901) is cited in 2011 by a patent for a new audio encoding technology (US Patent 7447629) patented in 2008: aspects of how to efficiently convert ocean waves into electricity helped to store and transmit audio waves more efficiently. Pushing scientific frontiers in a narrow sector can have widespread benefits beyond that sector.

Such non-obvious connections are clearly a challenge when assessing the value of one technology field compared with another. Things get even more removed if we take into account that the effect of a particular innovation might not only be non-obvious but also very indirect: that is, innovation A inspires innovation B which then goes on to inspire innovation C, without C ever directly referring to A. However, tracing such indirect connections is important in order to assess the full contribution of different innovation areas.

Dechezleprêtre et al. (2017)[61] develop a new approach dubbed Patent Rank to deal with this, adapting a methodology from Google to rank the importance of webpages to patent data. Using this approach we can assess the global value of specific innovation areas, and also compute what we call the 'national spillover value': that is, a government considering

[58] Dechezleprêtre et al. (2013) op. cit.

[59] Dechezleprêtre et al. (2013) op. cit. Bowen A, Duffy C, Fankhauser S (2016) Green growth and the new Industrial Revolution. Policy Brief. Grantham Research Institute on Climate Change and the Environment and Global Green Growth Institute. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2016/01/Bowen-et-al-2016.pdf

[60] Dechezleprêtre A, Martin R, Bassi S (2016) Climate change policy, innovation and growth. London: Grantham Research Institute on Climate Change and the Environment and CCCEP. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2016/01/Dechezlepretre-et-al-policy-brief-Jan-2016.pdf

[61] Dechezleprêtre A, Martin R, Mohnen M (2017) Towards a rational national industrial policy. Mimeo. January. http://www.ralfmartin.me.uk/pub/RM/IndustrialPolicy/rational.pdf

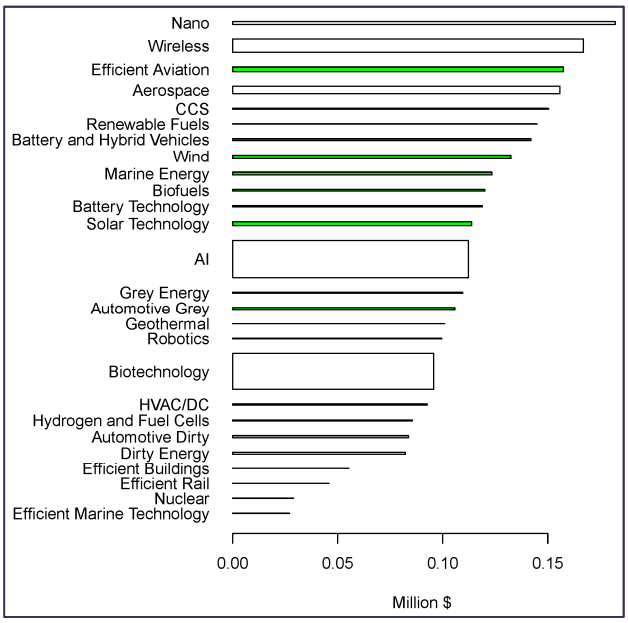
innovation subsidies will not necessarily be interested in the global value but rather in the value of a particular innovation area to its own jurisdiction, even if the chain of spillovers is very indirect. For example, an innovation in the UK inspires innovation in the US that subsequently inspires further innovation in the UK. Therefore, we argue that this national Patent Rank would be an informative indicator for designing a national or regional industrial strategy, in addition to the more traditional focus on comparative advantage. For this report we provide updated Patent Rank figures for the UK using detailed new classifications with a focus on low-carbon technologies.[62]

Figure 2.6 reports the Patent Rank score for key technology categories, showing the magnitude of spillovers they generate worldwide (panel A) and within the UK (panel B). A number of clean technologies feature in the top 10 in terms of international spillovers (panel A), notably: renewable fuels, efficient aviation, grey energy (technologies to improve the efficiency of fossil fuels), carbon capture and storage (CCS) and wind energy.

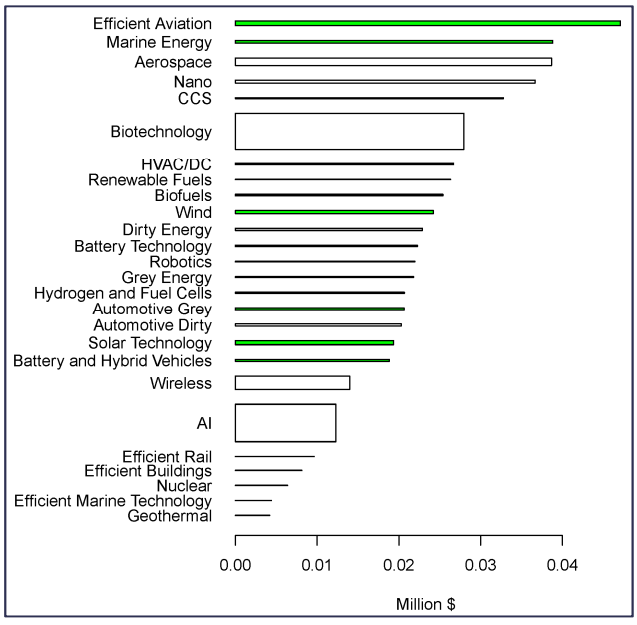
Various ICT technologies feature more prominently around the top. However, when looking at the national spillovers values in panel B, it is striking that ICT technologies vanish almost entirely from the top and are by and large replaced by various clean technologies. Indeed, efficient aviation as well as marine energy technologies (ocean wave and tidal energy technologies) are at the top of the ranking. Incurring such fixed costs might only be advisable if they can be expected to be spread over a large enough number of potential projects, of which the current size can be an indicator. Second, providing support for a specific technology will always raise concerns of giving unfair competitive advantage to supported firms. This will be less of a concern if support is given widely, so that there is enough competitive pressure among the group of supported firms (see Aghion et al., 2015).[63]

Figure 2.6. Technology areas with highest Patent Rank for UK (2000–2014)

2.6 A. Global spillovers



2.6 B. National spillovers



Notes: The width of the bars indicates the relative size of the various categories.
Clean technologies are marked in green. Source: Authors' estimates based on PATSTAT and ORBIS data.

[62] In order to estimate spillovers in financial terms, we assign a private value of US$1.75 million to multi-country innovations and a zero private value to single-country innovations. We derive these figures from running regressions of the stock market value of firms on firm-level patenting. In other words, we assume that the private value of an innovation is equivalent to the improvement in stock market values when successfully developing a new innovation. For this analysis we rely on firm-level data from the ORBIS database.

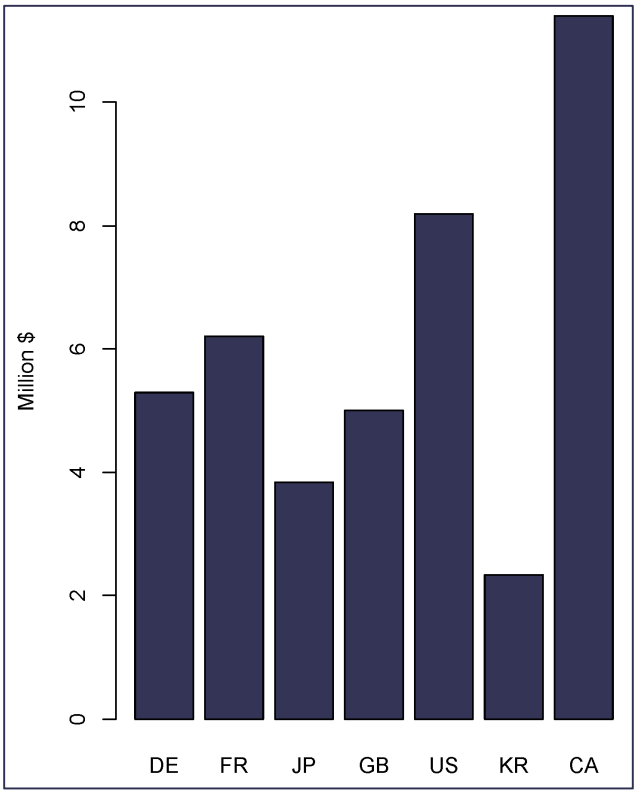
[63] Aghion P, Cai J, Dewatripont M, Du L, Harrison A, Legros P (2015) Industrial Policy and Competition. American Economic Journal: Macroeconomics, 7 (4): 1-32.

The width of the bars in these charts represents the size of the categories in terms of number of patents in the UK in those categories. The size of the categories is of interest for two key reasons. First, designing technology-specific support is likely to incur a certain amount of fixed costs, because it is likely to require relevant sectoral expertise on the part of government.

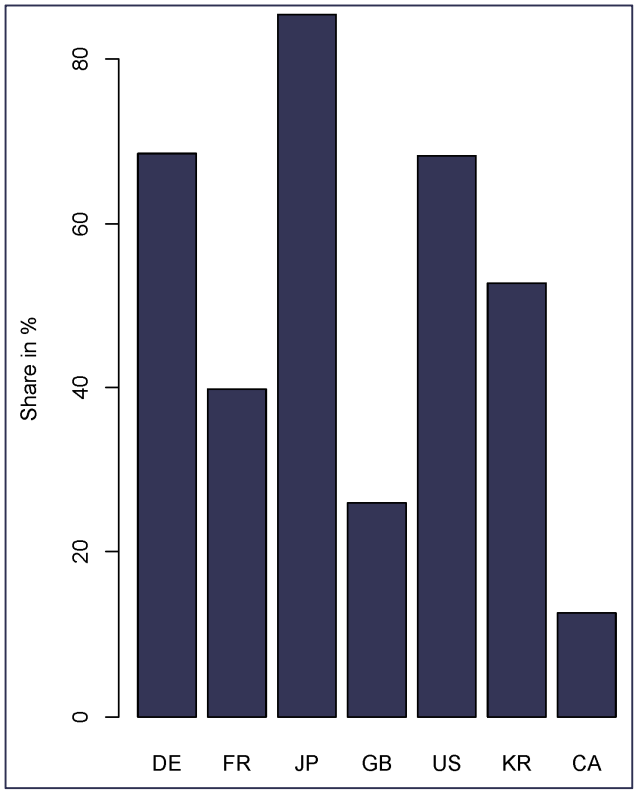
It is also informative to compare these UK patterns with equivalent figures for all G7 countries plus South Korea. Figure 2.7 reports the average value of global spillovers (Panel A) and the share of national in global Patent Rank – which gives a measure of the share of global spillovers retained nationally – and shows that there is a more pronounced gap between global and national spillovers in the UK than for the other countries. At 26 per cent, the UK has one of the smallest shares. In other words: while the UK generates similar average levels of knowledge spillovers to Germany and France, a larger fraction of the UK-generated spillovers is enjoyed by non-domestic innovators than is the case for Germany or France.

Figure 2.7. Knowledge spillovers across countries (2000–2014)

2.7 A. Average value global spillovers



2.7 B. Share of global spillover retained



Notes: Panel A reports the average global Patent Rank across countries. Panel B reports the share of national Patent Rank as a fraction of global Patent Rank. Source: Authors' estimates based on PATSTAT and ORBIS data.

Box 2.1. Examples of high spillover technologies from UK inventors

In Figure 2.5 we show that efficient aviation and marine energy generate high levels of spillover for the UK. What kind of inventors and technologies are responsible for this?

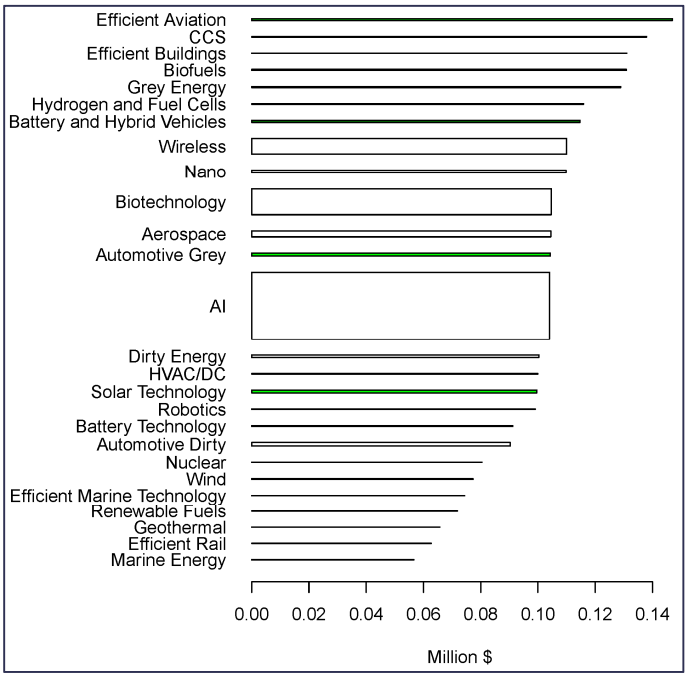
As an illustration we consider a number of specific inventions and innovators that were found to have high Patent Rank values. Top performers in the marine energy category are innovations by Marine Current Turbines Ltd (MCT), a Bristol-based company ultimately owned by Siemens, as well as Tidal Generation Ltd, a company that is now owned by General Electric. Their top ranking innovations include designs for mounting power turbines in tidal waters which requires special provisions for keeping the turbines at different vertical levels (e.g. European Patent EP1183463). Examples of spillover linkages – that is, other innovations referring back to these directly or indirectly – include innovations in refrigeration and air conditioning units (e.g. US2008011007).

High spillover 'efficient aviation' innovations come from firms like Rolls Royce and Airbus. High Patent Rank innovations include improved turbine designs (e.g. EP1589195) but also aeroplane fuel tank venting designs that make aeroplanes significantly lighter (e.g. EP1591359).

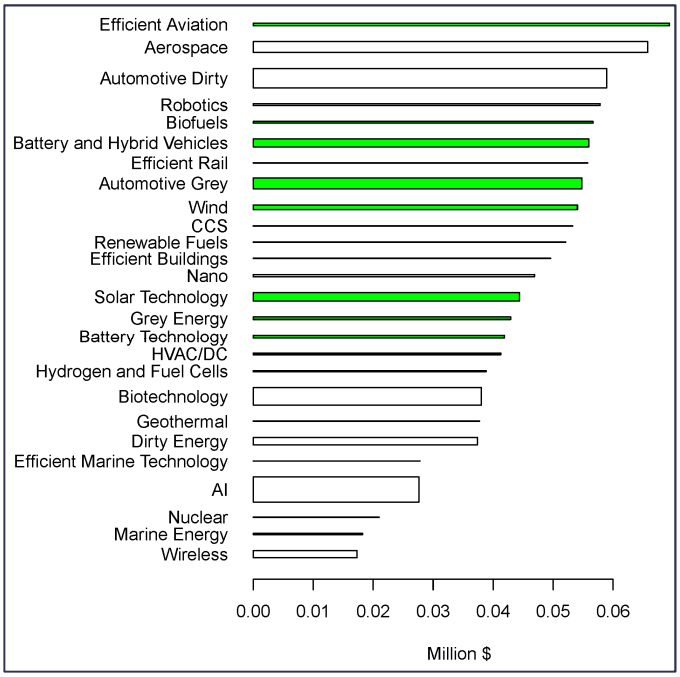
Moreover, considering which technology areas have the highest national Patent Rank in the United States and Germany (see Figure 2.8, which replicates Figure 2.6, panel B for these countries) the UK appears to have a rather narrow concentration of national high-spillover technologies compared with these countries. This means that in the UK there are a relatively small number of technologies that generate very large spillovers, whereas in the United States and Germany there is a wider breadth of technologies with large spillovers.

Figure 2.8. National spillover for the United States and Germany (2000–2014)

2.8 A. United States



2.8 B. Germany



Notes: The width of the bars indicates the relative size of the various categories.
Clean technologies are marked in green. Source: Authors' estimates based on PATSTAT and ORBIS data.

How do the Patent Rank indicators compare with the comparative advantage figures discussed above? There is clearly some correlation. Notably, both efficient aviation and marine energy perform well in terms of comparative advantage as well as spillover effects. But there also notable exceptions. For instance, in aerospace the UK has a comparative

disadvantage, although the spillover effect captured by Patent Rank is nearly at the top in this field. A similar story arises for nanotechnology. On the other hand, while biotechnology has the undisputed lead in terms of comparative advantage, it comes only seventh in terms of Patent Rank.

There is some degree of overlap between the priority ranking implied by Patent Rank and current UK government policy. The Department for Business, Energy & Industrial Strategy (BEIS) is in the process of negotiating a variety of sector deals to facilitate such vertical interventions. This includes an aerospace sector deal which comprises efficient aviation technologies. There are also sector deals related to renewable energy although the focus there appears to be primarily on offshore wind energy.

The starkest omission in light of the Patent Rank findings concerns marine energy technologies. Indeed, with the recent decision by BEIS not to support the Swansea tidal lagoon – despite earlier assurances – it would appear that the Government is backtracking on this sector. However, our results imply that the sector could be important for the UK beyond levelised costs for electricity calculations. Our analysis also suggests that there should be careful consideration of support for electric vehicles. The results indicate that a rationale for support in this area would need to go beyond benefits for UK productivity.

2.4. Spillovers and regional policy

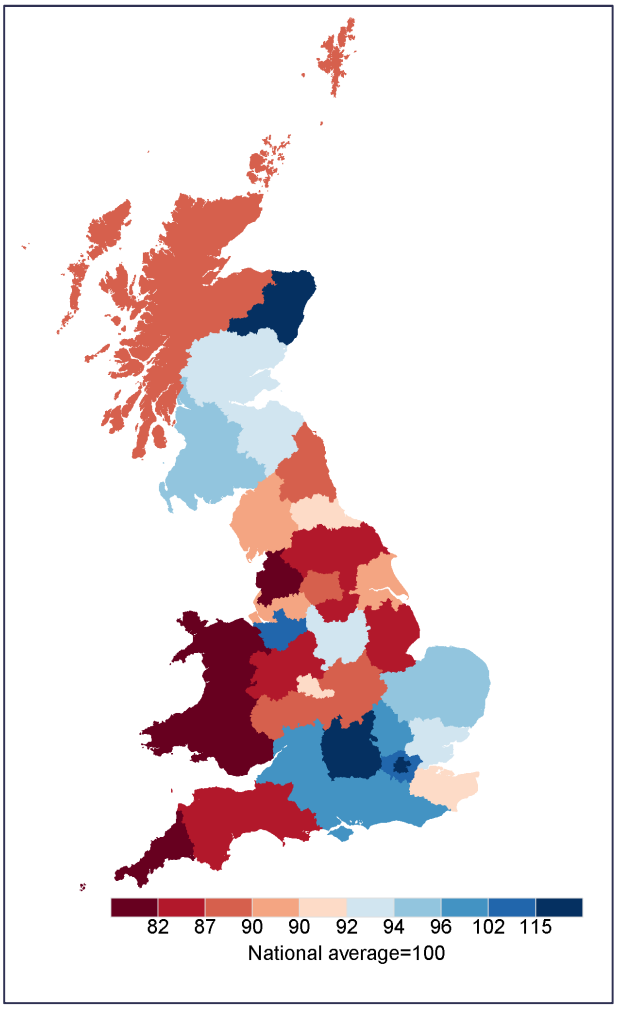
The UK suffers from serious regional disparities in productivity. Regions in the top decile, which include parts of inner London, areas around Oxford, and Edinburgh, are nearly 40 per cent more productive than those in the bottom decile, which includes Cornwall and large parts of Wales (see Figure 2.8, Panel A). If government targets industrial policies towards regions that generate higher levels of spillovers, will this exacerbate these disparities?

We try to answer this question by looking at spillovers – as measured by Patent Rank – across various regions (NUTS2)[64] of the UK in Figure 2.9. Panel A reports global spillovers across UK regions relative to the UK-wide average level. While there is some overlap between high spillover and high productivity regions – e.g. Northeast Scotland, East London, Cheshire – there are considerably more areas with low productivity but above average amounts of national spillovers. These include the Scottish Highlands and Islands, Kent, Essex, Greater Manchester. Figure 2.10 illustrates this further by showing a scatter plot of productivity and national spillovers. Below average productivity areas with above average spillovers are found in the bottom right-hand section of the scatter plot. Therefore, targeting such areas with special R&D grants and similar policies could be part of a strategy to simultaneously increase national growth and reduce regional disparities.

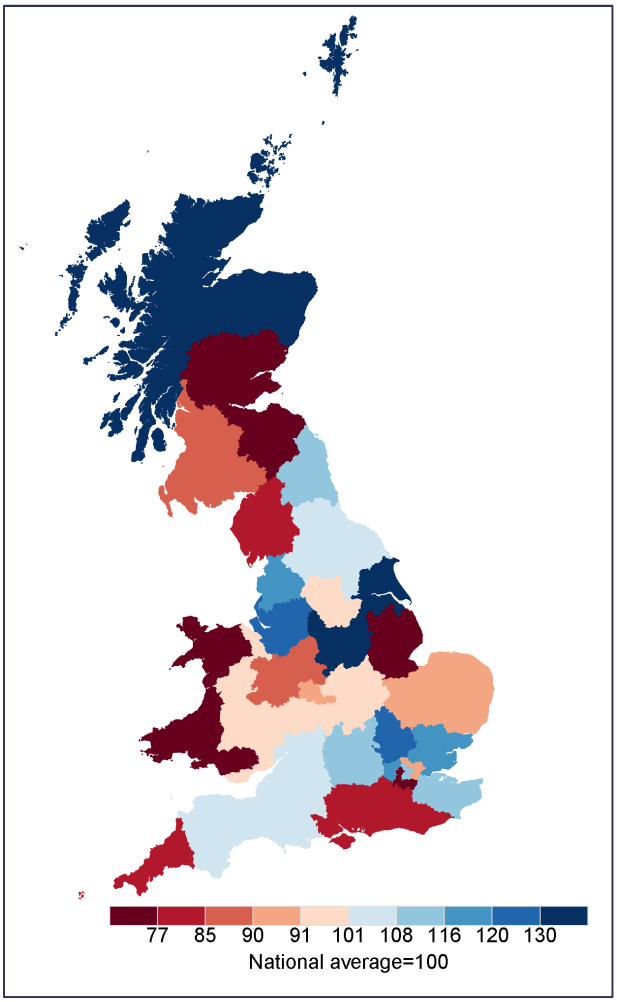
[64] The NUTS classification (nomenclature of territorial units for statistics) is a hierarchical system for dividing up the economic territory of the EU. NUTS2 regions are relevant for the application of regional policies.

Figure 2.9. Productivity and innovation spillovers across NUTS2 regions of the UK (%)

2.9 A. Relative regional productivity (2014)

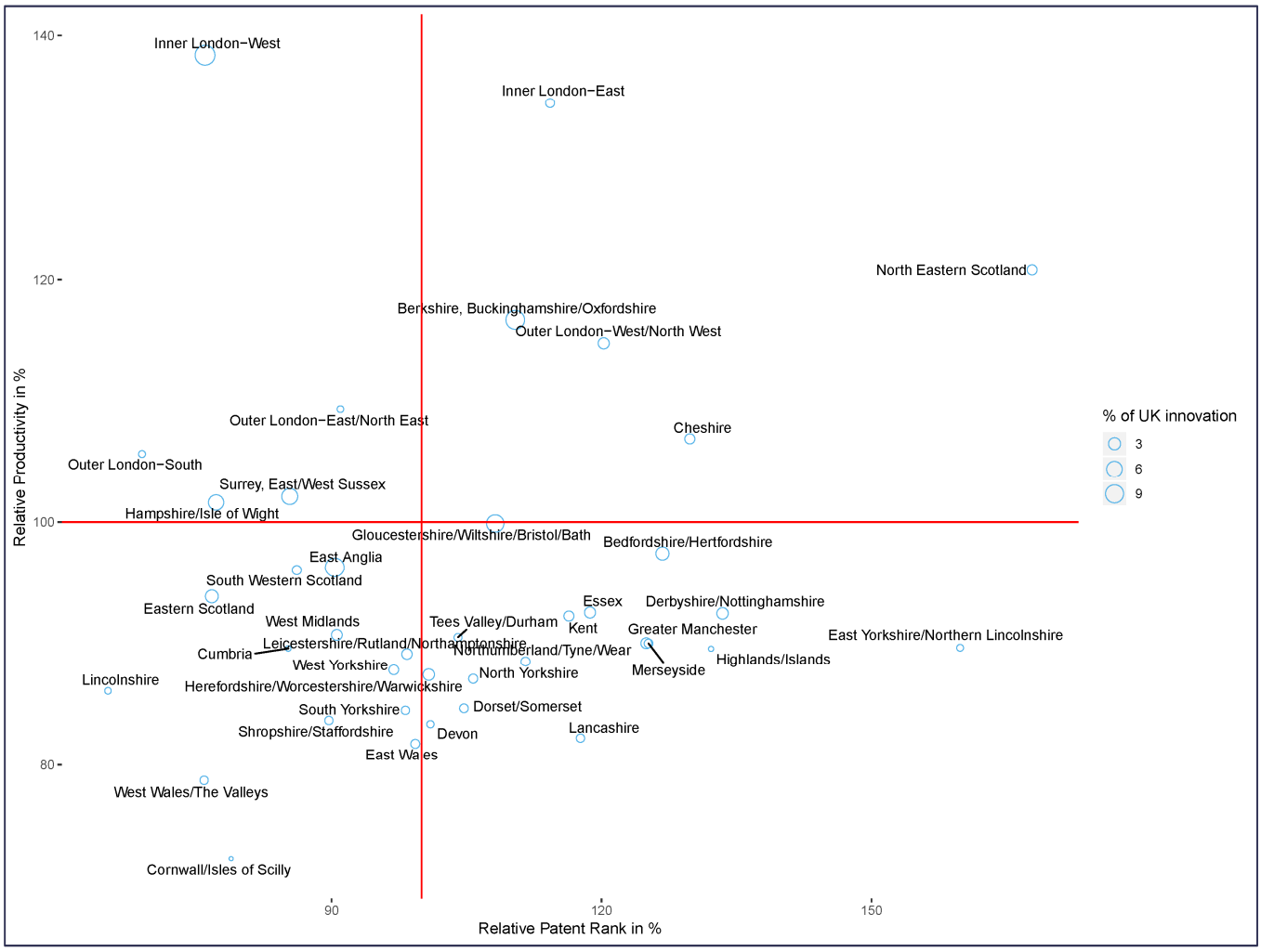


2.9 B. Relative national spillovers (2000–14)



Notes: Panel A reports an area's labour productivity relative to the UK-wide average level (in %). Panel B reports average national spillovers (national Patent Rank) in an area, relative to the UK average national spillover level (%).
Source: Authors

Figure 2.10: The relationship between productivity and spillovers



Note: The figure shows a scatter plot of relative regional productivity and relative regional average spillovers for NUTS2 regions of the UK. Source: Authors

2.5. Diffusion of low-carbon innovations

The technology story does not end with innovation. The commercialisation of new technologies is also essential. This comprises the conversion of innovations into marketable products and also promoting the diffusion and uptake of existing marketable products.

With respect to clean technologies, there are a number of policies in the UK that support the conversion of low-carbon innovations into marketable products. This includes measures to help innovations through the so-called 'valley of death', where funding scarcity prevents a new technology from progressing to commercialisation. In the business sector, these policies include taxes and levies such as the climate change levy, the climate change agreement, the EU emissions trading system (EU ETS) and the carbon price floor. There are also a number of subsidies that aim specifically to stimulate the diffusion and uptake of marketable low-carbon energy technologies, such as contracts for difference for large-scale power generation, the Energy Company Obligation (ECO) for low-income households, and small-scale feed-in tariffs and renewable heat incentives for households and firms.

However, the layering of climate and energy policies, and successive interventions that have tinkered with their formulation, have led to inconsistencies and overlaps.[65] There is considerable scope to improve the cost-effectiveness of UK energy and climate change policies, and their ability to stimulate the market for low-carbon innovations.

Carbon pricing

A priority area for reform is carbon pricing, which could help to shift expectations and behaviour in the innovation process towards low-carbon, both on the production and consumption sides. A strong and credible carbon price would also support the efficiency and effectiveness of policies for infrastructure, skills and cities (see Chapters 3 to 5), and decentralise decision-making in scenarios where policymakers cannot know how to allocate quantities of emissions reductions efficiently across the economy. The recent *Cost of Energy Review* for government by Dieter Helm stresses that an economy-wide carbon price would in principle be more efficient than the current patchwork approach to reducing emissions.[66] Bowen (2011) suggests that a carbon price of around £40 in 2020, rising to around £55 in 2030, would be appropriate for the UK, given its decarbonisation commitments.[67] The Government's short-term traded carbon values, used for valuing the impact of government policies on emissions in sectors covered by the EU ETS, is around £4.50 per tonne of CO_2e in 2020, rising to around £80 per tonne in 2030 (central estimates in real 2017 terms).[68]

There is emerging empirical evidence that carbon prices currently in place around the world have not harmed economic growth.[69] They can potentially enhance macroeconomic and fiscal efficiency if the tax or auction revenues are recycled through the economy in productive ways.[70] They can also spur clean innovation, with potentially high spillovers, increasing the dynamic array of substitution options available during the transition to a low-carbon economy, reducing costs. That costs can be low or mitigated entirely is often contrary to public belief, which is a major barrier that needs to be overcome to reduce resistance to carbon prices.[71]

In practice, the potential for reducing the economic cost of carbon pricing will depend on the nature of pre-existing distortions or inefficiencies in a country's tax system, the nature of the revenue recycling, and the level of political resistance. Revenues could be used in ways that do not enhance productivity, such as free permits to carbon-intensive industry. The use of carbon tax or auction revenues should be guided by good principles of public finance, including efficiency, distribution and incidence.[72] However, recent evidence concludes that the productivity gains from particular revenue recycling options should serve only as a benchmark, while behavioural considerations aimed at achieving greater political

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[65] Bassi S, Dechezleprêtre A, Fankhauser S (2013) Impacts of climate change policies on the UK business sector. London: Grantham Research Institute for Climate Change and the Environment and Centre for Climate Change Economics and Policy. http://www.lse.ac.uk/GranthamInstitute/publication/climate-change-policies-and-the-uk-business-sector-overview-impacts-and-suggestions-for-reform/. Advani A, Bassi S, Bowen A et al. (2013) Energy use policies and carbon pricing in the UK. IFS Report R84. https://www.ifs.org.uk/comms/r84.pdf

[66] Helm D (2017) Cost of Energy Review. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/654902/Cost_of_Energy_Review.pdf

[67] See Bowen A (2011) The Case for Carbon Pricing. Policy Brief. Grantham Research Institute on Climate Change and the Environment. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2014/02/PB_case-carbon-pricing_Bowen.pdf

[68] See BEIS (2018) Updated short-term traded carbon values. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/671194/Updated_short-term_traded_carbon_values_for_appraisal_purposes.pdf

[69] Murray B and Rivers N (2015) British Columbia's revenue-neutral carbon tax: A review of the latest 'grand experiment' in environmental policy, Energy Policy, Vol. 86, pp. 674-683. Rydge J (2015) Implementing Effective Carbon Pricing. New Climate Economy Working Paper. http://newclimateeconomy.report/2015/wp-content/uploads/sites/3/2015/10/Implementing-Effective-Carbon-Pricing.pdf. Yamazaki A (2017) Jobs and climate policy: Evidence from British Columbia's revenue-neutral carbon tax, Journal of Environmental Economics and Management, Vol. 83, pp.197- 16.

[70] New Climate Economy (2014) op. cit.

[71] Carattini S, Carvalho M, and Fankhauser S (2018) Overcoming public resistance to carbon taxes. WIREs Climate Change: http://dx.doi.org/10.1002/wcc.531

[72] See Bowen A (2015) Carbon pricing: how best to use the revenue? Policy Brief. Grantham Research Institute on Climate Change and the Environment. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2015/11/Bowen-policy-brief-2015.pdf

acceptance, such as compensating low-income households, should take precedence.[73] A clear message from the literature is that revenues must be put to good use as far as is politically possible as their use has a large impact on the cost-effectiveness of carbon pricing.[74]

Other supporting policies

Carbon pricing, while necessary, is not sufficient on its own. Additional policies that are well coordinated with carbon pricing, fiscal and other growth policies will be needed to overcome other market failures and behavioural barriers that may hamper the innovation process. These failures and barriers include information asymmetries, lack of awareness of options to reduce emissions, credit constraints that hold back investment, principal-agent problems (e.g. between tenants and landlords, where the landlord has no incentive to invest in energy efficiency that will benefit the tenant), and conflicts with existing regulations. Such market failures and barriers are by definition not sensitive to changes in prices. Technology support, for example, will still be needed to promote the diffusion and uptake of low-carbon generation technologies that are not yet fully competitive with fossil fuel generators in the presence of the UK carbon price. However, as technology costs fall and carbon prices rise the number of technologies needing support will fall. Better planning and policy to ensure adequate risk-adjusted returns would improve the business case for investment in low-carbon power generation. Additional measures, if well designed, such as product standards, labelling or tax rebates for low-carbon goods and services, can help stimulate demand and promote uptake.

Policies will also need to account for competitiveness impacts and distributional concerns. This may require devising packages of measures that include revenue redistribution to compensate firms and households for possible energy price increases. Policy frameworks for innovation and change are examined in detail in the *New Climate Economy* report (2014).[75]

Business product innovations can also encourage the diffusion of low-carbon technologies. An example is Barclays Green Home Mortgages, which offer lower rates for the purchase of homes with high energy efficiency ratings.[76]

2.6. Resource productivity

The UK's average growth rate between 1830 and 2008 was 2 per cent per annum in real terms.[77] At this rate material living standards double every 35 years. Resource productivity was a key driver of this impressive growth story. Technologies, in particular steam, lighting and modern transport, delivered important gains in resource productivity that came through over many decades, with considerable benefits for living standards.

The low-carbon transition offers important opportunities for resource productivity, potentially on the scale of past periods of dynamic change. For example, there are great advances emerging in materials science and digitisation, which are driving resource productivity and reducing emissions, both through incremental improvements and disruption of existing industries.[78] This has the potential to further advance so-called 'weightless' assets like knowledge and to dematerialise existing resource-intensive goods and services. Cloud computing has substantially reduced overhead costs, energy use and related emissions. For example, for an office with 50 people, Google estimates IT energy use with internal email servers at 175kWh per person per year, compared with 2.2kWh when using Gmail.[79] Cloud

[73] Klenert D, Mattauch L, Combet E, et al. (2018) Making carbon pricing work for citizens. Nature Climate Change 8, 669-677. https://www.nature.com/articles/s41558-018-0201-2#Sec5
[74] New Climate Economy (2014) op. cit.
[75] ibid. Also see Klenert et al. (2018) op. cit. on carbon pricing design.
[76] Barclays Green Home Mortgages, https://www.barclays.co.uk/mortgages/green-home-mortgage/
[77] LSE Growth Commission (2013) op. cit.
[78] New Climate Economy (2014) op. cit.
[79] ibid.

technologies reduce the need for IT capital costs such as hardware and software expertise and equipment.

Digital systems are also changing behaviours in ways that can lead to reduced emissions. Ride-sharing apps reduce car use and congestion; banking apps reduce the need to travel to the bank. New applications and business models that encourage sharing and save time and resources are appearing almost daily, transforming the way we live. But encouraging resource productivity will require clear, credible and predictably flexible policy frameworks for market failures across the key policy areas discussed in this report. Resource productivity without a low-carbon transition could see rebound effects, where reduced costs increase demand, which increase emissions, energy use and waste.

Circular economy

Materials-related innovation and digitisation are also driving a resurgence in the concept of a 'circular' economy that radically improve resource productivity. Companies are discovering new growth opportunities from recycling, reusing and remanufacturing materials, by capturing lost potential revenues from resources that were previously wasted. For example, 11 companies worldwide, which together use over 6 million tonnes of plastic packaging per year, have committed to 100 per cent reusable, recyclable or compostable packaging by 2025. They include Mars, Marks & Spencer, PepsiCo and Unilever.[80]

Circular economy actions include recirculating a larger share of materials, reducing waste in production, light-weighting products and structures (for example, reengineering products using new designs and lighter materials), and extending the lifetimes of products. Digitisation is helping to reduce the costs of tracking complex supply chains and material flows, to optimise sharing business models, and to automate materials-handling in construction. A more circular economy would have many other benefits as well, such as reduced geopolitical risks, local job creation, less air pollution, and reduced water use.[81]

Growing the circular economy and ensuring circularity measures are cost-effective will require better policy and regulations. For example, product manufacturers lack incentives to enable high value recycling several steps later in the value chain. A higher carbon price would help on the margin, but capturing a large share of the opportunities will require tackling these barriers directly.[82] Governments can assist through regulatory change including better labelling of goods that contain reused materials and reducing taxes on goods with refurbished components. For example, VAT can discriminate against reuse if it re-taxes goods at every stage of recycling.[83] The Government's announcement of a consultation on a plastic tax, which would impose a levy on all packaging that does not include at least 30 per cent recycled material, is a positive move, but a more systemic approach is needed, in particular for hard-to-decarbonise industries.

There is great potential to develop a circular economy in a range of hard-to-decarbonise UK industries, including plastics, steel, cement and aluminium. Strong action in these energy-intensive industries would reduce emissions and the scale of the challenge of decarbonising materials production, and contain the cost of achieving a low-carbon industrial base.[84]

The Government can also act to increase consumer and business demand for sustainable, low waste and low-carbon products, which will increase market incentives for innovation and

[80] Ellen McArthur Foundation (2018) Eleven companies take major step towards a New Plastics Economy. News, 22 January. https://www.ellenmacarthurfoundation.org/news/11-companies-take-major-step-towards-a-new-plastics-economy

[81] Material Economics (2018) The Circular Economy: A Powerful Force for Climate Mitigation. https://europeanclimate.org/wp-content/uploads/2018/06/MATERIAL-ECONOMICS-CIRCULAR-ECONOMY-WEBB-SMALL2.pdf

[82] ibid.

[83] New Climate Economy (2014) op. cit.

[84] Material Economics (2018) op. cit.

diffusion of existing technologies. Government can do various things to stimulate demand, including 'nudging' people through information campaigns, taxes, for example on plastic bags, subsidies, and so on.

The growth opportunity from resource productivity gains in a circular economy is potentially immense. The Ellen MacArthur Foundation estimates[85] that a global circular economy could contribute US$1 trillion globally by 2025, while reducing greenhouse gas emissions at the same time.[86]

The potential benefits from a circular economy in the UK are also large, estimated in one study at £29bn (1.8 per cent) of GDP per year.[87] A scenario in a separate study indicates the creation of around half a million jobs (gross), reducing unemployment by around 102,000, and potentially offsetting around 18 per cent of the expected loss in skilled employment over the next decade; this scenario assumes an extensive expansion of circular economy activities, including more remanufacturing (dismantling, restoring and returning a used product to its original performance at least), more effective use of assets, for example leasing rather than consumption of new assets, and a higher incidence of repair.[88]

The London Assembly estimates the potential benefits of a circular economy for the capital to include a reduction in waste of 60 per cent by 2041, 12,000 new jobs by 2030, and £7bn of net benefits to the city's economy.[89] The Mayor of London would be well placed to support the success of the London Waste and Recycling Board's *Circular Economy Route Map*, by using the purchasing power of the Greater London Authority to engage business and encourage its participation in London's circular economy.[90]

2.7. Innovation – conclusions and recommendations

Innovation, rightly, is central within the UK's *Industrial Strategy* and *Clean Growth Strategy*. It is embedded throughout the former, with a diverse range of commitments to enhance the UK's innovation leadership.

Innovation in the 21st century should be directed towards clean technologies. It is important that relevant policy is coordinated and offers coherent incentives towards R&D in clean products and processes that will raise productivity for both inventors and adopters, and move the UK onto a sustainable growth path. A national innovation strategy is required that recognises and reflects the UK's commitment to a low-carbon economy and sustainable growth.

> **Recommendation 1: Bring together existing growth and green innovation strategies and ensure clean innovation is embedded across the economy. Part of this should be developing an understanding of sectors in which the UK has a comparative advantage and those with the greatest potential for productivity-enhancing spillovers, e.g. marine energy, nanotechnologies and carbon capture and storage.**

Effective support is needed to scale and shift R&D to low-carbon. This can potentially deliver far greater spillovers than for high-carbon R&D. The Government has committed to raising R&D investment to 2.4 per cent of GDP by 2027. In order to avoid the mistakes of the past and ensure more effective use of taxpayer resources, R&D funding and incentives should avoid trying to pick winners. Government funding and policies to incentivise business R&D could be

[85] Ellen McArthur Foundation (2018) What is a circular economy? https://www.ellenmacarthurfoundation.org/circular-economy/concept
[86] New Climate Economy (2014) op. cit.
[87] Voulvoulis N (2015) The circular revolution. Imperial College London/Veolia. https://www.veolia.co.uk/sites/g/files/dvc1681/files/document/2015/07/LIVING_CIRCULAR_BROCHURE.pdf
[88] Morgan J and Mitchell P (2015) Employment and the circular economy: Job creation in a more resource efficient Britain. WRAP and Green Alliance. http://www.wrap.org.uk/sites/files/wrap/Employment%20and%20the%20circular%20economy%20summary.pdf
[89] London Assembly Environment Committee (2017) Waste: The Circular Economy, September.
[90] ibid.

organised around research missions, with innovation spillovers, which are especially high in low-carbon technologies, a key metric for allocation of funding.

Recommendation 2: Develop UK research missions with support based on a range of metrics, including technology spillovers, rather than comparative advantage alone. This approach suggests high productivity benefits from R&D support for efficient aviation and marine technologies.

Policy support is needed to help shift and align expectations towards low-carbon innovation. Government should support efforts to bridge the 'valley of death' in technologies yet to become commercially viable like carbon capture and storage. It should also continue to support diffusion and uptake of renewable energy in the power sector through contracts for difference. In particular, an effective carbon price can increase the coherence of incentives for clean innovation.

Recommendation 3: Create a clear low-carbon price signal across the economy to replace the existing less efficient patchwork approach to reducing emissions.

Improvements in resource productivity are driven by individuals and businesses adopting cleaner and less resource-intensive products and processes. The interaction of new digital and low-carbon technologies is creating new possibilities for resource productivity.

Recommendation 4: Relevant UK government departments should work with hard-to-decarbonise sectors to create circular economy roadmaps to 2050 that include measures such as lower taxes on reused materials, and that are designed to deliver substantial increases in resource productivity and lower emissions.

3. Infrastructure

Summary

- Investment in sustainable infrastructure creates networks and connections that spur creativity, innovation and productivity. Social and institutional networks also depend on physical infrastructure. UK infrastructure is not fit for the 21st century due to years of underinvestment and poor planning. This constrains aggregate growth and regional development, and increases the potential for lock-in to high-carbon, resource-intensive structures and behaviours.
- Government action is needed to crowd in investment in sustainable infrastructure. With positive social returns on these investments and historically low real interest rates, there is strong evidence that they will pay for themselves in the long run.
- Effective institutional frameworks and sound policies are crucial for tackling network externalities and other market failures that hold back investment. They will help to ensure adequate risk-adjusted returns to attract private investment at both the construction and operating phases of sustainable infrastructure projects.
- Recent institutional reforms are moving in the right direction, but more can be done, including the establishment of a National Infrastructure Bank with a clear sustainability mandate, and stronger governance structures that enable greater coordination of infrastructure at the regional and city level.
- Scaling and shifting private finance for sustainable infrastructure investments will require systemic transformation of the finance sector. The Government can support and help to accelerate this transformation.

3.1. The importance of sustainable infrastructure and growth

Investments in physical infrastructure, such as transport, water, energy, telecommunications and housing, are essential for growth. The International Monetary Fund (IMF) finds that increased public infrastructure raises output in both the short and long term, particularly during periods of economic slack and when investment efficiency is high.[91] Evidence on specific types of infrastructure highlights its importance. For example, research on broadband has shown that a 10 per cent increase in the penetration rate in OECD countries from 1996 to 2007 resulted in a 0.9 to 1.5 per cent increase in annual per capita GDP growth.[92]

Infrastructure investments create networks that spur innovation and interact in important ways with other forms of capital such as human and natural. They define our cities and how we live. They tend to be large-scale and long-term in nature, with asset lifespans of 20 years or more. They usually construct a network, the social returns to which are greater than any private sector provider is willing to invest in (positive network externalities arise in cases where an increase in the number of users increases the value to each: the classic example being the telephone). These dynamic processes and long time frames lock the economy into long-run growth paths that define our future living standards.

[91] International Monetary Fund (2014) Is it time for an infrastructure push? The macroeconomic effects of public investment. In World Economic Outlook. October 2014: Legacies, Clouds, Uncertainties. IMF, Washington, DC. 75-114. http://imf.org/external/pubs/ft/weo/2014/02/

[92] Czernich N, Falck O, Kretschmer T, Woessmann L (2011) Broadband Infrastructure and Economic Growth. The Economic Journal 121 (552), pp.505-532. https://doi.org/10.1111/j.1468-0297.2011.02420.x

Infrastructure will also be underprovided by the private sector due to the presence of network externalities and heightened risks in both the construction and operating phases (for example, long operating timeframes increase risk from policy and technological change and other environmental factors). These characteristics make it inevitable that governments will play a vital role in planning, delivering and (to some extent) financing such projects.[93]

We must ensure that sustainability is integrated into all types of infrastructure. The physical infrastructure built in the coming decades will also lock in future emissions of greenhouse gases. The Treasury estimates that UK infrastructure (defined as energy, transport, waste and communications) accounts for over 50 per cent of total UK emissions today, and could account for around 90 per cent of the 2050 carbon budget, leaving very little room for emissions from other areas of the economy.[94] The Government must ensure that all future infrastructure is sustainable, resilient, flexible and consistent with decarbonisation objectives. The resilience of local infrastructure, in particular energy, transport and communication systems, will also define the risks to local communities and economies from the impacts of climate change, especially flooding.[95]

The national and regional growth benefits from sustainable infrastructure investments could be substantial and help the UK to avoid lock-in to a high-carbon and resource-intensive infrastructure pathway. Such investments can spur innovation and resource productivity in key economic systems such as energy and transport, reduce operating costs, provide comparative advantage and export potential, reduce air pollution and help achieve decarbonisation targets.[96] The Treasury estimates that application of today's level of sustainability best practice across the infrastructure sector could save up to 4 million tonnes of carbon dioxide equivalent ($MtCO_2e$) per year in construction and 20 $MtCO_2e$ per year from operations by 2050, representing a net benefit to the UK economy in 2050 of up to £1.46bn per year.[97] Accounting also for induced innovation and falling capital costs from the further development of low-carbon technologies, emissions savings and net benefits could be far higher.

In addition, sustainable, low-carbon infrastructure could lead to higher productivity and GDP than a high-carbon counterfactual, due to spillovers from the innovation it spurs (see Chapter 2), and the multiple benefits this infrastructure can provide, including reductions in fuel costs, air pollution and other savings.[98] The likely costs from future climate change impacts in a high-carbon scenario make the case for sustainable infrastructure even stronger. However, such infrastructure requires careful planning and often comes at greater upfront capital cost – these investments will not be costless and not all will pay off quickly for private investors. The appropriate metric for assessment of sustainable infrastructure projects is the 'final dynamic net economic cost', which requires us to consider the full range of costs and benefits, including the private and social returns to the upfront investments.[99] In most cases the *social* payback period will be fast and the dynamic benefits to the UK economy significant. However, because the payoffs come in the form of spillovers and network effects, assessment of projects needs to go beyond private returns, noting that social returns are hard to estimate with precision.

[93] Zenghelis (2016a) op. cit. LSE Growth Commission (2013) op. cit.
[94] See: HM Treasury (2013) Infrastructure Carbon Review. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/260710/infrastructure_carbon_review_251113.pdf
[95] Committee on Climate Change (2017a). Meeting Carbon Budgets: Closing the policy gap 2017 Report to Parliament. London: Committee on Climate Change. https://www.theccc.org.uk/publication/2017-report-to-parliament-meeting-carbon-budgets-closing-the-policy-gap/.
[96] New Climate Economy (2016) The Sustainable Infrastructure Imperative. Financing for Better Growth and Development. Global Commission on the Economy and Climate. https://newclimateeconomy.report/2016/wp-content/uploads/sites/4/2014/08/NCE_2016Report.pdf
[97] HM Treasury (2013) op. cit.
[98] New Climate Economy (2014) op. cit.
[99] See New Climate Economy (2014) op. cit. Chapter 5, Page 5. https://newclimateeconomy.report/2014/wp-content/uploads/sites/2/2014/08/NCE_Chapter5_EconomicsOfChange.pdf

Investment in sustainable infrastructure networks can support a dynamic transition to sustainable growth, which is illustrated through two examples: digital infrastructure and transport.[100]

Digital infrastructure

The UK is already a global leader in the digital economy, which is creating new jobs, innovative new low-carbon firms and future comparative advantages. But further investments are needed, beyond the £400 million Digital Infrastructure Investment Fund announced by the Government in 2017, if the UK is to maintain its leadership and fully realise growth opportunities. For example, one estimate indicates that creating an ultra-fast broadband network could add around £17bn to UK output by 2024 – but this will require further investment.[101]

Investment in an ultra-fast fibre broadband network, as recommended by the National Infrastructure Commission, would provide fast and reliable Internet access for all UK households and businesses, with many benefits for sustainable growth. If well managed – and this has proved a significant challenge for similar projects in other advanced countries[102] – the scale of the investment and learning-by-doing would lower the price of this technology over time. Further investment in this technology would then become increasingly attractive relative to conventional or alternative technologies, where gains from learning-by-doing and scaling are smaller.

As this investment is realised, engineers will learn how to install, connect and repair the technology more cheaply. Planning processes and institutions will be updated to better coordinate rollout across multiple regions. A new more reliable national network will be built and old, slow and unreliable internet service networks replaced.[103] Existing consumers and businesses will start to observe and realise the benefits and opportunities available, demand access to the network, change behaviour, and start to develop innovative and productive ideas, skills and low-carbon digital business models and applications. Digital ideas and innovation, made possible by an ultra-fast broadband network, will offer new solutions to the challenge of sustainable growth, including car sharing, reduced travel due to home working, video conferencing, home shopping, electricity grid management, smart electric vehicle charging, apps that control building climate, connected health and social care, and interactive home learning.

In other words, investment in this infrastructure network will complement and enable low-carbon investments. This will lead to further demand for the network. Very quickly, the economy could switch from an old internet technology network not fit for purpose in the 21st century, to another that supports investment, productivity and sustainable and inclusive growth.

Transport – electric vehicles

Policy to incentivise private sector investment in a national electric vehicle charging infrastructure could follow a similar path. This network will be underprovided by the private sector due to network externalities. Recent estimates indicate the number of charging points required in the UK by 2020 needs to increase by more than 80 per cent.[104] Therefore it would

[100] This dynamic process is often labelled 'endogenous growth theory', which argues that economic growth is driven by learning and innovation and the accumulation of ideas, skills and knowledge.

[101] National Infrastructure Commission (2018) National Infrastructure Assessment. https://www.nic.org.uk/wp-content/uploads/CCS001_CCS0618917350-001_NIC-NIA_Accessible.pdf

[102] Lessons from Australia's National Broadband Network project are starting to emerge. See, for example, Fildes N and Smyth J (2017) Australia counts the cost of broadband blunders. Financial Times, October. https://www.ft.com/content/5e709192-b983-11e7-9bfb-4a9c83ffa852

[103] The National Infrastructure Commission reports that full fibre networks provide several benefits relative to a copper network upgrade, including five times fewer faults than copper-based networks. These include operational savings, which would come through quickly, could amount to over £5bn from 2020 to 2050. National Infrastructure Commission (2018) op. cit.

[104] Emu Analytics (2018) A Sustainable Future: Preparing for Electric Vehicles. White Paper. May. https://s3-eu-west-1.amazonaws.com/open.emu-analytics.com/A+Sustainable+Future+-+Preparing+for+Electric+Vehicles.pdf

be sensible for the UK government to support its ban on new petrol and diesel cars and vans from 2040 by announcing a clear and credible regulatory and investment strategy for an interconnected electric vehicle charging infrastructure, which would unlock private investment in the network.

Expectations around the future of electric vehicles are currently muddled. A clear strategy would align and anchor expectations, which is crucial for aligning actions and reducing costs of acting.[105] It would encourage all levels of government to plan and remove barriers to private sector investment, for example by introducing smart charging equipment standards under the Automated and Electric Vehicles Act 2018.

Such a strategy would shift the incentives for research and development towards electric cars and away from combustion engine vehicles, leading to further cost reductions and improvements in electric cars. For example, it would encourage participation in the UK funding competition for electric vehicle innovations such as wireless charging.[106] It would encourage UK car makers to phase out production of internal-combustion-engine-only vehicles, as Sweden-based Volvo has already committed to doing by 2019. It would encourage households, businesses and government agencies to purchase electric and plug-in hybrid vehicles. The provision of a network, or clear expectations that a coherent policy framework is coming, would encourage people to buy electric vehicles, which would increase the demand for a larger network. Interconnected digital networks can ensure the network is 'smart', helping to avoid problems at times of peak electricity demand.

A tipping point could be reached very rapidly where the future of vehicle transport shifts permanently onto a new path; this is a dynamic process that goes far beyond the installation of charging points. It would open up new productivity and growth opportunities including for UK electric car and charging equipment manufacturers. With time it would also reduce fuel costs for UK consumers and businesses and reduce air pollution and greenhouse gases.

This path would of course likely require additional investment in low-carbon electricity generation capacity and grid infrastructure, but the benefits are potentially many times greater and would accrue quickly. The savings from lower outdoor air pollution alone, which causes around 40,000 early deaths and costs the UK economy around £20bn per year,[107] would be substantial.[108] Combining digital infrastructure with electric vehicles, by encouraging car-sharing and autonomous driving technologies, could also reduce congestion and wasted time. In London, time wasted in gridlock at traffic 'hotspots' could cost drivers £42bn by 2025.[109]

Not all infrastructure investments will be national-scale projects. It is important to bear in mind the tensions between 'jam-spreading' (spreading resources across locations resulting in too little for everyone) and the ability to build up successful hubs in the UK's leading cities that benefit from network effects.[110] Considering the regional and local level, infrastructure investment should be targeted at sectors and regions where productivity would be most responsive to higher capital intensity:[111] for example, high-speed electrified rail links between

[105] Clear, credible and publicly observable announcements, in particular in infrastructure investments, generate common and shared knowledge. Recent social psychology literature finds that this common and shared knowledge, where everyone knows that everyone knows the same things, anchors expectations, encouraging more people to come together and attempt 'risky coordination', which in this case will be electric vehicle investments that rely on this network. Thomas K, Haque OS, Pinker S and DeScioli P (2014) The Physchology of Coordination and Common Knowledge, Journal of Personality and Social Psychology, 107, 657-676.

[106] https://apply-for-innovation-funding.service.gov.uk/competition/198/overview

[107] Around 15 per cent of the current annual NHS budget.

[108] Royal College of Physicians (2016) Every breath we take: the lifelong impact of air pollution. Report of a working party. London: RCP. https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution

[109] INRIX Research (2016) Europe's Traffic Hotspots: Measuring the impact of congestion in Europe. November. http://www2.inrix.com/traffic-hotspots-research-2016

[110] Overman HG (2013) The Economic Future of British Cities'. CentrePiece Summer 2013. http://cep.lse.ac.uk/pubs/download/cp389.pdf

[111] Organisation for Economic Cooperation and Development (2017) OECD Economic Surveys - United Kingdom. Paris: OECD. http://www.oecd.org/eco/surveys/economic-survey-united-kingdom.htm

major northern cities, which are currently served mainly by congested roads and diesel-powered rail and bus services.

To maximise the effectiveness of local infrastructure projects, they should be accompanied by policies on housing and skills that help move areas into a 'virtuous cycle' of growth. Northern cities could also form the basis of hubs for sustainable infrastructure and develop a comparative advantage in high-tech low-carbon manufacturing. For example, renewable energy systems with storage could power electric vehicle manufacturing.

Below we set out the current state of the UK's infrastructure and its needs, before outlining the policy priorities for meeting those needs.

3.2. UK infrastructure today: underinvestment and future needs

It is hard to determine the 'right' amount of infrastructure investment. The Organisation for Economic Co-operation and Development (OECD) suggests the UK has significant infrastructure needs and that well targeted infrastructure spending would increase the capital stock and improve resource allocation in the economy, raising productivity.[112] UK public investment in infrastructure was one percentage point below the OECD average in 2017, suggesting underinvestment continues to be an issue.[113] The OECD reports that UK public infrastructure investment, as a share of GDP, fell below that of the United States, France, Canada and Switzerland in the late 1970s and has remained there since, and there is a perception that the UK's infrastructure assets are of lower quality than other G7 nations'.[114] The World Economic Forum *Global Competitiveness Report 2015–2016*[115] ranked the UK 24th out of 144 countries for the overall quality of its infrastructure, behind most of its main competitors.

There are persistent inadequacies in all areas of UK infrastructure, leading to detrimental impacts on growth. The first *National Infrastructure Assessment*, published in 2018 by the recently established National Infrastructure Commission, outlines many of these inadequacies and in particular notes that the delivery of UK infrastructure projects has been slow and uncertain. For example: the Mersey Gateway Bridge was proposed in 1994 and opened in October 2017; London's Crossrail was proposed in 1974 and will open in 2019.[116]

The LSE Growth Commission outlines several factors leading to weaknesses in major public sector capital projects. They include: vulnerability to policy instability – a lack of clarity about strategy, frequent reversals and procrastination over key decisions; difficulty in basing decisions on sound advice and assessment of policy alternatives built on unbiased appraisals (as opposed to being influenced by lobbyists); limitations of a planning system that does not properly share the benefits of development from implementing strategy and tackling problems; and a series of public sector accounting distortions.[117]

Consequently, much of the country's infrastructure has not kept pace with population growth, demand or advances in technology.[118]

[112] OECD (2017) op. cit.
[113] ibid.
[114] OECD (2015) Improving Infrastructure in the United Kingdom. OECD Economics Department Working Papers No. 1244. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ECO/WKP(2015)62&docLanguage=En
[115] Schwab K (2015) *Global Competitiveness Report 2015–2016.* World Economic Forum. http://www3.weforum.org/docs/gcr/2015-2016/Global_Competitiveness_Report_2015-2016.pdf
[116] National Infrastructure Commission (2018) op. cit.
[117] LSE Growth Commission (2013) op. cit.
[118] National Infrastructure Commission (2017a) National Infrastructure Commission report: Congestion, Capacity, Carbon: Priorities for national infrastructure. Consultation on a National Infrastructure Assessment. https://www.nic.org.uk/wp-content/uploads/Congestion-Capacity-Carbon_-Priorities-for-national-infrastructure.pdf

Sustainable infrastructure needs in the UK

The need for sustainable infrastructure is urgent yet policy uncertainty has impacted the UK National Infrastructure and Construction Pipeline. For example, planned renewable energy investments in 2020/2021 are around 95 per cent lower than in 2017/2018.[119] An appropriate pipeline of public infrastructure investments is a priority for governments investing in sustainable growth. While we focus on physical capital in this chapter, a sensible asset diversification strategy will also require investment in natural capital for air quality and biodiversity protection.[120]

The National Infrastructure Commission's first *National Infrastructure Assessment* (2018) sets out a long-term strategy for the UK's economic infrastructure from 2020 to 2050.[121] This can help to inform the development of an appropriate pipeline of sustainable investment projects. The Commission has released analysis – taking into account the UK's legal commitment to cut greenhouse gas emissions by at least 80 per cent on 1990 levels by 2050 – recommending the following infrastructure investments: nationwide full fibre broadband by 2033; half of the UK's power provided by renewables by 2030; three-quarters of plastic packaging recycled by 2030; £43bn of stable long-term transport funding for regional cities by 2040; preparing for 100 per cent electric vehicle sales by 2030; ensuring resilience to extreme drought; a national standard of flood resilience for all communities by 2050.

Analysis and assessments conducted by the Government's independent advisory body the Committee on Climate Change can also inform future sustainable infrastructure strategy and pipeline development.[122] In light of these assessments, the sustainable infrastructure pipeline should consider investment across four key areas, detailed further below:

- Low-carbon energy and carbon capture and storage
- Sustainable transport and connectivity
- Decarbonisation of households and industries
- Resilience and adaptation to climate change

Low-carbon energy and carbon capture and storage

The UK must achieve a balance of security, stability and affordability in energy supply, while at the same time complying with relatively stringent carbon targets.[123] Two-thirds of the UK's current power stations will close by 2030 and investment in new capacity is required to replace them.[124] At the same time, to meet its carbon targets, the UK needs to accelerate the deployment of low-carbon energy sources well beyond current plans.

According to the Committee on Climate Change, carbon emissions in the power sector will need to be reduced by 62 per cent between 2016 and 2030 in order to meet the fifth carbon budget.[125] This will require developing 50–70TWh of low-carbon energy sources above the commitments set out in the *Clean Growth Strategy*.[126] Moreover, it follows that as the share of intermittent renewable sources increases, further infrastructure investment will be needed to

[119] Benton D (2016) The UK's infrastructure pipeline. London: Green Alliance. http://www.green-alliance.org.uk/2016_UK_infrastructure_pipeline_analysis.php
[120] Estimates by Eftec (2015) indicate that additional investment for peatland, saltmarsh, wetland, woodland and marine improvements in England could require additional £4.4bn over 50 years. Eftec (2015) The economic case for investment in natural capital in England. https://www.cbd.int/financial/values/uk-naturalinvestments-2015.pdf
[121] National Infrastructure Commission (2018) op. cit.
[122] Committee on Climate Change (2017a) op. cit. Committee on Climate Change (2017b) An independent assessment of the UK's Clean Growth Strategy - From ambition to action. https://www.theccc.org.uk/wp-content/uploads/2018/01/CCC-Independent-Assessment-of-UKs-Clean-Growth-Strategy-2018.pdf. Committee on Climate Change (2017c) UK Climate Change Risk Assessment 2017 Evidence Report. https://www.theccc.org.uk/tackling-climate-change/preparing-for-climate-change/uk-climate-change-risk-assessment-2017/
[123] LSE Growth Commission (2013) op. cit.
[124] National Infrastructure Commission (2017a) op. cit.
[125] Committee on Climate Change (2017a) op. cit.
[126] Committee on Climate Change (2017b) op. cit.

provide additional interconnectors, energy storage, flexible generation, and smart demand-side response technology in order to increase the flexibility of the energy system.

There are also issues of interconnection between the UK, Ireland and continental Europe. Physical interconnections for energy transfer will require not only financial investment, but also strong international cooperation following Brexit, to ensure that infrastructure is used as efficiently as possible. In particular, it will be crucial that future agreements maintain the Single Electricity Market across the island of Ireland, as failure to do so could result in an expensive duplication of infrastructure and governance.[127]

Carbon capture and storage (CCS), the process through which a large fraction of carbon dioxide emissions from energy-intensive industry can be captured and prevented from entering the atmosphere, will be crucial for meeting the UK 2050 emissions reduction target of 80 per cent-plus. While the associated technologies are established, CCS is yet to be rolled out at scale in non-power industries,[128] and doing so will require careful planning and significant investment.

This investment in a low-carbon energy system must also consider the rapidly changing economics of the energy industry (see below).

Sustainable transport and connectivity

The UK's transport infrastructure is under pressure from a growing population and changing needs across the country. The 2006 *Eddington Transport Study*[129] suggested a potential cost of £22bn per annum in increased congestion by 2025 if the transport network did not keep up with demand. Significant emissions reductions are also required from the transport sector. According to the Committee on Climate Change these should be in the order of 44 per cent between 2016 and 2030.[130]

Investment in transport infrastructure is underway, especially in the rail sector, which can help to reduce emissions from road transport by reducing the number of car journeys. Major projects under development include the HS2 high-speed rail link, connecting Northern cities with London and the South, and East West Rail, which is re-establishing a rail link between Cambridge and Oxford. Other initiatives are being planned, including a Northern Powerhouse Rail (NPR) connection between Manchester and Leeds.

However, urban transport is often not joined up or integrated, and most cities have lacked the funding and powers to address this.[131] And while it is sensible for the Government to prioritise the highest value-for-money projects through the 'Five-Case model' used for project appraisal,[132] additional considerations need to be factored into the investment decision-making process. In particular this includes the potential for projects in some places to foster agglomeration (see Chapter 5) and productivity benefits,[133] and also environmental impacts and emissions reductions.

Electric vehicles are also being developed quickly, with the support of government. However, the scale of uptake required to meet the carbon budgets will involve a radical transformation

[127] Froggatt A, Wright G, Lockwood M (2017) Staying Connected Key Elements for UK–EU27 Energy Cooperation After Brexit. Research Paper. London: Chatham House. https://www.chathamhouse.org/sites/files/chathamhouse/publications/research/2017-05-10-staying-connected-energy-cooperation-brexit-froggatt-wright-lockwood.pdf

[128] There are a number of established international projects (see http://www.ccsassociation.org/why-ccs/ccs-projects/international-projects/ for a summary), but in the UK, CCS is largely at the proposal stage.

[129] HM Treasury (2006) The Eddington Transport Study: The case for action: Sir Rod Eddington's advice to Government. http://webarchive.nationalarchives.gov.uk/20090115123503/http://www.dft.gov.uk/162259/187604/206711/executivesummary.pdf

[130] Committee on Climate Change (2017a) op. cit.

[131] National Infrastructure Commission (2017a) op. cit.

[132] The Five Case Model comprises the following five components: Strategic, Economic, Commercial, Financial and Management Cases and is explained in detail in: HM Treasury (2015) Public sector business cases using the five case model: Updated guidance. Green Book supplementary guidance on delivering public value from spending proposals. http://www.ampres.com.mx/assets/green_book_guidance_public_sector_business_cases_2015_update.pdf

[133] OECD (2017) op. cit.

of transport modes and of the infrastructure supporting them. The Committee on Climate Change has called for 60 per cent of new cars and vans to be ultra-low emission by 2030, and potentially a complete shift of the fleet by 2050.[134] This would require a rapid and extensive development of the infrastructure network for electric charging (see 3.1 above).

To add to the points raised in section 3.1, carbon reductions can also be achieved through improvements in digital infrastructure, which can reduce the need for transport as well as increase economic productivity. Moreover, digital infrastructure will need to be able to support demands for other infrastructure sectors, such as 'smart' power technologies, and to improve their resilience, including through cyber security. According to the National Infrastructure Commission, substantial investment is still needed in this area. The UK was 17th out of 19 countries in 2015 for access to 'full fibre' connectivity. In Japan and South Korea, over 70 per cent of broadband connections are 'full fibre' compared with less than 2 per cent in the UK.[135] The UK also continues to lag behind in 4G availability.

Decarbonisation of households and industries

Housing supply has failed to keep pace with demand in the UK, and affordability has increasingly become an issue. There is also a lack of responsiveness of new infrastructure planning in relation to housing supply. The National Infrastructure Commission recommends better coordination between housing and infrastructure in order to enable infrastructure to be put in place in good time so that housing is not delayed.[136]

In this regard, it will be important for future developments to be consistent with sustainability and low-carbon objectives. This will require radical improvements in the energy efficiency of new buildings, strengthening energy standards for buildings and, ideally, reintroducing clear objectives for zero-carbon homes, which were cancelled in 2015. Innovations in building materials, for example the potential to reduce emissions from cement by blending 'clinker' with alternative materials, and other innovations in cement use and production techniques, have the potential to reduce building emissions without the need for carbon capture and storage.[137]

Furthermore, well planned, sustainable infrastructure has a key role to play in the decarbonisation of residential and commercial heat, an area where carbon reduction is particularly difficult to achieve, but is crucial to UK decarbonisation. The Committee on Climate Change highlights the need for a clear, combined strategy for energy efficiency and low-carbon heat, including the delivery of heat networks and heat pumps in cost-effective locations for both households and businesses.[138] Such a strategy should also test the possibility for low-carbon hydrogen to meet heat demand. Should hydrogen be considered a viable option, strategic planning and resources for the development of the related infrastructure will be required as soon as possible to reduce costs and scale up sustainable production.[139]

These investments will not be costless and not all will pay off quickly or even with time. However, in most cases the social payback period will be fast and the dynamic benefits to the UK economy significant.

[134] Committee on Climate Change (2017a) op. cit.
[135] National Infrastructure Commission (2017a) op. cit.
[136] ibid.
[137] Lehne J and Preston F (2018) Making Concrete Change: Innovation in Low-carbon Cement and Concrete. Chatham House Report, June. https://www.chathamhouse.org/sites/default/files/publications/2018-06-13-making-concrete-change-cement-lehne-preston-final.pdf
[138] Committee on Climate Change (2017a) op. cit.
[139] Burke J and Rooney M (2018) Fuelling the Future Hydrogen's role in supporting the low-carbon economy. Policy Exchange, September. https://policyexchange.org.uk/wp-content/uploads/2018/09/Fuelling-the-Future.pdf

Resilience and adaptation to climate change

Even if national and global efforts are successful at reducing carbon emissions, the effects of climate change will still be felt. Risks to communities and local economies from the impact of climate change will be closely linked to the resilience of local infrastructure, including housing and other buildings.

The UK Climate Change Risk Assessment warns that increasing frequency and severity of flooding from a range of sources represents the most significant climate change risk to the country's infrastructure.[140] This will include potential damages to coastal infrastructure, particularly ports, as well as to rail networks, bridges, electricity and communication cables and gas pipelines near coasts and rivers. Changes in temperature, rainfall and storm intensity and frequency will create additional pressures, in particular for rail, road and energy infrastructure. Moreover, increased risk of drought, together with a growing population, will place additional strain on the water infrastructure, exacerbating existing inefficiencies in the water network. The Environment Agency estimates that 3 billion litres of water are lost daily through leaks from pipes, equivalent to the amount of water used by more than 20 million people on an average day.[141]

The impacts of climate change could also be amplified by interdependencies between infrastructure sectors. For example, flood damage to the foundations of a bridge may cut off the rail line that uses that bridge and disrupt transport. As yet, understanding of these interdependencies is far from comprehensive, and responsibilities for assessing and managing the risks are unclear.[142]

Reducing the risk of disruption from extreme weather will be an essential part of infrastructure planning to minimise the costs associated with climate change and is one of the infrastructure investment priorities highlighted by the National Infrastructure Commission.[143] Coordinating action and information-sharing across climate adaptation policy and infrastructure planning will help ensure that future infrastructure is resilient and help address vulnerabilities.

3.3. Towards a strategy for sustainable infrastructure in the UK

The UK government has a history of leadership in tackling underinvestment in networks. For example, the Electricity (Supply) Act of 1926 created the Central Electricity Board, which constructed the UK's first national interconnected grid by 1938. Growth in the number of electricity users was the fastest in the world, increasing from around 750,000 in 1920 to 9 million by 1938.[144] The impact on growth and living standards was profound.

The UK can lead again, not only on broadband and electric vehicles, but also in energy, waste and other forms of transport networks such as trains and buses. This would trigger growth across the regions, moving the UK onto a more sustainable and inclusive growth path.

The multiple benefits from sustainable infrastructure – many of which would be felt immediately – combined with historically low interest rates, suggest that now is the time to invest. In addition, the UK government has room to borrow and there is strong *ex ante* demand for UK bonds (gilts), as reflected in their price.[145] Given low real interest rates, investing in sustainable

[140] Committee on Climate Change (2017c) op. cit.
[141] Environment Agency (2018) The state of the environment: water resources. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/709924/State_of_the_environment_water_rSe sources_report.pdf
[142] See also detailed recommendations by the Committee on Climate Change (2017a) op. cit.
[143] National Infrastructure Commission (2017a) op. cit.
[144] The Independent (2010) Power struggle: The National Grid was created to provide energy for all - but that's when the problems really began. 22 October. https://www.independent.co.uk/arts-entertainment/tv/features/power-struggle-the-national-grid-was-created-to-provide-energy-for-all-but-thats-when-the-problems-2113229.html
[145] Allen K (2018) Low gilt yields show there is room for higher UK public spending. Financial Times, 20 June. https://www.ft.com/content/7f3a1bf2-73b2-11e8-aa31-31da4279a601

infrastructure with a positive social return will have no net cost. In other words, the returns on well managed, carefully selected public sustainable investment assets could exceed their financing costs.[146]

Sustainable infrastructure investments will also complement investments in other assets, including human capital (see Chapter 4), and will facilitate diversification. Asset diversification maximises productivity, economic flexibility and the capacity to diffuse and absorb knowledge and innovation.[147] Complementarity and coordination within physical infrastructure is also important: transport needs energy; housing needs transport, communications, energy and water; energy requires water and digital smart grids. A joined-up strategy that encompasses these key and interdependent forms of infrastructure is essential. Together these investments can form a forward-looking risk-management and hedging strategy that will allow the UK economy to respond rapidly to the uncertainties and surprises that the coming transformation is likely to throw its way.

Failure to invest in infrastructure that is fit for the 21st century, and hence a failure to capture the benefits from the endogenous forces of transformation and sustainable growth, could continue to hold back UK productivity growth in the future. Road, railway and airport congestion will reduce productivity in factor and product markets; energy supplies could become unreliable and more costly,[148] hurting output and competitiveness; communications could be inadequate, reducing low-carbon business opportunities in the new digital economy; human capital will be less productive as poor education, hospitals, housing infrastructure and air pollution reduce productivity and lead to poor health outcomes; water supply and flood defences will be unable to cope with the risk of extreme floods and drought; and the private sector will fail to invest, placing additional burden on scarce public finances. The UK's stock of assets across all dimensions, physical, knowledge, human and natural, will fall further behind. This will leave the nation less prepared to respond to the great economic and social transformation that is already underway.

The UK therefore faces a stark choice that will impact the lives and living standards of its citizens for decades to come. The Government has a central role to play in these infrastructure investment choices. It has led on infrastructure in the past during periods of rapid change and it is time to lead again. That leadership must start by strengthening institutions and policies to overcome weaknesses in UK sustainable infrastructure planning, financing and delivery.

A good place to start is with existing strategies. The *Industrial Strategy White Paper* and *Clean Growth Strategy* both recognise the importance of sustainable infrastructure. However, these two publications are not well coordinated. For example, details of investments in a national charging infrastructure do not appear consistent across the reports. The *Industrial Strategy White Paper* mentions a new £400 million charging infrastructure investment fund. The *Clean Growth Strategy* mentions investing an additional £80 million to support charging infrastructure deployment, alongside £15 million from Highways England.

[146] Zenghelis D (2016b) Building 21st century sustainable infrastructure, time to invest. Part 1. Grantham Research Institute on Climate Change and the Environment. http://www.lse.ac.uk/GranthamInstitute/publication/building-21st-century-sustainable-infrastructure-part-1-time-to-invest/

[147] Recent research suggests that a prerequisite for a robust and viable economic transformation is institutions and incentives that facilitate asset diversification. See: Peszko G, van der Mensbrugghe D, Golub A, et al. (2018) Crossroads: Climate strategies of fossil fuel-dependent countries, managing risks and harnessing opportunities of global low-carbon transition through diversification and cooperation. The World Bank, May 21.

[148] Deploying energy flexibility technologies alone could save the UK £17- £40bn from now to 2050, by reducing the required expenditure in low-carbon generation, peaking plant and network reinforcement. Carbon Trust (2016) An analysis of electricity system flexibility for Great Britain, with Imperial College London. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/568982/An_analysis_of_electricity_flexibility_for_Great_Britain.pdf

3.4. Policies to unlock productive and sustainable infrastructure investments

The LSE Growth Commission (2013) proposed a new institutional architecture for infrastructure to provide better strategy, delivery and funding of major infrastructure, in particular in transport and energy. This architecture could reduce the policy instability that has led the UK's infrastructure to be poor in comparison with other countries and which is holding back growth. The recent establishment of the National Infrastructure Commission and the Infrastructure and Projects Authority have been welcome developments, consistent with the LSE Growth Commission's recommendations, but much more needs to be done.

There are several crucial areas the UK government must get right if it is to deliver on the advice of institutions like the National Infrastructure Commission and the Committee on Climate Change, and deliver sustainable infrastructure networks that are fit for purpose in the 21st century.[149] These areas of focus include institutions for policy stability and credibility; for reducing the risk of stranded assets, in particular in energy markets, which are already undergoing massive transformation; and for catalysing public and private sustainable finance. We discuss these in turn below.

Increasing policy stability and credibility

Sustainable infrastructure investments are mostly made in heavily regulated policy-driven sectors such as energy and transport, where government defines the size, profitability and scope of the sustainable infrastructure market. As such they will require a stable and credible policy and regulatory environment to ensure adequate risk-adjusted returns to attract private investment.[150]

Policy-induced uncertainty has been high in the UK, in part the result of unexpected changes to policies due to fiscal austerity and concerns around industrial competitiveness. Unplanned changes to the subsidy regime for renewable energy and energy efficiency, the scrapping of the zero-carbon homes commitment, freezing of the carbon price floor, and cancelling funding for the carbon capture and storage commercialisation programme have undermined confidence in government policy and deterred investors.[151]

This policy uncertainty has reduced the country's attractiveness to renewable energy investors, according to the Ernst & Young Renewable Energy Country Attractiveness Index, although it is now recovering ground (see Figure 3.1). The UK's downgrading was largely attributed to the closure of the Department of Energy and Climate Change (DECC) and the approval of Hinkley Point C nuclear power station, combined with a lack of plans for wind and solar energy and the uncertainty caused by Brexit. These events combined to raise concerns about the commitment of the Government to climate policy and clean energy.[152]

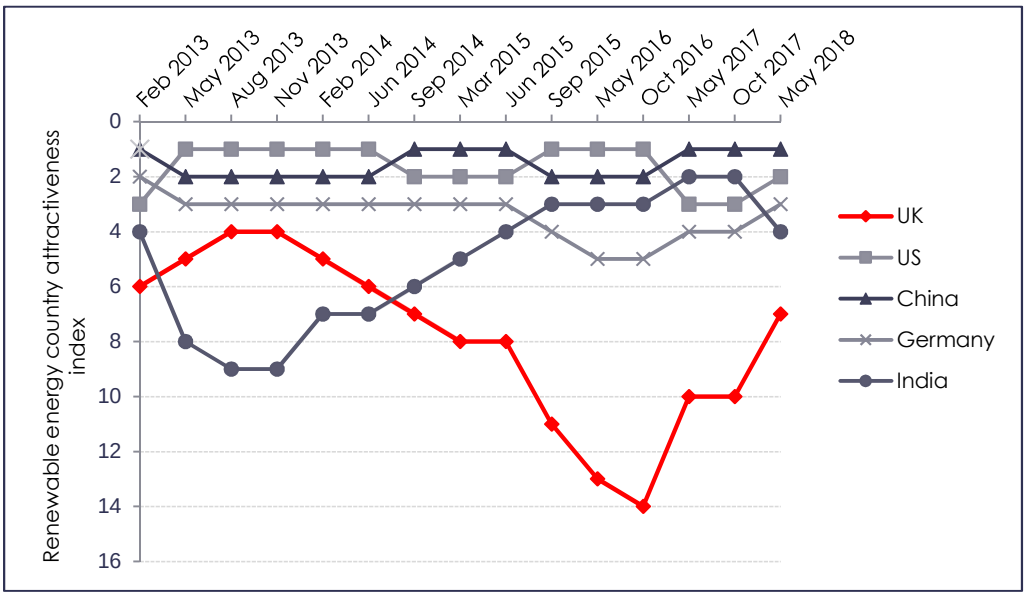
[149] These actions have been comprehensively examined in detail in Zenghelis (2016a) op. cit.

[150] Zenghelis (2016a) op. cit. House of Commons Energy and Climate Change Committee (2016) Investor confidence in the UK energy sector. https://www.publications.parliament.uk/pa/cm201516/cmselect/cmenergy/542/54207.htm.

[151] Zenghelis (2016a) op. cit. Clark P (2015) UK energy policy under fire as Drax quits carbon-capture project. The Financial Times, 24 September. https://www.ft.com/content/0290c57e-62da-11e5-a28b-50226830d644 Oldfield P (2015) UK scraps zero carbon homes plan. The Guardian, 10 July. https://www.theguardian.com/environment/2015/jul/10/uk-scraps-zerocarbon-home-target

[152] EY (2016) Renewable Energy Country Attractiveness Index. Issue 48, October. https://www.ey.com/Publication/vwLUAssets/EY-recai-issue-48-october-2016/$FILE/EY-recai-issue-48-october-2016.pdf

Figure 3.1. Renewable Energy Attractiveness Index (2013–2018): UK and top rank countries



Source: Authors' calculations based on Ernst & Young Renewable energy country attractiveness index.[153]

Policy uncertainty in the UK also stems from limitations in the planning system, which does not adequately share the benefits of proposed infrastructure developments with the communities that are affected by them.[154] The result has been chronic 'NIMBY-ism', where local communities and politicians veto or delay projects that would have economic or environmental benefits far beyond the local area. This has happened a lot in the case of onshore wind proposals in particular.

People value natural landscapes and are willing to pay to preserve them. A simple estimate based on existing assessments suggests the visual impact of onshore wind energy could equate to between 0.3p and 4p/kWh.[155] These costs need to be factored in when considering the location of a new wind farm installation, on top of technical and financial considerations. There is also a need for a more consultative process, involving communities early on, and designing creative mechanisms (over and above monetary compensation) in order to share the gains of development and increase the acceptability of onshore wind projects, including through information campaigns and awareness-raising of the benefits of renewable energy, including emissions reductions, new local jobs and reduced air pollution.

Strong institutions can increase the quality, stability and credibility of policy, which can steer expectations and build trust in private investors. This will reduce the risk premium they attach to low-carbon projects. The UK has led in the creation of strong, independent institutions that are free from short-term political interference. For example, the Climate Change Act 2008 sets a series of five-year emission reduction budgets (the 'carbon budgets'), based on a long-term target for 2050. There are numerous examples in other areas of economic policy: the Bank of England assumed operational independence in setting monetary policy in 1997, and the Office for Budget Responsibility (OBR) provides independent analysis of the UK's public finances. Along these lines, the independence of the National Infrastructure Commission from government could be strengthened further.

[153] EY (n.d.) Renewable Energy Country Attractiveness Index, 2013-2018. https://www.ey.com/gl/en/industries/power---utilities/ey-renewable-energy-country-attractiveness-index-library-2018
[154] LSE Growth Commission (2017) op. cit.
[155] Bassi et al. (2013) op. cit.

Additional institutional reforms that could promote both public and private investment in sustainable infrastructure include: the Treasury adopting fiscal rules, with OBR support, that allow for borrowing to invest over the economic cycle for projects expected to provide positive financial returns; adopting natural capital accounting; and devolving decision-making and financing to the regional or local level where many of the benefits are readily observable and as local officials are more likely to be held accountable.[156] Moreover, there is room for improving capacity to coordinate a range of investments across housing and infrastructure at the local and national level.

More broadly, to put industrial strategy on an equal footing with some other areas of economic policy, the LSE Growth Commission proposed in 2017 stronger institutions governing the Government's new *Industrial Strategy*, to help create a longer-term and independent growth strategy, joining up all key stakeholders across national and regional government.[157] Since then, government has established a new Industrial Strategy Council. Given that clean growth is one of the Government's four cross-cutting 'Grand Challenges',[158] this institution should promote a consistent emphasis on sustainable growth across policy areas.

Effective planning for technological change

Economies change. Resources are constantly re-allocated from sector to sector, people are reskilled and retrained, capital depreciates and is replaced. However, every so often, change is so large or so sudden (or both) that substantial economic assets are rendered stranded (the risk of stranding of human capital is discussed in Chapter 4). While not all stranding will be possible to predict and plan for, risks are higher in goods and services that rely on integrated networks, especially mass transport, communication and energy. This has happened in the UK before: for example, the stranding of the UK canal network as railways were built.[159]

The low-carbon energy transition is already well underway and future change is likely to be rapid, extensive and hard to predict, increasing the risk of asset stranding. Renewable energy costs continue to fall faster than expected, with wind and solar increasingly cost-competitive with all other alternatives, and battery and smart grid technologies are developing rapidly.[160] At the same time, reliance on subsidies to drive progress in renewable deployment is falling and is being replaced by auctions that are driving innovation and efficiency.[161] As a result, project developers are now in a global race to build projects of ever increasing size, with major utilities transforming their business models, including through international acquisitions, to achieve economies of scale in their renewable portfolio operations.[162]

The economics of the energy industry are being transformed by technological change, and a global tipping point for renewable energy is close, but it is hard to predict exactly when it will happen.[163] At such a profound point in the energy transition, the risk of stranded assets is high if government fails to plan carefully. To reduce this risk, the UK government must ensure that all future energy infrastructure projects are consistent with its decarbonisation targets, including the fifth carbon budget under the Climate Change Act and its Paris Agreement commitments,[164] and reflect the rapid transformation of the energy industry and its changing

[156] Zenghelis (2016a)
[157] LSE Growth Commission (2017) op. cit.
[158] Along with artificial intelligence and data, an ageing society and the future of mobility. See https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges
[159] Zenghelis D, Fouquet R and Hippe R (2018) 'Stranded assets: then and now', in Caldecott B (ed.) Stranded Assets and the Environment: Risk, Resilience, and Opportunity. Routledge.
[160] The cost of offshore wind in the UK has declined by more than half in three years. See Arie S (2018) Renewables are primed to enter the global energy race. Financial Times, 13 August. https://www.ft.com/content/4079d82a-9e1f-11e8-b196-da9d6c239ca8
[161] Auctions may still result in strike prices that are above the cost of conventional energy sources, so there may still be a subsidy.
[162] Arie (2018) op. cit.
[163] Beinhocker E, Farmer JD, Hepburn C (2018) The Tipping Point: How the G20 Can Lead the Transition to a Prosperous Clean Energy Economy. INET Oxford Working Paper No. 2018-09. https://www.inet.ox.ac.uk/library/view/963
[164] Considering the Paris Agreement alone, even if all current plans and construction projects for additional coal and gas power generators globally were suspended today, between 10 and 20 per cent of existing operating capacity worldwide would be stranded if we are to meet the

economics. This means that all future investments must avoid locking into high-carbon capital assets, as these are highly likely to render the UK uncompetitive or require scrapping or costly retrofitting.

With this in mind, there is a risk of overexposure to gas assets. Electricity generation from gas is increasing strongly (29 to 42 per cent in 2015–2016) as coal-fired power is phased out (from 40 to 9 per cent, 2010–2016).[165] Forty combined cycle gas turbine (CCGT) power plants are in operation across the UK, with a capacity of over 30GW (close to 35% of total capacity). About a third of this generation capacity is relatively new, operating for less than 10 years, and another third is less than 20 years old.[166]

Recent analysis shows that, unless combined with carbon capture and storage, all the UK's current gas assets must be steadily phased out over the next 35 years and almost entirely removed by 2050 in order to meet the UK's decarbonisation targets.[167] This means the use of gas in electricity generation would need to drop by approximately 60 per cent in the 2020s. The rapid transformation of energy industry economics will also influence the rate of decline. Government planning institutions will need to take these risks into account. While investors could still be incentivised to build new CCGT, for example via a capacity market, where the government pays generators to invest in new capacity (or maintain existing capacity) to ensure adequate supply of electricity, the risks of asset stranding are high. Alternatively, CCS will need to be developed urgently to retain gas in the power generation mix, but policy to progress CCS has been cancelled and the changing technologies and economics of the industry may see gas retired anyway.

The risk of overexposure to high-carbon assets applies on the fuel production side as well as to electricity generation. Development of a shale gas industry and related infrastructure must consider the high risk of stranding, and the risks are high if the UK meets its decarbonisation targets and CCS does not progress, as this would imply no role for gas.

Crowding in infrastructure finance

The role of financial institutions

The European Investment Bank (EIB) and the Green Investment Bank (GIB) (now Green Investment Group, GIG) have both played important roles in infrastructure finance in the UK, most significantly by undertaking due diligence on complex and 'first of a kind' projects,[168] but the extent to which they can continue to do so is unclear.

The EIB's continued role in the UK after Brexit is uncertain and dependent on the UK's future relationship with the EU. The EIB has provided liquidity in large projects and credit guarantees across Europe,[169] and the UK has been one of the largest subscribers of capital, having provided around €39bn (6 per cent of the total) since 2013. Moreover, the UK is one of the largest recipients of funding.[170] Between 2012 and 2016, the EIB lent €31.3bn to the UK, half of

Agreement's goals. Pfeiffer A, Hepburn C, Vogt-Schilb A, Caldecott B (2018) Committed emissions from existing and planned power plants and asset stranding required to meet the Paris Agreement. Environ. Res. Lett. 13, 054019.

[165] In 2016, there was a switch in the main sources of electricity generation away from coal to gas generation. Generation from coal fell by 60 per cent, as a number of plants closed or switched to burning biomass; gas rose by 46 per cent. Department for Business Energy and Industrial Strategy (2017) Digest Of United Kingdom Energy Statistics 2017 – Main Chapters and Annexes. London: BEIS. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/643414/DUKES_2017.pdf

[166] ibid.

[167] McGlade C, Pye S, Ekins P, Bradshaw M, Watson J (2018) The future role of natural gas in the UK: A bridge to nowhere? Energy Policy. Elsevier Ltd, 113(January). doi: 10.1016/j.enpol.2017.11.022

[168] National Infrastructure Commission (2018) op. cit.

[169] European Investment Bank (2017a) Guarantees & Securitisation. http://www.eib.org/products/blending/guarantees/index.htm. Business, Energy and Industrial Strategy Committee (2017) Leaving the EU: negotiation priorities for energy and climate change policy (Fourth Report of Session 2016–17). London: House of Commons. https://publications.parliament.uk/pa/cm201617/cmselect/cmbeis/909/909.pdf

[170] European Investment Bank (2017b) EIB confirms £5.5bn backing for investment across the UK in 2016. Press release, 24 January. Luxemburg: EIB. http://www.eib.org/infocentre/press/releases/all/2017/2017-010-eib-confirms-gbp-5-5-billion-backing-for-investment-across-the-uk-in-2016.htm

which was for infrastructure. The largest investments have been for energy projects, at €9.3bn.[171]

The EIB has also supported regional growth. For example, it has invested almost £2bn over the last 20 years in a range of public and private sector projects in Wales.[172] Overall, EU funds and EIB loans account for around £2.5bn of the UK's energy-related infrastructure, climate change mitigation, and R&D funding per year.[173]

Post-Brexit, it might be possible for the UK to continue benefitting from EIB funding through a special relationship with the EU or through a new offshoot of the EIB focused on international investment.[174] However, should access to EU funding cease, the GIG, British Business Bank, UK Guarantee Scheme and National Infrastructure Fund could potentially make up some of the difference.[175]

To date, the GIB/GIG has directly invested £2.8bn and mobilised a further £8bn in private capital, and its Offshore Wind Fund has made it the largest renewable energy fund in the UK.[176] Nevertheless, its contributions to all low-carbon projects was around £700m in 2016, compared with EIB financing for renewable energy projects of £1.2bn in that year. The GIG would need to triple its annual outlay to cover the gap from loss of EIB funding, or even more if other types of infrastructure, such as water, are taken into account.[177] Given that current levels of investment are not sufficient to meet the UK's long-term decarbonisation targets, the GIG will need to scale up significantly to replace lost EIB funding and close the investment gap.[178]

Against this backdrop, there are concerns as to whether the GIG can remain a leading investor in green infrastructure following its privatisation. The new owner plans to sell some assets, but denies large-scale asset-stripping.[179] Any impact will depend on what happens to the sale proceeds. For example, selling more mature projects to re-invest in earlier-stage technologies could be desirable and crowd in new capital, whereas distributing the profits as dividends to shareholders, for example, would not.[180] The GIG could also choose to operate more internationally, rather than continue to focus investment in the UK.

Furthermore, it is unclear if the GIG will continue to be able to crowd in other investment by providing expertise and reassurance on larger or riskier projects, or if it will be competing with other private sector actors for similar projects. At this stage, the privatisation is too new to offer sufficient data from which to draw conclusions. However, the Government should carefully monitor whether the special share arrangement is fulfilling its purpose, and whether larger or riskier investments need government support by other means.[181]

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[171] Froggatt et al. (2017) op. cit.

[172] Welsh Government (2017) Mark Drakeford meets European Investment Bank to discuss infrastructure investment opportunities in Wales. Press release, 9 February. https://gov.wales/newsroom/finance1/2017/58902382/?lang=en

[173] Froggatt et al. (2017) op. cit.

[174] Jones M, Guarascio F (2017) European Investment Bank plans internationally-focussed offshoot. Reuters, 6 December. https://uk.reuters.com/article/uk-eu-eib-exclusive/exclusive-european-investment-bank-plans-internationally-focussed-offshoot-idUKKBN1E02XE. Stone J (2017) EU investment bank 'will owe Britain money for 35 years after Brexit'. The Independent, 27 October. http://www.independent.co.uk/news/uk/politics/brexit-european-investment-bank-eib-britain-alexander-stubb-a8023516.html

[175] Matikainen S (2017a) Financing low carbon growth and innovation in the UK Industrial Strategy. London: Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy. http://www.lse.ac.uk/GranthamInstitute/publication/financing-low carbon-growth-and-innovation/

[176] Infrastructure and Projects Authority (2016) National Infrastructure Delivery Plan Funding and Finance Supplement. London: Infrastructure and Projects Authority. https://www.gov.uk/government/ publications/national-infrastructure-delivery-plan-fundingand-finance-supplement

[177] Matikainen (2017a) op. cit.

[178] Blyth W, McCarthy R, Gross R (2015) Financing the UK power sector: Is the money available? Energy Policy, 87, pp. 607–622. doi:10.1016/j.enpol.2015.08.028

[179] Martin B (2017) Macquarie denies asset stripping plan as it buys Green Investment Bank for £2.3bn. The Telegraph, 20 April. https://www.telegraph.co.uk/business/2017/04/20/green-investment-bank-sold-macquarie-23bn/

[180] E3G (2017) Investigation finds Australian bank Macquarie could be poised to asset strip Green Investment Bank. Press release, 10 January. https://www.e3g.org/news/media-room/investigation-finds-australian-bank-macquarie-could-be-poised-to-asset-stri

[181] Matikainen S (2017b) Consultation response: House of Commons Environmental Audit Committee's 'Green finance' inquiry. London: Grantham Research Institute on Climate Change and the Environment and Centre for Climate Change Economics and Policy. http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/environmental-audit-committee/green-finance/written/75730.html

Other options to replace EIB funding could be further use of the UK Guarantees Scheme (UKGS) and the new National Productivity Investment Fund (NPIF). The UKGS aims to boost project finance by offering government guarantees on nationally significant infrastructure projects.[182] By 2016 it had issued guarantees for projects worth £4bn and provided advice to another 24 projects worth £32bn.[183] The £23bn earmarked for the NPIF could also help contribute to filling the green investment gap, with some of it already allocated to transport and R&D.[184] Ultimately, the surest way to leverage private finance is to improve the risk return profile of low-carbon investment. This requires clear and credible long-term policy as well as improvements in the design of financing instruments.

A National Infrastructure Bank

Existing institutions may still not have the capacity or the expertise to raise the significant amount of financial resources required for future sustainable infrastructure in the UK. Given constraints on public spending in the fiscal remit, private finance will be crucial for meeting the UK's infrastructure needs.

As stated above in the discussion on institutions for policy credibility, a new, independent and dedicated institution should be created, such as a National Infrastructure Bank, to provide transparency and credibility around finance for sustainable infrastructure. This institution could align expectations on the future growth path and avoid a muddled path where the UK invests in both inefficient high-carbon technologies and sustainable infrastructure. It could also share risk through a range of financing instruments, including loan guarantees and first loss insurance facilities, and work with international institutions. It would need an explicit sustainability mandate, which could take the form of an internal carbon price or other measures. A new National Infrastructure Bank was recommended by the LSE Growth Commission in 2013 and is an option being explored by the National Infrastructure Commission.[185]

Transforming the financial system

A National Infrastructure Bank, together with coherent national policy (indeed, the mere presence of the former makes the latter more credible, insofar as the state acquires 'skin in the game') will help align expectations and crowd in private finance for sustainable investment, but it is only part of the solution. Scaling and shifting private sector finance to sustainable investment will require a more systemic approach, including transformation of the financial system. Recent initiatives and reports have examined the system transformation required, including the UNEP Inquiry of 2015 (see Box 3.1) and the New Climate Economy report of 2016. The Government is taking action, including by establishing a Green Finance Taskforce.[186] This body is an alliance of individuals and organisations tasked with providing recommendations for delivery of the public and private investment needed to meet the UK's carbon budgets and related goals, and to maximise the UK's share of the global green finance market.[187]

[182] Blyth et al. (2015) op. cit.
[183] Infrastructure and Projects Authority (2016) National Infrastructure Delivery Plan Funding and Finance Supplement. London: Infrastructure and Projects Authority. https://www.gov.uk/government/publications/national-infrastructure-delivery-plan-funding-and-finance-supplement
[184] Matikainen (2017a) op. cit.
[185] National Infrastructure Commission (2017a) op. cit.
[186] UNEP Inquiry (2015) The Financial System We Need: Aligning the Financial System with Sustainable Development. The UNEP Inquiry Report. UNEP Inquiry into the Design of a Sustainable Financial System. Nairobi: United Nations Environment. http://unepinquiry.org/publication/inquiry-global-report-the-financial-system-we-need. New Climate Economy (2016) op. cit.
[187] Green Finance Taskforce (2018) Accelerating Green Finance. http://greenfinanceinitiative.org/wp-content/uploads/2018/08/Report-of-the-Green-Finance-Taskforce.pdf

Box 3.1. Priorities for transforming the financial system

The UN Environment (UNEP) Inquiry into the Design of a Sustainable Financial System, launched in 2014, examined transformation of the financial system. It identified five priorities: reallocation of private finance to low-carbon investments through green bonds and green banking; enhancing systemic risk management frameworks to account for macro-prudential or systemic risks in the financial system; clarifying the core responsibilities of financial institutions under fiduciary duty or legal liability to account for environmental, social and governance (ESG) factors; better reporting and disclosure across the first three actions; and harmonising and linking various transformation initiatives across countries to achieve coherence at the systems level.

Actions are accelerating in the UK, including through the Task Force on Climate-related Financial Disclosures (TCFD), which has developed recommendations for voluntary climate risk disclosures. This is being backed up by the Climate Disclosure Project (CDP), which will integrate the TCFD within its climate change questionnaire this year.

Sources: New Climate Economy (2016); UNEP Inquiry (2015)

Much of the private finance for the construction stage of sustainable infrastructure projects will come from corporate finance (companies' balance sheets) and project finance. Project finance uses a separate special purpose vehicle (SPV) entity to raise funds through debt and equity. Both corporate and project finance rely largely on debt financing through syndicated bank loans. This allows banks to develop special expertise to monitor the early stages of projects, which are higher risk and may require intervention in response to unforeseen developments. To unlock private finance for the construction phase of sustainable infrastructure projects, UK banks will need to strengthen their expertise in sustainable infrastructure lending, as the Government strengthens institutions and policies. This should include an internal carbon price across all business units that lend to infrastructure projects.

Institutional investors, including banks and insurance companies, pension funds and sovereign wealth funds, are potentially an important source of sustainable finance but currently allocate only a small share of their investments to infrastructure. They face many of the same constraints discussed above, but also legal constraints on the types of assets they can invest in and the challenge that infrastructure is not listed as an asset class. However, even in the absence of all these constraints, their scope to redirect funds to sustainable infrastructure will be limited due to asset diversification requirements.[188] Where they do have scope to invest, their finance is more suited to the operating stage of projects when underlying cash flows are more stable and reliable, and look more like a fixed-income security. Green bonds and other instruments can be used to refinance once the project is operating, freeing up public capital for new projects. But as discussed, the potential for private finance is highly dependent on the Government establishing clear strategies and plans, and strong institutions and policies.

3.5. Infrastructure – conclusions and recommendations

Sustainable infrastructure will deliver and connect environments where people can innovate, learn and be more productive. It will also be more resilient, reduce emissions and can deliver multiple other benefits, including reductions in fossil fuel use. Delivering sustainable infrastructure will require systemic change across the public and private sectors.

The *Industrial Strategy White Paper* and *Clean Growth Strategy* both recognise the importance of sustainable infrastructure but are not well coordinated. The *Industrial Strategy* positions the low-carbon economy as a discrete economic sector, with potential to outperform the rest of the UK economy.

[188] New Climate Economy (2016) op. cit.

Recommendation 5: Develop a coherent strategy to drive sustainable infrastructure investment across the economy, which is consistent with the National Infrastructure Commission's plans and the UK's decarbonisation targets. This should bring together the *Industrial Strategy*, the *Clean Growth Strategy*, and incorporate the additional efforts required to meet the fourth and fifth carbon budgets, and the broader environmental goals set out in the Department for Environment, Food & Rural Affairs' *25 Year Environment Plan*.

The UK has a history of leadership in overcoming barriers to the construction of key public networks, such as a national electricity grid. It can lead again by investing in sustainable infrastructure projects that can set off a dynamic process of sustainable growth.

Recommendation 6: Develop and publish a pipeline of clean and sustainable infrastructure investments. The pipeline would contribute to meeting the UK's 2050 decarbonisation targets, avoid locking into capital assets that could render the UK uncompetitive or require scrapping or retrofitting, and be consistent with the recommendations of the National Infrastructure Commission and other relevant statutory bodies.

The UK needs a clearer strategy for strengthening key institutions and policies for sustainable infrastructure investment. The aim is to provide a stable and credible, yet flexible, policy and planning environment that fosters private sector investment. This will align expectations on the future growth path and avoid investment in inefficient high-carbon infrastructure.

Recommendation 7: Establish a new National Infrastructure Bank, with an explicit sustainability mandate, that can signal both the scale and type of sustainable finance needed from the private sector and employ a range of financial instruments to help 'crowd in' private finance.

The UK needs a much stronger governance structure for infrastructure – joining up local authorities, and increasing the powers of city regions to allow progress at the regional level.

Recommendation 8: Develop a governance structure for infrastructure that joins up and empowers local authorities, enabling coordination of infrastructure investments across regions and cities, in particular across housing and related infrastructure. Priority should be given to regions where productivity would be most responsive to higher capital intensity, and where network and agglomeration effects can be exploited to support low-carbon innovation hubs.

4. Skills

Summary

- Enhancing skills and human capital is crucial for achieving sustainable growth. As the low-carbon transition combines with emerging technologies, the nature of work and skills needed could change radically and rapidly, with the risk of hardship for workers and constraints on growth.
- A key role for government is to create a strong institutional framework and sound policies for flexible labour markets and a 'just transition' for workers during a process of creative destruction whereby the demand for some existing occupations or skills might disappear.
- Universities, colleges and schools have key roles to play in equipping workers with the skills and adaptability to deal with and embrace inevitable change throughout their lives, and in maximising their potential.
- Sound policies can limit the harm to people's lives and livelihoods from job displacement. Investors and financial markets, as stewards of assets and allocators of capital, can also make a valuable contribution to achieving a just transition.
- Place-based policies will be necessary in regions likely to face higher adjustment costs, such as South Wales and Northeast England. Working together with local decision-makers, education institutions in these regions will be a crucial part of delivering a just transition for workers.
- Effective policymaking requires better data on jobs in the clean and sustainable economy. There is currently no standardised approach to or definition of low-carbon jobs.

4.1. Low-carbon employment in the UK

Based on firm-level survey data, more than 200,000 people were employed in low-carbon activities[189] in 2016, representing around 1 per cent of the total UK workforce.[190] The design, manufacture and installation of energy efficiency products accounted for around 70 per cent of low-carbon employment in 2016, followed by the production of low-carbon electricity from nuclear, wind, solar, hydro and other renewable sources at around 15 per cent. Total low-carbon employment grew more than 3 per cent from 2015 to 2016.[191]

Our own analysis shows that low-carbon employment levels are highest in Scotland, with around 30,000 low-carbon employees, followed by the Southeast and Northwest of England,

[189] Section 4.4 explains different approaches to defining low-carbon jobs. Essentially these range from narrow definitions such as those related directly to natural resource protection, to wider definitions that encompass all occupations affected by the low-carbon transition.

[190] Office for National Statistics (ONS) (2018) Office for National Statistics, Low Carbon and Renewable Energy Economy Survey, 2018. https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/finalestimates/2016#main-points

[191] Further analysis based on 2015 microdata indicates that five sectors account for nearly two-thirds of low-carbon employment: specialised construction activities; rubber and plastics; architecture and engineering; professional scientific and technical activities; and electricity and gas. Low-carbon activity in these sectors largely involves services, including the sale, installation and maintenance of renewable energy and energy-saving products. The five sectors follow the 2 digit SIC classification and include: 'Electricity, gas, steam and air conditioning supply'; 'Other professional, scientific and technical activities'; 'Architectural and engineering activities, technical testing and analysis'; 'Manufacture of rubber and plastic products'; 'Specialised construction activities'. Office for National Statistics (ONS), Department for Business, Energy & Industrial Strategy, Welsh Government, Scottish Government, Northern Ireland Statistics and Research Agency, Northern Ireland. Department for the Economy (2017) Low Carbon and Renewable Energy Economy Survey, 2014-2015: Secure Access. [data collection]. UK Data Service. SN: 8206, http://doi.org/10.5255/UKDA-SN-8206-1

and then the Yorkshire and Humber region.[192] The share of low-carbon employment within total employment in these regions is above the UK average of around 1 per cent.

