The Manufacturing Technologies Association

Decarbonisation:
Future Growth for Manufacturing

Summer 2020

CATAPULT High Value Manufacturing

LlewellynConsulting Independent Economics

The Manufacturing Technologies Association

The Manufacturing Technologies Association is the UK's trade association for companies in the manufacturing technology sector. MTA members design, manufacture and supply the advanced machinery, equipment and intellectual property that enable the creation of the products we rely on from day to day and that drive our economy.

Key aspects of manufacturing technology include; machine tools, cutting tools, metrology (measuring) equipment, additive manufacturing (3D printing), surface finishing, robotics and computer aided design and manufacturing products (CAD/CAM), as well as the technology which is enabling the digitalisation of manufacturing – the fourth industrial revolution. These combine to make up complete systems – increasingly automated and adaptive – that manufacturers deploy, making the sector fundamental to the prosperity, health and defence of the nation.

The MTA also owns and runs MACH, the UK's premier event to showcase manufacturing technologies. The biennial exhibition, held at the NEC, attracts over 25,000 visitors, some 600 exhibitors and the last edition, MACH 2018, saw over £250,000,000 of business attributed to it.

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Authors

Preston Llewellyn, John Llewellyn, and Dimitri Zenghelis.

Significant contributions were made by Soyon Park and Silja Sepping.

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Foreword

As the urgency of the climate crisis facing the planet has become more apparent, the need to decarbonise our economy has become more and more obvious. As the evidence has mounted, what was once the preserve of the 'green' movement has now become economic and business orthodoxy. It is the most pressing international and national policy challenge facing us.

The challenge for manufacturers though is more complex than simply reducing their carbon footprints. The rapid escalation of global warming has occurred as a result of industrialisation but people – electors – around the world are simply not going to accept a dramatic roll back not only of the processes but also of the products that modernity has brought. So, manufacturers have to learn to do more while consuming less. We all now recognise that the cost of carbon is so much more than the price of electricity.

Happily, this is far from a great departure for manufacturers. Financial and resource efficiency are integral to how manufacturers make and supply their products. But they will have to think more inclusively about how, and for whom, they are being efficient, making sure that they are considering costs for a wider range of stakeholders than has been traditional.

Businesses are up for this challenge – this agenda has been catapulted to the top of corporate to-do lists – at least once the threat of COVID-19 recedes. