

Growing clean

Identifying and investing in sustainable growth opportunities across the UK

Brendan Curran, Ralf Martin, Sabrina Muller, Viet Nguyen-Tien, Juliana Oliveira-Cunha, Esin Serin, Arjun Shah, Anna Valero and Dennis Verhoeven

May 2022



Acknowledgements

We thank Pia Andres, Torsten Bell, Mike Brewer, Josh Burke, Jonny Marshall, Penny Mealy, Henry Overman, Nick Robins, Nicholas Stern and seminar participants at the Resolution Foundation and LSE Centre for Economic Performance for comments. Financial support from the ESRC under grant ES/T002506/1 that has enabled some of the data work upon which we have built here is gratefully acknowledged. The authors are grateful for support from the Grantham Foundation for the Protection of the Environment and from the ESRC through the Centre for Climate Change Economics and Policy. All errors remain the authors' own.

Citation

If you are using this document in your own writing, our preferred citation is:

B Curran, R Martin, S Muller, V Nguyen-Tien, J Oliveira-Cunha,

E Serin, A Shah, A Valero & D Verhoeven, *Growing clean* :

Identifying and investing in sustainable growth opportunities across the UK,

The Resolution Foundation, May 2022

Permission to share

This document is published under the [Creative Commons Attribution Non-Commercial No Derivatives 3.0 England and Wales Licence](#). This allows anyone to download, reuse, reprint, distribute, and/or copy Economy 2030 Inquiry publications without written permission subject to the conditions set out in the Creative Commons Licence.

For commercial use, please contact: info@resolutionfoundation.org

The Economy 2030 Inquiry

The Economy 2030 Inquiry is a collaboration between the Resolution Foundation and the Centre for Economic Performance at the London School of Economics, funded by the Nuffield Foundation. The Inquiry's subject matter is the nature, scale, and context for the economic change facing the UK during the 2020s. Its goal is not just to describe the change that Covid-19, Brexit, the Net Zero transition and technology will bring, but to help the country and its policy makers better understand and navigate it against a backdrop of low productivity and high inequality. To achieve these aims the Inquiry is leading a two-year national conversation on the future of the UK economy, bridging rigorous research, public involvement and concrete proposals. The work of the Inquiry will be brought together in a final report in 2023 that will set out a renewed economic strategy for the UK to enable the country to successfully navigate the decade ahead, with proposals to drive strong, sustainable and equitable growth, and significant improvements to people's living standards and well-being.

The Nuffield Foundation

The Nuffield Foundation is an independent charitable trust with a mission to advance social well-being. It funds research that informs social policy, primarily in Education, Welfare, and Justice. It also funds student programmes that provide opportunities for young people to develop skills in quantitative and scientific methods. The Nuffield Foundation is the founder and co-funder of the Nuffield Council on Bioethics and the Ada Lovelace Institute. The Foundation has funded this project, but the views expressed are those of the authors and not necessarily the Foundation. Visit www.nuffieldfoundation.org.

Contents

Acknowledgements	2
Executive Summary	5
Section 1	
Introduction	13
Section 2	
What are the UK's clean strengths?	18
Section 3	
How are clean activities spread across the country?	33
Section 4	
A closer look at key technologies in the UK's journey to net zero	47
Section 5	
How can the UK's financial sector help realise clean growth opportunities?	66
Section 6	
Conclusion	76
Annexes	78

Executive summary

The 2020s will see the UK's journey to net zero enter a new phase. In the decade ahead, large scale reductions in emissions will be required from buildings and surface transport, as well as continued rapid decarbonisation both in electricity supply and elsewhere. This will require major economy-wide changes that will have significant impacts on households and firms across the UK.

Investment and innovation will be key to achieving this: the Climate Change Committee estimated that an additional £13.5bn of investment will be needed in 2022, rising to over £50bn by 2030, to meet the UK's net zero goals, and around 85 per cent of decarbonisation between 2020 and 2035 will involve low carbon technologies or fuels alone or in combination with behaviour change. Both the invention of new technologies and the deployment of existing ones will be important. Globally, over the next three decades, the International Energy Agency estimates that "almost half the [emissions] reductions come from technologies that are currently at the demonstration or prototype stage". These conclusions spark a variety of responses. The required scale and pace of the investment lead some to question its viability. Others suggest that, given the UK's current low levels of investment, investing and innovating our way to net zero will address the UK's chronic underinvestment in innovation, capital and skills.

The reality is that change is coming over the next decade, and, although there will be upfront costs, these changes and the associated investments will provide opportunities for cost savings via improved resource efficiency, growth via the development of new products and services to serve growing domestic and international markets, and broader co-benefits such as cleaner air and improved health. But it is not realistic to assume that we can rely on the private sector to naturally choose the smoothest and cheapest path to net zero. The required innovation – which is radical, and involves the transformation of entire systems in many cases – will not happen at the necessary scale and pace without incentives, regulation, government spending and participation from civil society.

From the perspective of UK policymakers designing these interventions as part of a new economic strategy then, a key question is how to best target investments and design policies to promote the development of current and potential future competitive strengths, and to avoid the pitfalls of attempting to ‘pick winners’.

To inform this, this report provides a hard-headed assessment of the opportunities presented to UK plc by the move to net zero, and considers how best these can be unlocked. It does this by considering carefully the UK’s pre-existing relative strengths in technologies, goods and services that are relevant for net zero. It also undertakes a series of ‘deep dives’ into key areas in the UK’s decarbonisation journey to investigate the extent of UK strengths that can be built upon to accelerate domestic deployment of related technologies as well as unlock export opportunities. Finally, we assess how the UK’s financial sector can be oriented towards delivering the investment needed for net zero, and for realising related opportunities in the UK. The focus is on innovators or firms creating technologies, products and services that are relevant for delivering net zero and that can generate value in the UK; the implications of the net zero transition for workers will be considered in a future Economy 2030 report.

The UK is not yet a clean tech superpower, but it has strengths in technologies and products relevant for the net zero transition

The UK is specialised in clean technologies overall, as assessed by data on patenting, ranking fifteenth globally on this measure. In volume terms, the UK lags behind some countries that are also more specialised in clean technologies: for example, South Korea and Japan produce around four times as many clean patents per 100,000 workers compared to the UK. Nevertheless, within the overall category of clean technologies, there are a few subcategories that stand out for the UK, in particular tidal, offshore wind and nuclear energy and carbon capture usage and storage technologies.

Importantly, we also find that the expected ‘national’ returns from government support for innovation – including private returns for the innovator as well as direct and indirect knowledge spillovers for other UK innovators – are particularly high for both tidal and offshore wind energy technologies; these both have estimated returns of nearly three times the average across all technology fields. This means that government support for these technologies is particularly likely to generate value that is retained in the UK.

Overall, the UK is heavily specialised in services, and areas such as green finance and related services present key opportunities in the UK. But as we have highlighted in previous Economy 2030 reports, the UK also has revealed comparative advantage in certain goods categories such as pharmaceuticals, which rely heavily on the UK’s strong science base and universities. These are also a source of strength when it comes to net zero. In fact, the UK is already a major exporter of ‘green’ goods. The UK ranks 9th globally on ‘green’ exports, accounting for 2.5 per cent of global export volume of such products. This share is similar to France, but significantly lower than China, Germany and the US (at 19, 13 and 10 per cent respectively). Digging deeper at the product level, the UK is specialised in a number of ‘green’ areas. This includes some more complex green products which tend to be more technologically sophisticated, and there is evidence that specialisation in complex products is associated with higher incomes. Finally, among green products where the UK does not currently have comparative advantage, there are a number of complex products which are relatively close to the UK’s existing capabilities – including in

renewable energy and environmental monitoring equipment – that represent areas of opportunity.

This national-level analysis suggests that the UK is not the world leader overall in clean technologies or traded goods. It certainly does worse than Germany, which has stronger advantages in many areas of manufacturing, has more existing green strengths, and more proximate future opportunities, particularly in more complex goods. But the UK is among the top countries in terms of its specialisation in clean technologies and products, and there are specific areas of strength that can be built upon as part of a new economic strategy for the UK.

Net zero activity appears to be spread around the country, including in services

As well as being able to contribute to the UK's future prosperity, there are also opportunities for the transition to a cleaner economy to help reduce regional inequalities within the UK. Analysis of patent data shows that, although patents overall (as with R&D activity more generally) tend to be concentrated in the 'golden triangle' regions, including Oxford, Cambridge and London, areas outside these innovation-intense regions (such as Derbyshire and Nottinghamshire, Cornwall and the Isles of Scilly and Lincolnshire) tend to be more specialised in clean technologies.

There are also interesting – and, for a government wishing to redistribute R&D spending and 'level up' the country, helpful – geographic patterns in the returns to investments in clean innovation. Investments in certain clean technologies, such as tidal and offshore wind, are not only likely to generate relatively high national economic returns, but also have the potential to contribute to regionally balanced growth. Investments in these technologies in less innovation-intense regions generate strong returns for those regions (and little leakage). Moreover, government support for these technologies in more innovation-intense regions generates spillovers for the rest of the country, as well as returns in these regions themselves. This highlights the economic contribution that strong innovation clusters can have in other parts of the country.

We also find that less productive regions tend to be more specialised in firms producing clean goods and services. There are over 20,000 such firms spread across the country, with around half being in services. The largest single subcategory, representing nearly 40 per cent of these firms, relates to demand-side management and digital technologies, which includes AI and Internet of Things for energy management and smart systems, highlighting the interplay between clean technologies and digital. Although these firms are generally located in more productive areas (which also tend to have more businesses in general), the fraction of such firms that are 'clean' firms is higher, on average, in areas with lower regional productivity. This result does vary by subcategory, though, with firms producing products and services related to low-carbon heat and buildings being particularly likely to be found in areas with lower regional productivity (such as East Wales, South Western Scotland and South Yorkshire), while areas around London are more likely to specialise in other areas including consultancy and services.

A related analysis of firms in the UK's 'high-growth economy' (i.e. firms that have received growth finance or achieved rapid growth), finds consistent patterns. We find that a high share of these (38 per cent) tend to be located in London and the South East, but this is lower than the share of high-growth firms across all technologies (47 per cent). Within the high-growth economy, therefore, areas outside London and the South East appear to be more specialised in goods or services relevant for net zero.

This analysis suggests that doubling down on net zero capabilities in the UK as part of a coordinated growth policy could be consistent with both driving growth and addressing regional disparities in economic activity; future Economy 2030 Inquiry reports will analyse the jobs angle of the net zero transition explicitly.

In the areas where urgent action is needed, the UK has the potential to develop additional strengths

The next phase of decarbonisation requires change across the UK economy. Urgent action is needed especially in surface transport, electricity supply, buildings, manufacturing and construction, and removals – the top five sources of CO₂ abatement by 2050 under the Climate Change Committee's balanced pathway to net zero. The first four of these sectors will need to deliver the majority of

economy-wide abatement required by 2030 to keep the UK on track to meet net zero by 2050, with removals rapidly scaled up from 2030s. Within these sectors, we use various data sources to consider where opportunities might lie for the UK, looking at zero emission passenger vehicles (ZEVs) in surface transport; wind, nuclear and grid flexibility in electricity supply; low carbon heat and buildings; and carbon capture, usage and storage (CCUS), a set of technologies relevant for decarbonising heavy industry and enabling greenhouse gas removals.

Across these areas, we find varying evidence of pre-existing UK comparative strengths. For example, wind is an area where the UK has technological specialisation, and where we have seen that investments in innovation generate relatively high returns in the UK. However, the UK is not yet specialised in the exports of wind-related products. Denmark leads on this measure, despite having smaller installed capacity of wind power compared to the UK. Given its innovative strengths however, commitments to ramp up domestic deployment in the UK might generate new opportunities, including the potential to pioneer floating offshore wind.

CCUS and nuclear are areas where the UK is specialised in both the exports of products, and innovation. CCUS, as yet limited in commercial application globally, can benefit from the UK's transferrable expertise and capabilities in oil and gas. By contrast, on aggregate, the UK does not have comparative strengths in goods or technologies relating to ZEVs or grid flexibility. But the UK does have digital strengths which are not fully captured in such data, and which apply across both of these areas, for example in the development of connected and autonomous vehicles or smart grids. Finally, heat and buildings constitute an area where the evidence suggests that the UK does not yet have comparative advantage overall, but is specialised in specific products including heat pumps and insulation that are highly relevant for decarbonising its building stock and where largescale domestic deployment could generate new opportunities.

The UK leads in green finance, but there are investment challenges to be overcome if the UK is to realise the clean growth opportunities we identify

The scale and nature of the investment required to meet net zero requires the public and private sectors to work together. Some low carbon sectors, such as offshore wind, have reached a high degree of financial independence from public sources. Others, such as low carbon hydrogen, still require a large degree of support to become financially viable.

Different financial instruments are required at different levels of technological and commercial maturity. At the early stages of research and development, public finance has a role to play in technologically maturing low carbon sectors: for example, through providing grants to harness the UK's strong university research base. But there is also an important role for venture capitalists and private equity to invest in emerging technologies, taking risky, high-growth potential positions following these innovation grants. The volume of venture capital investment in the UK is the highest in Europe, and has been growing rapidly. But clean technology firms have attracted a relatively low share of this to date, and this share has fallen from over 10 per cent in the early 2010s to under 1 per cent in 2020. There is evidence that, in the past, investments in these technologies have been considered riskier than, for example, software start-ups. This is beginning to change given the tougher policy commitments to net zero, but there is a clear role for Government to develop investable business models and to de-risk emerging sectors such as hydrogen and greenhouse gas removals, particularly in commercially maturing sectors.

Moreover, a place-based lens is required in decision-making around net zero investments, given that there are different net zero growth opportunities across the country, and moving out of high carbon activities will have varying impacts on people and firms. By integrating considerations of place into capital allocation decisions and building capacity, the finance sector and related institutions can ensure that finance is channelled to the places that, socially and economically, stand the most to gain in the transition. The newly-formed UK Infrastructure Bank has a particularly central role to play in this area, given its dual objectives of supporting net zero and regional economic growth.

Building on its strengths in financial services, the UK has positioned itself as a leader in green finance, and is the first country to commit to creating a Net Zero Financial Centre by 2050. The UK has made a range of regulatory changes, including the introduction of mandatory climate reporting and transition plans for businesses, as well as the Bank of England's Net Zero mandate. This has created the basis for the UK to continue leveraging its specialisation in financial and related services and potential for financial innovation in the transition to net zero. But a number of challenges remain. Environmental Social and Governance (ESG) ratings are often the basis of funds with a 'sustainable' label. But such ratings evaluate financial risks related to sustainability, rather than environmental impacts of the business in question. There is, therefore, a risk that 'greenwashing' prevents finance flowing to projects that can deliver net zero and generate related opportunities.

Realising net zero opportunities across the UK requires the transition to be embedded in its new economic strategy

Net zero alone is not a silver bullet for reversing the UK's economic stagnation and addressing inequalities: domestic implementation of climate policies and targets does not necessarily lead to domestic economic benefits or ensuring that these, and costs, are shared fairly. To maximise the chances that these objectives can be achieved, it will be necessary for the transition to be embedded into a coordinated and system-wide policy approach that stimulates increased and well-targeted investments across innovation, infrastructure and skills.

Done right, in 2030 the UK could have higher living standards, and better health and wellbeing, underpinned by UK businesses innovating and adopting cutting-edge clean technologies and practices fit for the mid-21st century. Future Economy 2030 reports will examine the jobs aspects of the transition, examining how the benefits of net zero investments can be spread across the country and how displacements can be actively managed against the background of over a decade of stagnant living standards, weak productivity and low investment, and in parallel with other drivers of change including Covid-19, Brexit and geopolitical instability in Europe.

Section 1

Introduction

The 2020s is the decisive decade for the UK, and the world, to avoid the worst impacts of climate change. Accelerated and deeper emissions reduction this decade, as required to meet the UK's commitments to net zero by 2050, will need to occur against the background of over a decade of stagnant living standards, weak productivity and low investment, and in parallel with other drivers of change including Covid-19, Brexit and geopolitical instability following Russia's invasion of Ukraine.

There are reasons to be optimistic. The UK has made good progress in its decarbonisation journey so far: halving its territorial CO2 footprint in the 30 years since 1990, largely due to changes in electricity supply. The UK can build on its strong research base, and innovative strengths in clean technologies. It is also a leader in green finance which not only helps the UK meet its net zero targets, but can also generate service export opportunities.¹

But this next phase of net zero will look different, requiring substantially increased investment and action across the economy including in the decarbonisation of buildings and surface transport, and changes in diet, aviation and industry: all of these will have direct impacts on people's lives. Such system-wide change across energy, transport, and cities and the changing nature of decarbonisation will bring with it a new set of challenges, as set out in previous reports for the Economy 2030 Inquiry.²

Investments in new technologies will continue to be crucial for achieving decarbonisation. In the UK, it has been estimated that around 85 per cent of decarbonisation between 2020 and 2035 will involve low carbon technologies or fuels alone or in combination with behaviour change, with only 15 per cent primarily involving behaviour change (see Figure 1). Both the invention of new technologies, and the deployment of existing ones will be important. Globally and over the horizon to 2050, the International Energy Agency estimates that "almost half the [emissions] reductions come from technologies that are currently at the demonstration or prototype stage".³ Recent

¹ In this report, we use the terms 'clean', 'green' and 'sustainable' interchangeably in relation to growth, and the technologies, products and services that can help to achieve such growth, largely driven by the broadly consistent definitions of these terms used in the datasets we are analysing. The fundamental definition of sustainability is for this generation to offer the next generation opportunities in terms of well-being that are at least as good as those which they had, assuming that the next generation behaves in a similar way to those that follow. In 1987, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising on the ability of future generations to meet their own needs". For more discussion, see N Stern & A Valero, *Innovation, growth and the transition to net-zero emissions*, Research Policy 50(9), November 2021.

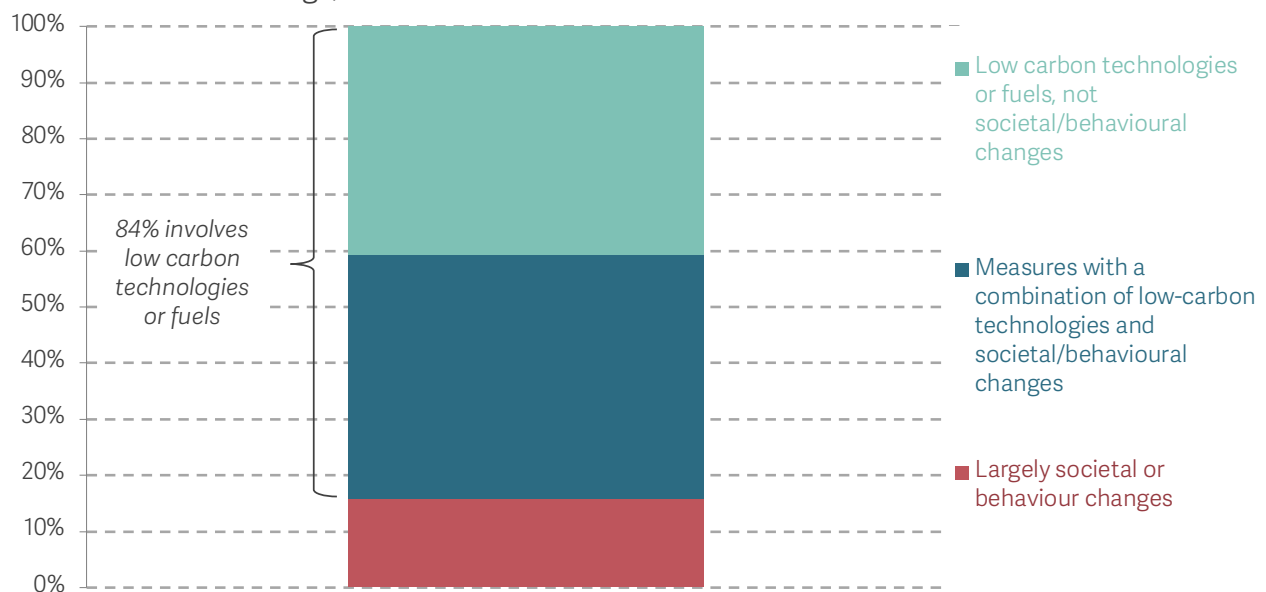
² J Marshall & A Valero, *The Carbon Crunch: Turning targets into delivery*, Resolution Foundation, September 2021.

³ International Energy Agency, *Global Net Zero Emissions Roadmap to 2050*, 2021.

years have demonstrated that clean technologies are particularly effective at generating economies of scale in production and innovation: in the 2010-2019 period, there have been sustained decreases in the unit costs of solar energy (85 per cent), wind energy (55 per cent), and lithium-ion batteries (85 per cent).⁴

FIGURE 1: Low carbon technologies and fuels are required across most of the UK's decarbonisation to 2035

Proportion of decarbonisation from 2020 to 2035 that requires technologies, behavioural change, or both



SOURCE: CCC Sixth Carbon Budget Advice Report, Figure B2.2.

It has also been suggested that increased innovation and its diffusion is key to generating sustained increases in productivity growth in the UK. While there is disagreement among economists as to whether advanced economies can return to pre-crisis productivity growth trends, there is reason to believe that there is room for improvement via effectively addressing the UK's chronic underinvestment in innovation, capital and skills relative to its main peers.⁵

But, the 'direction', as well as the amount, of growth matters. According to the literature on the environment and directed technological change, steering innovation onto a sustainable path can improve living standards while also decarbonising economies.⁶ However, in the presence of a series of market failures and path dependencies in innovation systems, markets will not move towards a green economy at the pace required without active and 'directional' industrial, innovation and environmental policies

⁴ IPCC, *Climate Change 2022: Mitigation of Climate Change. Working Group III Contribution to the IPCC Sixth Assessment Report*.

⁵ J Oliveira-Cunha et al., *Business Time: How ready are UK firms for this decisive decade?* Resolution Foundation, November 2021.

⁶ See chapter 9 of P Aghion et al., *The Power of Creative Destruction*, Harvard University Press, for a summary. See also: N Stern & A Valero, *Innovation, growth and the transition to net-zero emissions*, *Research Policy* 50 (9), November 2021.

that can set expectations and incentives for the private sector. Over and above the greenhouse gas externality which calls for robust carbon pricing and regulation, market failures that justify support for innovation (via government funding or de-risking) – such as the presence of knowledge spillovers and capital market imperfections – appear to be particularly relevant in the case of clean technologies. Coordination of energy, urban, transport and land systems and overcoming information asymmetries are also important for enabling investments and informing the decisions of consumers, investors and those at various points of the business supply chain.

The UK Government's Net Zero Strategy highlights the role of innovation in delivering both emissions reductions and future growth.⁷ However, from the perspective of UK policymakers, a key question is how to best target investments and design policies to promote the development of current and potential future competitive strengths, and to avoid the pitfalls of attempting to 'pick winners'. Doing this will require understanding the UK's current and potential strengths in the technologies, goods and services that are likely to be in increased global demand in this transition. Understanding these, and the barriers to growth that policy can address, will help to inform industrial, innovation, skills, trade and places policies for sustainable growth this decade and beyond.

This report sheds light on these issues, using a range of complementary datasets and approaches. In the context of the largescale and economy-wide change that is expected this decade, understanding clean growth opportunities requires looking beyond supporting a narrowly defined 'low carbon sector' as it stands today.⁸ We therefore undertake three types of forward-looking, data driven approaches, each with its own advantages and drawbacks.

The first relies on patents. A large literature has analysed clean innovation using patents data which provides an indication of the output of innovative activity. While not all innovations are patented,⁹ the advantages of this approach include the fact that patents data are available across countries with detailed geographic information, over time, and technologies can easily be classified as being 'clean'. Previous work for the Economy 2030 Inquiry highlighted that the UK is specialised in clean technologies, and we explore this in more depth here.¹⁰

⁷ Department for Business, Energy & Industrial Strategy, [Net Zero Strategy: Build Back Greener](#), October 2021.

⁸ Surveys that analyse environmental goods and services sectors estimate that the low carbon and renewable energy economy accounts for around 1 per cent of non-financial turnover and employment. See: Office for National Statistics, [Low carbon and renewable energy economy UK: 2020](#), February 2022. Broader approaches for classifying 'green' occupations across industries generate higher employment estimates. See: Valero et al., [Are 'green' jobs good jobs?](#), Grantham Research Institute and Centre for Economic Performance, October 2021.

⁹ Innovations in the service sector are less likely to be patented than in manufacturing, and innovations that relate to new processes within firms tend not to be patented.

¹⁰ J De Lyon et al., [Enduring Strengths: Analysing the UK's current and potential economic strengths, and what they mean for its economic strategy at the start of the decisive decade](#), Resolution Foundation, April 2022.

Second, we analyse data on exported ‘green’ goods.¹¹ Considering patterns of exports tells us something about how good the UK is at producing products that are valued on the world stage. Here we draw on analysis of specialisation, product complexity, and the ‘proximity’ of products to the UK’s capabilities, something that can help shed light on future opportunities. These data have the advantages of being available at a disaggregated level across countries on a consistent basis and over time, but are available only at the national (rather than regional) level, and exclude the service sector, which we know dominates the UK economy and its exports.

Third, we analyse firms in the UK that specialise in providing goods or services that are relevant for the transition to net zero, using classifications of firms into different technology areas or ‘sectors’ based on how they describe themselves on their websites.¹² Here, we are able to consider where in the UK firms are located, and which broader sectors they are part of. We also analyse the extent to which ‘clean-tech’ firms are active in the UK’s high growth economy.

Our next step is to consider a few areas in more depth, highlighting technologies or sectors that are important in the UK’s decarbonisation journey, and where previous work has pointed to certain underlying capabilities in the UK which can be built on. These are: zero emission passenger vehicles, wind energy, nuclear, grid flexibility, heat and buildings; and carbon capture usage and storage.

Finally, we set out how the UK’s strengths in financial services can be oriented towards investing in and realising net zero related growth opportunities, and summarise the challenges that remain.

The remainder of this report is structured as follows:

- Section 2 considers the UK’s comparative strengths in clean technologies and products.
- Section 3 explores where innovation and business activity relevant for net zero is located across the UK.
- Section 4 considers the opportunities and policy context in some key areas of focus in the UK’s journey to net zero.
- Section 5 asks how the UK financial sector can be supported to invest at scale in net zero opportunities as well as reviewing how to maintain its international sustainable finance leadership.

¹¹ This part of the analysis draws upon: P Andres & P Mealy, Green Transition Navigator, 2021. www.green-transition-navigator.org, accessed April 2022.

¹² This has an advantage over traditional firm level datasets that rely on Standard Industrial Classification (SIC) codes for sectoral analysis. These were last updated in 2007, and are relatively uninformative for the analysis of emerging technologies or subsectors.

- Section 6 concludes with a brief discussion of the implications of our findings for policy making in the 2020s.

Given the largescale and rapid change that is required to meet net zero commitments at the national and international levels, it is particularly challenging to use data from the past to inform the future. Our aim in this report is to use a range of forward-looking approaches that try to shed light on the net zero economy and associated opportunities, but this is the start of a research agenda. It will be important for the policy and research communities to build definitions, mappings and measurement methods in real-time, including agreement on how these should be updated over time, that are sound, practical and widely shared.¹³

¹³ N Stern & A Valero, Innovation, growth and the transition to net-zero emissions, Research Policy 50(9), November 2021.

Section 2

What are the UK's clean strengths?

Judged using patent data, the UK is relatively specialised in clean technologies overall, and especially so in a few subcategories, such as carbon capture usage and storage, as well as tidal, wind and nuclear energy technologies. A new methodology that estimates the expected 'national' returns from government support for innovation – including private returns as well as direct and indirect knowledge spillovers to other firms – shows that such returns are above average for clean technologies, and particularly high for tidal and wind energy technologies. This suggests that investments in these technologies are particularly likely to generate economic benefits in the UK.

The UK is also a major exporter of 'green' goods, accounting for 2.5 per cent of global exports of such products, ranking ninth globally. The UK has particular specialisations in some more complex green products which tend to be more technologically sophisticated and associated with higher growth potential. Moreover, amongst green products where the UK does not currently have comparative advantage, there are a number of complex products which are relatively close to the UK's existing capabilities – including in renewable energy and environmental monitoring equipment – and these represent areas of opportunity.

This suggests that, while the UK is not the world leader overall in clean technologies or traded goods, it is amongst the top countries in terms of specialisation in clean technologies and products, and there are specific areas of strength that can be built upon as part of a new economic strategy for the UK.

In this section, we consider the UK's strengths in technologies and goods that are relevant for net zero. The starting point is that patterns in patenting and goods exports reveal information about what the UK is good at, and how this compares with other countries. In each sub-section, we begin by outlining the data and concepts that can shed light on the UK's relative technological and product strengths, before describing key results at aggregate and disaggregated levels.

Patent data reveals the UK's innovative strength in clean technologies

Previous Economy 2030 work has analysed technology areas where the UK tends to specialise, as measured with patenting data.¹⁴ Because patents are a key measure of innovation output, these areas should be a good guide to where future value will be generated. To analyse innovative specialisation, we calculate revealed technological advantage (RTA), which compares a country's share of total innovation in a particular technology area to the global share. Box 1 explains the methodology and data.

Although it is true that not all innovation is patented – particularly in the services sector which is particularly of relevance for the UK economy – patents are a standard measure of innovation output, as data are available internationally, over time, and at a detailed technological level which lends itself to comparative analysis of this type. We also know that the transition to net zero will involve the further refinement and invention of a number of 'hard' technologies and equipment for which patenting data tends to have good coverage.

Box 1. Revealed Technological Advantage

Our measure of the UK's RTA in a particular technology class measures the share of all UK patents in that class, divided by the share of all global patents that same technology class. We adjust these RTA values so that they lie within between -1 and +1, so that numbers greater than zero reflect that

a country is specialised in a particular area.¹⁵ This offers a proxy measure of the areas in which the UK is relatively more innovative, and where advantages and value have been realised in production, or could materialise in the future.

¹⁴ J De Lyon et al., *Enduring Strengths: Analysing the UK's current and potential economic strengths, and what they mean for its economic strategy at the start of the decisive decade*, Resolution Foundation, April 2022.

¹⁵ The transformation takes the form $(RTA_{row} - 1)/(RTA_{row} + 1)$, where RTA_{row} refers to the untransformed RTA calculated as described in Box 1, and which takes values between zero and infinity.