We also find that the productivity of these activities varies across regions. London, the South, East Anglia and the West Midlands have the highest low-carbon labour productivity. In London, for example, most jobs are in high-value-added services, including engineering and management consultancy, with high output per worker. In contrast, Scotland has relatively low labour productivity. There, many jobs are in renewable energy installation and servicing, with lower output per worker.

This overview tells us that UK low-carbon employment is relatively small but growing, is highly concentrated in a few industries and in particular regions, and labour productivity varies by region and type of low-carbon activity. While this is a useful starting point for policy analysis, it is based on the status quo and tells us little about how labour markets might look in the future, in light of the low-carbon transition, anticipated rapid technological change and the corresponding institutional or policy responses. The success of advanced economies is likely to entail more idea-based industries in the future and these data fail to capture this. It does not get to the heart of the story on skills.[193]

Recent research supports this conclusion. For example, Blyth et al. (2014)[194] tackle the question of whether policies to support investment in renewable energy and energy efficiency create additional jobs and contribute to sustainable growth. In the short run, if the economy has an output gap or spare capacity, the higher labour intensity of low-carbon investments during their construction phase could lead to more jobs than investing in an equivalent level of high-carbon generation assets; a net gain in the total number of jobs. However, in the long run, the net impacts on employment from these investments are not so clear and a focus on the number of jobs created is less meaningful.[195] In the long run, high labour intensity is not in itself desirable as it implies lower labour productivity and economic growth, but it is uncertain how labour requirements are likely to evolve over a plant's life as learning-by-doing and technological progress take place.[196]

An important question is whether these investments will contribute to an efficient and fair transition to a low-carbon economy.[197] This implies investors have a critical role to play as allocators of capital across the economy, who need to ensure their investments incorporate the full range of environmental, social and governance (ESG) factors, including a just transition for workers.[198] In this way, a narrow assessment of low-carbon job numbers misses critical aspects of the long-run growth and investment in human capital story.

[192] Based on 2015 microdata: Office for National Statistics (ONS), Department for Business, Energy &Industrial Strategy, Welsh Government, Scottish Government, Northern Ireland Statistics and Research Agency, Northern Ireland. Department for the Economy. (2017). Low Carbon and Renewable Energy Economy Survey, 2014-2015: Secure Access. [data collection]. UK Data Service. SN: 8206, http://doi.org/10.5255/UKDA-SN-8206-. For plant location and employment used in the analysis, we use the BSD: Office for National Statistics (2017) Business Structure Database, 1997-2017: Secure Access. [data collection]. 9th Edition. UK Data Service. SN: 6697, http://doi.org/10.5255/UKDA-SN-6697-9.

[193] The low-carbon employment statistics also have serious shortcomings, which we discuss later in the chapter.

[194] Blyth W, Gross R, Speirs J, et al. (2014) Low carbon jobs: The evidence for net job creation from policy support for energy efficiency and renewable energy. A report by the UKERC Technology & Policy Assessment Function. www.ukerc.ac.uk/asset/0A611DB6-DCEA-4628-97FC16042EAD4F20/

[195] In addition to the narrow definition of low-carbon jobs, a focus on the number of low-carbon jobs also ignores the quality of jobs created compared with high-carbon equivalents, for example whether jobs are permanent or temporary, the employment conditions, and the relative wages paid. See Antoni M, Janser M, Lehmer F (2015) The hidden winners of renewable energy promotion: Insights into sector-specific wage differentials. Energy Policy, 86, 595-613

[196] Bowen A (2012) 'Green' Growth, 'Green' Jobs and Labor Markets. Policy Research Working Paper 5990. The World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/3277/WPS5990.pdf;sequence=1

[197] Blyth et al. (2014) op. cit.

[198] Robins N, Brunsting V, Wood D (2018, forthcoming December) Climate change and the just transition: A guide for investor action. Grantham Research Institute on Climate Change and the Environment and Initiative for Responsible Investment, Harvard Kennedy School.

4.2. Future job transformation

The low-carbon transition, the Fourth Industrial Revolution, and other forces of change such as globalisation, could all come together to influence the labour market in dynamic ways that are likely to be unpredictable at times. While recent evidence suggests change is likely to start with the 'greening' of existing skills, with similar skills required across jobs that are classified as low- and high-carbon (or 'green' and 'brown'),[199] the combination of these various forces could radically and rapidly change the nature of work and employment. Many new jobs will be created that are currently unheard of and existing jobs will disappear, especially in high-carbon industries such as coal extraction.

It is difficult to predict how labour markets will change and the extent of job displacement, but if history is any guide then change could be rapid and unexpected. Today, software engineers are designing apps for smartphones that power new low-carbon digital business models – these are jobs that were unheard of a decade ago. Similar examples of new jobs will emerge over the coming decades.

The UK's manufacturing sector has been in a continual process of transformation for decades and could face even more profound adjustment as the transition accelerates. Manufacturing jobs have been declining and transforming since the middle of the 19th century. In 1840 manufacturing employed around 40 per cent of UK workers; this had declined to around 25 per cent by 1980 and today the figure is less than 10 per cent.[200] This decline should be seen in the context of a modernising manufacturing industry that will increasingly compete globally based on quality and sustainability and will be transformed by the digital revolution. The manufacturing jobs of the future are likely to be higher skilled, requiring degrees to support high-tech and professional occupations, and many jobs will become service jobs as research and servicing generate larger shares of revenues.[201]

But this is not just a story of industrial transformation. The UK is predominantly a services economy – around 80 per cent of the UK's GDP comes from services – with many existing service jobs concentrated in major cities and surrounding urban areas, in particular London. Service jobs are also likely to experience profound changes as the digital and low-carbon transformations combine.[202]

Policies to promote renewable energy and other low-carbon activities will create demand for new service jobs. Examples include sustainable design, sustainability management, wind farm maintenance, solar panel installation, electric motor mechanics, climate modellers in public agencies, sustainability assessment (of green bonds, for example), and certified builders of low-carbon homes.

The following three examples, of financial services, retail, and architecture and construction, show that change is already underway.

Financial services

Financial services must transform to deliver the scale and quality of investment needed for the transition.[203] This will require financial professionals to add, among other things, the full range of environmental, social and governance (ESG) dimensions into their skill set, and then incorporate this into their investment practices.[204] In many financial institutions this will involve

[199] Vona F, Marin G, Consoli D, Popp D (2018) Environmental regulation and green skills: an empirical exploration. Journal of the Association of Environmental and resource economists, 5(4), pp. 713-753

[200] The Economist (2016) Britain's manufacturing sector is changing beyond all recognition. 5 November. https://www.economist.com/britain/2016/11/05/britains-manufacturing-sector-is-changing-beyond-all-recognition

[201] For example, over 60 per cent of Rolls-Royce £2bn defence and aerospace revenues in 2015 came from research and servicing, rather than sales of manufactured goods. See: The Economist (2016) op. cit.

[202] The agricultural sector will also experience change. For example, farmers will need to learn sustainable and more resilient farming methods as the climate becomes more variable.

[203] New Climate Economy (2016).

[204] Robins et al. (2018) op. cit.

overcoming resistance to sustainability practices, which some believe are inconsistent with their fiduciary responsibilities and can harm investment returns. Financial professionals will also need to build skills in sustainable lending, enabling them to make more informed risk assessments, more accurately assess the cost of capital, and increase lending to profitable low-carbon projects managed by businesses at various stages of maturity, from start-ups to established corporations.

Fashion

Fashion (along with most other consumer goods) will be impacted as, for example, online shopping grows and consumer preferences shift towards sustainable clothing and transparent low-carbon supply chains. New technologies such as Blockchain (which themselves are energy-intensive and will need to be powered with low-carbon energy) could allow consumers to trace the origin of their clothing back to the raw materials and even send tips to farmers who grew the cotton for their T-shirts. The shift to online shopping could also see displacement of high-street workers and future fashion job descriptions requiring digital skills.

Architecture and construction

Architects and builders will be required to focus more on sustainable design and develop new technical skills in response to innovation. One example is the use of 3D printers in construction, which combines new, highly efficient and sustainable materials with architectural design software and robotic technology, enabling the automation and improvement of building processes that have previously been done manually.[205] Projects of this nature are already underway, with the first 3D-printed housing development in Europe close to being realised.[206]

4.3. The crucial role of institutions in securing a 'just transition'[207]

History points to the central role of institutions in enabling the development of the different types of capital (human, social, infrastructure, intellectual) that are essential pre-conditions for growth, and in cushioning the damaging effects of recessions and transitions on human capital.[208]

Past economic transitions characterised by rapid technological change have had immense impacts on labour markets. Job displacement and loss of livelihoods is common during these periods, which can increase inequality and social discord. The coming economic transition, which will see the low-carbon transition intertwine with the Fourth Industrial Revolution, could lead to even larger displacement as high-carbon jobs disappear and new technologies such as artificial intelligence are expected to go beyond replacing mechanical and manual labour to replacing some cognitive 'thinking' workers.[209] Some estimates suggest automation could replace over half of all jobs by 2055, and, when combined with further globalisation, it could accelerate the trend in the hollowing out of middle-skill jobs that require routine manual and cognitive skills such as machine operators and clerical workers.[210] This could make the low-

[205] Ghaffar S (2018) How to print a building: the science behind 3D printing in construction, The Conversation, 19 June. http://theconversation.com/how-to-print-a-building-the-science-behind-3d-printing-in-construction-98490

[206] Boffey D (2018) Netherlands to build world's first habitable 3D printed houses. The Guardian, 6 June. https://www.theguardian.com/artanddesign/2018/jun/06/netherlands-to-build-worlds-first-habitable-3d-printed-houses

[207] A just transition involves policies and measures to reduce the impact of job losses and industry phase-out on workers and communities, and measures to produce new, low-carbon and decent jobs, sectors and healthy communities; it aims to address environmental, social and economic issues together. Just Transition Centre (2017) Just Transition, A report for the OECD. https://www.oecd.org/environment/cc/g20-climate/collapsecontents/Just-Transition-Centre-report-just-transition.pdf

[208] Haldane A (2018) Ideas and Institutions – A Growth Story. Speech to the Guild Society, University of Oxford. 23 May. https://www.bankofengland.co.uk/-/media/boe/files/speech/2018/ideas-and-institutions-a-growth-story-speech-by-andy-haldane.pdf

[209] Ahmed K (2018) Bank of England chief economist warns on AI jobs threat. BBC News online, 20 August. https://www.bbc.co.uk/news/business-45240758

[210] Autor D, Katz L and Kearney M (2006) The Polarization of the US Labor Market. American Economic Review 96 (2): 189–94. Goos M and Manning A (2007) Lousy and Lovely Jobs: The Rising Polarization of Work in Britain. The Review of Economics and Statistics 2007 89:1, 118-133. Goos M, Manning A and Salomons A (2009) Job Polarization in Europe. American Economic Review, 99: 2, May, p. 58-63.

carbon transition much harder for some workers, in particular those in middle-skill, middle-level high-carbon jobs that disappear.

The rich Schumpeterian tradition of analysis on medium- to long-run technological transformations argues that capitalism develops through innovations by entrepreneurs, namely the creation of new production technologies, products and markets. Young innovative firms and progressive ideas displace existing firms and ideas from the previous period,[211] a process referred to as 'creative destruction'. Governments need strong institutional and policy frameworks to cultivate the creative and disarm the destructive impacts on workers, if innovation is to translate into increasing levels of social, human and infrastructural capital and, then, higher living standards.

A range of institutions emerged in past transitions, including trade unions, social housing, healthcare systems and an expanded university system. These institutions helped cushion the financial and social impacts of job losses, and contributed to reskilling. The success of the low-carbon transition will depend on the strength of these and other institutions, including financial institutions, and their ability to ensure a just transition for workers and communities affected by technological change.

The UK's relatively flexible job markets and strong employment laws provide a good foundation for managing the impacts of change. Strengthening key institutions and additional policies to ensure a just transition for workers who are hit the hardest will also be needed. The UK needs to start thinking about these policies now, not retroactively as disruption becomes evident.

The education system

The LSE Growth Commission (2013, 2017) has outlined persistent problems with the UK education and skills system and recommends several measures to strengthen human capital, including improved teaching quality in schools, a better technical training system and a greater focus on outcomes for disadvantaged pupils. These measures are even more crucial given the low-carbon transition and wider technological transformation that is coming. UK schools will need to equip young people not only with skills to address the current skills gaps, but also with skills to cope with rapid change during their relatively long working lives of possibly 60 to 70 years.

Today there are too many poorly educated young people emerging into a rapidly changing world of work. A key issue is that the correlation between disadvantage and poor school outcomes is particularly strong in the UK. A failure to allow children from disadvantaged backgrounds to realise their productive potential is detrimental for both productivity growth and social mobility. In order to achieve sustainable and inclusive growth in times of change, this problem must be dealt with effectively.

A better education will mean equipping young people with the skills they will need for the sustainable jobs of the future. We know what some of these might be and innovative, community-based education programmes have emerged to help children where schools are falling short. Coding, for example, will be a key technical skill across low-carbon digital jobs. Code Club is a nationwide network of volunteers and educators who run free after-school coding clubs for young people aged 9–13, providing important foundations for digital literacy in the UK (and elsewhere).[212] The school system should also offer subjects and improve current curricula to develop these skills. Japan is investing in pre-school education to foster creativity, critical thinking and communication skills as the country recognises the need to prepare for a

[211] New Climate Economy (2014) op. cit.

[212] https://www.codeclub.org.uk/ This initiative is now active across 100 countries, with 10,000 clubs run in 28 languages.

machine-dominated future, one that the current Japanese rote-learning-based system will not serve.[213] In contrast, cuts to creative subjects in schools are pushing the UK in the wrong direction.[214]

Improved and more targeted careers advice for school leavers (particularly those from disadvantaged backgrounds[215]) will increase the chance that students will reach their productive potential and improve their labour market resilience by continuing their education, if appropriate. Universities and technical colleges will need to play an increasing role in lifelong learning,[216] offering upskilling or reskilling in particular in management, digital and soft skills.

A shortage of trade skills is already constraining UK productivity and growth.[217] The UK will need skilled tradespeople and builders who are digitally literate, including in innovative design software and 3D printing, and who also have skills in sustainability, for example, installation of energy efficiency technologies. Current reforms seek to improve the quality of technical education[218] and new 'T-level' qualifications are being introduced,[219] which will need to focus on clean technologies and processes, but the sector faces significant financial constraints.[220]

The UK has a world-class university system and this advantage extends across the country, including to the Midlands and North of England where job displacement may be high. Cities such as Liverpool and Newcastle may be suffering from industrial decline today, but they were highly productive in the 19th century following the Industrial Revolution. The wealth they generated supported the development of leading universities that remain strong. These institutions have the capacity to adapt and provide lifelong skills and retraining options to the surrounding workforce as traditional high-carbon industries continue to transform or decline, and high-skilled jobs replace low-skilled. For example, as UK manufacturing transforms it is using more high-skilled, higher paid workers, but is having to look overseas to fill vacancies.[221] There is strong evidence that research universities create innovation spillovers for nearby industry,[222] and the university sector more broadly could also play more of a role in the diffusion of new productivity-enhancing technologies to the UK's underperforming 'tail' of firms.[223] This might involve training or other programmes of support for local businesses.

In regions with a high risk of job disruption, additional place-based policies are likely to be required to support vulnerable workers. Recent experience shows that where job losses are concentrated in particular regions or where losses hit older or less skilled workers, these workers can remain long-term unemployed for many years, even decades, or drop out of the labour force altogether. The impact on lives, including psychological distress, and on communities, can be immense. This is the case in South Wales, for example, where the coal pit closures of

[213] Hamada K (2018) In the AI revolution creative children – not wannabe bots – are the future. South China Morning Post, 26 February. https://www.scmp.com/comment/insight-opinion/article/2134699/ai-revolution-creative-children-not-wannabe-bots-are-future

[214] Busby E (2018) Decline in creative subjects at GCSE prompts fears that arts industry could be damaged. The Independent, 2 August. https://www.independent.co.uk/news/education/education-news/creative-arts-gcse-subjects-ebacc-drama-music-design-technology-school-funding-a8473211.html

[215] For more details about the participation gap and how policy can help address this see Azmat G, Murphy R, Valero A and Wyness G (2018) Universities and Industrial Strategy in the UK: Review of Evidence and Implications for Policy, CEP Industrial Strategy Paper No. CEPIS06.

[216] Haldane (2018) (op. cit.)

[217] Insufficient technical training has failed to provide the UK construction sector with the skilled workers it needs, and the existing workforce is ageing, constraining productivity and growth. See Jackson G (2018) How a lack of skilled building workers is stunting UK growth. Financial Times, 16 August. https://www.ft.com/content/53713cfe-93eb-11e8-b747-fb1e803ee64e

[218] BEIS and DfE (2016) Post-16 skills plan and independent report on technical education. https://www.gov.uk/government/publications/post-16-skills-plan-and-independent-report-on-technical-education

[219] T-Levels are new two-year technical programmes designed with employers to give young people the skills that industry needs. From 2020, they will give students aged 16 to 18 a technical alternative to A-levels and will help them to get a skilled job. https://www.gov.uk/government/publications/introduction-of-t-levels/introduction-of-t-levels

[220] Belfield C, Farquharson C and Sibieta L (2018) 2018 Annual Report on Education Spending in England. London: Institute for Fiscal Studies

[221] The Economist (2016) op. cit.

[222] For a summary, see Azmat et al. (2018) op. cit.

[223] Haldane (2018) op. cit.

the 1980s have led to persistent high unemployment, poor health outcomes and social dislocation.[224]

In these cases, the Government may need to provide a targeted package of measures, including unemployment benefits, mental health services, job search resources, relocation assistance, improvements to the flexibility of the housing market, geographic mobility programmes to get people back to work, and economic regeneration initiatives. In cases where workers are unable to retrain or relocate, the provision of social protection mechanisms to ensure they receive adequate pensions and healthcare is key to achieving a just transition and to help overcome resistance to change.[225] In these regions a well-resourced National Health Service will be crucial, as will other institutions that provide support, such as social housing. These institutions need to be strengthened and programmes planned now so that government can respond quickly and flexibly when the need arises.

Labour market institutions

Supporting and protecting the employment rights and conditions of workers in insecure working arrangements, especially in the rapidly expanding 'gig' economy (short-term self-employment via one-off 'gigs') that is transforming how people work, will become increasingly important.[226] For example, new low-carbon firms, based on digital platforms, are employing 'independent' contractors and claiming they have few employment rights.[227] There is some backlash against this and a Supreme Court decision in June 2018 unanimously held that heating engineer Gary Smith, employed by Pimlico Plumbers, was entitled to employment rights.[228] Unions can play an important role in ensuring workers' rights are protected, including by encouraging the UK government to enforce employment laws consistent with decisions by the courts.[229] Furthermore, a stronger voice for workers could also help ensure the productivity benefits from new technologies and business models are shared more equally between workers (as wages) and owners of capital (as profits). This role could be crucial as the pace of change accelerates and new digital and low-carbon business models provide opportunities for firms to recast their contractual relationships with employees.

[224] Foden M, Fothergill S, Gore T (2014) The state of the coalfields: Economic and social conditions in the former mining communities of England, Scotland and Wales. Centre for Regional Economic and Social Research, Sheffield Hallam University. https://www4.shu.ac.uk/research/cresr/sites/shu.ac.uk/files/state-of-the-coalfields.pdf

[225] New Climate Economy (2014) op. cit.

[226] The 2016 Taylor Review considers how employment practices need to change in order to keep pace with modern business models. The review considers the implications of new forms of work, driven by digital platforms, for employee rights and responsibilities, employer freedoms and obligations, and the UK's existing regulatory framework surrounding employment. https://www.gov.uk/government/publications/good-work-the-taylor-review-of-modern-working-practices

[227] This discussion highlights the limitations of using 'number of jobs created' in new low-carbon industries to evaluate policy; this measure ignores the quality of jobs created, for example whether jobs are permanent or temporary, the employment conditions, and the relative wages paid (Antoni et al., 2015, op. cit.).

[228] This case was of wider interest because it appeared to support a trend for finding that such individuals are 'workers' for the purposes of employment rights. The decision found Smith was a limb (b) worker, which is a category of self-employed individual entitled to basic rights such as paid holidays, minimum wage and protection from discrimination. See: https://www.theguardian.com/commentisfree/2018/jun/14/gig-economy-workers-pimlico-plumbers-employment-rights

[229] Unions could also encourage governments to design a tax and minimum wage system that is neutral with regards to different forms of employment, as recommended by the LSE Growth Commission (2017) op. cit.

Box 4.1. Lessons from past experiences of managing change

Experience has shown a range of risks that governments should be aware of when implementing labour market transition policies.

- **Unemployment benefits must be designed to motivate workers to re-enter the workforce**, in particular because learning on the job remains an effective way to prevent skill atrophy. This means finding the right level for benefits that incentivise re-entry into the labour market without creating financial distress for the unemployed, and provision of in-work credits or wage subsidies to get people back to work.
- **Suitable training that improves employability needs to accompany severance payments or loans.** Poorly designed training programmes and work creation schemes can develop the wrong skills and fail to increase the employability of workers. Inadequate schemes can send negative signals to employers, who then avoid employing these workers. Moreover, providing multiple training programmes can reduce the motivation of workers to search for new jobs, and so these should be limited and well-targeted. And retrained workers can end up displacing existing workers. Despite the complexities and pitfalls of transition training programmes, experience has shown that propping up declining sectors rather than actively managing structural change is counterproductive.

Examples from Japan, Poland and the United States

- **Japan** provides a good example of actively managing structural change in industries that are in decline. From 1987, the government provided long-term support to smooth the decline of what it called 'structurally depressed' industries, including textiles and ship-building. This support reallocated resources within and outside the depressed industries, provided financial assistance to troubled firms, and mitigated negative impacts on the labour force.
- In **Poland,** starting in 1990 during the post-Communist transition, the government restructured its loss-making mining sector through debt restructuring, mine closures and a radical reduction in employment. Initial reforms were resisted as they did not provide adequate support for miners. From 1998 the employment reduction programme was accompanied by incentives for firms to hire ex-miners; free retraining programmes financed by the European Commission; social benefits and severance payments, which were effective but very costly for government; loans and credits for ex-miners, which were mainly used for household consumption; job guarantees for miners close to retirement; and benefits for miners with long tenure, such as five-year voluntary vacations at 75 per cent pay. These measures were designed in cooperation with the unions, which helped overcome resistance to the reforms. From 1998 to 2002 alone, some 53,000 workers left the industry and 33,000 received some form of support (total coal mining employment in Poland fell from around 390,000 in 1990 to 120,000 in 2006).
- The **United States** instituted the US Trade Adjustment Assistance (TAA) programme several decades ago to help workers adjust to trade liberalisation. The programme provides: income support for over 100 weeks; training expenses; health coverage tax credit; wage insurance that 'tops up' a potential lower income in a new occupation for up to two years for workers over 50 years of age; and costs associated with job search and relocation. This assistance package is designed to be targeted and calibrated to worker needs. However, recent assessment of its effectiveness finds mixed results.

Source: New Climate Economy (2014) Better Growth, Better Climate

Other policies for labour market adaptability and flexibility

There is also a role for governments to provide incentives for firms to retrain workers in-house as jobs change and new skills are required. Recent research shows that while human capital accumulation is a key driver of growth, there are no across-the-board incentives for UK firms to invest in the training of their workers.[230] These incentives are warranted as, similar to R&D, investment in skills produces positive externalities, including knowledge spillovers, which will deter firms from investing.[231] These arguments are particularly applicable to the low-carbon transition. A 2011 review by the UK government found that very few firms have currently taken measures to address the skill needs of a low-carbon transition.[232] Also, recent evidence suggests some high-carbon jobs appear similar to their low-carbon counterparts, such as administrative or transport jobs, differing in only a few skill-specific aspects. For workers in these jobs, retraining will therefore be possible on the job at relatively low cost.[233]

The UK government can further support labour market flexibility by providing low-cost finance for individuals to undertake training and retraining, and for start-ups that have high productivity potential. It can move more government activities to the North to provide employment and stimulus in areas likely to face higher adjustment costs. It can also invest in people who want to move to where productive and suitable jobs are located that match their skills. The Government will need a coherent and flexible strategy that is responsive to rapid change and accounts for variations between places.

Box 4.1 above summarises some recent research from the New Climate Economy that considers some key lessons from policies to manage labour market transitions.

In summary, in the face of substantial labour market transformation over the coming decades, the role for government is to ensure strong institutions and sound policies for flexible labour markets and a just transition for workers. The Government will need support from the private sector, in particular financial institutions, who allocate capital across the economy. In regions with higher adjustment costs, place-based policies will be necessary. These policies can help to ensure that workers have the right skills and support to be innovative and limit the harm to lives and livelihoods from job displacement. This will help to maximise potential productivity gains from the transition. The alternative – failure to invest in institutions and weak policy – could lead to hardship for workers and communities. It would leave labour markets more rigid and workers less prepared for change. This could create social disruption, especially in areas with declining high-carbon firms and few viable employment alternatives.

4.4. Defining a 'low-carbon job': limitations of existing assessment techniques

Several recent studies have highlighted the need for better statistics in order to measure green economic activity or green employment, particularly in the measurement of 'low-carbon' skills, for which there is currently no standardised definition.[234]

Assessments of existing 'low-carbon jobs' typically follow one of three approaches, which range from a relatively narrow to a broader definition of low-carbon employment:

[230] Costa R, Datta N, Machin S, McNally S (2018) Investing in People: The Case for Human Capital Tax Credits. Paper IS01. Centre for Vocational Education Research, Centre for Economic Performance, London School of Economics and Political Science, February. http://cep.lse.ac.uk/pubs/download/is01.pdf

[231] Firms also worry that benefits will accrue to the (mobile) worker and not to them.

[232] HM Government (2011) Skills for a green economy: A report on the evidence. https://www.gov.uk/government/publications/skills-for-a-green-economy-report-on-the-evidence. Company directors and senior management will be responsible for managing changes in work, workers and the workplace. Guidance for governing the future of work is now available for company directors: see AICD (2018) Directors' playbook: The future of work. Governance Leadership Centre with Deloitte. https://aicd.companydirectors.com.au/-/media/cd2/resources/advocacy/governance-leadership-centre/pdf/glc-directors-playbook-on-the-future-of-work.ashx

[233] Bowen A, Kuralbayeva K, Tipoe EL (2018) Characterising green employment: The impacts of 'greening' on workforce composition. Energy Economics 72, 263-275. May. https://www.sciencedirect.com/science/article/pii/S0140988318300963

[234] Bowen et al. (2016) op. cit.

- **Industry:** Jobs associated with products and services directly related to natural resource protection and conservation. This is the approach used by Eurostat, for instance.
- **Output and process:** Jobs that produce goods or provide services that benefit the environment or conserve natural resources. This has been used, for instance, by the US Bureau of Labor Statistics[235] and by the UK Office for National Statistics (ONS) in its *Low-Carbon and Renewable Energy Economy* survey.
- **Occupations affected by the low-carbon transition**, whether directly or indirectly. This has been used by the O*NET database, based on the US workforce, for instance.[236]

Estimates of low-carbon employment differ widely according to the definition used. Under the narrowest 'industry' definition (using US Bureau of Labor Statistics data), US low-carbon employment was around 1 per cent in 2014. Under the broadest definition, used by O*NET, it could have been nearly 20 per cent in that year (see Box 4.2 below).

Low-carbon jobs are also often measured in terms of full-time-equivalent (FTE), rather than the absolute number of workers. This illustrates the point that 'green' is not a binary characteristic (meaning that a job is either considered 'green' or 'not green'), but rather a continuous measure, with each job varying in the number of green tasks and frequency of use.[237]

Adopting a clear definition at the national level will help achieve a consistent assessment of the current size of the low-carbon job market, which will enable a better understanding of the employment impacts of the low-carbon transition over time. Regular updating of employment statistics will also facilitate future research and policy analysis. Furthermore, to ensure international comparability, cross-government collaborations should be sought to establish a common definition and methodology for estimating low-carbon employment.

Box 4.2. Low-carbon jobs and skills in the United States

A recent study by Bowen et al. (2018) gives a snapshot of low-carbon employment today. Based on 2014 employment data from the US Bureau of Labor Statistics, and using the O*NET definition of 'green jobs', its key findings include:

- As many as 19.4 per cent of US workers are potentially employed in the green economy, either directly or indirectly. In addition, 44.3 per cent of US workers have non-green jobs that use similar skills to green jobs.
- Green jobs vary in the importance and use of green tasks, suggesting that the term 'green' should be considered as a spectrum rather than a binary characteristic.
- Green jobs differ from their non-green counterparts in only a few skill-specific aspects, suggesting that most retraining can happen on the job.

These findings highlight the importance of having a nuanced classification of low-carbon or green jobs, and the need for detailed occupation-level data to understand labour market dynamics. A database for the UK that is similar in detail to O*NET would enable a better assessment of the current and future state of low-carbon employment in the UK.

[235] Note that this BLS database, which uses the narrow industry definition of green employment, was discontinued in 2013 with 2011 being the final data release: https://www.bls.gov/ggs/#news
[236] https://www.onetonline.org/
[237] Bowen et al. (2018) op. cit.

4.5. Skills – conclusions and recommendations

Policy interventions are needed to strengthen the UK's education institutions at all levels in order to drive sustainable and inclusive growth. The policies and initiatives announced in the Government's *Industrial Strategy White Paper* of 2017 should be strengthened across a number of key dimensions.[238]

The UK's *Clean Growth Strategy* does not propose a strategy on human capital, except for mentioning new T-levels and new skill requirements in forest design and farm management. The *Industrial Strategy* goes much further, with several strategies and policies around apprenticeships, technical education, STEM skill shortages, and a national retraining scheme to support re-skilling.

> **Recommendation 9: Coordinate a forward-looking skills policy across and within government, ensuring that appropriate investments are made across all education levels. This should include a particular focus on improving educational outcomes and labour market opportunities for disadvantaged students.**

The impact of the transition will likely be felt throughout the economy, including in services, but particular places could face more rapid and extensive job disruption. Northeast England, which is home to many of the UK's high-carbon industries, is particularly exposed. Retraining and transition policies could smooth the adjustment for workers into more productive low-carbon services and low-carbon industrial jobs, significantly reducing the costs of the transition.

> **Recommendation 10: Establish integrated place-based transition policies in areas at high risk of disruption, such as Northeast England**.

A key role for the education system is to equip people to deal with change throughout their lives, and to enhance the technical and creative skills needed in the jobs of the future. For example, new T-levels could include relevant training on clean technologies or processes.

> **Recommendation 11: Education institutions need to be responsive and flexible as the economy changes and the demand for skills shifts, working closely with other economic, environmental, technological and social institutions. This will require better data and metrics for assessing employment changes and demand for skills.**

Large companies may have in-house training programmes that could be adapted to include low-carbon skills training and take pressure off colleges and universities. Government can provide tax incentives for firms to train workers. However, smaller firms may have difficulty providing the training their employees need, so partnerships between businesses and higher education institutions could enable provision of individual, tailor-made units.

> **Recommendation 12**: **Help firms overcome barriers to in-house retraining through tax incentives and partnerships.**

[238] There is good evidence that social capital, as a stock accumulated through time that can be used in production or distribution, is something that has a strong influence on economic and social outcomes. Examples include World Bank measures of: membership of groups and networks; extent of trust; extent of participating in community activities; access to information; social inclusion; and empowerment. See World Bank (2004) Measuring Social Capital: An Integrated Questionnaire. http://documents.worldbank.org/curated/en/515261468740392133/pdf/281100PAPER0Measuring0social0capital.pdf

5. Cities

Summary

- Cities and urban areas are central to the UK's economic and social success. They are places where physical and human capital closely interact to spur creativity and innovation, which is particularly important in the UK's service-driven 'knowledge economy'.
- UK cities face considerable challenges as they continue to grow and develop, including poor planning, housing shortages, congestion, air pollution, urban sprawl and an overreliance on private transport.
- Well planned and governed UK cities that are compact, efficient, interconnected, and make appropriate use of technology – so-called 'smart cities' – can maximise agglomeration economies. This benefits the flow of ideas, creativity and low-carbon innovation as well as attracting skilled workers and capital. Better planning will help to build on the regeneration underway in Northern and Midlands cities.
- Conversely, poorly planned, badly connected and weakly governed cities will constrain productivity growth and the extent to which growth can be both sustainable and inclusive. They will fail to maximise the returns to human capital and exacerbate existing challenges. These will not be good places in which to live.
- Developing smart cities in the UK is crucial for improving the performance of all regions. Progress on northern development, for example, can be accelerated through further devolution of political and fiscal powers, enabling local residents to have a greater say in smart city planning and investments.

5.1. Compact and connected cities and their potential for sustainable growth

Around 55 per cent of UK residents, around 35 million people, live in cities.[239] Together, the four largest UK cities (London, Birmingham, Manchester and Glasgow) are home to almost a quarter of the total UK population. Cities take up less than 10 per cent of the UK's land area but account for around 60 per cent of all jobs.[240] London is a key driver of the UK's economic growth, accounting for around £410bn or 23 per cent of the UK's gross value added (GVA) for 2016.[241]

This places a relatively small number of UK cities and their surrounding areas at the centre of UK economic activity.[242] They will largely determine the UK's success at achieving sustainable and inclusive growth over the coming decades. They directly affect how resources are allocated, how innovation takes place, whether innovation is used well or badly and, if badly, how much

[239] Using research from the Centre for Cities, this includes the UK's 63 largest towns and cities, defined as primary urban areas (PUAs) – a measure of the 'built-up' area of a city, rather than individual local authority districts. See Centre for Cities (2017a) Cities Outlook 2017. London: Centre for Cities. http://www.centreforcities.org/wp-content/uploads/2017/01/Cities-Outlook-2017-Web.pdf UNDESA (2018) World Urbanization Prospects: The 2018 Revision https://esa.un.org/unpd/wup/

[240] Centre for Cities (2017b) How do we encourage innovation through clusters. http://www.centreforcities.org/wp-content/uploads/2017/08/17-08-10-How-do-we-encourage-innovation-through-clusters-1.pdf

[241] City of London. Statistics about the City. https://www.cityoflondon.gov.uk/business/economic-research-and-information/Pages/economic-statistics.aspx

[242] The other 45 per cent of the UK population that live outside cities also make a crucial contribution to growth. Rural communities, in particular, have their own unique growth challenges, for example around the protection and enhancement of natural capital, including bringing ecosystem services into economic decision-making. See, for example, Bateman I, Harwood A, Mace G et al. (2013) Bringing ecosystem services into economic decision-making: land use in the United Kingdom. Science, 341(6141), 45-50. The UK Natural Capital Committee (NCC) provides the Government with independent advice on protecting and improving natural capital. https://www.gov.uk/government/groups/natural-capital-committee

damage it inflicts on others now and in the future.[243] If cities are planned badly they could also face high adjustment costs as change accelerates.

Sustainable growth is largely driven by learning, innovation and the accumulation of ideas, skills and 'knowledge capital'. Smart cities[244] enhance these very features, providing a special environment that can drive low-carbon innovation, productivity and sustainable growth.

Features of smart cities include integrated public transport systems and networks based on smart grids, rapid bus transit systems, trams and rail, electric and self-driving cars, car sharing and cycle lanes. Smart cities are likely to reduce emissions directly and encourage clustering of mobile capital, talent, ideas, skills, knowledge and creativity. The more efficient these networks, the greater the economic benefits through economies of scale, agglomeration effects and networking advantages.[245]

The specific benefits from agglomeration or 'clustering' can include: reduced transport costs; better matching of consumers with goods and services; pooling of a diverse and specialised labour force that better matches workers and firms; more access to and variety of culture; and generation of a dynamic environment for innovation in ideas, technologies and processes, which in turn enhances human capital. One estimate suggests a doubling of urban density alone can add 5 to 30 per cent to productivity.[246] Clustering is also highly complementary with infrastructure investments in networks like broadband (Chapter 3), which increase the returns to new ideas and enable greater knowledge-sharing. Such integrated technologies also help make dense and complex cities work more efficiently: a broadband digital infrastructure can connect people to people, people to city systems, and city systems to city systems, enabling cities and residents to respond to changing circumstances in near real-time.[247]

Conversely, cities that are poorly planned will deter investment and skilled workers and subdue creativity, failing to maximise the returns to human capital. They will also lock in inefficient infrastructure, behaviours and institutions for many decades, leading to urban sprawl, pollution, congestion, poor health outcomes, crime and waste. They can be very exposed and vulnerable to climate risks such as water shortages, floods and heat stress.

Poor urban infrastructure decisions can create path dependencies that can last for decades if not longer. Investing in building new roads encourages car use, which increases the demand for more roads and highways, and locks in personal transport behaviours and pollution. In contrast, building cycle-ways increases bike use, which increases cyclists' demands for better infrastructure, locking in behaviour change, better health outcomes[248] and higher productivity. Poor planning on housing will also increase inequality. Returns to knowledge-driven agglomeration are highest for high-skilled workers, but the costs from negative externalities apply to all. As a result, cities tend to accumulate high-skilled workers, whose higher wages and demand drive up property prices. A lack of affordable housing will force people to spend a higher share of their income on rent, reducing disposable incomes and increasing inequality.

[243] Stern N and Zenghelis D (2015) Climate change and cities: a prime source of problems, yet key to a solution. The Guardian, 19 November. https://www.theguardian.com/cities/2015/nov/17/cities-climate-change-problems-solution

[244] There are a number of definitions of what makes a 'smart city'. What most have in common is that such cities use technology and data to solve their economic, social and environmental challenges. See http://www.centreforcities.org/reader/smart-cities/what-is-a-smart-city/

[245] Rode P, Floater G, Thomopoulos N, Docherty J, Schwinger P, Mahendra A, Fang W (2014) Accessibility in Cities: Transport and Urban Form. New Climate Economy Cities Paper 03. LSE Cities. London School of Economics and Political Science.

[246] Greater density creates vibrant markets and fertile environments for innovation in ideas, technologies and processes, spurring innovation and productivity. See: Avent R (2011) The Gated City. How America Made its most Productive Places Ever Less Accessible. Amazon Digital Services. http://a.co/d/5bVJgEy

[247] Stern and Zenghelis (2015) op. cit.

[248] A recent study finds commuting by bicycle was associated with a lower risk of a range of adverse health outcomes including cardio-vascular disease and cancer, suggest population health may be improved by policies that increase active commuting, particularly cycling. Celis-Morales C, Lyall D, Welsh P, et al. (2017) Association between active commuting and incident cardiovascular disease, cancer, and mortality: prospective cohort study. British Medical Journal, 357 :j1456. https://www.bmj.com/content/357/bmj.j1456

The extents to which the economic and social benefits of well-planned cities are realised, and the costs of poorly planned cities are avoided, will largely be determined by the coherence and strength of planning policies, institutions and city governance. It is not the invisible hand of the market that has determined the success of the world's best cities today, but a few who looked decades ahead and planned.[249]

Opportunities for UK cities

In this context, there are significant opportunities for UK cities to drive productivity and sustainable growth. The UK can build on and learn from its strengths in urban planning and architecture and also technological innovation, with some of the world's leading urban technology providers being present here. London is also a policy innovator, currently increasing its density and aiming for greater urban agglomeration economies. Transport for London integrates policy programmes at the metropolitan level. Road charging in the capital's central congestion charge zone, and bike-share stations, help to reduce congestion and deliver co-benefits such as cleaner air and lower carbon emissions. When operational, London's new Crossrail link, which uses land value capture[250] to fund new local public infrastructure, will also contribute to these benefits. Lessons from its anticipated success can then be translated to the rest of the country.

Yet while London is considered the economic engine of the UK, its economy accounting for more than a fifth of the UK's output and growing at twice the national rate,[251] it faces a number of pressing challenges. These include housing shortages, air pollution, congestion and ageing transport infrastructure, and impacts from more extreme weather in the form of heatwaves, flash floods and drought.

Outside of London, urban development in and around cities has been characterised by fragmented planning, urban sprawl, inadequate public transport infrastructure and an over-reliance on private transport. The gap between London and the Southeast on the one hand and other UK cities on the other has widened over time and policies to narrow the gap are still to deliver meaningful results.[252] Regional disparities in labour productivity are the highest of all OECD countries.[253] While Manchester, Leeds, Birmingham and Liverpool have had the highest growth in population and jobs in 2018 (London is 20th in this ranking), [254] these cities are less productive and have lower average wages and employment rates than London and the Southeast. They are also more at risk of job losses from globalisation and automation.[255]

A number of recent initiatives have sought to strengthen cities outside the Southeast, including 'the Midlands Growth Engine' and the so-called 'Northern Powerhouse' initiative. The Government's commitment to these initiatives is welcome and a strong starting point. It shows recognition that the lack of economic and physical connections between Midlands and

[249] Fuller B and Romer P (2014) Urbanization as Opportunity. World Bank Policy Research Working Paper No. 6874. May. https://ssrn.com/abstract=2439696.

[250] Land Value Capture involves financing the construction of new (transport) infrastructure with the profits generated by the increase in land value stimulated by the presence of that infrastructure. The profits can be 'captured' in a number of ways, including development impact fees, tax incremental financing, public land leasing and development right sales, land readjustment programmes, connection fees, joint developments, and cost/benefit-sharing (New Climate Economy, 2014. op. cit.).