Data comes from the 2021 Autumn edition of the Worldwide Patent Statistical Database (PATSTAT Global) published by the European Patent Office (EPO). Given that data are available with lags, the latest complete year in our analysis is 2018. Our analysis focuses on patent ‘families’: sets of patents that cover similar technical content. We restrict the analysis to patent families which consist of more than one patent application, which is a way of including only higher-quality

patents. We identify the country of origin for these patent families by mapping them to the current country of residence of the corresponding inventors (see Annex 1 for details). Patents are classified in specific technological classes according to the Cooperative Patent Classification system, which includes a category of patents which relate to climate change mitigation and adaptation (the Y02 class) which we label as ‘clean’ technologies.

We have previously noted that the UK is an innovation intense economy: it is in the top ten countries globally in terms of total patenting volumes.¹⁶ This also applies in the case of ‘clean’ technologies, where the UK accounts for over 3 per cent of global patents over 2015-2018, ranking seventh in the world.¹⁷ Analysis of RTA reveals that the UK is also specialised in clean patents overall, an area of patenting that has been growing in recent years, as shown in Figure 2. The UK is also highly specialised in the life sciences, in areas such as pharmaceuticals, biotechnology as well as medical devices and ‘trending’ growth areas including 3D printing and Robotics.¹⁸

Other countries are more specialised in clean patenting overall, however. In fact, the UK ranks fifteenth overall in terms of RTA, and behind Germany and France (see Figure 3). And the UK’s patenting intensity is lower than some of the most specialised countries. Over the period 2015-2018, the UK produced over ten clean patents per 100,000 workers, while Denmark, South Korea and Japan produced around four times this quantity.

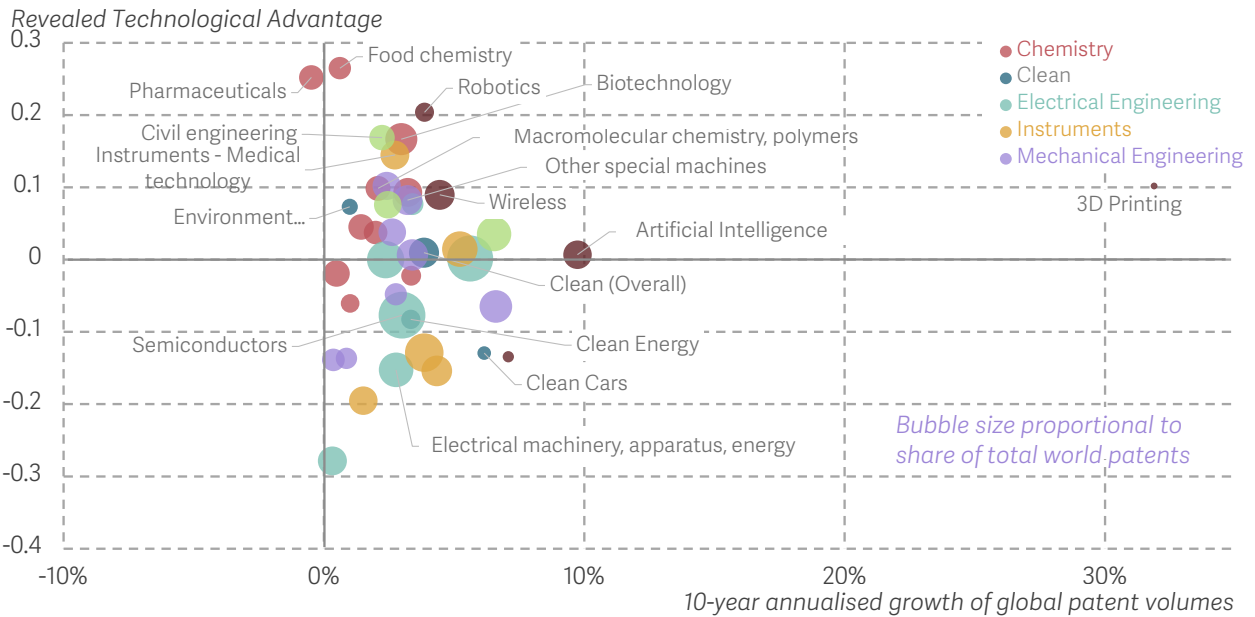
¹⁶ J De Lyon et al., *Enduring Strengths: Analysing the UK’s current and potential economic strengths, and what they mean for its economic strategy at the start of the decisive decade*, Resolution Foundation, April 2022.

¹⁷ Ahead of the UK in volume terms are Japan and the US which account for 23 per cent each, followed by China, Germany, South Korean and France. Together, these countries account for around 90 per cent of total ‘clean’ patents in the 2015-2018 period.

¹⁸ This analysis shows broadly the same patterns as our previous Economy 2030 analysis (J De Lyon et al., *Enduring Strengths: Analysing the UK’s current and potential economic strengths, and what they mean for its economic strategy at the start of the decisive decade*, Resolution Foundation, April 2022) which was based on 2015, and which we update here for the four most recent years available in the data. Pooling patents over more years is useful for the purposes of this paper, since we perform more disaggregated analysis at the technology and geographic level. As we found was the case using 2015 patents, the UK is specialised in clean technologies overall, though this has fallen slightly, a trend which appears to be driven by a lower RTA in clean energy.

FIGURE 2: The UK is specialised in life sciences, but clean technologies present a growth opportunity

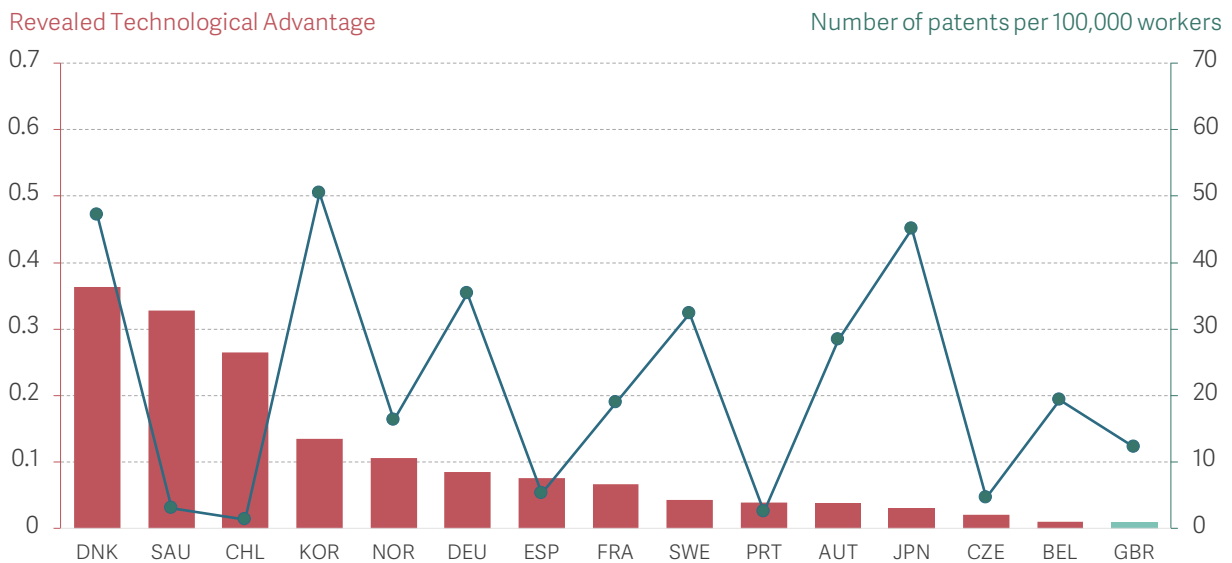
Revealed Technological Advantage by broad technology categories: UK, 2015-2018



NOTES: The vertical axis denotes the RTA bounded between -1 and 1, the horizontal axis represents the 10-year annualised growth for broad technological categories (2008-2018), and the size of the bubbles represents the share of the technological category in overall patenting activity between 2015-2018. Clean (overall) includes all patents under the CPC class 'Y02' i.e., climate change mitigation and adaptation technologies. These also include patents under the other technology categories such as clean cars, environmental technology and clean energy.
 SOURCE: Analysis of PATSTAT 2021, Autumn edition.

FIGURE 3: The UK ranks fifteenth in terms of overall specialisation in clean technologies, and lags on overall clean patent intensity

Revealed Technological Advantage, top fifteen countries, and patents per 100,000 workers, 2015-2018



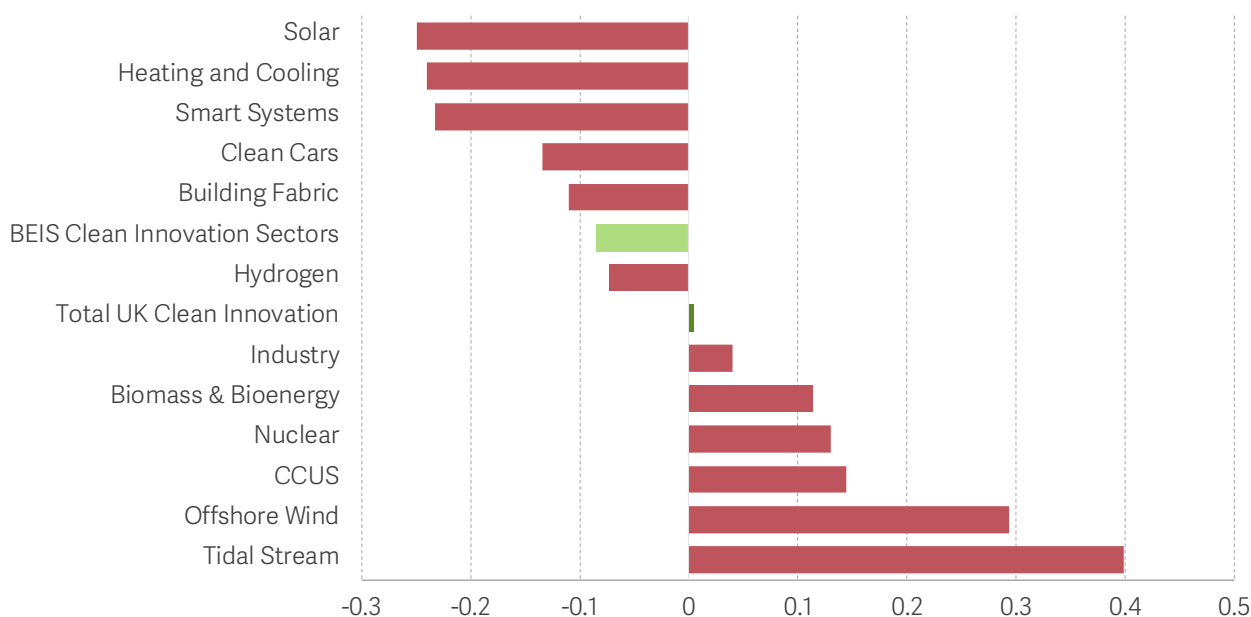
NOTES: Number of patents per 100,000 workers as of 2018. GBR is the 3-digit country code for the UK.
 SOURCE: Analysis of PATSTAT 2021, Autumn edition.

The UK's overall specialisation in clean technologies masks significant variation at a more detailed level. For example, while Figure 2 shows that the UK is not specialised in clean car technologies (a subset of the overall clean category), other analysis at a more disaggregated level has shown that there are specific technologies where the UK is specialised, including connected and autonomous vehicle technologies.¹⁹ The same goes for clean energy, where previous analysis has shown that the UK has revealed technological advantage in wind and tidal energy technologies.²⁰

To shed further light on the UK's relative performance across a number of key technology areas we draw upon categories designed in collaboration with the Department for Business Energy and Industrial Strategy (BEIS).²¹ Overall, the UK does not have an RTA in the BEIS clean technology category (see Figure 4), but within this, four broad areas stand out where the UK has strengths: offshore wind and tidal stream; nuclear; and carbon capture, usage and storage (CCUS). These areas (and others) are explored in more depth in Section 4.

FIGURE 4: Within clean technologies, the UK is particularly specialised in offshore wind, tidal, nuclear and CCUS technologies

Revealed Technological Advantage by selected clean technologies: UK, 2015-2018



NOTES: Revealed Technological Advantage for the categories in R Martin & D Verhoeven, [Knowledge spillovers from clean and emerging technologies in the UK](#), CEP Discussion paper 1834, March 2022. Category 'clean cars' added. Total UK Clean Innovation refers to all patent families under the CPC class 'Y02'
SOURCE: Analysis of PATSTAT 2021, Autumn edition.

¹⁹ S Unsworth et al., [Seizing sustainable growth opportunities from zero emission passenger vehicles in the UK](#), Centre for Economic Performance - Grantham Research Institute Special report for the LSE Growth Commission, February 2020.

²⁰ R Martin et al., [Innovation for a strong and sustainable recovery](#), LSE CEP, December 2020.

²¹ These technologies include many of the technologies in the Y02 CPC class, plus some others that are deemed relevant. For the purposes of this paper, we have added the category 'clean cars'. For detail on how these sectors were derived, see Appendix 2 in: R Martin & D Verhoeven, [Knowledge spillovers from clean and emerging technologies in the UK](#), CEP Discussion paper 1834, March 2022.

The economic returns to clean innovation are also relatively high

The RTA gives an indication of a country's specialism in a given area of innovation to date, but it does not give an indication of the economic value that can be generated from these innovations within particular countries, regions or even globally. It also does not capture differences in the knowledge spillovers that different technologies generate, or variation in the ability of governments to promote further innovation in specific areas via investments in research and development (R&D).

The Industrial Strategy Index (IStraX) methodology, which we explain in detail in Box 2, provides a framework to take these issues into account.²² It estimates the economic return on potential government R&D subsidies to different technology areas, and takes into account variation in the private returns on innovation in different sectors, as well as direct and indirect knowledge spillovers to other firms (as measured through citations in patents). It also takes account of the possibility that innovators in different areas might vary in their responsiveness to government R&D support.²³ (Given the increased emphasis on 'place' in the allocations of publicly funded R&D,²⁴ we consider geographic patterns in these returns within the UK in Section 3.)

Box 2. The Industrial Strategy Index (IStraX)

The IStraX is based on a model of the innovation process, which is fitted to global data on patenting and valuations of companies undertaking innovation.

Resulting values therefore reflect the total economic value of an innovation in a certain field calculated as the difference between the expected increase in total value (private value as well as external values from knowledge spillovers) generated by that innovation and the expected cost of the subsidy,

scaled by the expected cost of the subsidy.

In this methodology, the value of an innovation is captured only to the extent it translates into some firm's profit. Private value of an innovation is assumed to be captured by the short-term response of the stock market price of innovating companies when a patent is granted (private values of patents for non-stock-listed companies are based on the most similar patents

²² C Guillard et al., *Efficient industrial policy: Standing on the shoulders of hidden giants*. CEP Discussion Paper No. 1813, November 2021.

²³ We look at the period 2005-2014; the authors are currently updating this analysis for the most recent version of the patents data.

²⁴ The Levelling Up White Paper pledges that, by 2030, domestic public investment in R&D outside the Greater South East will increase by at least 40 per cent. See: Department for Levelling Up, Housing and Communities, [Levelling Up the United Kingdom](#), February 2022.

from stock-listed companies). The value of knowledge spillovers created by an innovation is calculated as a portion of the private value of all innovations that build upon it. Since knowledge spillovers constitute value that is not internalised by the organisation that invests in R&D, they represent an externality that justifies government support for R&D.

We infer the average R&D investment required to generate an innovation from

the observed shape of the private value distribution in a particular technology area. If we observe relatively few low value innovations, it is a sign that the costs of R&D projects in that area are higher; i.e. innovators will ensure that they can recover those higher costs – on average – by only pursuing the most promising ideas. If average R&D costs in a technology area are high, it will require more government funding to increase innovation.

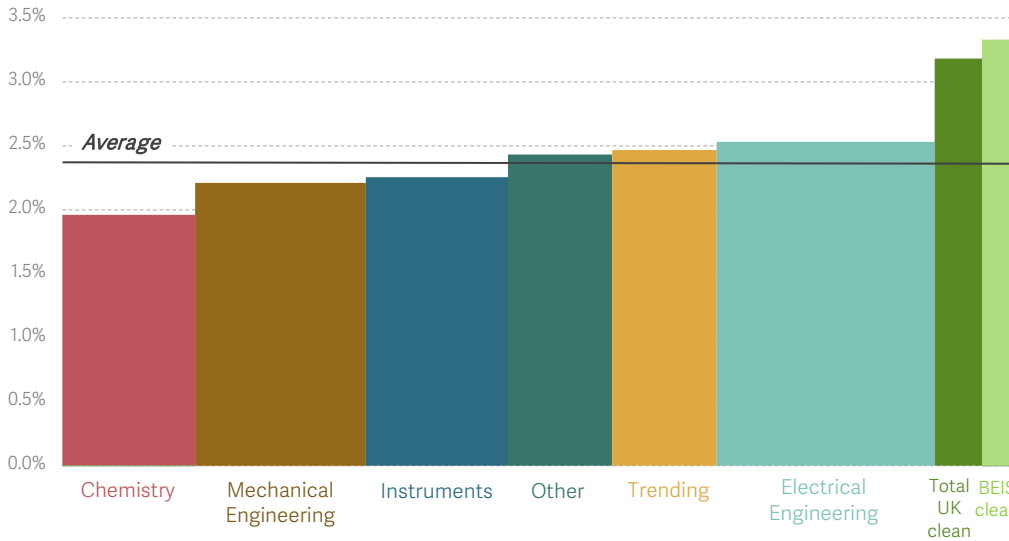
Figure 5 shows that the UK returns to R&D support varies across broad technology categories. The return on clean innovations – defined either by the BEIS definition or the EPO definition – exceeds that of any other technology category, including the ‘trending’ category (which contains a set of cutting-edge fields that often receive attention in the public debate on innovation: AI, 3D printing, biotechnology, aerospace, robotics and wireless).²⁵ The width of the bars is proportional to total UK patenting in each category and shows that overall the share of patents in clean categories is smaller than in the other categories, though it is expected to grow given enhanced net zero commitments in the UK and globally.

Figure 6 focuses on the BEIS Clean Innovation sectors plus clean cars, as well as trending technologies, showing that there is a lot of variation within these broad categories. Here, the vertical axis plots the average returns within each technology class, and the horizontal axis shows the size of that technology category in terms of UK patent numbers. Tidal Stream and Offshore Wind technologies stand out as having particularly high returns, at more than twice the average return across all categories. CCUS, Smart Systems and Building Fabric are further categories that are above average returns. AI – the largest area in terms overall patenting – generates a relatively low economic return in the UK.

²⁵ It is important to note that these are estimates, and subject to error, particularly in smaller categories with fewer patents on which to calculate the returns. But the estimated returns for ‘clean’ technologies are significantly different from those in the next highest category (electrical engineering). For more detail, see: R Martin & D Verhoeven, [Knowledge spillovers from clean and emerging technologies in the UK](#), CEP Discussion paper 1834, March 2022.

FIGURE 5: Average returns to investment in clean innovation are higher than other areas, but this is a smaller area of patenting than other established areas

UK returns to additional public investments in innovation, clean technologies and other broad groups

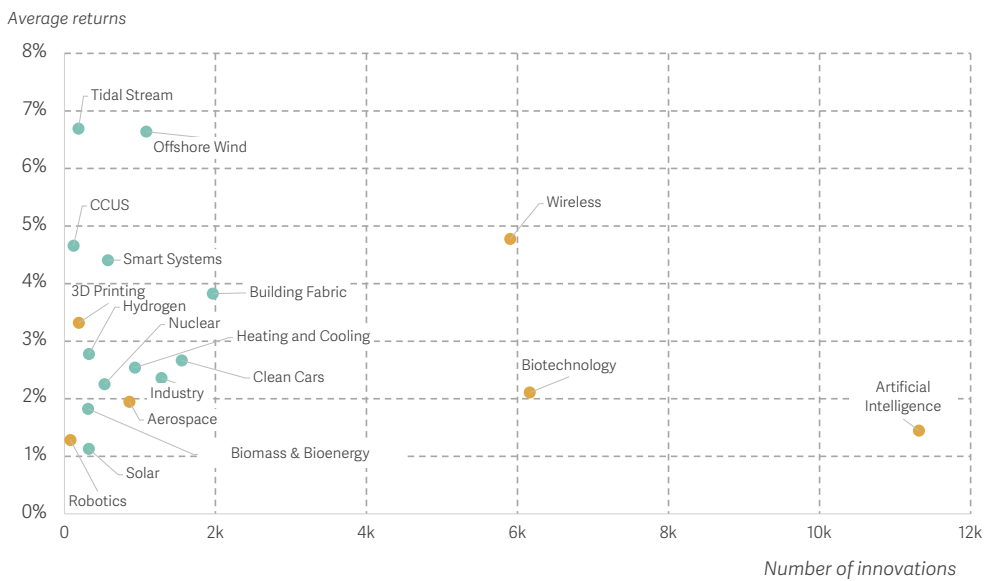


NOTES: The vertical axis shows the estimated within-UK returns to a £1 additional R&D subsidy in the field. The horizontal width of a bar indicates the size of a particular technology grouping by the total number of innovations. Patents from 2005-2014 are included. The horizontal+ line is the weighted average across all technologies.

SOURCE: R Martin & D Verhoeven, *Knowledge spillovers from clean and emerging technologies in the UK*, CEP Discussion paper 1834, March 2022. Category 'clean cars' added.

FIGURE 6: Average returns are particularly high in certain clean technologies including tidal stream and offshore wind

UK returns to additional public investments in innovation: specific clean technologies and other subfields of focus



NOTES: The vertical axis indicates the estimated within-UK returns to a £1 additional R&D subsidy in the field. The horizontal axis indicates the size of a particular technology grouping by the total number of innovations. Patents from 2005-2014 are included. The dashed line is weighted average. Green bubbles are clean technology categories, and yellow bubbles are technologies within the 'trending' category

SOURCE: R Martin & D Verhoeven, *Knowledge spillovers from clean and emerging technologies in the UK*, CEP Discussion paper 1834, March 2022. Category 'clean cars' added.

These analyses help to shed light on national strengths, and the extent to which investments in different areas could generate national economic returns (although it is important to note that these estimated economic returns do not include the value of other important externalities associated with favouring some technological fields over others, such as the widespread benefits of mitigating climate change). Nonetheless, combined with a consideration of the RTA, this methodology can help to compare the potential for different technologies to contribute to growth. Conversely, in areas where the UK does not exhibit an RTA, and where spillovers generated in the UK appear lower, a more cost-effective strategy could be to achieve net zero targets by adopting innovations invented elsewhere.

Analysis of traded goods highlights existing strengths and areas of opportunity

When a country exports a product, this tells us that the country is either efficient at producing it, relative to other countries and to other products; or that it offers a unique (or differentiated) product or service that is desired by other countries. Looking at exports, therefore, rather than production more broadly, tells us something about how good the UK is at producing products that are valued on the world stage.

While the UK is a services-exporting superpower, our previous work has shown that there are also some broad categories of goods where it has strengths, such as aircraft, art, beverages and pharmaceuticals.²⁶ Here we focus on goods exports, for which data are available at a very disaggregated level, and where specific products with environmental benefits can be classified as being 'green'.

Looking at specialisation within goods exports only, we find that there are a number of green products where the UK has a 'revealed comparative advantage'.²⁷ But data on exports can also be used to assess areas of opportunity for a particular country. Places are more likely to develop a comparative advantage in products and sectors that involve similar underlying capabilities to those where they already have comparative advantage.²⁸ This notion of 'proximity' can be combined with measures of product 'complexity' to shed light on where growth opportunities lie for particular countries – the export of more complex, technologically sophisticated products tends to be associated with higher economic prosperity and growth. We apply these concepts for the UK and key

²⁶ J De Lyon et al., *Enduring Strengths: Analysing the UK's current and potential economic strengths, and what they mean for its economic strategy at the start of the decisive decade*, Resolution Foundation, April 2022.

²⁷ RCA is calculated by comparing the proportion of a country's total exports that are accounted for by a good or service with the proportion of total global exports accounted for by that good or service. For the purposes of this analysis this is defined on goods exports only. Services data are not available at such a detailed level of disaggregation.

²⁸ C Hidalgo et al., *The Product Space Conditions the Development of Nations*, *Science* 217(5837), July 2007; F Neffke et al., *How do regions diversify over time? Industry relatedness and the development of new growth paths in regions*, *Economy Geography* 87(30), 2011.

comparator countries drawing on the Green Transition Navigator.²⁹ Further details on the underlying methodology are set out in Box 3.

Box 3. The Green Transition Navigator

The Green Transition Navigator (GTN) is an online resource which draws upon methodologies and concepts developed in peer reviewed research which developed a quantitative methodology for measuring countries' current green export capabilities, identifying new green export opportunities, and predicting likely future green export growth.³⁰ The data and concepts have been used in previous work highlighting UK economic opportunities in key net zero aligned areas of investment and more specifically in Carbon Capture Usage and Storage.³¹

The variables in the GTN are calculated using country-level data on traded goods exports (at the 6-digit product level) over the period 1995 to 2020. The focus is on 'green' products, which are classified based on lists from the APEC, the OECD and the WTO which are filtered and categorised. They key concepts which are combined to consider green strengths and opportunities are as follows:

- Revealed Comparative Advantage (RCA): A country is said to have RCA in a product when the product's share of that country's exports is greater than its share of global trade. If a country has RCA in a product, it can be thought of as exporting that product competitively.
- Product Complexity Index (PCI): This index ranks products according to the similarity of countries that export them competitively. High PCI products tend to be more technologically sophisticated.
- Proximity: This can be defined at the product-to-product level as the probability that a country has RCA in one product given that it has RCA in another. It can then be defined at the product-to-country level, as the average proximity of a product to all the products that a country has RCA in.

More detail is given in the documentation in the GTN and associated references.

²⁹ P Andres & P Mealy, Green Transition Navigator, 2021. Retrieved from www.green-transition-navigator.org.

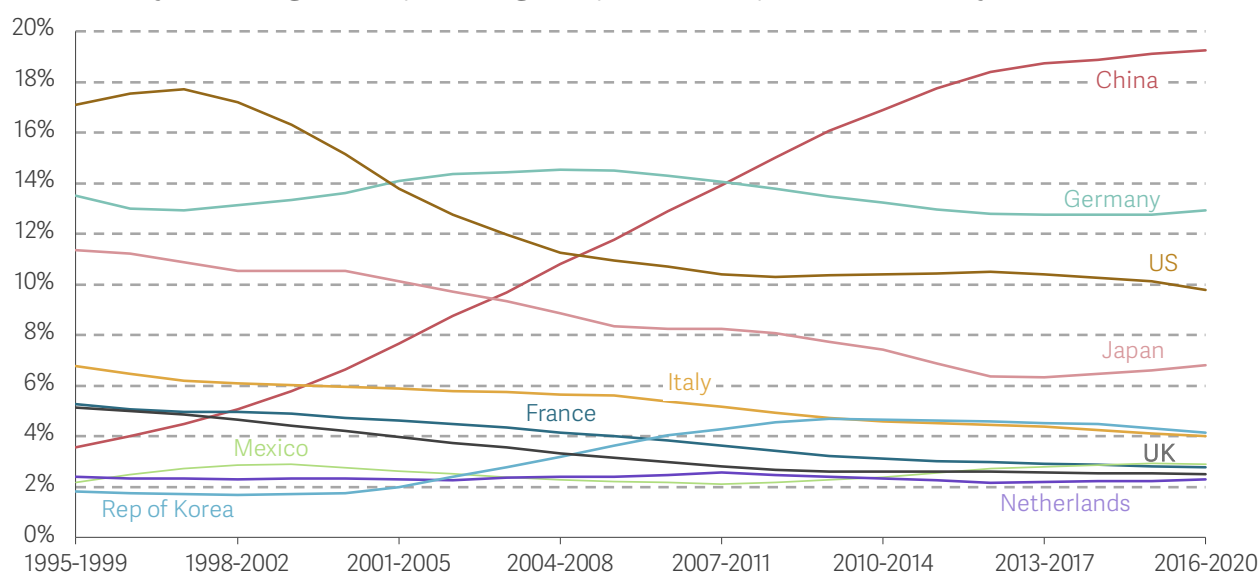
³⁰ P Mealy & A Teytelboym, [Economic complexity and the green economy](#), Research Policy, Special Issue on Economic Complexity, April 2020.

³¹ See, respectively: S Unsworth et al., [Jobs for a strong and sustainable recovery from Covid-19](#), LSE CEP, October 2020 and: E Serin et al., [Seizing sustainable growth opportunities from carbon capture, usage and storage in the UK](#), Grantham Research institute report, SP38, September 2021.

Figure 7 shows that the UK is a major exporter of green products, accounting for 2 per cent of global exports in this category in the 2016-2020 period, similar to the level of France (3 per cent). This places the UK in the top ten globally, but other countries account for a much higher share. China (at nearly 20 per cent) has seen major growth in this area since the mid-1990s when its share of green product exports was under 4 per cent. As China has gained market share, the UK has experienced a fall in its total green product exports share over the same period, a trend also experienced in the US (which accounts for a higher share), but in contrast with Germany, which has retained a share above 12 per cent.

FIGURE 7: The UK is among the top ten exporters of green products

Country share in global exports of 'green products', top ten countries by share



NOTES: The top ten countries together accounting for 67 per cent of green product exports.

SOURCE: Analysis of P Andres & P Mealy, Green Transition Navigator, www.green-transition-navigator.org.

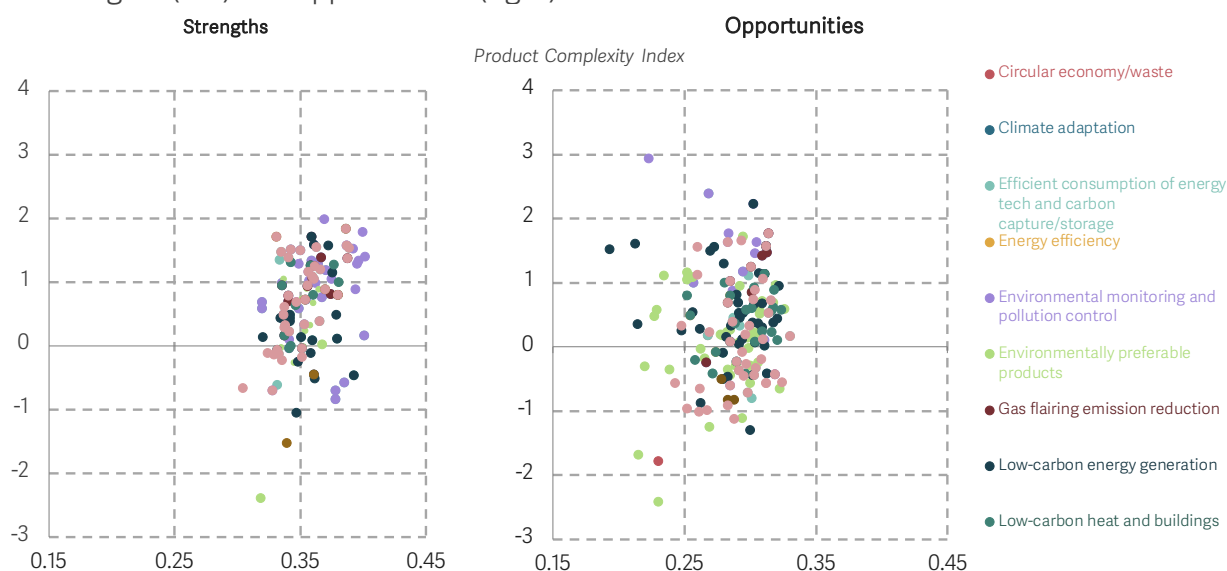
Next, we divide green products into those where the UK has comparative advantage and those in which it does not: the former can be thought of as current strengths and the latter as potential areas of opportunity. Figure 8 plots the product complexity index and proximity measures for strengths (left) and opportunities (right). This analysis shows that there a number of products across goods categories where the UK has current strengths, some of which are relatively high up in terms of product complexity, particularly in environmental monitoring and pollution control and low carbon energy generation.