[251] Office for National Statistics (2017a) UK environmental accounts: Low carbon and renewable energy economy survey, final estimates: 2015. https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/finalestimates/2015results. Office for National Statistics (2017b) Regional gross value added (balanced), UK: 1998 to 2016. https://www.ons.gov.uk/economy/grossvalueaddedgva/bulletins/regionalgrossvalueaddedbalanceduk/1998to2016

[252] Recent analysis of mortality rates has shown that North–South disparities have risen since the 1990s. See Buchan IE, Kontopantelis E, Sperrin M, Chandola T and Doran T (2017) North–South Disparities in English Mortality 1965–2015: Longitudinal Population Study. Journal of Epidemiology and Community Health, 7 August.

[253] In terms of gross value added (GVA) per worker. OECD (2017) op. cit.

[254] Elliott L (2018) Cities in north and Midlands dominate growth measure, The Guardian, 21 March. https://www.theguardian.com/business/2018/mar/21/north-midlands-england-jobs-growth

[255] For example, around 30 per cent of jobs in Mansfield in the Midlands are considered to be at risk by 2030 compared to around 13 per cent in Oxford. Centre for Cities (2018) Cities Outlook 2018. http://www.centreforcities.org/wp-content/uploads/2018/01/18-01-12-Final-Full-Cities-Outlook-2018.pdf

Northern cities and regions, which are home to around 16 million people, is holding back their growth.

The major achievement to date from these initiatives is the Strategic Transport Plan, a 30-year plan outlining how transport connections across the North of England need to transform to achieve sustainable growth.[256] However, funding for the plan still remains dependent on Westminster. A further achievement is the election of six metro Mayors in May 2017, including in Greater Manchester, Tees Valley, and the Liverpool city region.[257] In those locations, clear policy platforms have been established and resources pooled from disparate local authorities and Local Enterprise Partnerships to create clearer visions for change.[258] But there is a concern from local residents that overall the northern strategy is failing to deliver, with growth in the northern regions being neither sustainable nor inclusive. Many people still find themselves stuck in low-paid and insecure employment.[259]

To tackle this challenge, there is a strong desire from local residents for greater devolution of powers from Westminster, particularly in areas such as finance, employment and skills, where top-down policymaking fails to reflect the local economic context (see also the discussion in Chapter 3 on the need for stronger governance to boost local authorities and enable coordination of infrastructure investment across cities and regions). Of particular concern is the fragmented nature of central policymaking in Westminster and government department 'silos'. There is also a need to think beyond cities to include surrounding regions and their specific economic and social needs and characteristics. Local people need to be central to planning and decision-making, and coordination needs to be enhanced across the region, implying that greater devolution of powers will be needed in the coming years.[260]

The Convention of the North, held in September 2018, is a first step in exploring greater citizen participation in the democratic process and could help to tackle the sustainable and inclusive growth challenges of the North. A number of further measures could be taken. New fiscal powers could be devolved to northern regions to fund investment plans for smarter, low-carbon urban infrastructure, including scaling-up land value capture to finance major infrastructure such as low-carbon transport and new buildings/homes. Regional and integrated land-use and transport authorities, such as Transport for the North,[261] could be expanded, with the possibility of using congestion changing and other schemes, drawing on lessons from London. Smart cities competitions could be used to identify northern cities that want to take a lead on becoming smart. And northern cities could build on the Future Cities Catapult programme, to become strong technology leaders.

5.2. The features of smart cities: learning from best practice

A successful strategy for smart cities should learn from best practice. Pioneering cities across the world are demonstrating that more compact and connected urban development, built around mass public transport, can create cities that are economically more dynamic and

[256] Transport for the North (2018) Strategic Transport Plan. Draft for Public Consultation. https://transportforthenorth.com/wp-content/uploads/TfN-Strategic-Plan_draft_lr.pdf

[257] A metro mayor is the chair of a combined authority that has agreed to a Devolution Deal and is voted in by the electorate in the combined authority area. These combined authorities are made up of several local authorities. A directly-elected metro mayor will have powers and responsibilities to make strategic decisions across whole city regions, in contrast to existing city mayors (who are also directly elected) or local council leaders who only make decisions for, and on behalf of, their local authority. See: http://www.centreforcities.org/publication/everything-need-know-metro-mayors/#whois

[258] See Cox E (2018) Five years after its launch, the Northern Powerhouse is still a work in progress, inews, 16 February. https://inews.co.uk/opinion/five-years-launch-northern-powerhouse-still-work-progress/

[259] IPPR North (2017) The People's Powerhouse. Putting the People in the Northern Powerhouse. A report capturing discussions from the first People's Powerhouse Convention, Doncaster, July 2017. https://peoplespowerhouse.org.uk/downloads/report.pdf

[260] IPPR North (2017) op. cit.

[261] See https://transportforthenorth.com/about-transport-for-the-north/

healthier, and have lower emissions.[262] Examples of international cities pioneering best practice are illustrated in Box 5.1.[263]

Box 5.1. Pioneering cities

Stockholm, Sweden – transport: Stockholm has an efficient multi-model public transport system and high quality pedestrian environment and has been effective at promoting high-density development on redundant industrial land. The result of strong land-use planning and an extensive rail-based service is that 40 per cent of residents live within 500 metres of a metro station and the city has significant areas of open space. This is due to prioritisation of distinct development corridors running along rail lines from its urban centre.[264]

Barcelona, Spain – residential neighbourhoods: Barcelona is one of Western Europe's most densely populated cities. Although a popular place in which to live and work, Barcelona struggles with air pollution, noise, limited green space, social isolation and – increasingly – climate impacts. A particular issue is that around 85 per cent of the city's land area is dedicated to private vehicles (including parking spaces).

Local authorities in Barcelona are tackling these challenges with an innovative Superblock model, piloted in the central neighbourhood of Eixample. Eixample's widened, octagonal intersections were meant to be meeting squares, but many are now utilitarian, unfriendly intersections dominated by traffic. Barcelona is attempting to revitalise these public spaces. Superblocks are designed to form mini-neighbourhoods, typically comprising 12 blocks (400x400 metres) that house 5,000 to 6,000 residents. The Superblocks' surrounding roads serve through-traffic, but internal roads are reserved for residents' vehicles travelling below 10km/hr. This improves access and safety for pedestrians and cyclists, as well as the quality of public and green space.

Initial interventions in Eixample have required minimal infrastructure – mostly new signage, road markings and street furniture. Future plans include permanent installations like playgrounds, 300km of new cycling lanes (increased from today's 100km) and 23 hectares of car-free space. In September 2017, Barcelona created the newest Superblock on 40 acres in the El Poblenou neighbourhood and another five are planned by 2018. This effort could decrease traffic by around 20 per cent, and also reduce emissions by as much as 75 per cent.

Singapore – green space: Singapore has focused on the distribution and connectivity of parks, not just on the total area of parkland. Hundreds of kilometres of green, pedestrian 'park connectors' mean that people have easy access to green space despite high-density living. This network of parks reduces temperatures, filters air pollution and mutes street noise.

Between 1986 and 2007, green cover in Singapore grew from 36 to 47 per cent, despite a 68 per cent increase in population, and average temperatures fell by between 0.5 and 5°C. Given that a drop of 1°C in air temperature lowers peak electricity demand by as much as 4 per cent, this translates into reduced energy consumption and emissions. The government now requires property developers to replace any greenery lost during construction, and covers 50 per cent of the costs of installing green roofs and walls on existing buildings, spurring innovations to develop lighter and more robust rooftop and vertical greening systems (structures that enable vegetation to spread over a building facade or interior wall). This has also driven prices lower: the cost of greening has fallen from S$150/$m^2$ to S$100/$m^2$ in a two-year period.

Source: New Climate Economy, 2014, 2018.[265]

Existing evidence suggests that these pioneering cities share a range of common characteristics, discussed below.

[262] New Climate Economy (2014) op. cit.
[263] UK examples are available from the Centre for Cities. http://www.centreforcities.org/publication/smart-cities/
[264] See also: LSE Cities (2013) Stockholm: Green Economy Leader Report: A report by the Economics of Green Cities Programme at the London School of Economics and Political Science. https://files.lsecities.net/files/2013/06/LSE-2013-Stockholm-Final-Report-webhighres.pdf
[265] New Climate Economy (2018) Unlocking the inclusive growth story of the 21st Century. Accelerating climate action in urgent times. Global Commission on the Economy and Climate. https://newclimateeconomy.report/2018/

High-tech clusters

Smart cities often contain high-tech clusters (including eco-innovation or low-carbon technologies). Such clusters tend to involve strong 'horizontal' connections between different parts of the city's ecosystem, including collaboration between universities, research institutions, start-ups and the wider business community. Clusters are beneficial where an industry exhibits significant network externalities. However, policies that explicitly aim to create or support clusters have often been ineffective[266] and therefore it would be challenging to replicate existing success stories. More sensible is policy that promotes density and innovation.[267]

A key consideration is the appropriate spatial scale for more horizontal interventions to address market failures (for example, in the supply of skills or access to finance), which might stimulate or enable agglomerations to grow.[268] Local interventions should be supported by national innovation policy to encourage investment in research and development (see Chapter 2).[269]

Urban innovation districts

Successful smart cities tend to support cross-fertilisation of ideas, technologies and behaviour, which can be promoted via dedicated urban innovation districts. The features of such districts are more prescriptive than the 'clusters' discussed above. Districts involve the establishment of mixed residential and work environments that are pedestrian-friendly and 'walkable' in an effort to induce creativity through random encounters. This is particularly suited to sectors where businesses benefit from collaborating openly or even pursue open innovation.[270]

There are already a number of innovation districts focusing on low-carbon technologies but even innovation districts focused on other areas are likely to reduce carbon emissions due to their design. There is, however, still a lack of empirical evidence to show that these districts benefit creativity and eventually result in innovation that would not have occurred otherwise.[271]

Substantial demand for low-carbon goods and services can also be created at the local level. Some of the features of innovation districts are also meant to make cities more attractive to their users, for example walkability. Cities that deliver on these types of features may have an edge in the competition for attracting and retaining talent in the future.

Local government policies for low-carbon lifestyles

Smart cities also adopt local government policies that promote low-carbon lifestyles directly, including in recycling, public transport and energy. Beyond providing services directly and immediately relevant to the low-carbon transition, they can also influence the diffusion of sustainable alternatives of a much wider range of goods and services, via establishing their own environmental standards and procurement policies. Doing so can help create additional demand in markets where market failure is a concern. Furthermore, research from the US shows that this creates spillover effects, in the form of the private sector adopting the same standards and increasing local suppliers' knowledge about greener alternatives.[272]

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[266] According to an evidence review on the effectiveness of policies supporting innovation conducted by the What Works Centre for Local Economic Growth, traditional local cluster programmes have a very poor success rate and there is a lack of evidence on how to capture the benefits of innovation locally.

[267] In the United States patent rates have been found to be positively associated with employment densities in the urbanised parts of metro areas, suggesting that density helps spur innovation. Centre for Cities (2017b) op. cit.

[268] See Nathan M and Overman HG (2013) Agglomeration, Clusters and Industrial Policy. Oxford Review of Economic Policy, Vol. 29, Issue 2, 1 July.

[269] Centre for Cities (2017b) op. cit.

[270] Katz B and Wagner J (2014) The Rise of Innovation Districts: A New Geography of Innovation in America. Metropolitan Policy Program at Brookings, May. https://c24215cec6c97b637db6-9c0895f07c3474f6636f95b6bf3db172.ssl.cf1.rackcdn.com/content/metro-innovation-districts/~/media/programs/metro/images/innovation/innovationdistricts1.pdf

[271] ibid.

[272] Simcoe T and Toffel M (2014) Government green procurement spillovers: Evidence from municipal building policies in California, Journal of Environmental Economics and Management 68: 411–434

Early leadership and experience-sharing

Early leadership and diffusion of proven policies and lessons learned is also a shared characteristic among pioneering smart cities. For example, leading cities set ambitious regulatory standards and agendas (on issues such as climate change, renewable energy targets, air pollution, recycling targets and cycling lanes). These initiatives may serve as guiding examples for others that may wish to adopt similar initiatives. As a result of early leadership, these policies are often promoted by NGOs who create larger partnerships and national or global networks for collaboration and sharing, for example in the case of 100 per cent renewable energy targets that are championed by dedicated city alliances such as ICLEI – Local Governments for Sustainability, and C40 cities.

5.3. Fostering sustainable growth in the UK's cities and regions

In order to support the development of smart cities in the UK, issues in four key policy areas should be considered, discussed below.

Financing and resourcing

In order to make the investment required to move onto a sustainable and smart growth path, cities will need sufficient finance and resources. Cities are directly responsible for providing a number of key services to their populations, such as housing, transport and waste management. They generally have a high degree of policy control over these services – which are also large contributors of greenhouse gas emissions, and thus key targets for decarbonisation efforts. Municipal government initiatives could therefore make large contributions to meeting national emissions targets, and central government should ensure that resources and financing are available.

However, local government resources are already stretched and opportunities to raise finance are limited. UK cities rely mostly on government transfers, and much of this is ring-fenced for specific policy areas. In London these transfers account for 74 per cent of revenues but in New York City for only 31 per cent, in Paris for 18 per cent and in Tokyo for even less – 8 per cent.[273] In the UK the current devolution debate includes demands for greater fiscal autonomy for local government, to enable UK cities to increase revenues themselves. Greater fiscal autonomy would also allow cities more flexibility to set local priorities.

Some change is happening, with local governments now able to increase business rates by up to 2 per cent to fund infrastructure improvements, although this is subject to certain conditions.[274] Other ideas involve raising revenues by establishing revolving funds for new energy-efficient homes or by capturing increased land values that follow improved transport connections, which can be used for further transport investment.[275] Alternatives to fiscal measures exist. Local government needs to be able to mobilise private capital to cover funding gaps for sustainable urban infrastructure projects. This can be achieved by improving cities' credit-worthiness, thereby allowing them to use the municipal bond market to raise finance or to set up pooled financing among a group of cities. This will require a much more enabling environment, coordinated with national government, to improve the risk-return profile for sustainable infrastructure investments.

[273] Slack E (2016) International Comparison of Global City Financing. Report to the London Finance Commission. Institute on Municipal Finance and Governance Munk School of Global Affairs, University of Toronto. https://www.london.gov.uk/sites/default/files/03_international_comparison_of_global_city_financing_october_2016.pdf

[274] This is conditional on having an elected metro mayor in place and subject to a local vote of the Local Enterprise Partnership. City-regions will then be able to raise the business rate up to 2 per cent in order to fund infrastructure improvements.

[275] National Infrastructure Commission (2017b) Economic growth and demand for infrastructure services. https://www.gov.uk/government/publications/economic-growth-and-demand-for-infrastructure-services

Coordination and governance

While cities may set very ambitious decarbonisation targets themselves, and are recognised actors in their own right, for example at the United Nations Framework Convention on Climate Change (UNFCCC), their actions contribute to meeting national targets. For this reason, coordination between the different levels of government on reducing emissions will be necessary.

However, this does not imply all cities will follow the same strategy. While all cities can leverage their expertise and experience in areas such as housing, energy and waste management, following exactly the same blueprint may be neither practical (due to different local needs or stage of decarbonisation) nor desirable. Using the exact same methods and best practices everywhere and across different domains may prevent inventiveness, experimentation and further improvements. Moreover, best practice is always evolving. Cities that first encounter changing demands from residents and workers need to be offered the flexibility to adapt accordingly. Mechanisms should be found to highlight and diffuse particularly good initiatives, and to do so iteratively.

A centralised body, such as the existing Future Cities Catapult, is a good solution to facilitate communication between cities and other actors, such as businesses, universities and research institutions, and could serve to inform emerging and changing best practices. Moreover, links between these actors at the local level, such as university–business collaborations, are important in their own right, as spillovers from basic research into industry can fuel an area's innovation output and help form and expand clusters.

Scaling up successful practices

In order to scale up policies and practices that are considered successful, central government can set standards that regional or local governments, or the private sector must meet. This would involve identifying successful initiatives as well as providing resources for these policies to be more widely adopted. In order to find policy designs that work, some risks need to be taken, enabling cities to experiment with policy design. It is also crucial that such experiments are evaluated effectively (as discussed in the next point). This is particularly challenging in the current context, where squeezed public sector budgets can reduce the appetite for experimentation, and there can be a temptation to stick with the safer option as well as to focus on short-term rather than long-term goals. Greater fiscal autonomy could play a key role in financing policy innovation and scaling up best practice.

Improving evidence and information

A lack of policy evidence is constraining evidence-based policy recommendations. This is true with respect to policies supporting 'clusters', where there is little evidence that policies have been successful, as well as for policies more specific to individual cities.[276] A key research constraint is the difficulty establishing counterfactuals for robust policy evaluations. Cities are also inherently very different, each one shaped by diverse local conditions. Isolating the effect of the features that make cities successful is therefore challenging and they may not always be transferable to other contexts anyway. Natural experiments, such as the reunification of Berlin,[277] and policy experimentation (using randomised control trials) may be useful tools for establishing the causal effects of policies, although they may not be feasible or applicable for all types of policies (in particular those that take a more holistic approach or emerge more organically). It will also be important to work closely with international bodies such as C40, ICLEI

[276] The What Works Centre for Local Economic Growth provides comprehensive literature reviews in key policies areas relevant for increasing local growth. Policy toolkits set out areas where there is extensive evidence, and where more work is needed.

[277] See, for example, Ahlfeldt GM, Redding SJ, Sturm DM and Wolf N (2015) The Economics of Density: Evidence From the Berlin Wall, Econometrica 83(6): 2127-2189

and the Covenant of Mayors to learn from best practice and how to overcome barriers to progress.

Measuring and monitoring the efficiency of urban systems also needs improving. Data will be essential for better management and pricing of externalities like pollution and congestion as well as scarce resources such as water, land and biodiversity. Recent research shows there are risks for UK cities from policies focussed on reducing production-based, rather than consumption-based emissions.[278] For example, Bristol's consumption-based emissions are three times its production-based emissions, largely due to the impacts of imported food and drink.[279] But designing policies and tools will require better data on city consumption emissions. The development of a system of integrated cities accounts, a framework similar to the UN System of National Accounts, is also long overdue. Cities that transparently release data also generate creativity and activity, for example the creation of phone apps giving real-time bus and train information, which in turn makes smartphones more attractive.

City planning cannot wait for the evidence to improve. Action creates evidence, which creates more action. The existing literature, based on the latest available evidence, for example the work of the New Climate Economy Coalition for Urban Transitions Initiative, and the discussion in this chapter, can provide qualitative guidance for mayors and local policymakers.

5.4. Cities – conclusions and recommendations

Cities are rightly attracting the attention of policymakers, academics and innovators across the UK. Smart cities can maximise creativity, ideas, low-carbon innovation and productivity growth. They will also have less congestion, better housing and public transport, and cleaner air. In short, they will be better places to live.

The *Industrial Strategy* and *Clean Growth Strategy* recognise the importance of sustainable development of cities and urban areas and are moving in the right direction but could be strengthened.

Recommendation 13: Ensure there is a national urban strategy that prioritises smart cities and empowers local communities across all UK regions. This could sit at the heart of government, with oversight from a high-level cross-ministerial committee. Such a strategy should be well coordinated with local industrial strategies, local city development and decarbonisation plans, and aligned with national emissions reduction commitments.

Encouraging cities and regions to compete for parts of the innovation architecture can be a powerful driver for change and a way to increase the spillovers from basic research into industry. While policies designed to encourage clusters have been shown to be ineffective in many cases, horizontal policies based on local strengths can generate the conditions for clusters to emerge or grow. The Government's Science and Innovation Audits are a promising mechanism for bringing local actors together, with the aim of mapping out local strengths and opportunities.

Recommendation 14: Encourage deeper partnerships between universities, colleges, local leaders and businesses, which can help build on local strengths and address local weaknesses.

[278] Sudmant A , Gouldson A, Millward-Hopkins J et al. (2018) Producer Cities and Consumer Cities: Using Production- and Consumption-Based Carbon Accounts to Guide Climate Action in China, the UK, and the US. Journal of Cleaner Production, 176. pp. 654-662

[279] Millward-Hopkins J Gouldson AP, Scott K et al. (2017) Uncovering Blind Spots in Urban Carbon Management: The Role of Consumption-Based Carbon Accounting in Bristol, UK. Regional Environmental Change, 17 (5). pp. 1467-1478

Innovation in governance may be as important as innovation in technologies. Consistent with the UK's wider devolution agenda, it is increasingly recognised that greater local control is important. Greater fiscal autonomy, for example, can help unlock finance, institutional capability and land needed for smart urban infrastructure, including housing. It can also help to boost R&D. In particular, there is scope to increase locally raised revenues by capturing some of the increased land value from improved transport connections, as was successfully achieved with London's Crossrail project.

Recommendation 15: A national urban strategy should devolve greater policy and fiscal autonomy to cities and regions, while concurrently building their fiscal capabilities. This should build on the Cities and Local Government Devolution Act 2016, and other recent moves to empower cities such as metro Mayors. Such a move will enable local communities to have a greater say in smart city planning and investments.

For policymakers to gain a better understanding of the types of policies that are likely to stimulate sustainable city growth, there should be more experimentation, along with a focus on evidence building, evaluation of examples, and data collection built into policy design.

Recommendation 16: Encourage creativity and experimentation around policies for productivity and sustainable growth and improve evidence, evaluation and data collection to gain a better understanding of what works.