Looking at areas of potential opportunity, there is no clear correlation between product complexity and proximity, but there are some products which have a relatively high

complexity and are quite proximate to the UK's current capabilities, including products within low carbon energy generation.

FIGURE 8: The UK has existing strengths and future opportunities in complex green products

Product complexity and proximity to current capabilities by product category, UK strengths (left) and opportunities (right)



NOTES: PCI and Proximity by green products. Strengths are areas where the country has RCA, opportunities are where the country does not yet have RCA.

SOURCE: Analysis of P Andres & P Mealy, Green Transition Navigator, www.green-transition-navigator.org.

Comparing the UK's strengths and opportunities with those of Germany reveals some interesting differences (see Figure 9). First, there are more product categories where Germany has current comparative advantage, as can be seen by the fact that there are more dots in the left-hand panel for Germany compared to the UK. Second, there is a clear positive relationship between product complexity and proximity to Germany's overall capabilities. The panel on the right shows that the areas where Germany does not yet have comparative advantage are also closer to its existing specialisms, again with some positive relationship between complexity and proximity. In sum, Germany has more existing strengths, and these are in more complex products, and it has closer opportunities in such products. (Annex 3 shows similar analyses for France, the US and China. France and the US look quite similar to the UK, though its green product opportunities are closer to current specialisms. China, other the other hand looks very different. It has a higher number of green product strengths, and both these and

potential opportunities are closer to its existing specialisms. However, there are more proximate products with lower levels of complexity.)

FIGURE 9: Germany has more existing strengths and closer opportunities in green products

Product complexity and proximity to current capabilities, strengths (left) and opportunities (right): UK and Germany

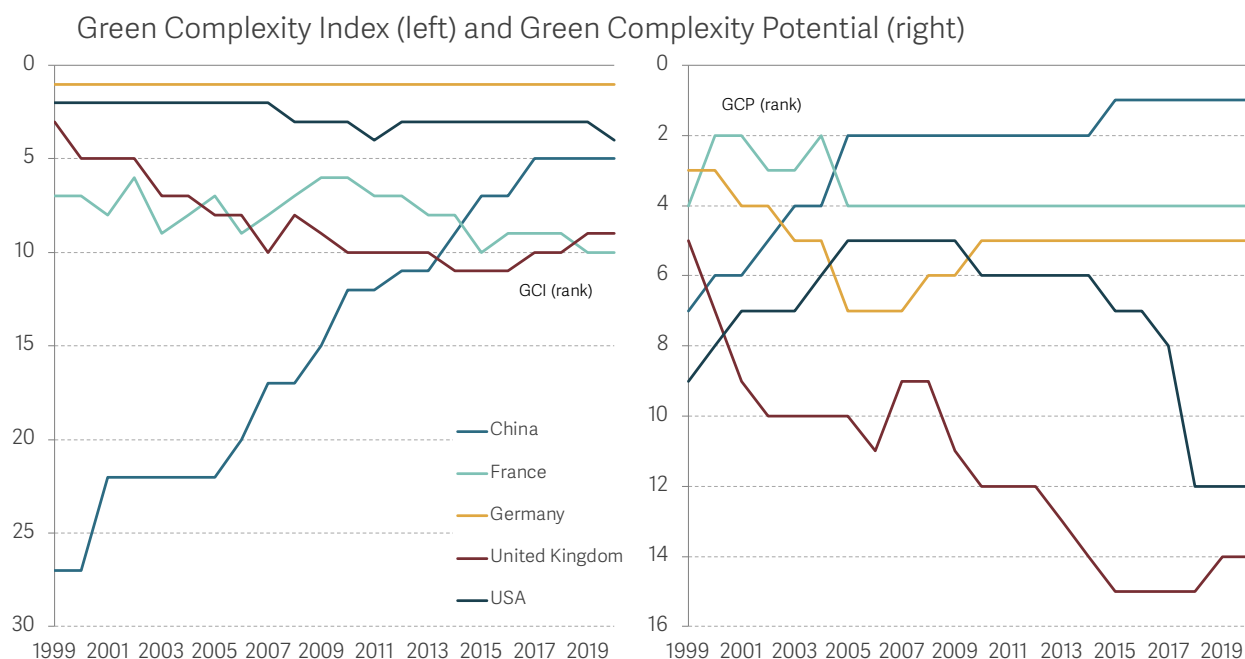


NOTES: PCI and Proximity by green products. Strengths are areas where the country has RCA, opportunities are where the country does not yet have RCA.

SOURCE: Analysis of P Andres & P Mealy, Green Transition Navigator, www.green-transition-navigator.org.

The key messages from this analysis are summarised in Figure 10. The left panel shows an overall measure of green competitiveness in complex products, the Green Complexity Index (GCI), which is a ranking of countries based on the number and PCI of green products they in which they have comparative advantage. The UK ranks ninth on this measure, losing some ground in recent years as China has moved up the rankings (Germany is consistently in first place). The right panel shows the Green Complexity Potential (GCP) index, which measures how much potential a country has to diversify into green, complex products in the future based on the proximity and complexity of products where it does not yet have comparative advantage. The UK ranks fourteenth on this measure, and China has moved into first place.

FIGURE 10: The UK's overall ranking in terms of the potential to move into complex green products been falling



NOTES: GCI measures countries' green competitiveness based on the number and PCI of green products they are competitive in. GCP measures how much potential a country has to diversify into green, complex products in the future based on the proximity and complexity of products it is not yet competitive in. SOURCE: Analysis of P Andres & P Mealy, Green Transition Navigator, www.green-transition-navigator.org.

We also conduct a more disaggregated analysis of RCA. This shows that, out of 294 'green' detailed products as defined in the Green Transition Navigator, the UK is specialised in 116 (39 per cent) of these. In Section 4 we use these data (and that on patents) as the basis for building relevant categories to examine the UK's specialisations in key areas where domestic action is required to meet net zero commitments.

Overall, the analysis of patents has shown that the UK specialises in a variety of technologies relevant for the net zero transition, and that some areas generate relatively high economic returns in the UK. Looking at traded goods, we find that the UK is amongst the top 10 exporters of green products, though not one of the biggest. There are opportunities for the UK including in more complex products, but these are perhaps less close to the UK's existing capabilities overall when compared with its key comparators. In previous work, we have documented persistence with respect to the products or technologies that countries tend to specialise in, deriving from a complex web of capabilities and institutional settings.³² We therefore expect the experience to date to be informative for identifying future opportunities. We note however, that the largescale and system-wide change required for net zero, both in the UK and internationally, suggests

³² J De Lyon et al., *Enduring Strengths: Analysing the UK's current and potential economic strengths, and what they mean for its economic strategy at the start of the decisive decade*, Resolution Foundation, April 2022.

that there might be more scope for countries with relevant specialisms to move into new areas this decade and beyond. In Section 4, we consider specific product and technology areas in more depth, outlining the context and potential for the UK to tap into global markets while other countries are seeking to do the same.

Section 3

How are clean activities spread across the country?

Understanding where clean innovation and business activity is occurring in the UK can help to shed light on the extent to which the net zero transition might affect the UK's regional disparities in economic performance. Patents data, and information about the location of goods and services relevant for net zero, both suggest that, although a higher share of the UK's total net zero activity occurs in more productive regions than in less productive regions, the latter regions appear to be more specialised, on average, in clean technologies, products or services. Moreover, investments in clean technologies in less innovative areas generate particularly strong returns in those areas, with little spillover outside. Investments in clean technologies within the 'golden triangle', on the other hand, generate returns in the rest of the country, and this is also the case in other broad technology areas – highlighting the wider benefits of strong innovation clusters. Together, these results suggest that doubling down on net zero capabilities in the UK as part of a coordinated growth policy – including complementary investments in skills and infrastructure – could be consistent with addressing regional disparities in economic activity in the UK.

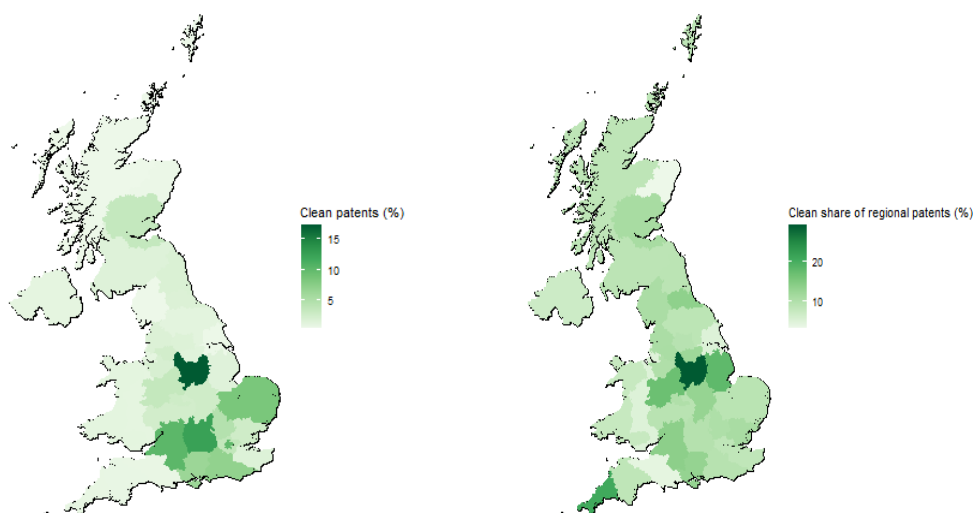
Having shown that the UK is a prominent inventor of some specific clean technologies, and exporter of certain green goods, we now turn to analysing where related activities are located in the UK. Understanding where regional strengths lie can help to inform regional development policies in the context of the transition to net zero. In this section, we leverage datasets that contain within-country location information to understand how the spread and intensity of net zero activity varies across the country.

Clean patenting intensity and returns tend to be higher in less productive regions

Using the patents data, we are able to locate inventors across the UK and consider how the spread and intensity of clean innovation varies across the country. Overall, a high share of the UK's clean patents tend to be around London and the South East (see Figure 11), but this is perhaps less so than total patenting.³³ When we look within regions, the share of total patenting that is 'clean' is higher in regions outside the golden triangle.

FIGURE 11: Areas with a lower share of the UK's total patents tend to have a higher intensity in 'clean' patenting

Regional share of total UK clean patents (left) and clean patents as a share of total region patents (right), 2015-2018



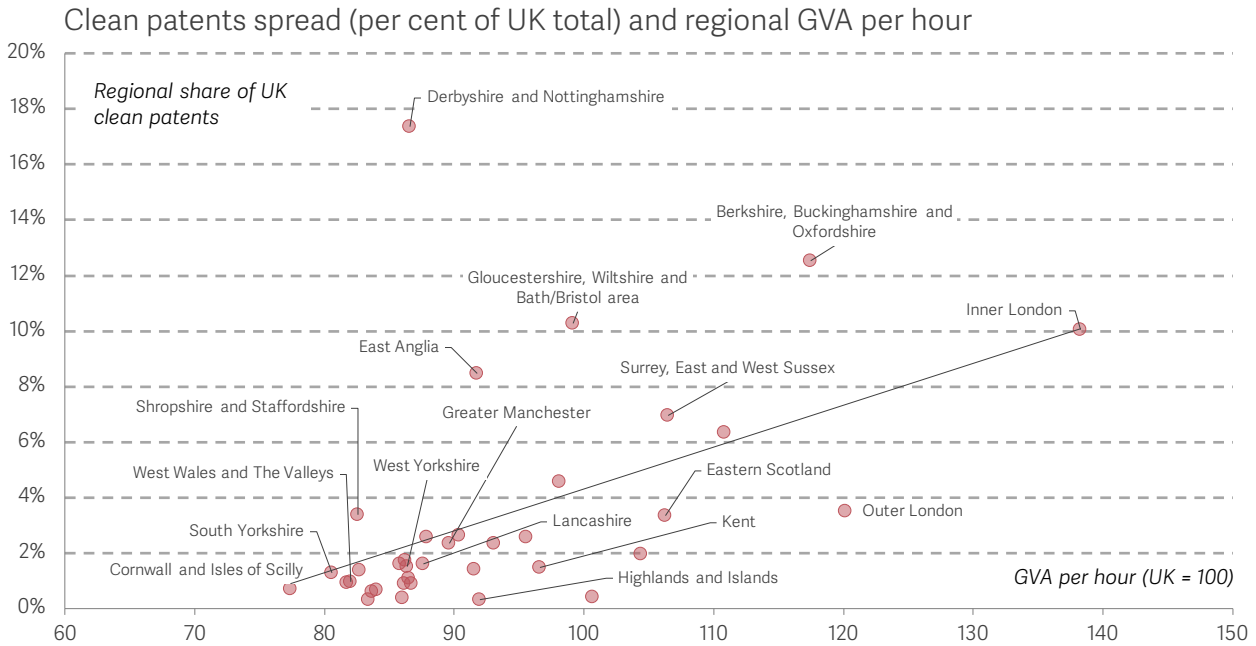
NOTES: Patents by NUTS2 region (2015-2018).

SOURCE: Analysis of PATSTAT. Five London regions are aggregated into inner and outer London due to an older disaggregation available in the patents data

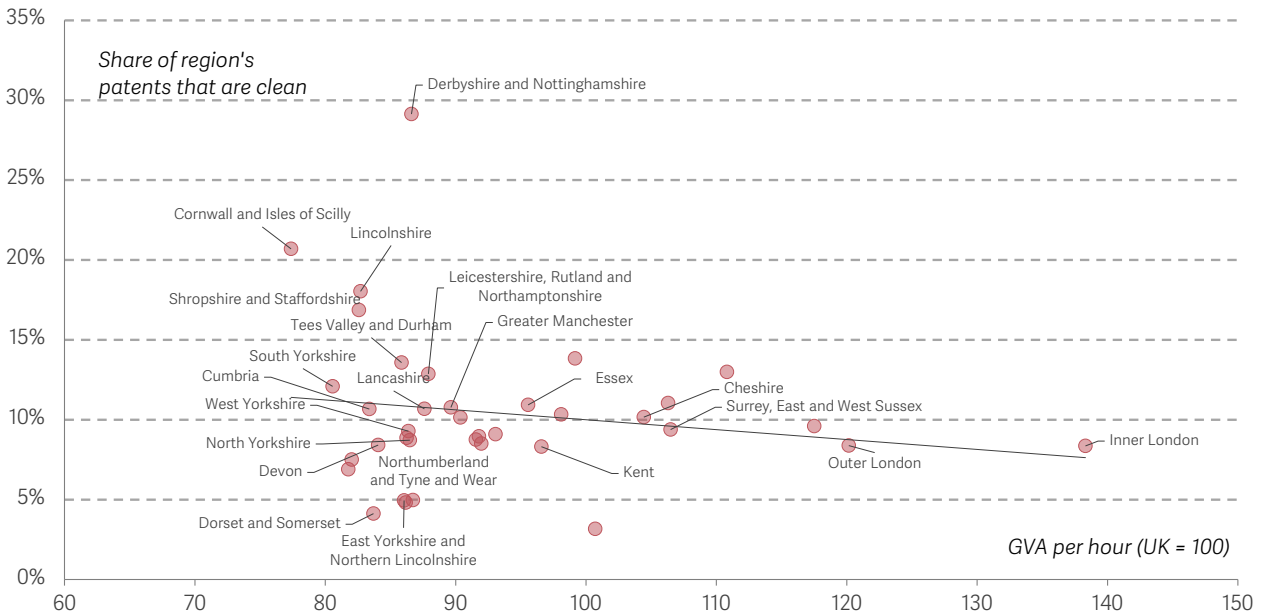
It is still the case that more productive regions account for a higher share of the UK's total clean patenting, as shown in Figure 12. But the second panel shows that, within a region, the share of total patenting that is 'clean' displays a negative relationship with regional productivity, which suggests that less productive regions – such as Derbyshire and Nottinghamshire, Cornwall and the Isles of Scilly and Lincolnshire – are relatively more specialised in clean technologies.

³³ The latter tend to be more concentrated in the 'golden triangle' of Oxford, Cambridge and London, as is the case with R&D activity more generally.

FIGURE 12: More productive areas account for a higher share of the UK's clean patents, but less productive areas are more specialised in clean technologies



Clean patents intensity (clean patents as a per cent of total regional patents) and regional GVA per hour



NOTES: Clean patents by NUTS2 region (2015-2018), and Regional GVA per hour at ITLS2 level (2019).
 SOURCE: Analysis of PATSTAT and ONS. Weighted average GVA per hour indices (using hours) are shown for London's regions given a more aggregated regional mapping available in the patents data.

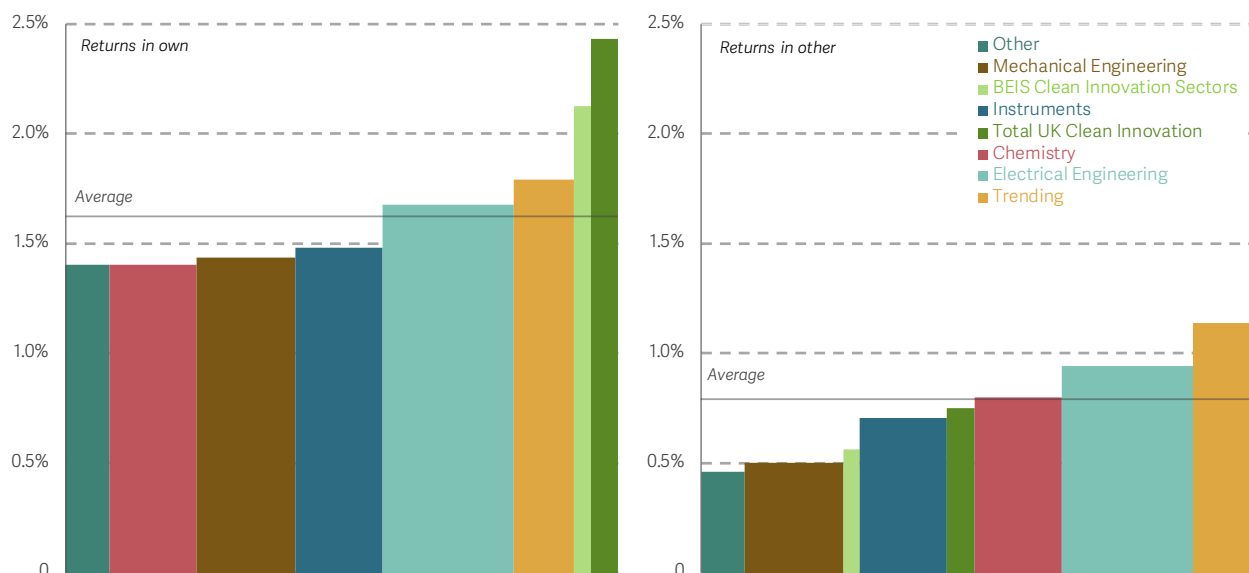
We next turn to the question of where in the UK the returns to investments in innovation are generated. Section 2 highlighted that government support for clean innovation tends to have relatively high returns in the UK, but what are the regional patterns to this? Are the benefits of investments mainly felt within the region they are made, or elsewhere? Do investments in more innovation-intense regions generate economic returns in less

innovation-intense regions, via spillovers? And to what extent do such patterns differ for clean technologies versus other technology areas?

To answer these questions, we introduce a new geographic dimension in the IStraX (defined in Box 2) calculations. We split the UK into two broad regions: the Golden Triangle (which includes London, Oxford and Cambridge and is home to a disproportionate share of the UK’s R&D activity), and the rest of the country.³⁴ For each of these broad regions, we calculate the economic returns to investments in innovation within that region that are retained in the region, and those that are felt in the other region.

FIGURE 13: Investments in clean innovation outside the golden triangle generate relatively high returns within these same regions

Returns to public investments in innovation taking place in non ‘golden triangle’ regions, retained in those regions (left panel) and felt in the rest of the country (right panel)



NOTES: The vertical axis shows the estimated returns to a £1 additional R&D subsidy in the field within the same region where investments are made (left panel), and in the rest of the country (right panel). The horizontal line is weighted average return across all technologies for the relevant geography. The horizontal width of a bar indicates the size of a particular technology grouping by number of innovations outside the golden triangle. Patents from 2005-2014 are included.

SOURCE: Analysis builds on R Martin & D Verhoeven, [Knowledge spillovers from clean and emerging technologies in the UK](#), CEP Discussion paper 1834, March 2022.

We begin by examining the less innovation-intense regions outside the golden triangle, finding that clean technologies generate relatively high returns which are retained

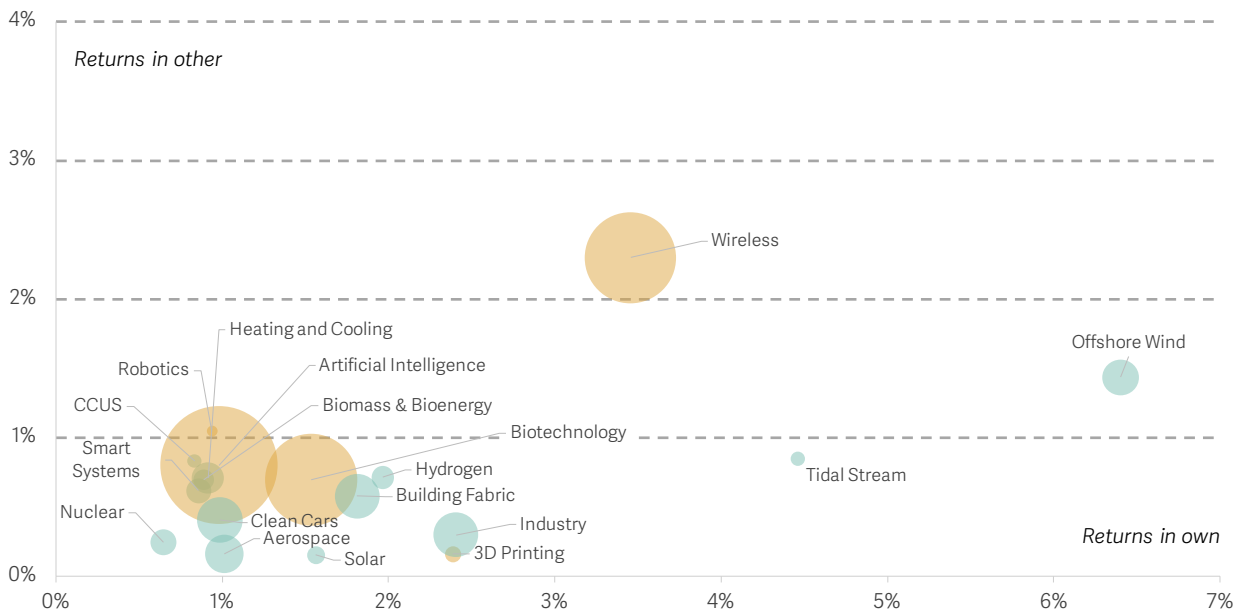
³⁴ These consist of all of the NUTS2 (ITL2) regions in London, plus East Anglia (that contains Cambridgeshire) and Berkshire, Buckinghamshire and Oxfordshire. Together these regions accounted for 36 per cent of R&D expenditure in 2017, but 21 per cent of the total resident population, according to ONS data. This provides a rough split of the country into an innovation-intense part and a less innovation-intense part.

within such regions (Figure 13, left panel), as do the trending categories (including AI, robotics etc. previously discussed), and electrical engineering more broadly. As shown by the dashed line which is lower in the right panel, the spillovers into the golden triangle are lower, and also below average for clean technologies. This evidence suggests that policies to stimulate clean tech innovation in less innovation-intense regions in the UK are particularly likely to generate economic benefits within the regions in which they are made.

Figure 14 explores which technologies drive these results, focusing on the specific technologies within the BEIS clean and trending categories. We find that it is offshore wind and tidal stream (which we saw in Section 2 generate particularly high returns for the UK) that generate the highest returns outside the golden triangle regions. These findings are of particular relevance for informing innovation policies in light of the Government’s recent pledge to achieve more regional spread in publicly funded R&D, as they help to shed light on the types of innovation that generate local economic benefits.

FIGURE 14: Outside the golden triangle, investments in offshore wind and tidal stream innovation generate particularly high returns in those same regions, and little spillover outside

Returns to public investments in innovation taking place in non “golden triangle” regions, retained in those regions, versus those felt in the rest of the country



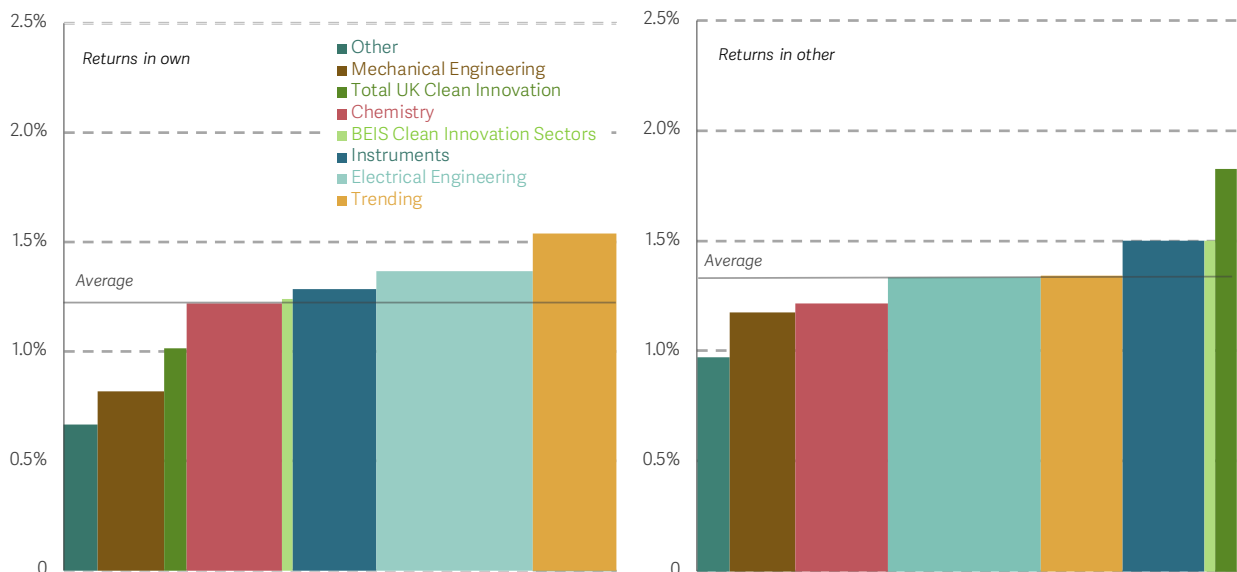
NOTES: The vertical axis shows the estimated returns to a £1 additional R&D subsidy in the field outside the region where investments are made, and the x-axis shows the equivalent for returns that are retained in the same region. The size of the bubbles indicates the relative size of a particular technology grouping within the regions in this chart. Patents from 2005-2014 are included. Green bubbles are clean technology categories, and yellow bubbles are technologies within the ‘trending’ category.

SOURCE: Analysis builds on R Martin & D Verhoeven, [Knowledge spillovers from clean and emerging technologies in the UK](#), CEP Discussion paper 1834, March 2022.

The story looks quite different when we perform the same analysis for the golden triangle regions (Figure 15). Investments in clean innovation within the golden triangle do not generate particularly high returns in these regions themselves. Where they do stand out, however, is in the returns that spill over to the rest of the country. More generally, this analysis also shows that investments in innovation within the golden triangle actually generate, on average, higher returns in the rest of the country than they do within their own regions, and that this is the case particularly for clean technologies. We also find that government investments generate returns outside the golden triangle that are comparable to direct investments in those regions themselves, and that this is particularly the case for investments in clean technologies.

FIGURE 15: Investments in clean technologies in golden triangle regions generate relatively high returns for the rest of the country

Returns to public investments in innovation taking place in ‘golden triangle’ regions, retained in those regions (left panel) and felt in the rest of the country (right panel)



NOTES: The vertical axis shows the estimated returns to a £1 additional R&D subsidy in the field within the same region where investments are made (left panel), and in the rest of the country (right panel). The horizontal line is weighted average return across all technologies for the relevant geography. The horizontal width of a bar indicates the size of a particular technology grouping by number of innovations inside the golden triangle. Patents from 2005-2014 are included.

SOURCE: Analysis builds on R Martin & D Verhoeven, *Knowledge spillovers from clean and emerging technologies in the UK*, CEP Discussion paper 1834, March 2022.

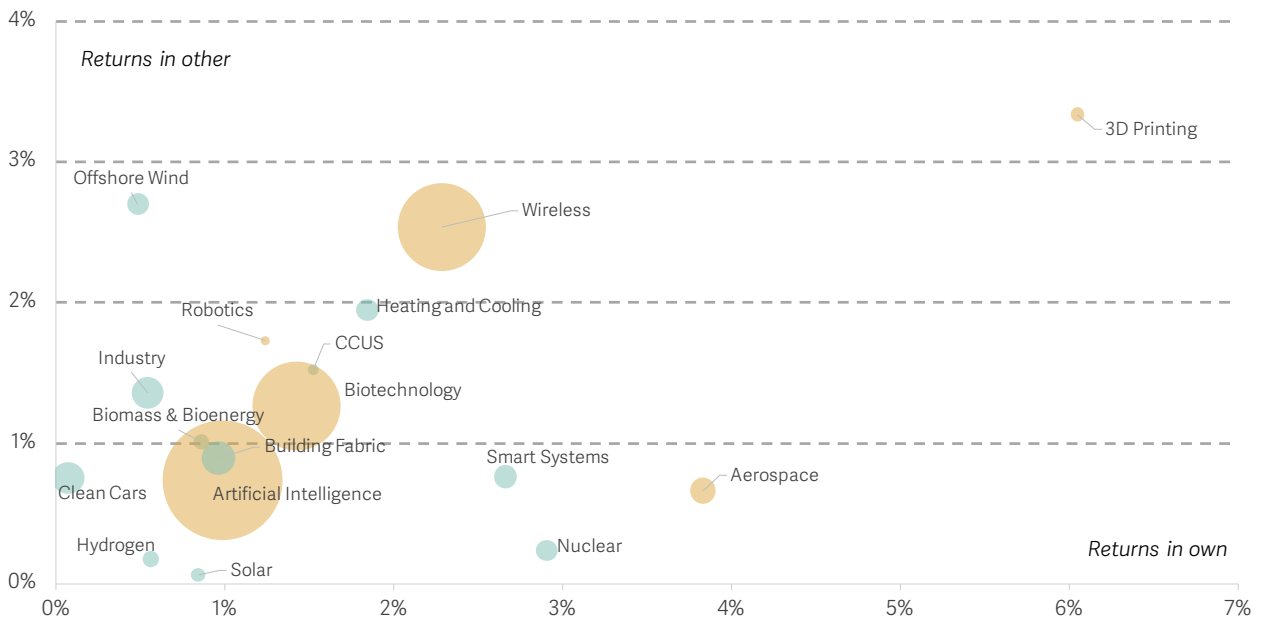
In Figure 16, we consider again the more granular technology groups. We omit tidal stream which is a small contributor in terms of patenting volumes in the golden triangle, but which generates very high average returns outside the golden triangle (bringing up the average across clean technologies as seen in Figure 15).³⁵ Offshore wind and heating

³⁵ The equivalent chart including this category is in Annex 2 (Figure 31).

and cooling display similar patterns. Wireless on the other hand, a larger area in terms of patenting volume, generates relatively high returns within and outside the golden triangle.

FIGURE 16: Investments in clean technologies in the golden triangle tend to generate more returns for other regions

Returns to public investments in innovation taking place in ‘golden triangle’ regions, retained in those regions, versus those felt in the rest of the country



NOTES: The vertical axis shows the estimated returns to a £1 additional R&D subsidy in the field outside the region where investments are made, and the x-axis shows the equivalent for returns that are retained in the same region. The size of the bubbles indicates the relative size of a particular technology grouping within the regions in this chart. Patents from 2005-2014 are included. Tidal stream has been excluded. Green bubbles are clean technology categories, and yellow bubbles are technologies within the ‘trending’ category

SOURCE: Analysis builds on R Martin & D Verhoeven, Knowledge spillovers from clean and emerging technologies in the UK, CEP Discussion paper 1834, March 2022.

Overall, these findings suggest it is important to consider the broader geographic impacts of innovation activity in regions that benefit from clustering when considering regional innovation policy. This analysis suggests there are important local and broader spillover effects that vary across technology types, and which decision making around public investments in R&D should consider. In the case of clean technologies, it appears to be the case that investments in clean technologies within and outside the golden triangle can play an important role improving growth outside the golden triangle.

Less productive areas tend to have a higher share of 'clean' firms

We can explore the location of businesses specialising in goods and services relevant for net zero and environmental sustainability, leveraging datasets that classify firms according to web-based information about their activities (such classifications can be particularly informative in emerging sectors where traditional industrial classifications do not provide sufficient detail).

We begin with analysis of firms as classified by The Data City, an organisation that matches registered companies to their websites, and uses information on websites to classify firms across technology areas, including a number of categories that are relevant for net zero, which we term 'clean' here. Box 4 describes the methodology in more detail.

Box 4. The Data City, and mapping the clean economy

The Data City³⁶ (TDC) is an organisation that maps emerging economy sectors in the UK, combining AI and 'expert-in-the-loop' training to classify firms based on textual descriptions found on their websites. Based on the population of firms registered in Companies House that can be matched to website (c.1.6 million firms), TDC has developed a new 'Real-Time Industrial Classification' which provides more detail on rapidly changing areas as compared to the Standard Industrial Classification (SIC) system which was last updated in 2007.

In September 2021, TDC carried out a mapping of the 'Net Zero Economy' which identified around 16,000 firms operating in relevant areas. The starting point for this was the text used to describe sectors in the ONS Low Carbon and Renewable Energy Economy Survey (excluding nuclear), and lists of specific companies

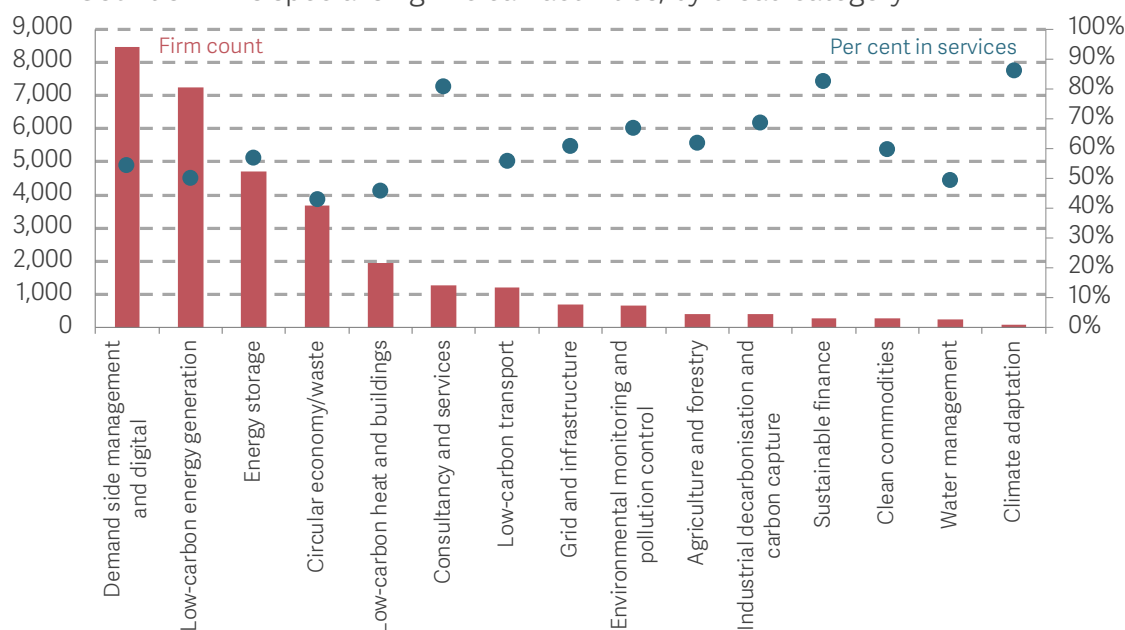
operating in relevant sectors obtained from the UK Department for Business Energy and Industrial Strategy. These pieces of information were used to create a training set, from which the platform identified firms with similar text. Lists were manually checked and verified with industry experts. Given the source of information, website text, this strategy picks up firms based on their main area of activity. It is therefore relevant for considering firms where net zero activity is core to the business. Large firms in the energy sector that carry out some CCUS activities, for example, will not be captured in the CCUS company lists. We defined 'clean' companies as those in the TDC Net Zero economy mapping exercise, plus additional RTICs that we considered to be relevant. The list of specific categories, and how we mapped them to more aggregated product and service areas is in Annex 1.

³⁶ <https://thedatacity.com/economy2030.resolutionfoundation.org>

On this basis, we find that there are over 20,000 such firms spread across the country, split roughly between those providing goods and services, as shown in Figure 17. The largest single subcategory, representing nearly 40 per cent of these firms, relates to demand-side management and digital, which includes AI and Internet of Things for energy management and smart systems, highlighting the interplay between clean technologies and digital technologies. Generally, these firms are mid-sized, with just over 60 employees, on average.

FIGURE 17: Firms specialising in clean activities are also in the service sector

Count of firms specialising in clean activities, by broad category



NOTES: Number of firms (business enterprises by category – note that classifications are not mutually exclusive. Share “services” is the share of businesses in service sector SIC codes (excluding production, manufacturing and construction)

SOURCE: Analysis of The Data City, based on the Net Zero Economy mapping, “clean tech” and other relevant RTIC codes.

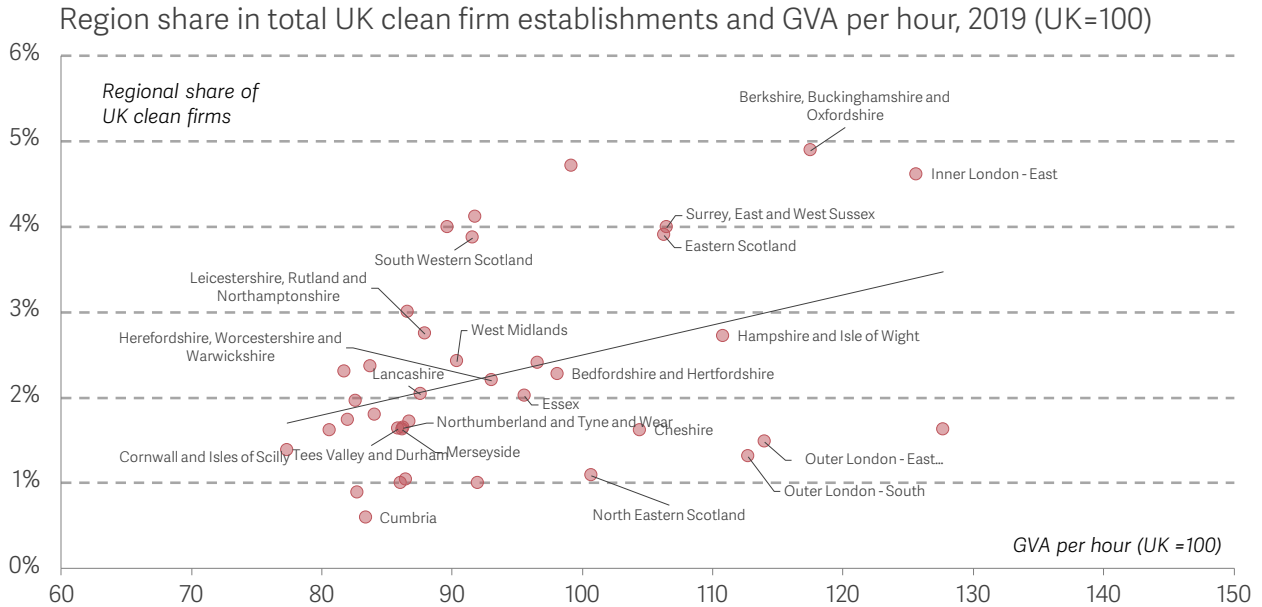
Within these 20,000 firms, there are over 40,000 business establishments in the firms we have classified as being ‘clean’.³⁷

On average, more productive regions have a higher share of clean firms (see Figure 18 for business sites (plants) and Figure 36 in Annex 2 for firms). But these more productive areas tend to have more businesses in general. Controlling for this, there is in fact a negative correlation between the intensity of clean businesses and regional productivity overall, as shown in the second panel: in other words, less productive areas, such as

³⁷ To do this, we consider the location of firms based on their registered address, and also the location of business sites (as identified on company websites) which are perhaps a better measure of where economic activity is taking place.

Cornwall and the Isles of Scilly, and South Western Scotland – have a higher fraction of firms classified as clean than high productive areas.³⁸

FIGURE 18: More productive areas account for a higher share of the UK’s clean firms, but less productive areas have a higher clean firm intensity



Clean firm establishments as a share of total businesses in a region and GVA per hour, 2019 (UK=100)



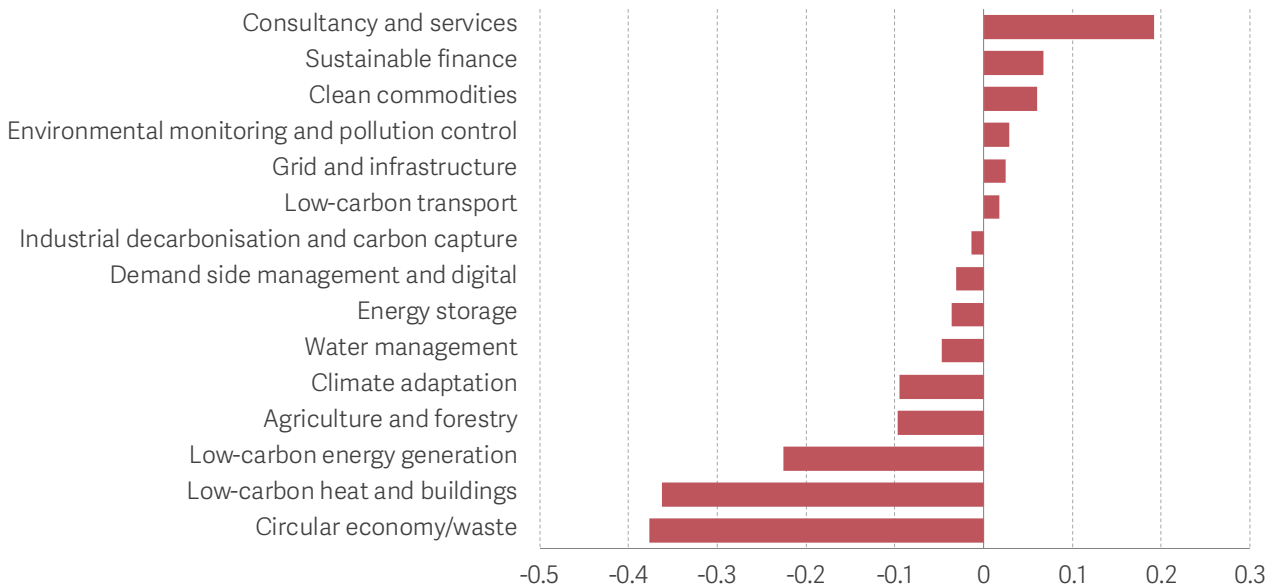
NOTES: Establishments are business addresses identified from company websites. ‘Inner London – West’ is dropped from this analysis.
SOURCE: Analysis of The Data City and ONS.

³⁸ We note that this is sensitive to the inclusion of an outlier region (‘Inner London – West’) which has particularly high productivity, and accounts for a particularly high share of clean firms.

If we drill down to subcategories, Figure 19 shows that firms specialising in circular economy and waste and low-carbon heat and buildings are particularly likely to be found in low productivity areas, whereas areas such as sustainable finance and consultancy and services are more prominent in higher productivity areas (consistent with a general clustering of these types of activity in London).³⁹

FIGURE 19: The relationship between clean firm intensity and productivity varies by sector

Correlation between clean firm plant intensity and regional productivity, by clean tech area



SOURCE: Analysis of The Data City and ONS.

Only a small share of ‘high growth’ firms are in clean tech, but this share is higher in less-productive regions

Finally, we can analyse the location and characteristics of fast growing ‘clean tech’ firms. This analysis is based on data from Beauhurst, an organisation that tracks over 40,000 firms which have hit any of a series of ‘triggers’, including securing growth finance, large innovation grants or being a university spin-off. More detail on the data is provided in Box 5.

Around 3 per cent (1,283) of the firms tracked by Beauhurst are classified as being in energy reduction technologies, clean energy generation, or other clean tech. As in the analysis of the broader clean economy, services are prominent, with around two-thirds of clean tech high-growth firms classified as being in service sectors. The overlap with digital is also evident, with 10 per cent of clean tech high growth firms classified as being

³⁹ These patterns look similar overall when using registered firm addresses instead of business establishment locations.

software providers by Beauhurst. We also find that clean tech firms are more likely to be patenters than the rest of the sample (13 per cent versus 3 per cent), highlighting the value of considering patenting activity as an indicator of future economic growth potential.

Box 5. High-growth clean tech firms in Beauhurst

Beauhurst⁴⁰ is a start-up and scale-up data platform, providing data and analysis on high growth companies. It is used by investors, government and researchers. We analyse an extract obtained in July 2021, which contained data on c.44,000 firms that were either currently or previously tracked. Since 2011, Beauhurst has tracked companies that hit any of the following triggers:

- Secured equity investment
- Secured venture debt
- Underwent a management buyout or buy-in

- Attended a selected accelerator programme
- Has been or is a scaleup
- Spun out of an academic institution
- Was featured in a selected high-growth list
- Accepted a large innovation grant

Companies are not tracked following IPO or acquisition, nor exit. The dataset consists of information on these triggers, accompanied by financial data, fundraising activity and Beauhurst's own classifications using web-based text and manual curation of the data by their team of analysts.

In the sample of firms where the address is available, a high share (38 per cent) are located in London and the South East. This is a sizable bias towards the prosperous parts of the UK, but this is actually a lower share than we see in high growth firms across all technologies, where 47 per cent are in London and the South East. Plotting the spread and intensity of clean tech firms against productivity reveals a story that is consistent with our previous analyses: more productive areas account for a higher share of the UK's high growth firms (Figure 20, first panel), but less productive areas – such as Devon, and Cornwall and the Isles of Scilly – have a higher share of clean tech firms (second panel) within the high growth economy.

⁴⁰ <https://www.beauhurst.com/>

FIGURE 20: More productive areas house more high-growth clean tech firms, but a higher share of high-growth firms are clean tech in less productive areas

Regional share of high-growth clean tech firms and regional GVA per hour



High-growth clean tech intensity and regional GVA per hour



NOTES: The first panel shows the region's share of total UK clean tech high growth firms on the vertical axis, and the second panel shows the share of clean tech firms in a region's high growth firms. In both charts, the horizontal axis is regional GVA per hour worked in 2019. Firm location is based on the location of headquarters. Where this is missing, the registered address is used.

SOURCE: Analysis of Beauhurst (2021 extract) and ONS.

Overall, these analyses of different datasets suggest that doubling down on net zero capabilities in the UK as part of a coordinated growth policy could be consistent with addressing regional disparities in economic activity, since less productive regions appear to be more specialized in such technologies, goods and services (including within the high growth economy). And our regional analysis of the economic returns to investments in innovation shows that investments in clean technologies have the potential to generate returns in less innovation-intense regions via two channels – investments made in those regions, and via spillovers from investments made in more innovation intense regions.

But, when considering outcomes for people and places, the extent to which innovative activity and the presence of firms translates into good jobs also matters. The labour market aspects of the net zero transition will be explored in depth in a future Economy 2030 Inquiry report.

Section 4

A closer look at key technologies in the UK's journey to net zero

The next phase of decarbonisation requires change across the UK economy. Urgent action is needed especially in surface transport, electricity supply, buildings, manufacturing and construction, and removals – the top five sources of carbon dioxide abatement by 2050 under the Climate Change Committee's balanced pathway to net zero. The first four of these sectors will need to deliver the majority of economy-wide abatement required by 2030 to keep the UK on track to meet net zero by 2050, with removals rapidly scaled up from the 2030s. Within these sectors, we use various data sources to consider where opportunities might lie for the UK, looking at zero emission passenger vehicles (ZEVs) in surface transport; wind, nuclear and grid flexibility in electricity supply; low carbon heat and buildings; and carbon capture, usage and storage (CCUS), a set of technologies relevant for decarbonising heavy industry and enabling greenhouse gas removals.

We find varying evidence of pre-existing UK comparative strengths. For example, wind is an area where the UK has technological specialisation, and where investments in innovation generate relatively high returns in the UK. However, the UK is not yet specialised in the exports of wind-related products. Denmark leads on this measure, despite having smaller installed capacity of wind power compared to the UK. Given its innovative strengths however, commitments to ramp up domestic deployment in the UK might generate new opportunities.

CCUS and nuclear are areas where the UK is specialised in both the exports of products, and innovation. CCUS, as yet limited in commercial application globally, can benefit from the UK's transferrable expertise and capabilities in oil and gas. By contrast, the UK does not have comparative strengths in goods or technologies relating to ZEVs or grid flexibility. But the UK does have digital strengths which are not

fully captured in such data, and which apply across both of these areas: for example, in the development of connected and autonomous vehicles, and smart grids.

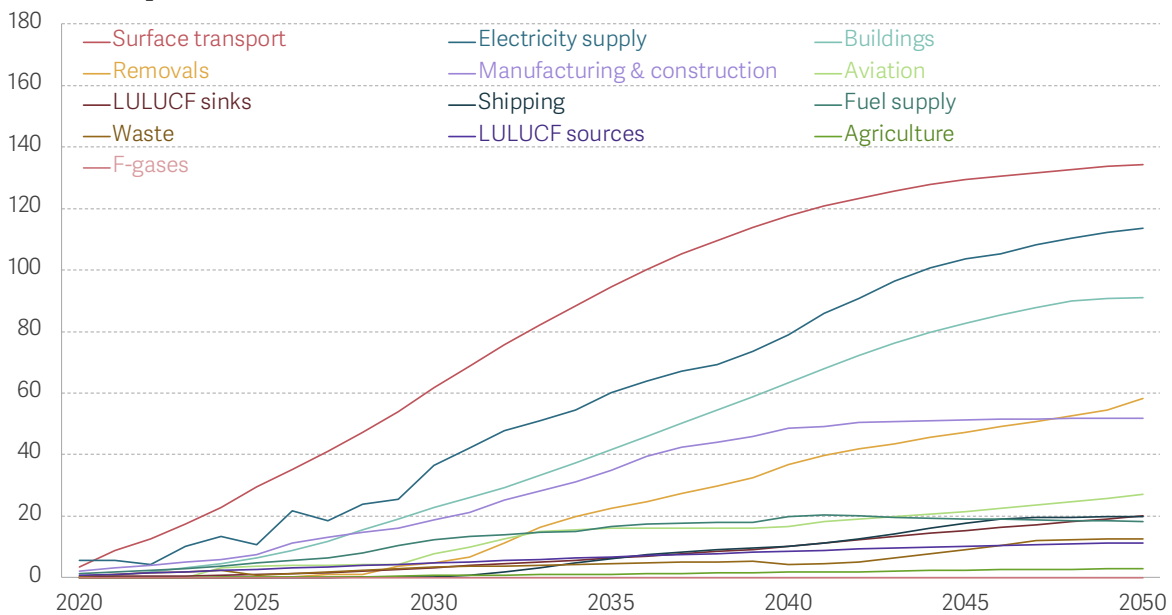
Heat and buildings constitute an area where the UK does not yet have comparative advantage overall, but is specialised in specific products, including heat pumps and insulation. These need to be deployed urgently in the UK, and they could lead to export opportunities along the way.

Further analysis is needed to understand the role of the UK’s service specialisms that are relevant for net zero, and associated export opportunities.

In this section, we do a deep dive into certain sectors, focusing on the top five sectors of required abatement by 2050 based on the CCC’s recommended pathway to net zero.⁴¹ These are: surface transport, electricity supply, buildings, manufacturing and construction, and greenhouse gas removals, as shown in Figure 21. Together, they account for over 80 per cent of the carbon dioxide abatement required by 2030 to keep the UK on track to meet net zero by 2050, although the contribution from removals becomes much more prominent post 2030.

FIGURE 21: Five key sectors together account for the majority of abatement to 2030 and beyond

Sector sources of carbon dioxide abatement in the CCC Balanced Net Zero pathway, MtCO₂e



SOURCE: Analysis of CCC 6th Carbon budget.

⁴¹ Sixth Carbon Budget, Climate Change Committee, December 2020. Differently to the CCC, we combine residential and non-residential buildings into one buildings sector.

Within these, we focus on several areas where pre-existing evidence points to UK strengths that can be built upon.⁴² In each case, we give an overview of the current context, employ our various datasets to shed light on opportunities and consider what these imply for a new economic strategy for the UK.

Specifically, we focus on:

- zero emission passenger vehicles (ZEVs) within surface transport;
- wind (onshore and offshore), nuclear and grid flexibility within electricity supply;
- heat and buildings; and,
- carbon capture usage and storage (CCUS) that spans both manufacturing & construction and removals.

Two recent publications set out both the context for these areas and the need for immediate action. The British Energy Security Strategy, through new commitments or reiterating existing ones, sets wind, nuclear, flexibility and energy efficiency in buildings as priority areas of focus – among others – in the face of the triple crises of climate change, energy security and cost of living facing the UK.⁴³ And the Intergovernmental Panel on Climate Change (IPCC) set out evidence that CCUS-enabled carbon dioxide removals will also be essential to global net-zero even if ambitious emissions reductions are achieved.⁴⁴

In 2019, the Department for Business, Energy & Industrial Strategy (BEIS) commissioned research on the UK's energy innovation needs, with a focus on areas which broadly correspond to our areas of focus in this section. This work estimated that business opportunities for the UK from these areas combined could reach around £50 billion in gross value added (GVA) in 2050.⁴⁵ In the rest of this section, we employ our datasets on exported goods and patents to shed light on the UK's current competitiveness in these areas, which can in turn inform the design of effective innovation policy to capture related opportunities into the future.

Zero emission passenger vehicles: UK's current competitiveness is weak but transforming supply chains could open up new avenues

The transition to net zero requires a drastic shift to cleaner alternatives in road transport,

⁴² For example, see: Unsworth et al., [Seizing sustainable growth opportunities from zero emission passenger vehicles in the UK](#), GRI & CEP, February 2020, and: Serin et al., [Seizing sustainable growth opportunities from carbon capture, usage and storage in the UK](#), GRI & CEP, September 2021.

⁴³ For a discussion of the British Energy Security Strategy, see: J Marshall, [Low Energy](#), Resolution Foundation, April 2022.

⁴⁴ [Mitigation of Climate Change – Summary for Policymakers](#), Intergovernmental Panel on Climate Change, April 2022.

⁴⁵ [Energy Innovation Needs Assessment: Overview](#), research led by Vivid Economics commissioned by the Department for Business, Energy & Industrial Strategy, October 2019. GVA figure cited is a combination of the following areas of this research: road transport, nuclear fission, offshore wind, CCUS, heating and cooling, smart systems and building fabric.

the highest emitting sector in the UK.⁴⁶ Some reduction in emissions can be achieved from reduced demand for car travel through behavioural and technological changes (such as shared mobility) and shifts onto lower-carbon modes of transport (such as cycling). But the UK's car fleet, responsible for over 60 per cent of the country's surface transport emissions,⁴⁷ will have to be the main target of intervention.

Fortunately, electric vehicle (EV) sales are already outpacing even the most ambitious scenarios – battery and plug-in hybrid EVs together accounting for 20 per cent of new car registrations in the UK in early 2022.⁴⁸ To further accelerate the switch to ZEVs, the Government has set a ban on the sale of new petrol and diesel cars by 2030.⁴⁹ A ZEV mandate is also forthcoming which will set targets from 2024 for a minimum share of manufacturers' annual car and van sales to be zero emissions.⁵⁰

A key driver for the growth in EV sales has been the rapid decline in their price, which in turn has been driven by product innovation and economies of scale – lithium-ion battery pack prices fell 89 per cent from 2010 to 2020.⁵¹ Running costs of EVs are also lower than petrol and diesel cars, and even more so now due to the surge in fuel prices.⁵²

The domestic deployment of ZEVs in the UK can be mutually reinforcing with growth opportunities along the associated supply chain, given fast-growing global demand. Although the immediate term will be characterised by ongoing supply chain shortages, with customers struggling to get their hands on a new EV⁵³, scenarios consistent with net-zero indicate 145 million EVs on roads globally in 2030.⁵⁴

The supply chains for ZEVs require different manufacturing techniques, skills sets, raw materials and component inputs compared to those of internal combustion engine (ICE) vehicles, and the switch to ZEVs occurs within a wider transformation of the transport sector, with digital technologies (including AI and IOT) enabling new ways of thinking about travel (for example, 'mobility-as-a-service'). Previous work has argued that there could be opportunities in these new supply chains for the UK if it effectively nurtures its existing innovative strengths: for example, in connected and autonomous vehicle technologies.⁵⁵ Overall, the UK does not have an RCA in exports related to ZEVs, and this has worsened over time (see Figure 22). Germany – Europe's largest automotive market

⁴⁶ [Transport and environment statistics: 2021](#), Department for Transport, May 2021

⁴⁷ *Ibid.*

⁴⁸ [Car Registrations – April 2022 Overview](#), SMMT, accessed 12 May 2022.

⁴⁹ [Government takes historic step towards net-zero with end of sale of new petrol and diesel cars by 2030](#), 18 November 2020.

⁵⁰ [Net Zero Strategy: Build Back Greener](#), Department for Business, Industry and Industrial Strategy, October 2021.

⁵¹ [Electric Vehicle Outlook 2021](#), BloombergNEF, 2021.

⁵² H Osborne, [Electric car cost advantage over petrol grows amid energy market turmoil](#), the Guardian, accessed 12 May 2022.

Electricity prices increased too in this period, although to a lesser extent. Running costs of EVs remain cheaper than petrol and diesel cars overall.

⁵³ J Jacobs, [Energy Source newsletter](#) (5 May 2022), Financial Times, accessed 12 May 2022.

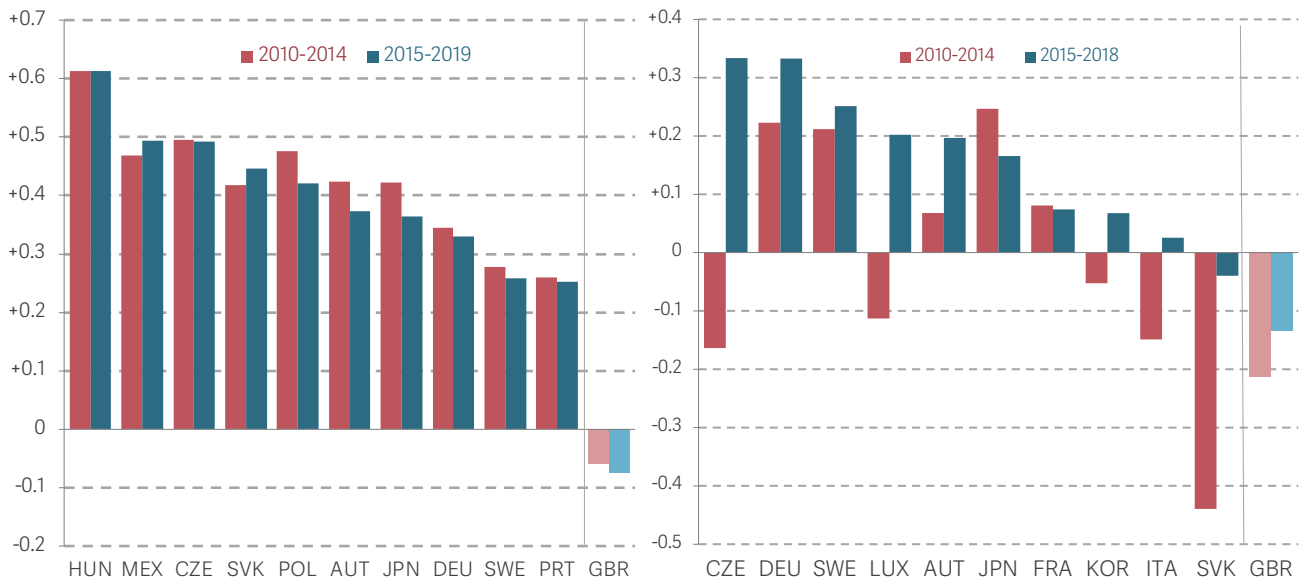
⁵⁴ [Global EV Outlook 2021](#)Global EV Outlook 2021, International Energy Agency, April 2021.

⁵⁵ Unsworth et al., [Seizing sustainable growth opportunities from zero emission passenger vehicles in the UK](#), CEP & GRI, February 2020.

in production and sales terms – ranks eighth, with some other European countries including Hungary, Czech Republic and Poland being more specialised in this area.⁵⁶

FIGURE 22: Overall, the UK is not specialised in ‘clean’ car goods or technologies

Revealed Comparative Advantage and Revealed Technological Advantage in ZEVs, 2010-14 and 2015-latest available year: various countries



NOTES: The vertical axis denotes the RCA within goods exports (left) and RTA (right), both bounded between -1 and 1. For both RCA and RTA, the chart shows the top ten countries among all OECD countries, China and Hong Kong, as well as the UK if not in the top ten. GBR is the 3-digit country code for the UK. See Annex 1 for details on product and technology classifications.
 SOURCE: Analysis of Harvard’s Atlas of Economic Complexity (left) and of PATSTAT 2021 Autumn edition (right).

The UK does not demonstrate an RTA overall in innovation in ZEVs, although the data shows a slight improvement over the 2010s. The Czech Republic and Germany are once again in leading positions, and this suggests a mutually reinforcing relationship between existing manufacturing advantage and innovative strength in ZEVs. Although clean cars represent one of the UK’s larger areas of patenting within clean categories, the UK lacks an RTA in many specific areas that will be key for decarbonising transport, such as batteries and charging systems for EVs.⁵⁷ The ongoing competition for a share of the global battery market is currently dominated by China, which holds 85 per cent of the global market.⁵⁸ Given the importance of batteries in decarbonising transport, as well as the energy system more widely, there could be specific opportunities for the UK from increasing its capabilities to serve domestic and overseas markets in this area.

⁵⁶ The Automotive Industry in Germany, Germany Trade & Invest, August 2020.

⁵⁷ See Figure 37 in Annex 3.

⁵⁸ Green Finance Institute, Powering the Drive to Net Zero, May 2022.

Wind: Potential for regionally balanced growth through innovation but lessons to be learned from missed opportunity during early days of offshore wind

Wind is a fast-growing source of low-carbon electricity globally. In 2021, it made up over 20 per cent of the UK's total electricity generation, with offshore wind accounting for 11.4 per cent and onshore wind accounting for 9.4 per cent.⁵⁹ The UK is a world leader in installed offshore wind capacity⁶⁰ and its flagship support scheme for low carbon electricity – Contracts for Difference (CfD)⁶¹ – has driven down costs of offshore wind through competitive auctions from £120/MWh in 2015 to around £40/MWh in 2019.⁶² Onshore wind, on the other hand, has seen little progress since 2015, as a result of being made ineligible for CfD auctions and changes that gave local councils more control over related planning decisions. Nevertheless, onshore wind is one of the cheapest forms of electricity generation, and its capacity almost doubles in all CCC scenarios that bring the UK to net zero emissions by 2050.⁶³ Both offshore and onshore wind will need to play an important role in fully decarbonising electricity generation in the UK by 2035.⁶⁴

Despite being a leader in offshore wind, the UK largely missed the opportunity during early deployment to develop substantial domestic intellectual property, technology and capability, meaning that supply chain benefits have been largely retained within non-UK businesses that have led the process.⁶⁵ But the UK is committed to changing this as it works to become the 'Saudi Arabia of wind power' with an industry ambition for 60 per cent UK content in offshore wind projects.⁶⁶ This will be supported by the Government with more stringent requirements for supply chains in CfD auctions and direct funding of modern ports and manufacturing infrastructure.⁶⁷

The UK Government has recently increased its 2030 offshore wind deployment target from 40 GW to 50 GW (from 11.2 GW installed at the end of 2021)⁶⁸ in light of energy security concerns. It also announced plans to work with supportive communities to enable local deployment of onshore wind and include the technology in future auctions

⁵⁹ [Renewable electricity capacity and generation](#), Department for Business, Energy and Industrial Strategy, March 2022.

⁶⁰ [Global Offshore Wind Report 2021](#), Global Wind Energy Council, September 2021.

⁶¹ The CfD scheme is the government's key mechanism for supporting low-carbon electricity generation in Great Britain. The scheme provides developers of long-term projects with high upfront costs with protection against wholesale price volatility, and shields consumers from paying higher support costs when electricity prices are high. For more detail, see [Contracts for Difference](#), Department for Business, Energy & Industrial Strategy, accessed 12 May 2022.

⁶² [Energy white paper: Powering our net zero future](#), Department for Business, Energy & Industrial Strategy, December 2020. Figures are presented in 2012 prices in line with government convention.

⁶³ [Sixth Carbon Budget: Electricity Generation Sector Summary](#), Climate Change Committee, December 2020.

⁶⁴ Given the commonly shared net zero target, we discuss the decarbonisation efforts and deployment targets relating to the electricity system broadly for the UK. However, it is important to note that Northern Ireland's grid is separate from that of Great Britain with associated policies also devolved which will have implications for implementation.

⁶⁵ M Whitmarsh, [The UK Offshore Wind Industry: Supply Chain Review](#), Offshore Wind Industry Council, February 2019.

⁶⁶ P Rincon, [UK can be 'Saudi Arabia of wind power' - PM](#), BBC, accessed 20 May 2022; and: [Offshore Wind Sector Deal](#), Department for Business, Energy & Industrial Strategy, March 2019.

⁶⁷ [Energy white paper: Powering our net zero future](#), Department for Business, Energy & Industrial Strategy, December 2020.

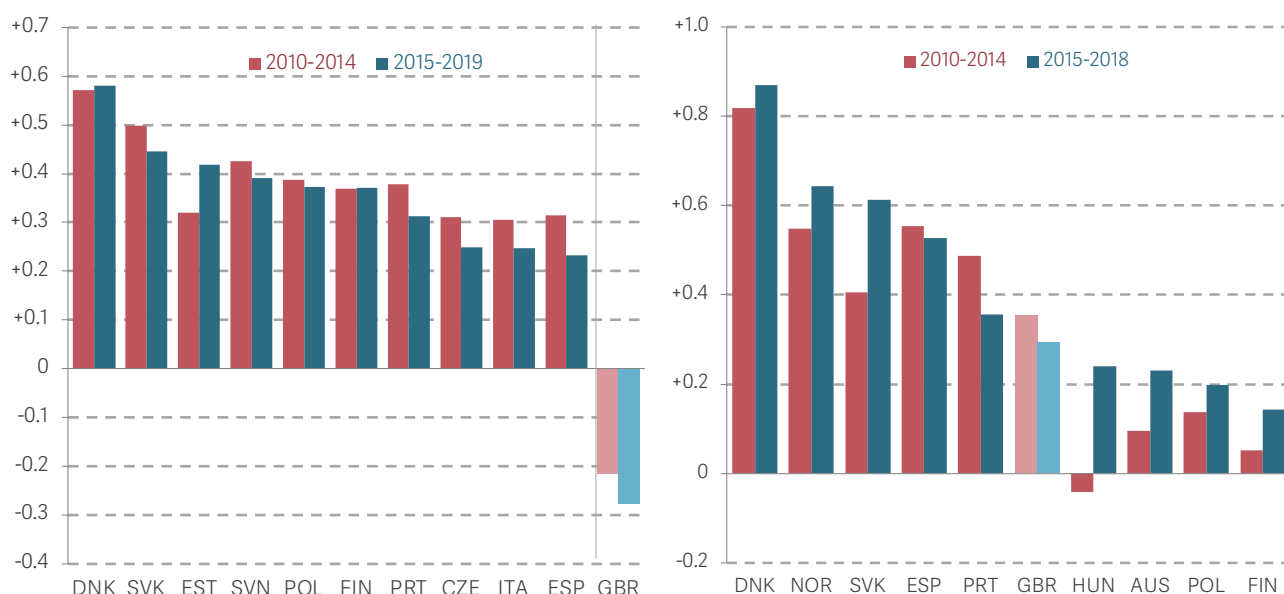
⁶⁸ [Renewable electricity capacity and generation](#), Department for Business, Energy and Industrial Strategy, March 2022.

under the CfD scheme (now to be held annually rather than every two years).⁶⁹ There could be significant economic opportunities for the UK supply chain for wind given the significant ramp up in domestic deployment that is now required, and its target for a five-fold increase in exports of offshore wind goods and services by 2030. Innovations in related technologies will play a crucial role in capturing this opportunity, where 5 GW of the UK’s overall 2030 deployment target is allocated to floating offshore wind backed with dedicated funding and R&D support.

What, though, does the existing data show? In fact, the UK is currently not specialised in wind exports, and its competitive position in this area has worsened (Figure 23). Denmark ranks first in both data periods, despite having less installed capacity of wind power than the UK. China and the US, the top two countries in the world in both cumulative and newly installed wind capacity in 2021, are not amongst the most specialised exporters here (reflecting their large volumes of exports in other product areas).⁷⁰

FIGURE 23: Despite innovative strengths in wind technologies, the UK is not currently specialised in related product exports

Revealed Comparative Advantage (left) and Revealed Technological Advantage (right) in wind, 2010-14 and 2015-latest available year: various countries



NOTES: The vertical axis denotes the RCA within goods exports (left) and RTA (right), both bounded between -1 and 1. For both RCA and RTA, the chart shows the top ten countries among all OECD countries, China and Hong Kong, as well as the UK if not in the top ten. GBR is the 3-digit country code for the UK. See Annex 1 for details on product and technology classifications.
 SOURCE: Analysis of Harvard’s Atlas of Economic Complexity (left) and of PATSTAT 2021 Autumn edition (right).

⁶⁹ [British Energy Security Strategy](#), HM Government, April 2022.

⁷⁰ [Renewable Capacity Statistics 2022](#), International Renewable Energy Agency, April 2022.

Despite its lack of specialisation in exports, the UK is among the most specialised innovators in wind, ranking sixth amongst comparators. Many countries leading in exports of goods relating to wind power also lead in related innovation, including Denmark (ranking first in both instances), Slovakia and Portugal. Norway is an interesting case, as it ranks second on RTA amongst comparators but is behind many of these countries in terms of installed wind capacity, with 4 GW of onshore wind but no operating offshore wind farms. At a disaggregated level, the UK demonstrates an RTA in many turbine components.⁷¹ The UK's RTA in floating structures is interesting, given that floating offshore wind is a R&D priority for the Government.

The analysis in Sections 2 and 3 has highlighted the relatively high returns to public investments in offshore wind technologies at the national level, and the potential for such investments to generate returns across the country. Together, this analysis suggests that wind is an area where the UK does have underlying strengths that could be better exploited via trade.

[Nuclear: Existing competitiveness and recent commitments to rapid capacity expansion put the UK in unique position in global market](#)

Nuclear has provided around 20 per cent of UK electricity generation since 2000.⁷² But all of the UK's existing nuclear power plants are due to retire by the end of 2030, with the exception of Sizewell B, which is planned to remain in operation until 2035, and Hinkley Point C (HPC), which is under construction. Nuclear is more expensive than some of the most common forms of renewables such as wind and solar, and the government support agreed for HPC has come under criticism on value-for-money grounds.⁷³ Nevertheless, nuclear can play an important role in fully decarbonising UK electricity generation as a source of predictable zero-carbon power at scale which can complement intermittent renewables. The CCC's Balanced Net Zero pathway assumes 10 GW of nuclear capacity by 2035, which would require new capacity to be built beyond HPC.⁷⁴

Energy security concerns have also led to a new push for nuclear power in the UK, and the Government has announced plans to progress up to eight new nuclear reactors by 2030.⁷⁵ Increased ambitions in the energy security strategy follow an existing commitment of up to £1.7 billion in direct government funding to enable at least one large-scale nuclear project to reach final investment decision by end of this Parliament.⁷⁶

⁷¹ Examples are blades, generators and rotors, as well as technologies especially relevant for offshore wind, such as arrangements for transmission via high-voltage direct current (HVDC) links, mountings on offshore structures, and remotely controlled surface vessels (which could help reduce maintenance costs for offshore wind farms). See Figure 38 in Annex 3.

⁷² [Sixth Carbon Budget: Electricity Generation Sector Summary](#), Climate Change Committee, December 2020

⁷³ For example, see [Hinkley Point C](#), National Audit Office, June 2017.

⁷⁴ [Sixth Carbon Budget: Electricity Generation Sector Summary](#), Climate Change Committee, December 2020.

⁷⁵ [British Energy Security Strategy](#), HM Government, April 2022.

⁷⁶ [Autumn Budget and Spending Review 2021](#), HM Treasury, October 2021.

The UK has not brought a new nuclear power plant online since 1995, and, at present, the UK is strongly reliant on foreign-owned firms (e.g. EDF Energy) for the development of new domestic nuclear capacity. There are clear ambitions to make the domestic supply chain more productive and competitive during the development of HPC and beyond, while bringing skilled jobs and prosperity to regions where nuclear sector activities concentrate.⁷⁷ The Government is working with the sector to enhance the ability of established companies to compete for high-value work and reduce barriers to entry for innovative companies. There could be export opportunities for the UK from a global market set to grow, especially in niche areas of expertise it already has, such as fuel fabrication and decommissioning.⁷⁸

Unlike many European countries, the UK has strong political support for, and minimal public opposition to, civil nuclear, which could make it fertile grounds to innovate and deploy the next generation of nuclear technology.⁷⁹ With an Advanced Nuclear Fund of up to £385 million, the UK is aiming to develop a domestic Small Modular Reactor (SMR) design and to build an Advanced Modular Reactor (AMR) demonstrator by the early 2030s; UK-based Rolls-Royce is among the pioneers of the development of SMRs.⁸⁰ The UK also has a research programme on nuclear fusion – an effectively unlimited source of low-carbon power – with an aim to build a commercially viable fusion power plant by 2040. Under a high innovation scenario (excluding fusion), there could be business opportunities for the UK from the nuclear sector exceeding £10 billion in GVA annually by 2050.⁸¹

Ambitions to create a pipeline of new nuclear projects have been complemented with intentions (yet to be detailed) to streamline regulatory processes and reduce the cost of raising finance through a Regulated Asset Base model. However, the Government has not yet proposed a long-term solution for nuclear waste, or offered clarity on how the relative inflexibility of nuclear power plants would be managed alongside an increasing share of renewables in the generation mix.

Nevertheless, the UK now has a major deployment target which warrants a close look at the domestic supply chain's strengths and weaknesses, and in turn its potential to capture growth opportunities domestically and abroad. Figure 24 shows that the UK ranks fourth amongst comparators in terms of its RCA in exports of goods relating to nuclear power, and is among the very few countries that have an overall comparative

⁷⁷ [Energy white paper: Powering our net zero future](#), Department for Business, Energy & Industrial Strategy, December 2020.

⁷⁸ [Energy Innovation Needs Assessment: Nuclear Fission](#), research led by Vivid Economics commissioned by the Department for Business, Energy & Industrial Strategy, October 2019.

⁷⁹ For example, see [BEIS Public Attitudes Tracker: Energy Infrastructure and Energy Sources - Winter 2021](#), Department for Business, Energy & Industrial Strategy, March 2022.

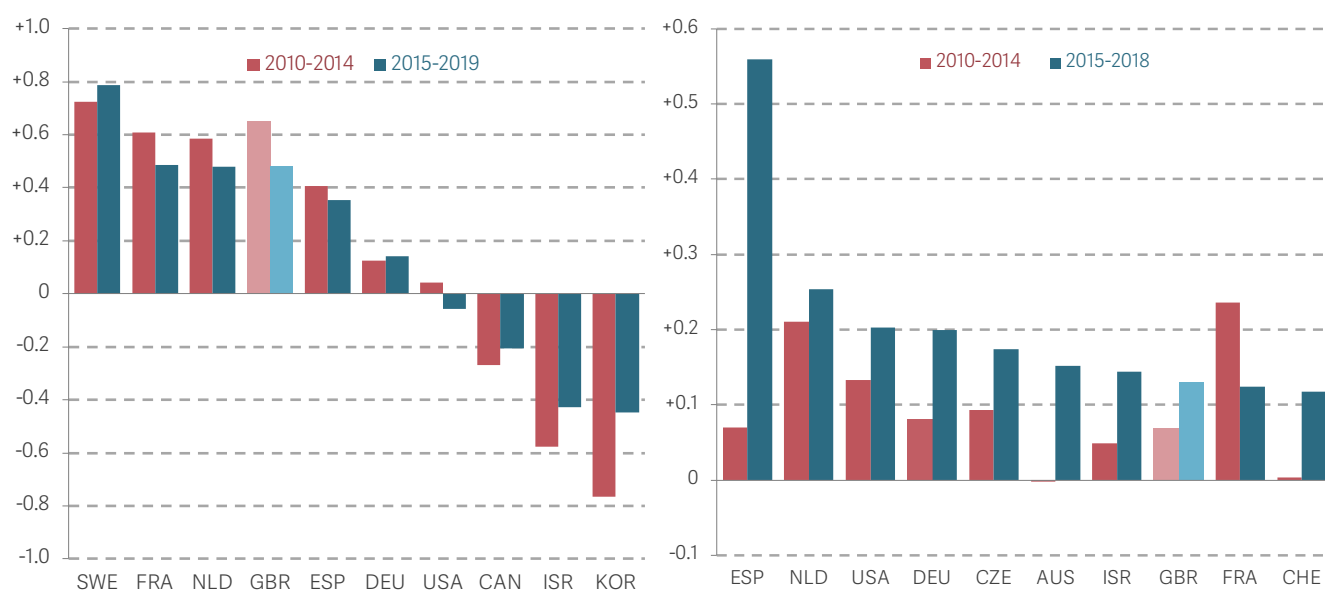
⁸⁰ Small Modular Reactors (SMRs) produce power in the same way as existing nuclear power stations but are smaller scale and could be faster and cheaper to deploy given the modular characteristic of their manufacture and assembly. Advanced Modular Reactors (AMRs), through innovative reactor designs, could open up a variety of functionalities for nuclear including in the provision of high-grade heat for industry as well as the efficient production of hydrogen and synthetic fuels.

⁸¹ [Energy Innovation Needs Assessment: Nuclear Fission](#), research led by Vivid Economics commissioned by the Department for Business, Energy & Industrial Strategy, October 2019.

advantage in this area. The UK is also specialised in nuclear technologies, ranking eighth in terms of RTA. There is significant overlap between specialism in exported goods and that in technological innovations relevant for nuclear with over half the countries appearing in the top ten for both RCA and RTA.

FIGURE 24: The UK has existing advantages in nuclear products and technologies

Revealed Comparative Advantage (left) and Revealed Technological Advantage (right) in nuclear, 2010-14 and 2015-latest available year: various countries



NOTES: The vertical axis denotes the RCA within goods exports (left) and RTA (right), both bounded between -1 and 1. For both RCA and RTA, the chart shows the top ten countries among all OECD countries, China and Hong Kong, as well as the UK if not in the top ten. GBR is the 3-digit country code for the UK. See Annex 1 for details on product and technology classifications.

SOURCE: Analysis of Harvard's Atlas of Economic Complexity (left) and of PATSTAT 2021 Autumn edition (right).

At the disaggregated level, the UK has an RTA in several reactor types that it has experience operating domestically such as Magnox (the UK's first-generation reactor design which was later discontinued) and pressurised water reactors (the reactor design used in the currently operational Sizewell B), as well as a number of areas that reflect its specialism in fuel fabrication.⁸² This analysis also suggests that the UK is a highly specialised innovator in nuclear fusion reactors, and within these, tokamaks in particular. In February 2022, the world's largest operational tokamak machine at the Joint European Torus (JET) facility in Oxford broke a historical record on sustained fusion energy.⁸³

Starting from a strong base, the UK may be in a unique position to capture supply chain opportunity as it works to deliver its ambitious domestic deployment programme. On the

⁸² See Figure 39 in Annex 3.

⁸³ [Fusion energy record demonstrates powerplant future](#), UK Atomic Energy Authority and Department for Business, Energy & Industrial Strategy, press release published 9 February 2022.

other hand, although the UK holds an overall competitive position in nuclear, we have shown in Sections 2 and 3 that returns to public investments in innovation in nuclear tend to be lower than most other clean technology categories, and perhaps generate lower spillovers to less innovation intense regions. Such distinctions can help to inform decisions around public support for innovation in specific places.

Grid flexibility: No easy wins in manufacturing or innovating hardware, but reason for optimism lies in innovative, digital services

The UK's target for a fully decarbonised power system by 2035 needs to be underpinned by increased grid flexibility – the ability of energy supply and demand to be balanced over different timescales.⁸⁴ This flexibility covers technologies including battery storage (which can provide within-day back-up power when renewable output falls rapidly), demand-side response (which can help mitigate demand peaks using smart technology) and interconnectors (which can allow trade of surplus, low-carbon electricity across borders). Such flexibility can help accommodate a higher share of intermittent renewables in the generation mix, as well as allowing for increasing numbers of decentralised, dynamic sources of demand and supply, such as electric vehicles, heat pumps and rooftop solar panels. And this flexibility is crucial for a cost-effective path to net zero as it minimises the amount of generation and network capacity that would otherwise be needed to meet the increasing demand for electricity. The CCC's recommended pathway to net zero assumes 20 per cent of electricity demand being flexible in 2035.⁸⁵

The required move towards flexibility does not typically make headlines to the same extent as some other areas of decarbonisation. For example, the Government's Ten Point Plan – in which the focus was generally skewed towards energy supply over demand – had minimal discussion of flexibility, but there has been momentum since.⁸⁶ In July 2021, the Government and Ofgem jointly published a Smart Systems and Flexibility Plan (building on the first such plan published in 2017) along with the UK's first Energy Digitalisation Strategy.⁸⁷ These set out measures to facilitate flexibility from consumers, remove barriers to flexibility on the grid (both for small- and large-scale long-duration electricity storage), reform markets to reward flexibility, digitalise the energy system, and increase interconnector capacity. The Government has also committed to creating a new impartial Future System Operator as soon as practicable which will oversee both electricity and gas systems to drive forward a coordinated and cost-effective transition

⁸⁴ See footnote 64.

⁸⁵ [Sixth Carbon Budget: Electricity Generation Sector Summary](#), Climate Change Committee, December 2020.

⁸⁶ [The Ten Point Plan for a Green Industrial Revolution](#), HM Government, November 2020.

⁸⁷ [Transitioning to a net zero energy system: smart systems and flexibility plan 2021](#), Department for Business, Energy & Industrial Strategy & Ofgem, July 2021, and: [Digitalising our energy system for net zero: strategy and action plan](#), Department for Business, Energy & Industrial Strategy, Ofgem, and Innovate UK, July 2021.

to net zero while maintaining energy security.⁸⁸ However, the CCC's independent assessment suggests that it is not clear these measures will be sufficient to meet the overall objective of fully decarbonising electricity generation by 2035, pointing to the need for an improved market design which provides certain and predictable investment signals, including in flexibility.⁸⁹

The recent British energy security strategy commits to undertaking a comprehensive Review of Electricity Market Arrangements (REMA) in Great Britain and to encouraging all forms of flexibility with an emphasis on sufficient large-scale, long-duration electricity storage. This follows existing plans to define electricity storage in primary legislation, and £100 million funding allocated to energy storage and flexibility innovation, focusing especially on long-duration storage technologies that could be deployed at large scale and provide novel services or system benefits.⁹⁰

Energy flexibility is inherently tied to developments in digitalisation. Accordingly, business opportunities extend beyond the production and export of hardware. There is much scope for innovation in consumer propositions including time-of-use tariffs. These tariffs, enabled through smart metering, reward consumers financially for using energy outside peak times, when demand is low or when there is excess generation available. They can be combined with automation to unlock associated savings (for example, by programming EVs to charge or appliances to work during off-peak hours). The UK has many innovative firms and start-ups operating in the intersection of digital and energy systems. For example, Limejump – a technology platform which optimises a large network of renewable energy assets using real-time data – has been among the UK's fast-growing clean tech firms, and was agreed to be acquired by Shell in 2019.⁹¹ The Government estimates that, by 2050, the domestic market for smart systems and flexibility solutions could contribute almost £1.3 billion to the nation's economy, with exports of these products and services adding a further £2.7 billion (in 2020 prices).⁹²

However, as shown in Figure 25, at present the UK does not have an overall RCA or RTA in grid flexibility. The analysis in Sections 2 and 3 showed that smart systems have above average returns to public investments in innovation overall in the UK, though this is an area where spillovers between regions appear to be lower. However, these datasets relate primarily to manufactured goods and patented technologies (which, as we have discussed previously, tend to be more prominent in manufacturing than services). The

⁸⁸ [Future System Operator: government and Ofgem's response to consultation](#), Department for Business, Energy & Industrial Strategy and Ofgem, April 2022.

⁸⁹ [Independent Assessment: The UK's Net Zero Strategy](#), Climate Change Committee, October 2021.

⁹⁰ [Energy white paper: Powering our net zero future](#), Department for Business, Energy & Industrial Strategy, December 2020.

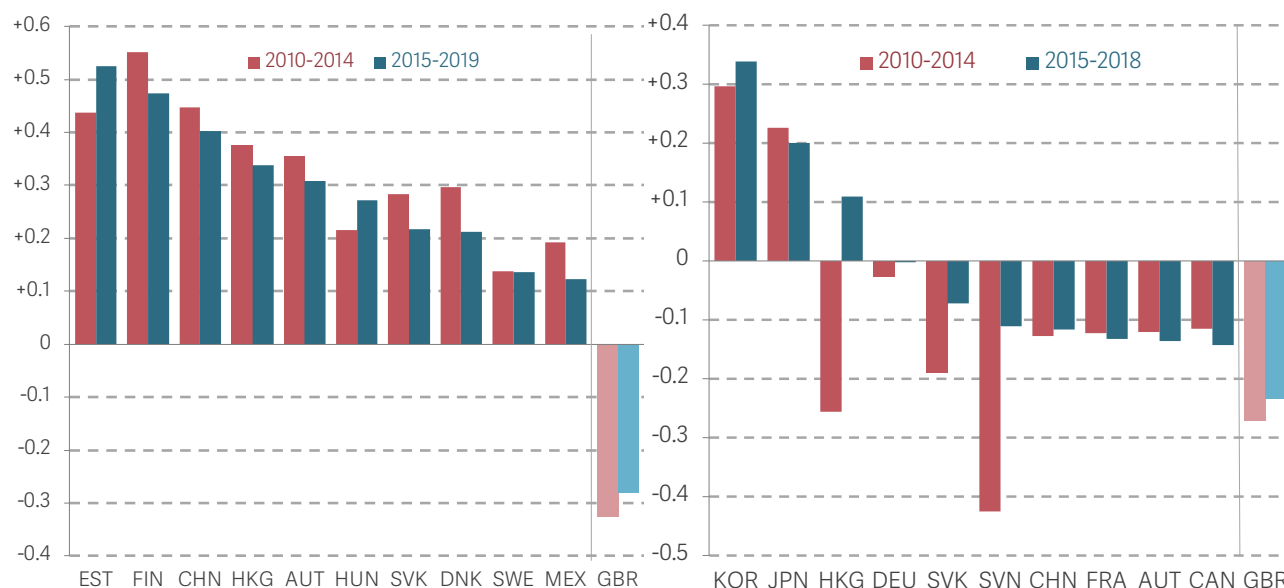
⁹¹ Estimates based on Beauhurst (July 2021 extract). For recent updates on UK clean tech companies that have attracted investment, see: Beauhurst, [Investment into Cleantech Companies in 2021](#), February 2022. Shell's takeover is confirmed in this [press release](#), accessed 12 May 2022.

⁹² [Energy white paper: Powering our net zero future](#), Department for Business, Energy & Industrial Strategy, December 2020.

economic opportunities in grid flexibility extend beyond the production of hardware, and perhaps a more pragmatic focus for the UK is to seek to build on its strengths in digital and related services. In fact, our analysis of the UK’s RTA in grid flexibility at the disaggregated level shows that the UK is a specialised innovator in areas relevant for developing innovative consumer propositions and flexibility services – these include: energy trading, market research and analysis, smart metering and demand response systems.⁹³

FIGURE 25: The UK is not specialised in products or patented grid flexibility technologies

Revealed Comparative Advantage (left) and Revealed Technological Advantage (right) in grid flexibility, 2010-14 and 2015-latest available year: various countries



NOTES: The vertical axis denotes the RCA within goods exports (left) and RTA (right), both bounded between -1 and 1. For both RCA and RTA, the chart shows the top ten countries among all OECD countries, China and Hong Kong, as well as the UK if not in the top ten. GBR is the 3-digit country code for the UK. See Annex 1 for details on product and technology classifications.
 SOURCE: Analysis of Harvard’s Atlas of Economic Complexity (left) and PATSTAT 2021 Autumn edition (right).

Heat and buildings: Domestic deployment could unlock supply chain opportunity and local benefits although established market leaders present challenge

Cutting emissions from the UK’s building stock presents two parallel challenges: drastically improving the efficiency of the buildings, while moving away from natural gas heating as quickly as possible. Both of these are particular challenges for the UK, whose homes are some of the oldest and leakiest in Europe, and where six-in-seven British

⁹³ See Figure 40 in Annex 3.

homes are currently heated by gas boilers.⁹⁴

Electrification, through a mass uptake of heat pumps, is currently seen as the main pathway to decarbonise home heating in the UK. The Government has a target to increase the installation of heat pumps from around 35,000 per year today to 600,000 per year by 2028.⁹⁵ However, despite their potential to offer significant lifetime savings given their higher efficiencies leading to lower operating costs, heat pumps currently remain more expensive to install than gas boilers.⁹⁶

Upfront costs continue to pose a barrier to the uptake of energy efficiency improvements as well, although it is estimated that 63 per cent of UK homes would need no more than £1,000 of investment on retrofitting energy efficiency measures.⁹⁷ In the long run, efficiency improvements would bring significant savings on energy bills and help shield UK consumers from future price spikes such as the one currently being experienced due to developments in global gas markets. Energy efficiency is also one of the most effective ways to increase energy security, although the recent energy security strategy made no additional commitments in this area.⁹⁸

The UK Government's policy focus is currently skewed towards the delivery of heat pumps over energy efficiency, although the two are inherently linked. On heat pumps, alongside regulations on new builds⁹⁹ and a proposed phase-out of new gas boilers from 2035¹⁰⁰, the Government is set to introduce a market-based approach backed with legislation in the forthcoming Energy Security Bill that will require boiler manufacturers to install a rising number of heat pumps.¹⁰¹ The Government hopes this will encourage industry to innovate and drive down costs of heat pumps to meet cost parity with gas boilers by 2030.

Post-2013 policies on energy efficiency have repeatedly fallen short of what is required to meet the UK's climate targets, as recently seen with the failure of the Green Homes Grant¹⁰² and the insufficient commitments made in the Heat and Buildings Strategy.¹⁰³ Action over this decade is essential to meet the Government's stated ambition of bringing as many homes as possible to EPC band C by 2035 – a level that only 40 per cent of UK homes currently meet.¹⁰⁴

⁹⁴ A Corlett & J Marshall, [Shrinking Footprints](#), Resolution Foundation, March 2022.

⁹⁵ [Heat and Buildings Strategy](#), Department for Business, Industry and Industrial Strategy, October 2021.

⁹⁶ The current very high gas prices do tilt the balance in favour of heat pumps, though. For a discussion of the impact of rising energy bills on UK households, see: A Corlett & J Marshall, [Stressed Out](#), Resolution Foundation, April 2022

⁹⁷ [Sixth Carbon Budget: Buildings Sector Summary](#), Climate Change Committee, December 2020.

⁹⁸ [British Energy Security Strategy](#), HM Government, April 2022.

⁹⁹ With respect to England, see: [The Future Homes Standard: changes to Part L and Part F of the Building Regulations for new dwellings](#), Ministry of Housing, Communities & Local Government, January 2021.

¹⁰⁰ [Heat and Buildings Strategy](#), Department for Business, Industry and Industrial Strategy, October 2021.

¹⁰¹ [A market-based mechanism for low-carbon heat - summary of responses received and government response](#), Department for Business, Industry and Industrial Strategy, May 2022.

¹⁰² [Green Homes Grant Voucher Scheme](#), National Audit Office, September 2021.

¹⁰³ For example, see: [Independent Assessment: The UK's Heat and Buildings Strategy](#), Climate Change Committee, March 2022.

¹⁰⁴ A Corlett & J Marshall, [Shrinking Footprints](#), Resolution Foundation, March 2022.

It is therefore important to understand the capabilities of the UK supply chain to innovate and deliver at scale the technologies needed to decarbonise heat as well as improve thermal efficiency in buildings. This will not only be key for bringing costs down – a prerequisite for domestic deployment – but can generate export opportunities. The EU market for heat pumps has been expanding by 12 per cent on average annually since 2015, and the global stock of installed heat pumps rises from 180 million units today to 600 million in 2030 under the IEA’s global net-zero scenario.¹⁰⁵

Figure 26 shows that the UK is not currently specialised in the exports of products relating to heat and buildings, and the global market may be difficult to break into given the lead exporters’ persistent competitive positions over the data period. There appears to be a strong link between a country’s specialism in exports of products relating to heat and buildings (measured by RCA) and its domestic market of heat pumps. Sweden, Estonia and Denmark are among the top five countries in Europe (for which data was available) by total heat pump installations per 1000 households by 2020.¹⁰⁶ These countries are also among the most competitive exporters of heat and building products. China ranks second on RCA of such products, and was home to over 30 per cent of the global heat pump stock in 2020.¹⁰⁷

The story is similar with respect to innovation: the UK is not specialised in building fabric or heating and cooling technologies overall (shown separately in Figure 26). But the specialisations of leading countries appear to vary over the two data periods. Five countries appear in the top ten for RTA in both ‘heating and cooling’ and ‘building fabric’, which suggests a joined-up supply chain strategy between heat and efficiency could unlock larger opportunity than addressing the two areas in isolation. However, looking at RTA at a more disaggregated level, we find that the UK does specialise in several key areas including heat pumps, and geothermal heat pumps within those, as well as insulation.¹⁰⁸ The analysis in Section 3 also showed that heat and buildings activity, and potential returns to public investments, has a strong regional dimension.¹⁰⁹ Overall, therefore, this is an area where increased domestic deployment could unlock supply chain opportunities, together with local benefits.

¹⁰⁵ [Heat Pumps – Tracking Report](#), International Energy Agency, November 2021.

¹⁰⁶ Based on European Heat Pumps Association data extracted from [The UK’s Poor Record on Heat Pumps](#), Greenpeace, September 2021.

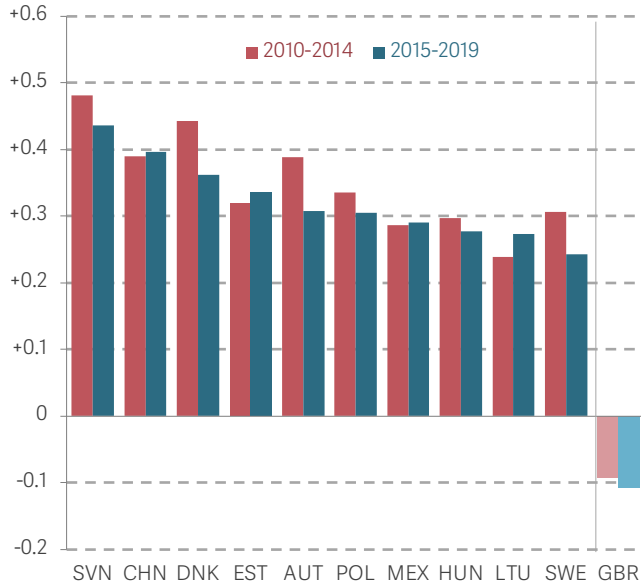
¹⁰⁷ [Heat Pumps Tracking Report](#), International Energy Agency, November 2021.

¹⁰⁸ See Figure 41 in Annex 3.

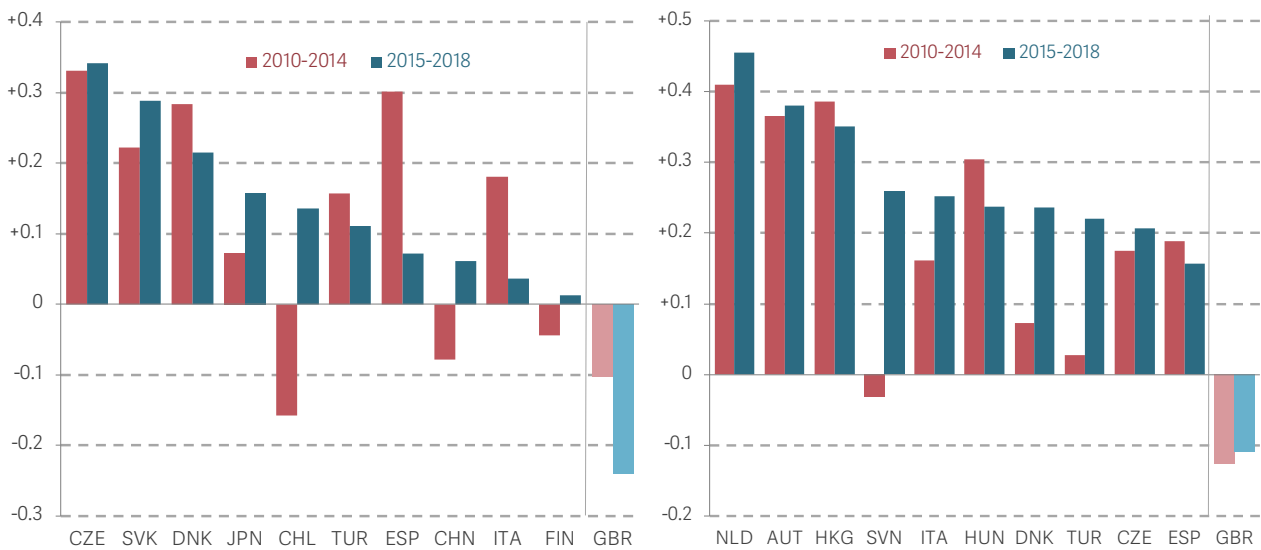
¹⁰⁹ Building fabric is an area where public R&D investments outside the ‘golden triangle’ generate relatively high returns for those same areas, and investments in heating and cooling innovation in the golden triangle generate as much returns in rest of the country as within the golden triangle. We also found that less productive areas are more likely to see a higher share of firms specialising in heat and buildings.

FIGURE 26: As yet the UK is not specialised in heat and buildings goods and technologies overall

Revealed Comparative Advantage in heat and buildings, 2010-14 and 2015-2019: various countries



Revealed Technological Advantage in heating & cooling (left) and building fabric (right), 2010-14 and 2015-2018: various countries



NOTES: The vertical axis denotes the RCA within goods exports (top) and RTA (bottom), both bounded between -1 and 1. For both RCA and RTA, the chart shows the top ten countries among all OECD countries, China and Hong Kong, as well as the UK if not in the top ten. GBR is the 3-digit country code for the UK. See Annex 1 for details on product and technology classifications.

SOURCE: Analysis of Harvard’s Atlas of Economic Complexity (top) and of PATSTAT 2021 Autumn edition (bottom).

Carbon capture usage and storage: the UK is starting from a competitive position but dynamic market requires continued effort

CCUS covers a suite of technologies that enable the capture of carbon dioxide from large point sources (or directly from the atmosphere) and transport it to be injected into deep geological formations (e.g. depleted oil and gas reservoirs) for permanent storage.¹¹⁰ CCUS needs to be deployed urgently to meet net zero targets in the UK¹¹¹ and globally¹¹²: it will play a key role in decarbonising hard-to-abate industries such as steel and cement, and in producing low-carbon hydrogen (which can in turn help decarbonise a variety of end uses)¹¹³, and it will also be needed to store removed carbon dioxide from the atmosphere. In particular, more than half of carbon dioxide captured in 2050 under the CCC's recommended pathway to net zero for the UK relates to carbon dioxide removal.¹¹⁴

While there are currently only limited commercial applications of CCUS (outside enhanced oil recovery),¹¹⁵ strengthened climate targets around the world, and recognition that CCUS will be key to achieve these, has led to more than 120 new CCUS projects being proposed in recent years.¹¹⁶ Currently, there are no commercial applications of CCUS in the UK, but the Government has a target to capture and store 20-30 MtCO₂ (including removals) per year by 2030, up from a previous target of 10 MtCO₂ per year.¹¹⁷ CCUS policy in the UK has stalled progress in the past with the cancellation of two major competitions,¹¹⁸ but there has since been a step change in policy support for CCUS alongside significant industry appetite. Two industrial clusters have been selected to lead UK deployment of CCUS, with emitter projects currently under review by BEIS for market mechanism support. Under government targets, these two 'track-1' CCUS clusters will be operating by the mid-2020s which will be followed by at least two 'track-2' clusters coming online by 2030. Additional removals project plans are expected to be put forward later in 2022.

Demand for CCUS products and services is therefore set to increase domestically and abroad. The ambition to build a competitive UK supply chain to seize commercial

¹¹⁰ Rather than being permanently stored, captured carbon dioxide can also be used to produce a range of commercial products. However, usage does not necessarily deliver a net climate benefit, once indirect and other effects have been accounted for, and therefore is not discussed in this report.

¹¹¹ For example, the Climate Change Committee's Balanced Net Zero Pathway requires over 20 MtCO₂ to be captured in the UK by 2030, starting from zero in 2020. See Climate Change Committee, [Sixth Carbon Budget](#), December 2020.

¹¹² For example, the International Energy Agency's Sustainable Development Scenario requires an eight-fold increase in annual global carbon capture capacity from 2020 to 2030. See [CCUS in Clean Energy Transitions](#), International Energy Agency, September 2020. See also: [Mitigation of Climate Change – Summary for Policymakers](#), Intergovernmental Panel on Climate Change, April 2022.

¹¹³ However, the actual emissions saving from the use of hydrogen produced with CCUS (i.e. blue hydrogen) needs to be assessed on a lifecycle basis as it will depend highly on the local context and on emissions upstream (e.g. fugitive methane) as well as downstream. For example, see R Howarth & M Jacobson, [How green is blue hydrogen?](#), Energy Science & Engineering, August 2021.

¹¹⁴ [Sixth Carbon Budget](#), Climate Change Committee, December 2020.

¹¹⁵ [Global Status of CCS 2021](#), Global CCS Institute, October 2021.

¹¹⁶ [CCUS in Industry and Transformation - Tracking Report](#), International Energy Agency, November 2021.

¹¹⁷ [Net Zero Strategy: Build Back Greener](#), Department for Business, Industry and Industrial Strategy, October 2021.

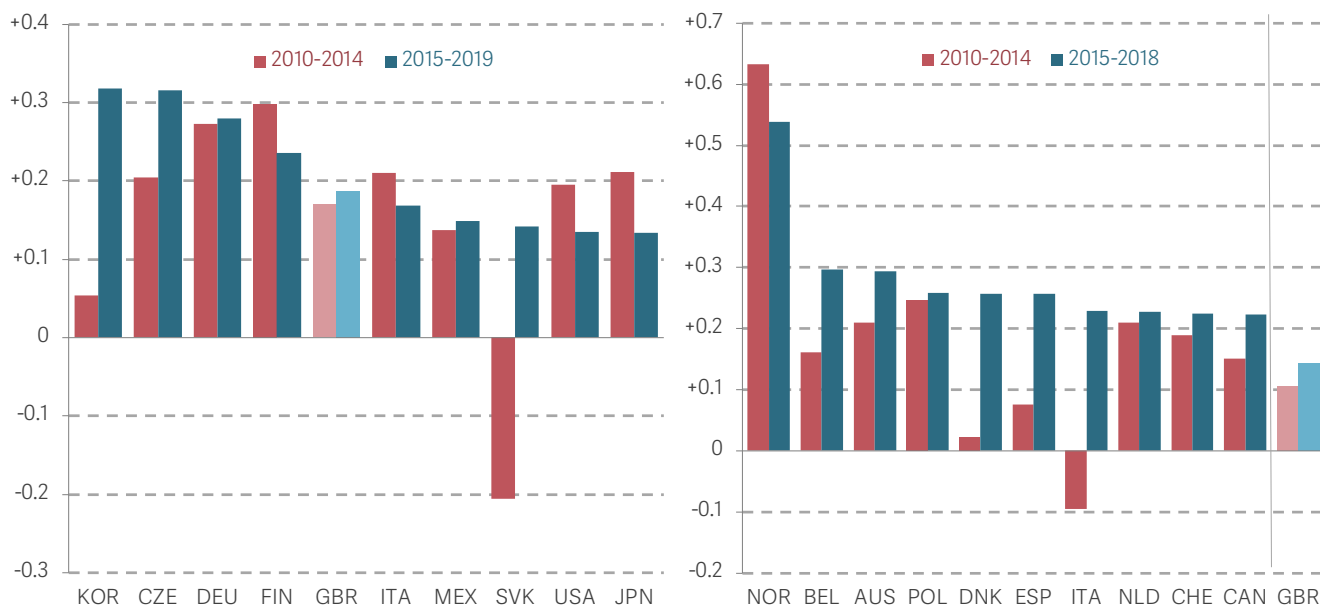
¹¹⁸ [Carbon capture usage and storage: third time lucky?](#), Business, Energy and Industrial Strategy Committee, House of Commons, April 2019.

opportunities from CCUS has already been articulated by the Government¹¹⁹ and internalised by industry.¹²⁰ There may be real economic benefits for the UK from CCUS, especially if it successfully transfers relevant expertise and physical capabilities from its long-established oil and gas sector, and pioneers innovations that bring down costs of associated technologies. The scope for transferable capabilities is demonstrated in our previous work, which identified a positive correlation between CCUS innovation and patenting in oil and gas extraction technologies.¹²¹

The UK has RCA in products relating to CCUS, and this has improved over the 2010s (see Figure 27). This is encouraging, given that the domestic CCUS industry in the UK is very nascent, but this is a position that the UK shares with most other countries that also rank highly on this measure. In fact, except for the US, none of the countries in the top ten by RCA in CCUS products has operational CCUS facilities at commercial scale. Furthermore, this appears to be an area where countries are rapidly building specialisation, with South Korea and Slovakia seeing large increases in their RCA over the 2010s.

FIGURE 27: The UK has pre-existing strengths in CCUS goods and technologies

Revealed Comparative Advantage (left) and Revealed Technological Advantage (right) in CCUS, 2010-14 and 2015-latest available year: various countries



NOTES: The vertical axis denotes the RCA within goods exports (left) and RTA (right), both bounded between -1 and 1. For both RCA and RTA, the chart shows the top ten countries among all OECD countries, China and Hong Kong, as well as the UK if not in the top ten. GBR is the 3-digit country code for the UK. See Annex 1 for details on product and technology classifications.
SOURCE: Analysis of Harvard’s Atlas of Economic Complexity (left) and of PATSTAT 2021 Autumn edition (right).

¹¹⁹ [CCUS supply chains: a roadmap to maximise the UK’s potential](#), Department for Business, Industry and Industrial Strategy, May 2021.

¹²⁰ [North Sea Transition Deal](#), Department for Business, Industry and Industrial Strategy, March 2021.

¹²¹ E Serin et al., [Seizing sustainable growth opportunities from CCUS in the UK](#), GRI & CEP, September 2021.

The UK also has an RTA in CCUS technologies, and this has increased, although it is not in the top ten amongst comparator countries. Norway is the most specialised in this area, and already has operating CCUS facilities relating to dedicated carbon dioxide storage.¹²² Australia and Canada also have operational CCUS facilities and rank highly on RTA.

An analysis of CCUS innovations at the disaggregated level shows that the UK is specialised in technologies related specifically to the capture of carbon and the application of CCUS in the chemical industry, but not in its application in power generation (i.e. in integrated gasification combined cycle plants).¹²³ We saw in Sections 2 and 3 that CCUS is also an area generating above average returns to public investments in innovation overall, and strong returns across the UK.

The UK has advantages in CCUS, but the global CCUS market is dynamic and in its early days and so there are no guarantees that the UK's relative strengths can be retained; strategic action and investment will clearly help here. Furthermore, there could be opportunities in services, given the UK currently successfully exports relevant expertise in related industries, notably in the oil and gas sector.¹²⁴ In previous sections, we have seen that around 70 per cent of UK-based firms that specialise industrial decarbonisation and carbon capture are services firms – a share that is higher than most other clean firm categories.¹²⁵

This section has considered a number of areas that are key for the next stage of the UK's journey to net zero, highlighting that there are several opportunities, particularly in the light of new commitments and deployment plans, but also varying amounts of pre-existing UK comparative strengths that can be built upon. Further analysis is needed, including on identifying specific service specialisms relevant for net zero, and associated export opportunities.

¹²² Saudi Arabia (not shown in this comparator group) is the country with the highest RTA in CCUS globally over the 2015-2019 data period. Saudi Arabia has CCUS facilities for enhanced oil recovery.

¹²³ See Figure 42 in Annex 3.

¹²⁴ *Energy Innovation Needs Assessment: CCUS*, research led by Vivid Economics commissioned by the Department for Business, Industry and Industrial Strategy, October 2019.

¹²⁵ See Figure 17.

Section 5

How can the UK's financial sector help realise clean growth opportunities?

Large-scale investment is required this decade in order to meet net zero, particularly in electricity supply, residential buildings and surface transport. The public and private sectors will need to work together in order to achieve this. Some low carbon sectors, such as offshore wind, have reached a high degree of financial independence from public sources. Others, such as low carbon hydrogen, still face challenging conditions in terms of access to and cost of capital, and therefore still require a large degree of support to become financially viable. Different financial instruments are required at different levels of technological and commercial maturity.

By better integrating place into capital allocation decisions and building capacity at the local level, the finance sector and related institutions can ensure that finance is channelled to the places that, socially and economically, stand the most to gain in the transition. The newly-formed UK Infrastructure Bank has a particularly central role to play in this area, given its dual objectives of supporting net zero and regional economic growth.

Building on its strengths in financial services, the UK has positioned itself as a leader in green finance, and is the first country to commit to creating a Net Zero Financial Centre by 2050. But a number of challenges remain. Environmental, Social and Governance (ESG) ratings are often the basis of funds with a 'sustainable' label. But such ratings evaluate financial risks related to sustainability, rather than environmental impacts of the business in question. There is therefore a risk that 'greenwashing' prevents finance flowing to projects that can deliver net zero and generate related opportunities.

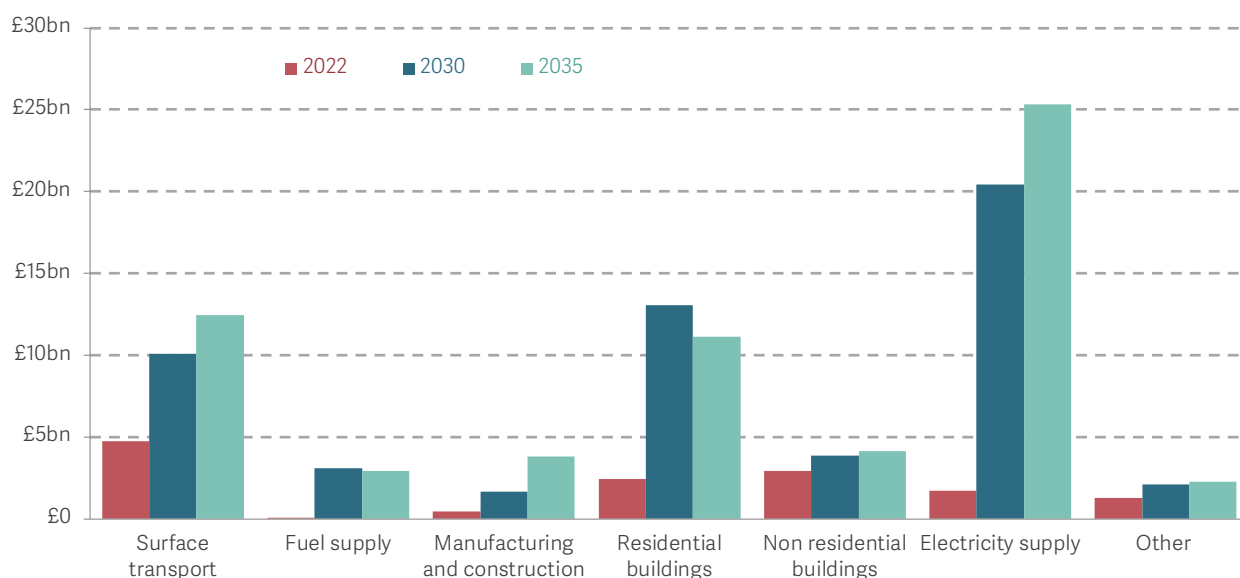
In this section, we ask how the UK's financial sector and its institutions – key sources of the UK's comparative advantage – can help to realise clean growth opportunities by enabling net zero investments across the economy, and by maintaining international leadership in sustainable finance.

Scaling net zero investment across sectors

Delivering net zero will require large amounts of investment across a range of sectors. The CCC estimates that an additional £13.5 billion of annual investment will be needed in 2022, rising to over £50 billion by 2030.¹²⁶ As Figure 28 illustrates, financing needs in the current decade are highest in electricity supply, increasing from £1.7 billion in 2022 to over £20 billion in 2030. But higher investment is needed across the board, and is also particularly high in residential buildings and surface transport. Investments will occur across the UK's regions and nations, based on needs and endowments. For example, new developments of offshore wind are taking place off the coast of England, Scotland and Wales, industrial clusters are benefitting from increased investment in hydrogen and CCUS, and investments in electric vehicles are affecting areas such as Wales, the Midlands and the North East of England.¹²⁷

FIGURE 28: **Additional capital investment needed to deliver net zero**

Annual additional capital investment needed to deliver net zero by 2035: UK



NOTES: Other = Agriculture, aviation, shipping, waste, F-gases, LULUCF & removals.

SOURCE: CCC, Sixth Carbon Budget Dataset, 2020.

¹²⁶ Climate Change Committee, *Sixth Carbon Budget*, December 2020. Additional investment has been calculated as the amount required on top of a path not in line with net zero, and would include, for example, the additional cost of a heat pump compared with a boiler.

¹²⁷ Department for Business, Energy & Industrial Strategy, *Net Zero Strategy: Build Back Greener*, October 2021. Previous CEP-GRI analysis has highlighted the geographic spread of net zero aligned investments; see: S Unsworth et al., *Jobs for a strong and sustainable recovery from Covid-19*, LSE CEP, October 2020.

The public and private sector will need to work together to enable these investments, but the vast majority of investment required will need to be met by the private sector. To enable this, the efficient deployment of public finance and policy support can allow nascent low carbon technologies to become ‘investment ready’ and attract finance from private actors. Indeed, some low carbon sectors, such as offshore wind, have now reached a high degree of financial independence from public sources (although floating offshore wind is still an emerging technology and is being supported by the UK Government Floating Offshore Demonstration Programme¹²⁸). Others, such as low carbon hydrogen, still require a large degree of support to become financially viable. Different financial instruments are required at different levels of technological and commercial maturity. In the case of commercially maturing sectors in particular, there is a clear role for the Government to help to develop investable business models and in de-risking emerging sectors.

In its Net Zero Strategy, the UK Government analysed the commercial maturity and related capital requirements of low carbon sectors, dividing those in need of support into the ‘Start-ups/R&D’ phase (e.g. low carbon hydrogen and advanced nuclear) and the ‘Scale up and Growth’ phase (e.g. long-term energy storage, energy efficiency retrofits and electrification of transport).¹²⁹ The Net Zero Innovation Portfolio and Clean Growth Fund are particularly applicable to sectors in the Start-ups/R&D phase, while the British Business Bank and UK Infrastructure Bank are more targeted towards sectors in the Scale up and Growth phase.

At the early stages of research and development, public finance has a role to play in technologically maturing low carbon sectors; for example, through providing grants to harness the UK’s strong university research base.¹³⁰ These early-stage R&D grants (for example, the Net Zero Innovation Portfolio) are essential for clean tech innovation, but there is also a role for venture capitalists and private equity to invest in emerging technologies taking risky, growth positions following these innovation grants.

However, in recent years, investments in early-stage clean technologies appear to have been viewed by investors as more risky than alternatives.¹³¹ Figure 29 shows that, although venture capital markets in the UK have scaled significantly in recent years

¹²⁸ Department for Business, Energy & Industrial Strategy, [Floating offshore wind demonstration programme: successful projects](#), January 2022.

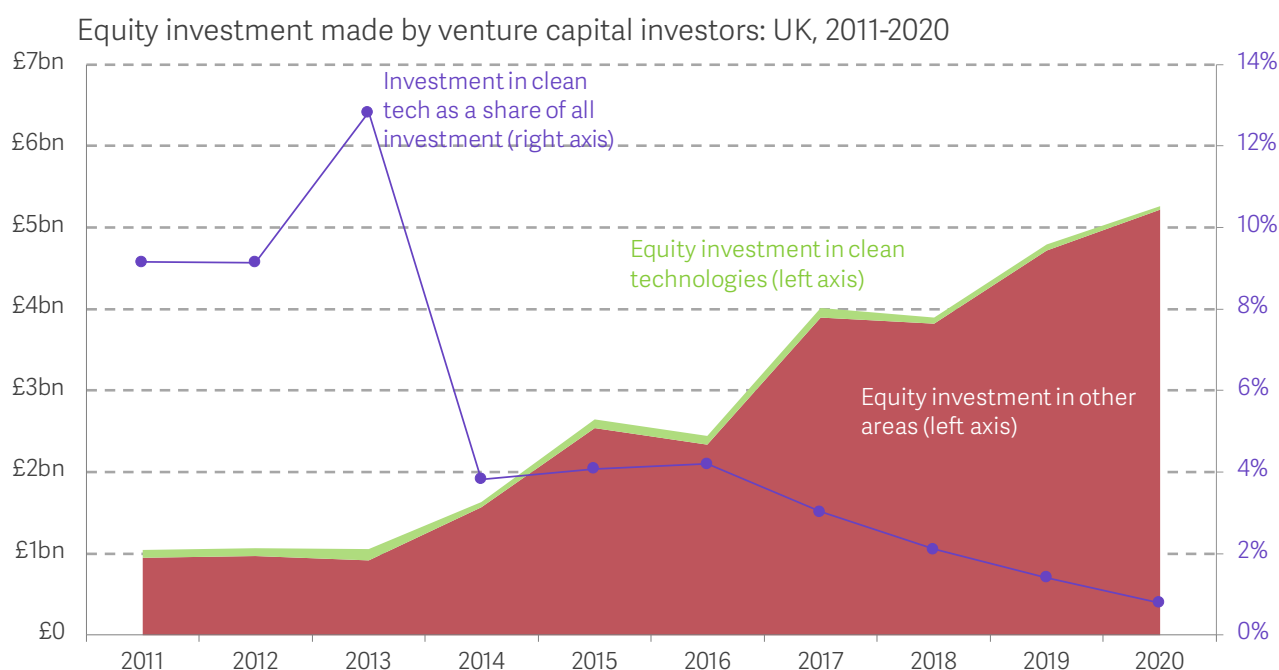
¹²⁹ Department for Business, Energy & Industrial Strategy, [Net Zero Strategy: Build Back Greener](#), October 2021.

¹³⁰ J De Lyon et al., [Enduring Strengths: Analysing the UK’s current and potential economic strengths, and what they mean for its economic strategy at the start of the decisive decade](#), Resolution Foundation, April 2022.

¹³¹ Analysis by Beauhurst suggests that the clean tech sector has been one of the riskiest in the UK for venture capitalists and private equity firms. See Beauhurst, [Growing Cleantech Funding](#), February 2019. A broader analysis of the private returns to clean innovations (i.e. the returns captured by innovating firms) in the United States affirms this view, with the returns to clean innovation being more dispersed than the returns to dirty innovations and the observation that after the Great Recession investors in R&D became more risk averse. See: R Martin & D Verhoeven, [The Private Value of Clean Energy Innovation](#), LSE mimeo, 2022.

(largely due to rapid increases in investments into software companies),¹³² this increase has not been matched by similar VC investment in clean tech: clean tech accounted for over 10 per cent of total venture finance in the early 2010s, but less than 1 per cent in 2020.¹³³ Total equity investments (made by all types of investor) display a similar pattern, with clean tech making up 2 per cent of the total equity funds raised in 2020 (compared with over 12 per cent in 2010). More recent data shows that UK clean tech equity investments reached record levels in monetary terms in 2021, reflecting the power of net zero commitments in the UK and internationally in providing 'direction' for private investment.¹³⁴

FIGURE 29: While venture capital has risen, the share going to clean tech has fallen



NOTES: Total equity investments where the venture capital/private equity investors are involved. The amounts of investment have been verified, and if not, the announced amount is given.

SOURCE: Analysis of Beauhurst data, July 2021 extract.

The UK Government has tried to stimulate greater investment in clean tech with the launch of its £40 million Clean Growth Fund (with £20 million provided by BEIS and £20 million from the institutional investor CCLA), and this has been investing in this space since its launch in 2019. The revised mission of the British Business Bank to drive sustainable growth and enable the transition to a net zero economy also has the

¹³² International data shows that the UK ranks first in Europe in terms of the volume of venture capital investments. See: Dealroom, [2021: the year London tech reached new heights](#), January 2022.

¹³³ Venture Capital investment is defined here as deals where venture capital or private equity investors were involved, as available in Beauhurst data at the fundraising level.

¹³⁴ Beauhurst, [Investment into Cleantech Companies in 2021](#), February 2022.

potential to increase investment in this area, but it will be important to review progress through investment tracking, as we discuss below.

Even when technologies are established, there will likely be a continued need for public finance to improve the economic viability of business models for critical low carbon sectors. In particular, this applies to energy efficiency sectors and retrofits for domestic buildings. One intervention of this type available to governments is revenue stabilisation policy tools which can reduce the cost of capital. A key example is the Contracts-for-Difference mechanism which was used to support wind generated electricity, and provided price stability which is influential for investor confidence. The investment-readiness of key low carbon infrastructure can also be enhanced through public finance instruments, such as grants, concessional finance and guarantees.

The Government can also contribute to lowering the cost of capital and making these technologies attractive for private financial actors by aligning with their risk appetites and rate of return hurdles. For example, the UK Infrastructure Bank has a guarantee book of £10 billion which it can deploy. This guarantee book can be used effectively to de-risk investments and allow private capital to be leveraged into sectors and transactions where they would not have been otherwise. The right mix of policy support and effective application of public finance will support these sectors and technologies to attract large-scale private finance.

It is important to note that the investment gap will not entirely need to be funded by new investment. Redirecting investments from carbon-intensive sectors to low carbon sectors can play a key role: for example, using funds previously used for fossil fuel subsidies to support clean innovation.

The regional aspects of investment in clean opportunities

As we discussed in the previous section, the geographical spread of clean firms and innovation suggests that investments in technologies, products and services relevant for net zero could play a role in reducing regional inequalities. By integrating place-based considerations into capital allocation decisions and building project development capacity at the local level, the finance sector and related institutions can ensure that finance is channelled to the places that, socially and economically, stand the most to gain in the transition.

It has been argued that place-specific approaches can be associated with lower investment costs and higher social co-benefits (such as cleaner air, reduced energy costs and improved health) in delivering net zero.¹³⁵ The establishment of the UK

¹³⁵ Innovate UK, *Accelerating Net Zero Delivery: Unlocking the benefits of climate action in UK city-regions*, March 2022.

Infrastructure Bank (UKIB) directly responds to the need to connect net zero with local economic development. Deep engagement with local government representatives to support pipeline development and ensure projects address local needs will be a crucial component if the UKIB is to deliver on its dual objective. To contribute to commercially maturing sectors, the impact of the UKIB would be maximised by providing capital for project development and crowding in private finance with a view to sectors reaching financial independence over time.

Private finance also has a range of tools available that allow for the adoption of a local focus to climate action. Banks can work with local authority clients to explore how to access finance for the investments needed for critical infrastructure, workers and skills, local businesses, households, and the public sector itself. Investors also have an important role to play, not least through real assets (including infrastructure and real estate) and private markets (covering private equity and private debt). Through their inherent ties to workers and the long-term investment horizon, pension funds can also be crucial actors, and it is in the interest of beneficiaries to increase future-proof investments in their regions. Innovative financial mechanisms can also offer promising solutions, such as sustainable municipal bonds, like those issued in countries such as France, Germany, Sweden and the US.¹³⁶

Overall, there is no shortage of local capital to invest in climate action, and no shortage of project ideas at the local level which would support the delivery of net zero. The bottleneck seems to lie primarily in pipeline development that ensures projects are bankable and investable. The Place-based Climate Action Network (PCAN) is currently designing a workstream trying to tackle this challenge through what it calls local climate finance hubs (as described in Box 6).

BOX 6: Local Climate Finance Hubs

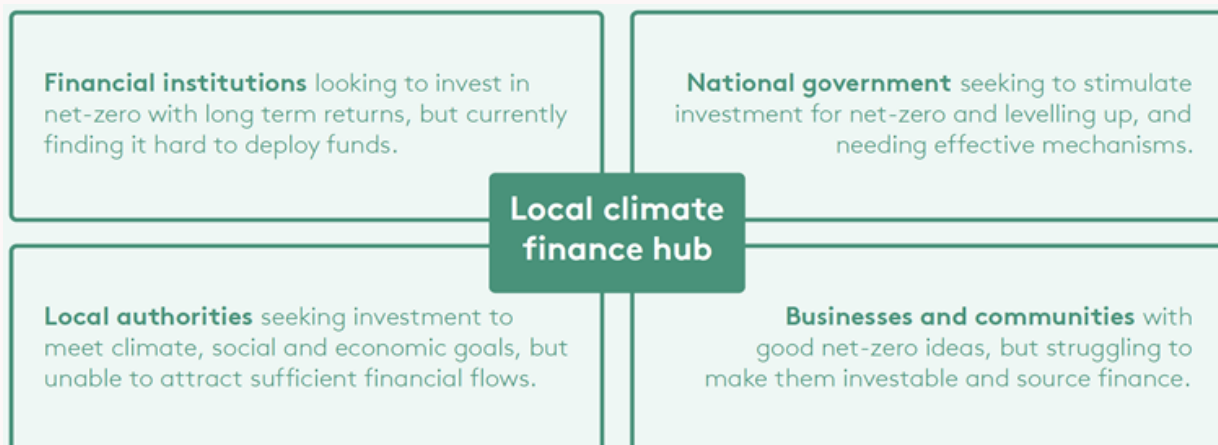
A local climate finance hub, as proposed by the Place-based Climate Action Network, would have a catalytic role and would be locally embedded to develop and maintain a pipeline of high-quality, high-impact projects informed by a deep knowledge of local

opportunities, needs, capabilities and capacities, and the benefits of place-based projects. The hubs aim to address the needs of four key audiences, described in Figure 30.

¹³⁶ N Robins et al., *Just Zero: 2021 report of the UK Financing a Just Transition Alliance*, October 2021.

FIGURE 30: **Local climate finance hubs can benefit a range of stakeholders**

Stakeholders of local climate finance hubs



SOURCE: N Robins et al., Just Zero: 2021 report of the UK Financing a Just Transition Alliance, October 2021.

Other actors beyond the finance sector can also play a critical supporting role in channelling capital towards place-specific approaches to net zero. In order for finance to effectively support place-based climate action, local authorities will need to clearly articulate their specific needs. Research institutions and collaborative fora between local authorities can meaningfully support this process.

The UK is a leader in green finance

Internationally, the UK has positioned itself as a policy leader in green finance through its progress on financial standards and regulations aimed at responding to climate risk and progressing in the UK's path to net zero.¹³⁷ In addition, the Chancellor has committed the UK to create a net zero financial centre by 2050.

A central area of regulatory leadership has been the introduction of mandatory disclosure of climate-related financial information for large UK companies and financial institutions, in line with the recommendations set out by the Task Force on Climate-related Financial Disclosures (TCFD).¹³⁸ This requirement came into effect in April 2022. In context of its move to make transition plans mandatory for listed companies and regulated investors, the Treasury has established a Transition Plan Task Force to develop a standard for climate transition plans. The UK has also followed the EU's lead in developing a green taxonomy to improve the data available on the environmental impact of firms, supporting investors, businesses and consumers to make informed financial decisions on green investment.

¹³⁷ HM Treasury, *Greening Finance: A Roadmap to Sustainable Investing*, October 2021.

¹³⁸ BEIS, *UK to enshrine mandatory climate disclosures for largest companies in law*, October 2021.

With regard to central banking, the Chancellor recently updated the remit for the Prudential Regulation Committee, the Monetary Policy Committee, the Financial Policy Committee at the Bank of England and the Financial Conduct Authority to more clearly align their mandates with the UK's net zero and wider climate goals.

These policy advancements have created the basis for the UK to continue leveraging its specialisation in financial services and potential for financial innovation in the transition to net zero. Public finance institutions, particularly the British Business Bank (BBB) and the UK Infrastructure Bank (UKIB), have a focus on climate considerations within their investment mandates. Through its inaugural and subsequent issuances of Green Gilts in 2021, the UK has been able to raise £16 billion for green infrastructure so far, with good take up from financial market participants.

The UK's private finance sector is also increasing its climate finance efforts. London ranks first in the Global Green Finance Index 9, ahead of Amsterdam and San Francisco.¹³⁹ COP26, hosted in the UK, has also brought important advances in global voluntary initiatives such as the announcement of the Glasgow Financial Alliance for Net Zero with over 450 members and \$130 trillion (US) in assets under management.

However, in terms of sustainable finance raised, the UK is lagging behind some of its peers. As Figure 31 illustrates, although the UK ranks among the top 10 places of green bond issuance globally, countries such as the USA, China, France and Germany are considerably ahead.

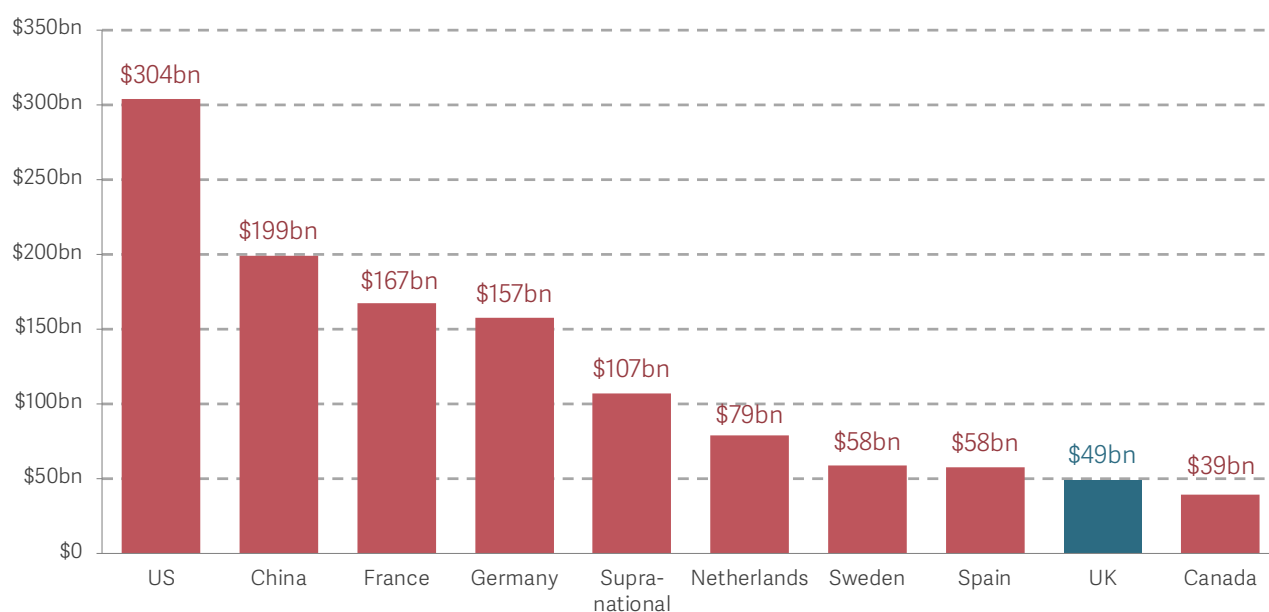
'Greenwashing' is also a key consideration: this has the potential to undermine the UK's position as a centre of green finance if left unaddressed.¹⁴⁰ However, the UK and the EU are both advanced in developing their green taxonomies which are aimed at countering unintentional misallocation of investment to non-green projects or businesses. Regulators should be exploring how to use the taxonomy to adopt enforcement mechanisms for transition alignment across economy and financial system actors.

¹³⁹ M Wardle et al., [The Global Green Finance Index 9](#), Long Finance and Financial Centre Futures, April 2022.

¹⁴⁰ This refers to when an organisation claims to be environmentally sustainable for marketing purposes, but is not in reality.

FIGURE 31: The UK is lagging behind some of its peers in sustainable finance raised to date

Total green bond issuance (\$ Billion), December 2021: various countries



NOTES: Figures represent total green bonds ever issued.
SOURCE: Climate Bonds Initiative, 2021.

Remaining challenges for cementing the UK as a centre of green finance

The UK has been making important progress towards decarbonisation and greening its finance sector, but a number of challenges remain. Brexit has created risks to the financial sector and London's role as an international financial centre.¹⁴¹

More substantively, clear plans are needed to bridge the investment gaps in central low carbon sectors, and to spur activity where progress has been slow so far, such as in the deployment of home energy efficiency solutions. As Aldersgate Group highlighted in their 'Net Zero Strategy Policy Tracker', the strategy produced a helpful narrative but did not include sufficient information on "how government will use standards, regulation or fiscal intervention to drive the change across the economy".¹⁴² For investment to flow, investors need to have confidence in the policy landscape and policy consistency across sectors. For example, the UK Green Buildings Council has highlighted the need for a National Retrofit Strategy which would be fully coordinated with local government, industry and relevant stakeholders.¹⁴³ Consistent policy like this contributes to investor confidence, and so the onus is now on policymakers to provide clear policy signals

¹⁴¹ J De Lyon et al., *Enduring Strengths: Analysing the UK's current and potential economic strengths, and what they mean for its economic strategy at the start of the decisive decade*, Resolution Foundation, April 2022.

¹⁴² Aldersgate Group, *Net Zero Strategy Policy Tracker – Key announcements and next steps*, October 2021.

¹⁴³ UK Green Buildings Council, *The Net Zero Whole Life Carbon Roadmap*, November 2021.

through national, devolved and local government policy, otherwise, sectors like energy efficiency in buildings may struggle to attract sufficient private finance.

There continues to be more that UK policymakers can do to ensure the net zero transition of the economy. The Net Zero Strategy committed to publish “a Net Zero transition pathway for the UK financial sector” within the updated Green Finance Strategy, which is due to be published later this year. However, the updated strategy should also look to adopt the wider ranging understanding of sustainability beyond simply climate to consider natural adaptation, the just transition (by linking net zero to the levelling up agenda) and how to drive local climate transitions within the UK regions and devolved administrations. The UK has the appropriate top-down commitments to net zero and a net zero financial system by 2050 in place, and it is now essential that policymakers demonstrate how regulation, policy and public finance will be mobilised to support that ambition.

Section 6

Conclusion

The UK Government's Net Zero Strategy highlights the role of innovation in delivering both emissions reductions and future growth. However, from the perspective of UK policymakers, a key question is how to best target investments and design policies to promote the development of current and potential future competitive strengths, and to avoid the pitfalls of attempting to 'pick winners'. This report has provided three types of analysis which have provided a hard-headed assessment of the role that clean growth and innovation can play in the UK's future economic strategy, and has considered how our financial system can be geared towards realising these. Our findings lie in three areas.

First, analysis of patenting and trade data at the national level has revealed that the UK is not the world leader overall in clean technologies or traded goods, but there are specific areas of strength that can be built upon as part of a new economic strategy for the UK. Within the UK, less productive areas are more specialised in innovation, goods and services relevant for net zero, pointing to the potential for net zero investments to be consistent with the ambition to address longstanding inequalities between regions.

Second, considering a number of key areas such as grid flexibility and CCUS in more depth, we find varying evidence of pre-existing UK comparative strengths in developing technologies, and exporting products overseas. For example, wind is an area where the UK has technological specialisation and these strengths could be better leveraged in trade: to date, the UK has not been specialised in the exports of wind energy products. This work should be extended to understand the role of service specialisms relevant for net zero, and associated export opportunities.

Finally, achieving net zero and realising related growth opportunities requires significant investment from both the private and public sectors, and coordinated policies and support to reduce uncertainty for investors. Building on its strengths in financial services, the UK has positioned itself as a leader in green finance, but challenges remain in terms of ensuring that adequate finance flows towards sustainable projects.

Our work shows that net zero is not a silver bullet for reversing the UK's economic stagnation and addressing inequalities. But embedding the transition into a coordinated and system-wide policy approach that stimulates increased and well-targeted investments across innovation, infrastructure and skills will maximise the chances that these objectives can be achieved. Our conclusions raise a number of important policy questions that must be addressed as part of a new economic strategy. These include:

- How can the UK build upon its existing comparative advantages in clean technologies, products and services and develop strengths in areas that are adjacent to its current strengths?
- What are the implications of net zero investments and growth opportunities for jobs and skill requirements, and how do these vary across the country?
- How can net zero be better aligned with other key areas of policy such as 'levelling up' to ensure that the required system-wide change occurs in a way that is consistent with stronger, more inclusive growth?
- What types of data and evaluation can best inform policy in a fast-changing and uncertain context?

These questions will be considered further in future reports in the Economy 2030 Inquiry.

Annex 1

Supplementary information on the key data sources

Patents

Our analysis uses the 2021 Autumn edition of the Worldwide Patent Statistical Database (PATSTAT Global) published by the European Patent Office (EPO). PATSTAT contains information on patent applications filed with patent authorities in various countries. Patent applications are grouped into 'patent families' if they cover similar technical content or refer to the same invention.

These patent families are the unit of measurement in our analysis. We assign a geographical location to each patent family by mapping it to the country of residence of the inventors when the patent application was filed. In case of missing observations, we impute the inventor country using the dataset created by Rassenfosse and Seliger that maps patent families to their countries.¹⁴⁴ We restrict our analysis to the period 1980 to 2018 for consistency. One of the drawbacks of this dataset is that missing country values for inventors associated with patent families still exist despite our efforts to enrich the dataset with the information on inventor countries. We restrict the dataset to patent families which include patent applications filed with more than one patent authority. Restricting patent families with such a constraint allows one to focus on higher-valued patents.¹⁴⁵ The resulting sample dataset of patent families with size greater than one includes a significantly larger share of patent families for which country information is available.

PATSTAT classifies patents according to the Cooperative Patent Classification system (CPC). The CPC classification system is a result of a joint effort between the United States Patent and Trademark Office (USPTO) and the EPO. Its objective is to harmonize the European Classification system (ECLA) and the United States Patent Classification (USPC) while being compliant with the International Patent Classification system (IPC). The CPC classifies patents at a very granular technological level. A patent can have more than one CPC classification if the innovation is pertinent in more than one technological context. We aggregate the classifications at the CPC class level for our analysis. There

¹⁴⁴ G de Rassenfosse & F Seliger, Imputation of missing information in worldwide patent data, Data in Brief, Volume 34, 2021. Note that one patent family can be assigned to multiple countries.

¹⁴⁵ D Harhoff, F Scherer & K Vopel, [Citations, family size, oppositions and the value of patent rights](#), Research Policy 32, September 2003.

are 126 CPC classes across nine sections: Human necessities; Performing operations, transporting; Chemistry, Metallurgy; Textiles, Paper; Fixed construction; Mechanical Engineering, lighting, heating, weapons, blasting engines or pumps; Physics; Electricity; New technological developments, cross-sectional technologies. The CPC also includes a specific class ('Y02') related to climate change mitigation and adaptation technologies of different types, which we use to classify technology areas as being 'clean'. In this report we also work with a different set of clean technologies, as defined in collaboration with BEIS.¹⁴⁶

One of the limitations of working with patents is that not all innovation is patented. For example, innovation in the services or in the creative sector is relatively harder to capture using patent data. Another limitation is the missing information such as technological classification or inventor country at a patent family level. There are inconsistencies of patent applications over time, but this is mainly limited to national patent authorities from industrialising countries.¹⁴⁷ For all the limitations associated with PATSTAT, it provides a rich dataset to observe innovative activity as well as to understand the innovative capabilities of countries.

The technology categories used for disaggregated analysis are drawn from aggregations in R Martin & D Verhoeven, Knowledge spillovers from clean and emerging technologies in the UK, CEP Discussion paper 1834, March 2022; with the addition of 'clean cars'. For the RTA calculations in our 'deep dives' in Section 4, we use aggregations of patent codes as follows:

- Wind: Aggregation of patents under the 'Offshore Wind' category.
- Nuclear: Aggregation of patents under the 'Nuclear Fission' category.
- Grid flexibility: Aggregation of patents under the 'Smart Systems' category.
- Heat and buildings: Aggregation of patents under the 'Heating & Cooling' and 'Building Fabric' categories.
- CCUS: Aggregation of patents under the 'CCUS' category.

We also add 'clean cars' in our analysis:

- Zero emissions passenger vehicles: Aggregation of patents under the CPC group 'Y02T 10'.

¹⁴⁶ R Martin & D Verhoeven. Knowledge spillovers from clean and emerging technologies in the UK, March 2022, CEP Discussion paper 1834.

¹⁴⁷ G Rassenfosse et al., Low-quality patents in the eye of the beholder: Evidence from multiple examiners, Journal of Law, Economics and Organisation 37(3), 2021.

Traded goods

From the Harvard's Atlas of Economic Complexity, we obtain an unbalanced panel of goods and services data derived from the United Nations Statistical Division (COMTRADE) and the IMF Direction of Trade Statistics, respectively. This dataset is based on raw trade flows reported by countries. It is cleaned and pre-processed in order to overcome several inconsistencies in the reporting process.

Our focus is on traded goods only, available in the Harmonised System (HS) 1992 classification format. The HS version offers a more granular classification of exports at the 6-digit level, covering 5,040 products over the period from 1995 to 2019.

We calculate revealed comparative advantage across two different classifications of green products, one obtained from the Green Transition Navigator (GTN) and the other based on a narrower mapping exercise carried out by Vivid Economics.¹⁴⁸ We use this latter mapping for the purposes of our analysis in Section 4. We note that ten of these HS codes are not available in the dataset and therefore not included in the analysis: 730411, 730419, 850231, 850400, 850610, 850630, 850640, 850650, 850660, 850680.

According to GTN, there are 294 'green' products, of which, the UK has revealed comparative advantage in 116 (39 per cent) over the period 2015-2019. For our 'deep dives' in Section 4, the six-digit harmonised system codes used in the RCA calculations are as follows:

- Zero emissions passenger vehicles. Products: Classification based on Vivid Economics, Energy Innovation Needs Assessment: Road Transport, October 2019. 840734; 840820; 840991; 840999; 870810; 870821; 870829; 870840; 870850; 870870; 870880; 870891; 870892; 870893; 870894; 870899.
- Wind. Products: Classification based on Vivid Economics, Energy Innovation Needs Assessment: Offshore Wind, October 2019. 730820; 730890; 841280; 841290; 848340; 850231; 850300; 850400; 853720; 854460 as well as 6-digit codes under 8482 (848210; 848220; 848230; 848240; 848250; 848280; 848291; 848299).
- Nuclear. Products: Classification based on Vivid Economics, Energy Innovation Needs Assessment: Nuclear Fission, October 2019. 840110; 840120; 840130; 840140; 284420; 284510; 284590.

¹⁴⁸ P Andres & P Mealy, Green Transition Navigator, www.green-transition-navigator.org.

- Grid flexibility. Products: All six-digit codes under 8504 based on Vivid Economics, [Energy Innovation Needs Assessment: Smart Systems](#), October 2019; and all six-digit codes under 8506 also added to cover batteries. 850410; 850421; 850422; 850423; 850431; 850432; 850433; 850434; 850440; 850450; 850490; 850610; 850630; 850640; 850650; 850660; 850680; 850690.
- Heat and buildings. Products: Classification based on 'Heat and Energy Management' product category from P Andres & P Mealy, [Green Transition Navigator, 2021](#), with the last three codes in the list also added to cover heat pumps. 381511; 390940; 392030; 392111; 392113; 450490; 540500; 680610; 680690; 680800; 681011; 681019; 681091; 700800; 701931; 701939; 701990; 841950; 841990; 850220; 853921; 853931; 853939; 902810; 902820; 902830; 902890; 903210; 940510; 940520; 940540; 841581; 841861; 841869.
- CCUS. Products: Classification based on Vivid Economics, [Energy Innovation Needs Assessment: CCUS](#), October 2019. 281121; 381400; 730411; 730419; 730511; 730512; 731100; 841480; 841490; 842139; 842199; 890520; 901580; 902610; 902620; 902690.

The Data City

Table 1 sets out how we have aggregated The Data City classifications into broad areas of goods or services relevant for net zero.

TABLE 1: Mapping from The Data City sectors to classifications used in this report

Classification in this report	TDC RTICS subsectors
Agriculture and forestry	CleanTech: Agriculture, Forestry and Biodiversity; Net Zero: Agritech
Circular economy/waste	Green Economy: Reduce, Reuse, Recycle and Repair; Net Zero: Diversion of Biodegradable Waste from Landfill; Net Zero: Waste Management and Recycling
Climate adaptation	Green Economy: Climate Adaptation
Consultancy and services	Green Economy: Climate Change Strategy Research Monitoring and Planning; Net Zero: Low Carbon Consultancy, Advisory and Offsetting Services
Demand side management and digit	Artificial Intelligence: GreenTech; Energy Management: AI and IoT; Energy Management: Energy Management Systems; Energy Management: Smart Meter; Internet of Things (IoT): Energy Management; Internet of Things (IoT): Smart Buildings; Internet of Things (IoT): Smart Cities and Transport; Net Zero: Renewable Energy Planning Database
Energy storage	Energy Storage: Batteries; Energy Storage: Hydrogen; Energy Storage: Mechanical; Energy Storage: Thermal; Energy Storage: Uninterruptible power supply; Li-ion battery supply chain: Battery assembly; Li-ion battery supply chain: Battery cells; Li-ion battery supply chain: Material suppliers; Net Zero: Energy Storage
Environmental monitoring and pollu	CleanTech: Environmental Protection and Monitoring; Green Economy: Reducing Localised Pollution; Net Zero: Pollution Control and Mitigation; Sensors: Environmental Monitoring
Grid and infrastructure	Energy Management: Smart Grid; Green Economy: Green and Blue Infrastructure; Net Zero: Grid
Industrial decarbonisation and carb	Green Economy: Industrial Decarbonisation, Hydrogen and Carbon Capture; Net Zero: Carbon Capture
Low-carbon energy generation	Energy Generation: Bioenergy; Energy Generation: Hydrogen; Energy Generation: Hydropower; Energy Generation: Nuclear; Energy Generation: Renewable Thermal; Energy Generation: Solar; Energy Generation: Wind; Green Economy: Power; Net Zero: Energy Cooperatives; Net Zero: Low Carbon Energy Generation; Net Zero: Renewables
Low-carbon heat and buildings	Green Economy: Homes and Buildings; Net Zero: Building Technologies; Net Zero: Heating
Low-carbon transport	Green Economy: Low Carbon Transport; Net Zero: Low Emission Vehicles
Clean commodities	CleanTech: Adapted Goods; CleanTech: Mining, Fuels and Biofuels
Sustainable finance	Green Economy: Green Finance; Net Zero: Green Finance
Water management	CleanTech: Water Processing

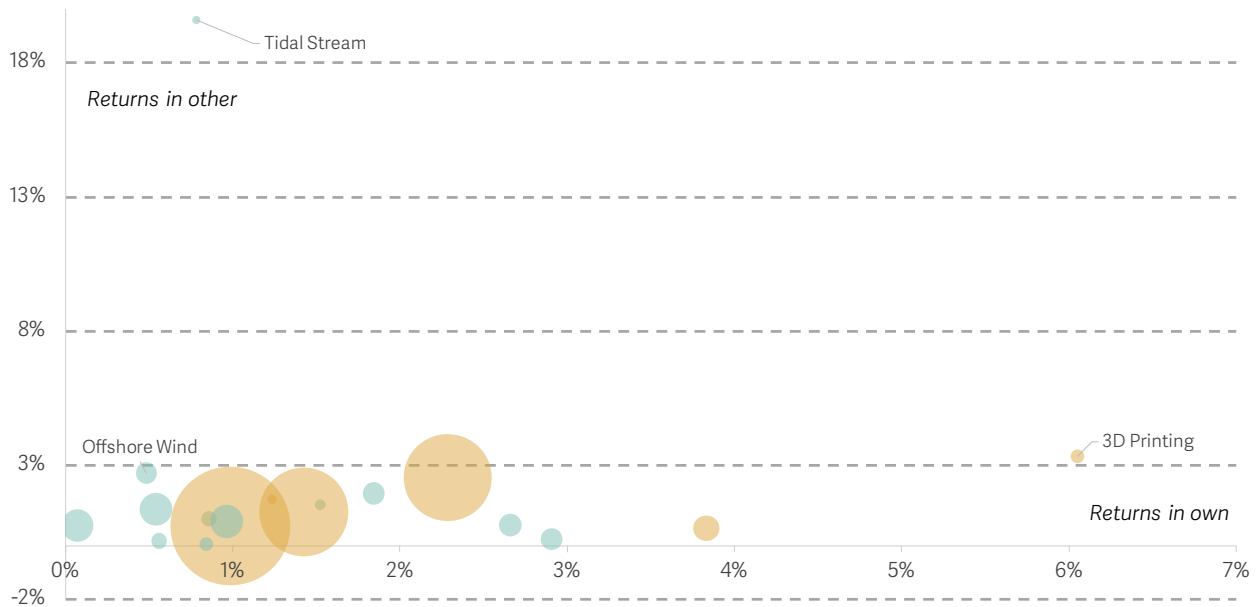
Annex 2

Supplementary analysis

Patents

FIGURE 32: Investments in clean technologies in the golden triangle tend to generate more returns for other regions

Returns to investments in innovation taking place in “golden triangle” regions, retained in those regions, versus those felt in the rest of the country, by technology field

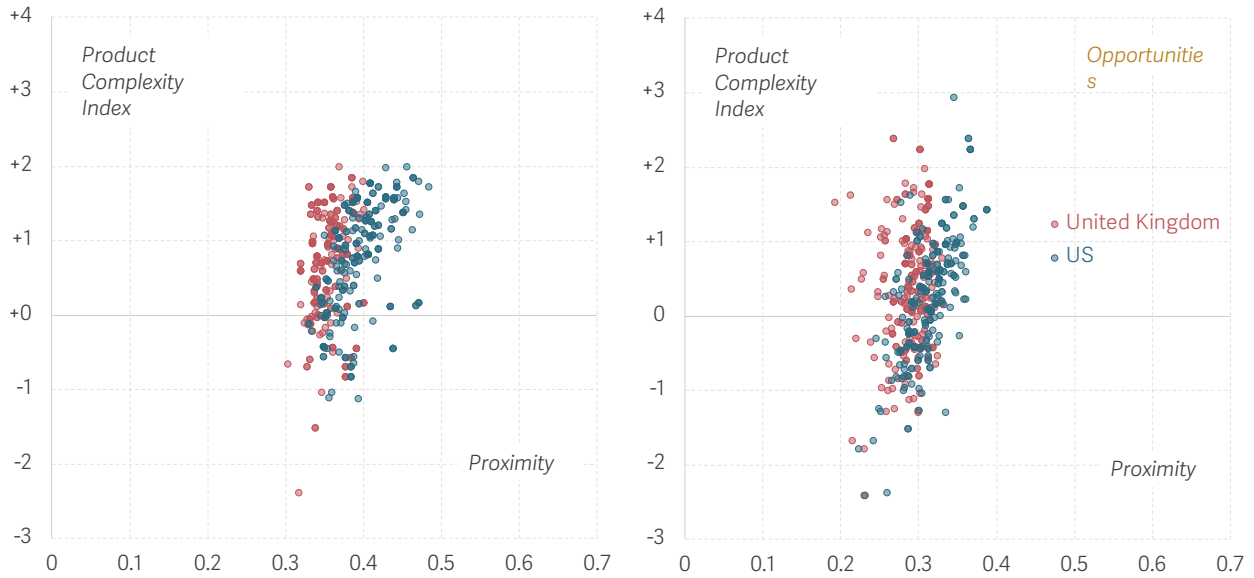


NOTES: The vertical axis shows the estimated returns to a £1 additional R&D subsidy in the field outside the region where investments are made, and the horizontal axis shows the equivalent for returns that are retained in the same region. The size of the bubbles indicates the size of a particular technology grouping by number of innovations in the region. Patents from 2005-2014 are included. Green bubbles are clean technology categories, and yellow bubbles are technologies within the ‘trending’ category
 SOURCE: Martin & Verhoeven (2022), with category clean cars added.

Traded Goods

FIGURE 33: United States

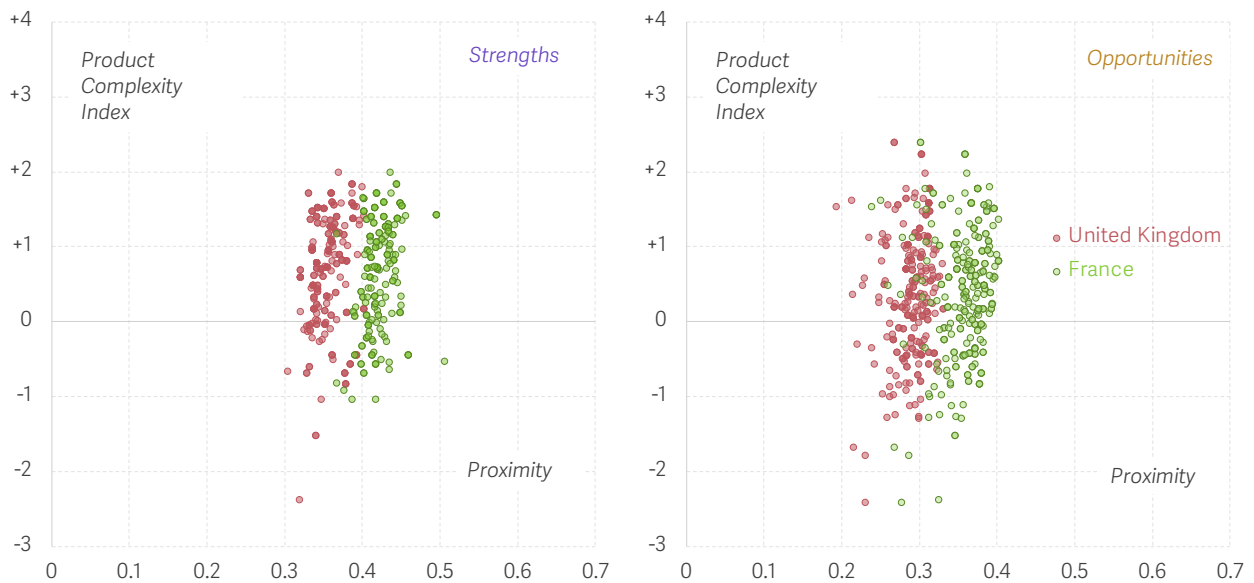
Product complexity and proximity to current capabilities, strengths (left) and opportunities (right): UK and US



NOTES: Strengths are areas where the country has RCA, opportunities are where the country does not yet have RCA.
 SOURCE: P Andres & P Mealy, Green Transition Navigator, www.green-transition-navigator.org

FIGURE 34: France

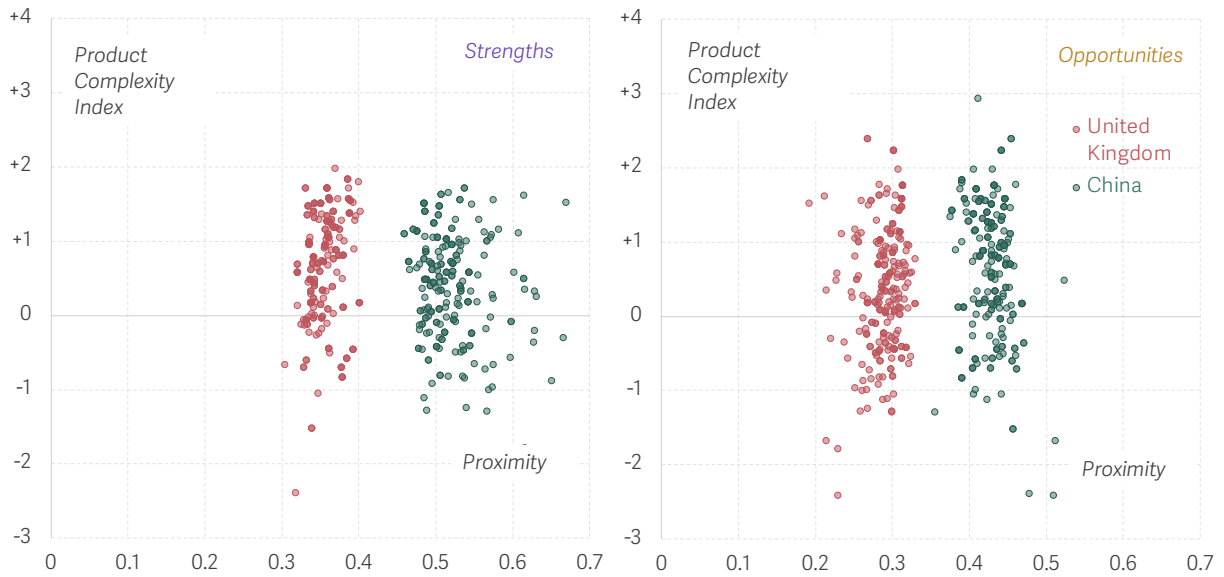
Product complexity and proximity to current capabilities, strengths (left) and opportunities (right): UK and France



NOTES: Strengths are areas where the country has RCA, opportunities are where the country does not yet have RCA.
 SOURCE: P Andres & P Mealy, Green Transition Navigator, www.green-transition-navigator.org

FIGURE 35: **China**

Product complexity and proximity to current capabilities, strengths (left) and opportunities (right): UK and China



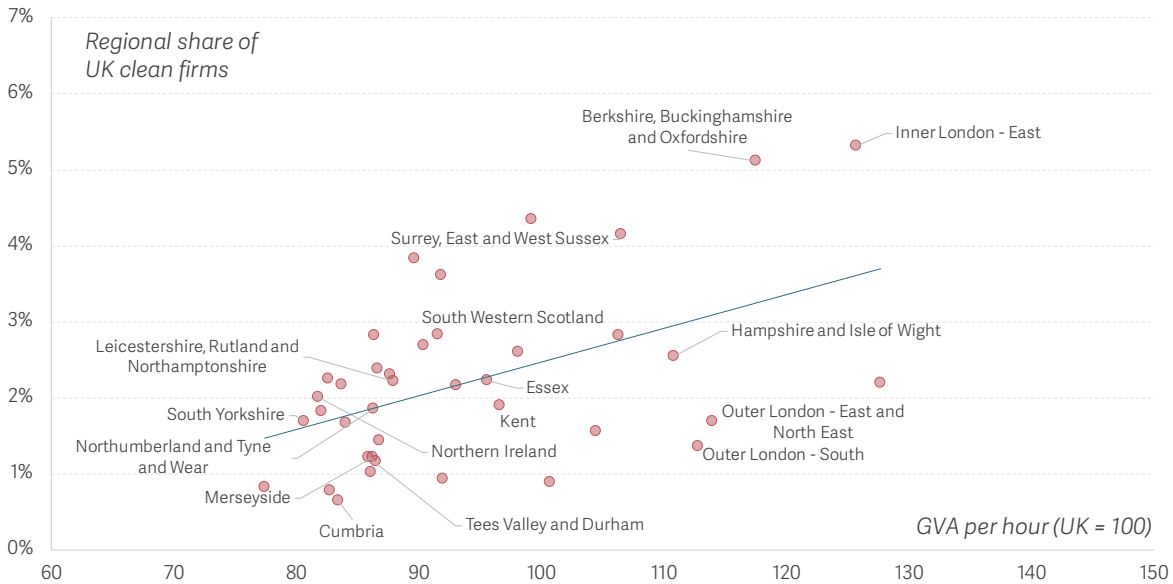
NOTES: Strengths are areas where the country has RCA, opportunities are where the country does not yet have RCA.

SOURCE: P Andres & P Mealy, Green Transition Navigator, www.green-transition-navigator.org

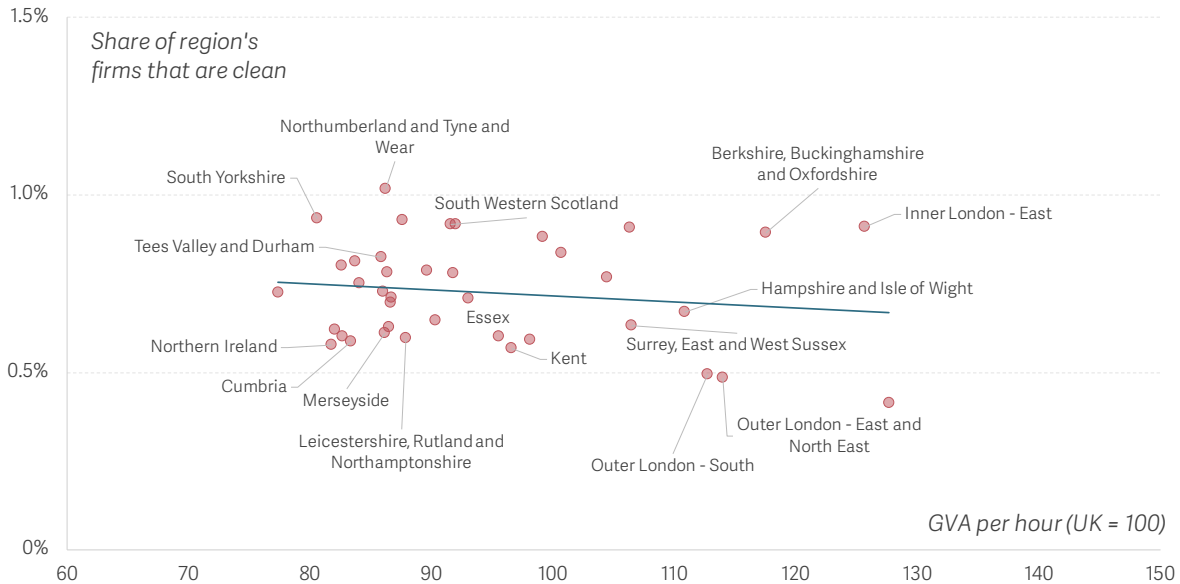
The Data City

FIGURE 36: More productive areas account for a higher share of the UK's clean firms, but less productive areas have a higher clean firm intensity

Regional share in total UK clean firms and GVA per hour (UK=100)



Clean firms as a share of total firms in a region and GVA per hour (UK=100)



NOTES: 'Inner London West' is dropped from this analysis.
SOURCE: Analysis of The Data City and ONS.

Annex 3

Supporting charts for Section 4

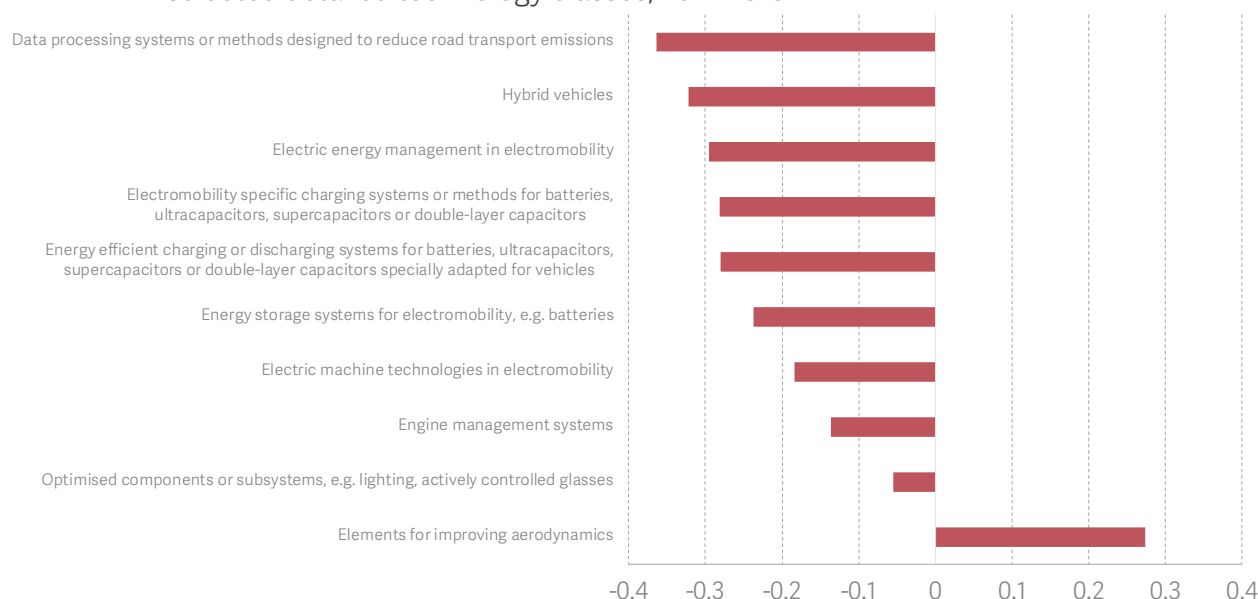
Section 4 included an analysis of the UK’s overall revealed technological advantage (RTA) in a number of clean technology areas compared to key competitors. The patent code aggregations we used for this analysis have been drawn from R Martin & D Verhoeven, [Knowledge spillovers from clean and emerging technologies in the UK](#), CEP Discussion paper 1834, March 2022; with the addition of ‘clean cars’.

As explained in Annex 1, PATSTAT classifies patents according to the Cooperative Patent Classification system which provides technological hierarchies. Within the overall aggregations of patent codes that correspond to our areas of focus in Section 4, we are able to analyse the UK’s strengths at a disaggregated level, yielding RTAs for specific technologies.

We show below the charts produced from this analysis, focusing on selected technologies that are particularly relevant for the decarbonisation efforts and the policy context around net zero in the UK; these should not be treated as exhaustive lists or as any indication of where the UK is the most or least specialised in as the selection has not been based on RTA performance.

FIGURE 37: Zero Emission Passenger Vehicles

RTA in selected detailed technology classes, 2014-2018

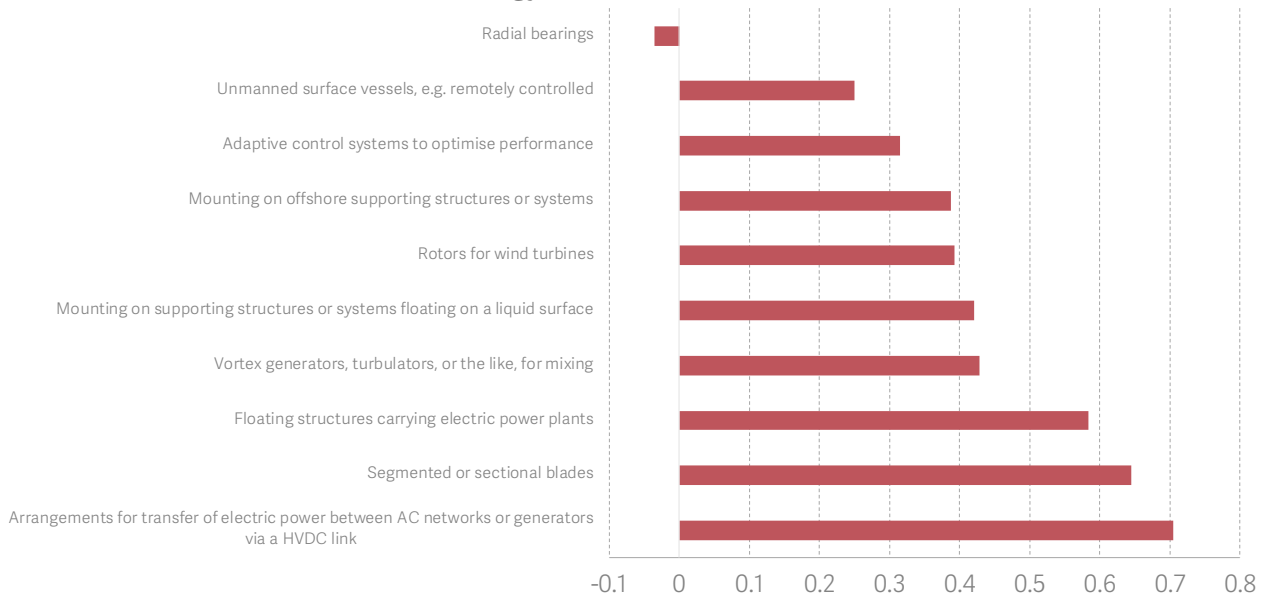


NOTES: The horizontal axis denotes UK RTA bounded between -1 and 1.

SOURCE: Authors’ analysis of PATSTAT 2021 Autumn edition.

FIGURE 38: Wind

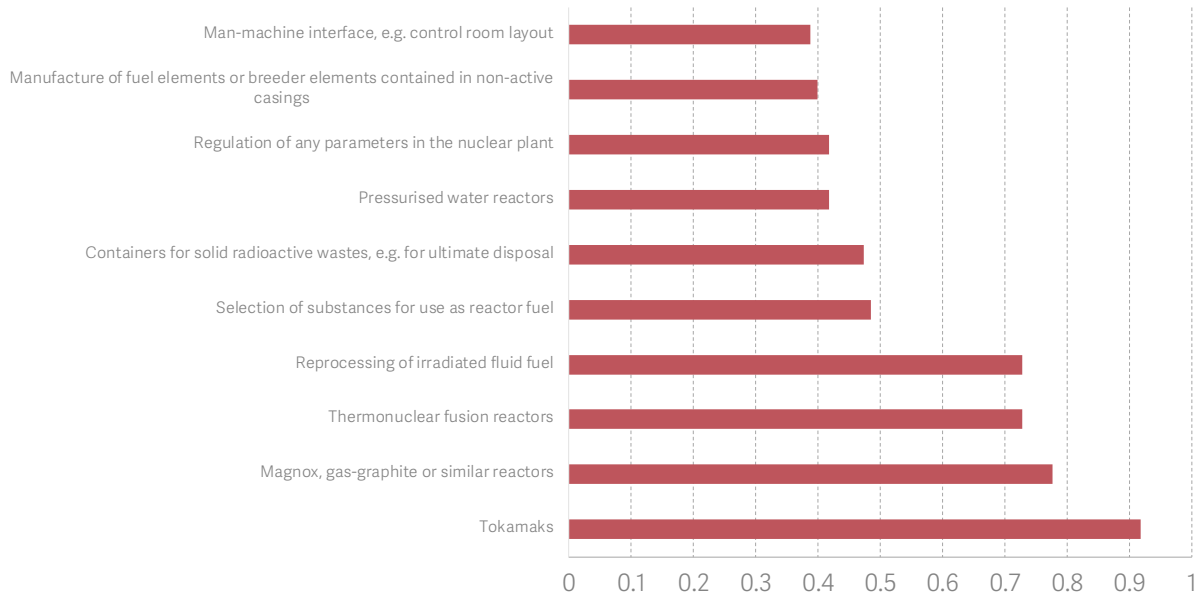
RTA in selected detailed technology classes, 2014-2018



NOTES: The horizontal axis denotes UK RTA bounded between -1 and 1.
 SOURCE: Authors' analysis of PATSTAT 2021 Autumn edition.

FIGURE 39: Nuclear

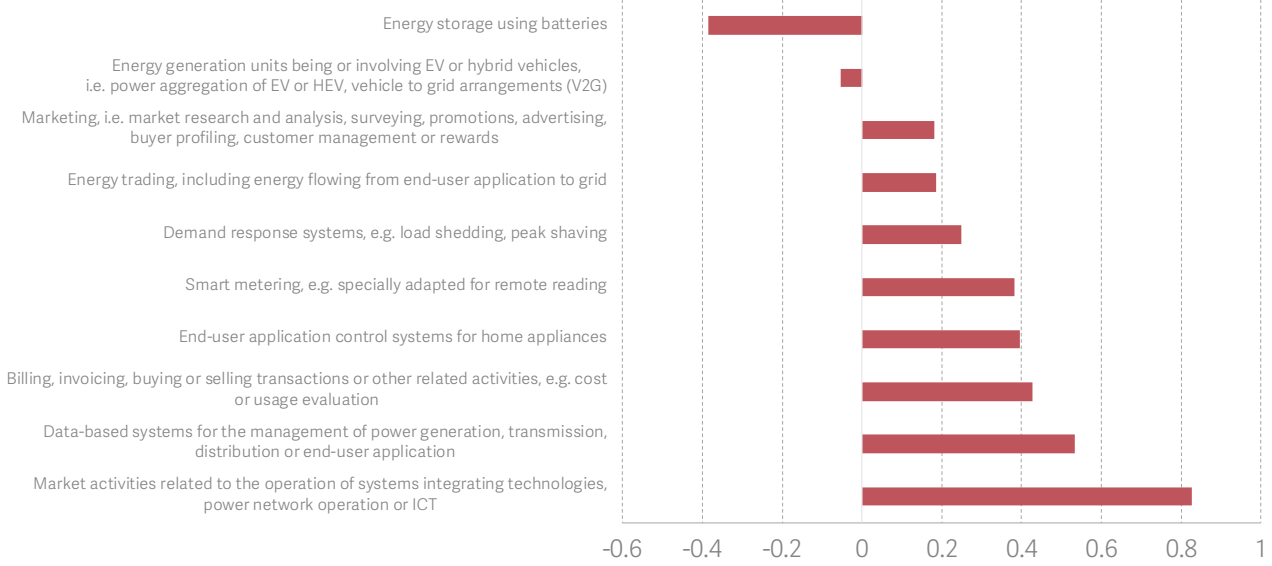
RTA in selected detailed technology classes, 2014-2018



NOTES: The horizontal axis denotes UK RTA bounded between -1 and 1.
 SOURCE: Authors' analysis of PATSTAT 2021 Autumn edition.

FIGURE 40: Grid Flexibility

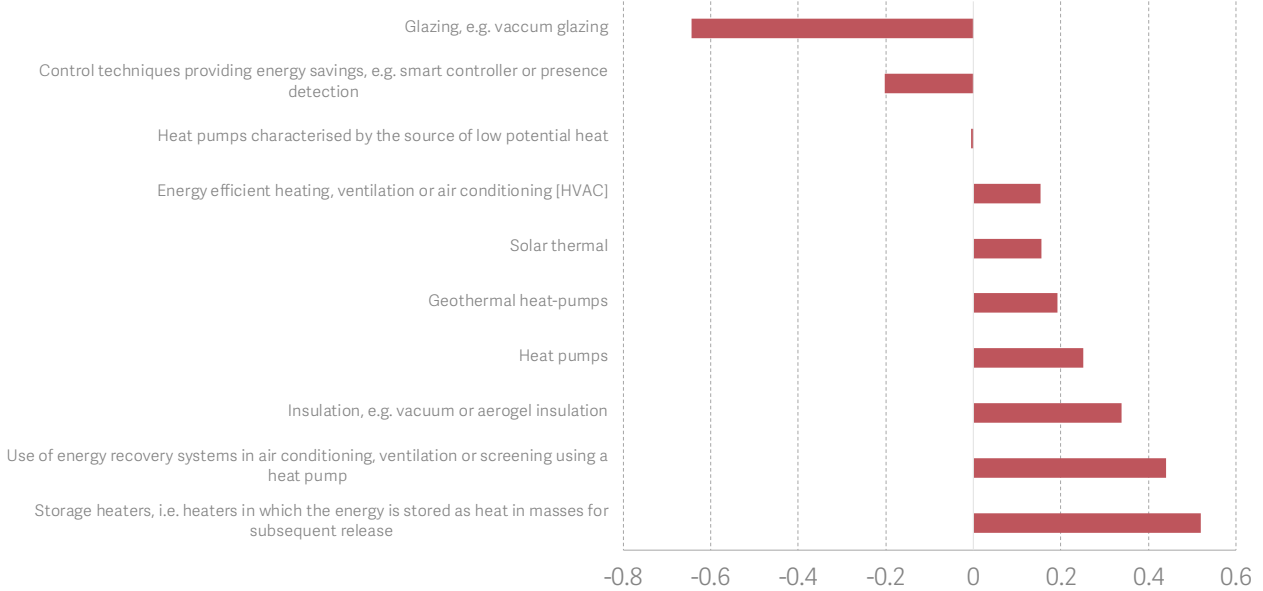
RTA in selected detailed technology classes, 2014-2018



NOTES: The horizontal axis denotes UK RTA bounded between -1 and 1.
 SOURCE: Authors' analysis of PATSTAT 2021 Autumn edition.

FIGURE 41: Heat and Buildings

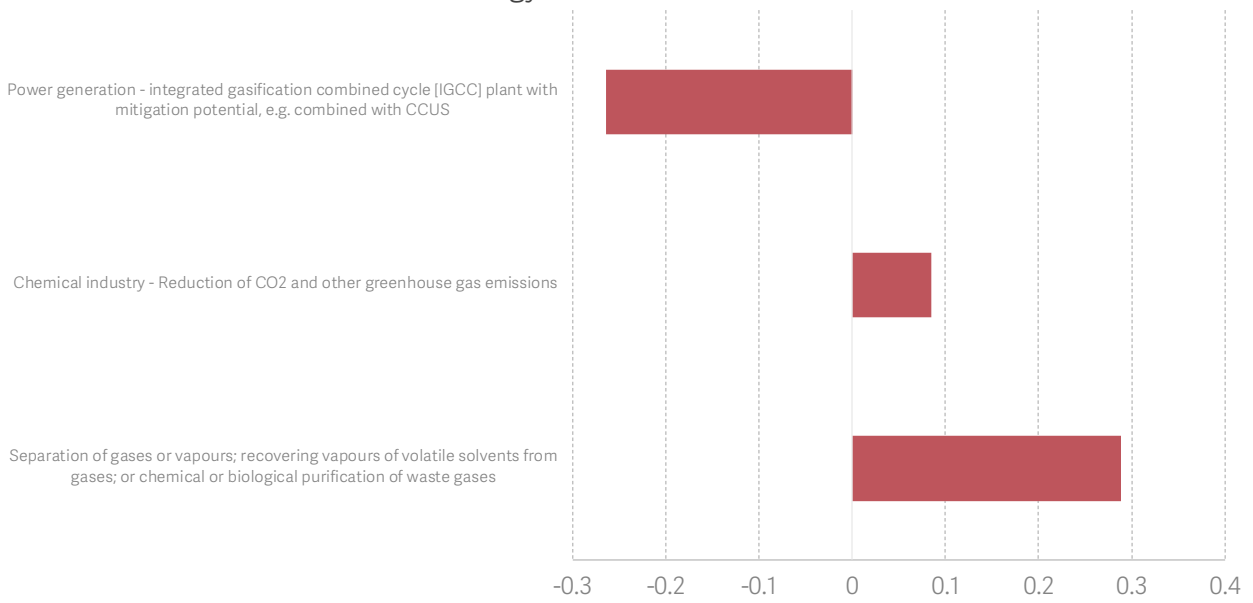
RTA in selected detailed technology classes, 2014-2018



NOTES: The horizontal axis denotes UK RTA bounded between -1 and 1.
 SOURCE: Authors' analysis of PATSTAT 2021 Autumn edition.

FIGURE 42: CCUS

RTA in selected detailed technology classes, 2014-2018



NOTES: The horizontal axis denotes UK RTA bounded between -1 and 1.
 SOURCE: Authors' analysis of PATSTAT 2021 Autumn edition.

Reports published as part of The Economy 2030 Inquiry to date

All publications are available on the [Inquiry's website](#).

1. The UK's decisive decade: The launch report of The Economy 2030 Inquiry
2. Levelling up and down Britain: How the labour market recovery varies across the country
3. Work experiences: Changes in the subjective experience of work
4. The Carbon Crunch: Turning targets into delivery
5. Trading places: Brexit and the path to longer-term improvements in living standards
6. Home is where the heat (pump) is: The Government's Heat and Buildings Strategy is a welcome step forward but lower-income households will need more support
7. Business time: How ready are UK firms for the decisive decade?
8. Begin again?: Assessing the permanent implications of Covid-19 for the UK's labour market
9. More trade from a land down under: The significance of trade agreements with Australia and New Zealand
10. Social mobility in the time of Covid: Assessing the social mobility implications of Covid-19
11. Changing jobs? Change in the UK labour market and the role of worker mobility
12. Social Insecurity: Assessing trends in social security to prepare for the decade of change ahead
13. A presage to India: Assessing the UK's new Indo-Pacific trade focus
14. Under pressure: Managing fiscal pressures in the 2020s
15. Under new management: How immigration policy will, and won't, affect the UK's path to becoming a high-wage, high-productivity economy

16. Shrinking footprints: The impacts of the net zero transition on households and consumption
17. Enduring strengths: Analysing the UK's current and potential economic strengths, and what they mean for its economic strategy, at the start of the decisive decade
18. Listen up: Individual experiences of work, consumption and society

THE ECONOMY 2030 INQUIRY

SHAPING A DECADE OF CHANGE

The UK is on the brink of a decade of huge economic change – from the Covid-19 recovery, to exiting the EU and transitioning towards a Net Zero future. The Economy 2030 Inquiry will examine this decisive decade for Britain, and set out a plan for how we can successfully navigate it.

The Inquiry is a collaboration between the Resolution Foundation and the Centre for Economic Performance at the London School of Economics. It is funded by the Nuffield Foundation.

For more information on The Economy 2030 Inquiry, visit
economy2030.resolutionfoundation.org.

For more information on this report, contact:

Anna Valero

Senior Policy Fellow at the Centre for Economic Performance
LSE

Email: A.A.Sivropoulos-Valero@lse.ac.uk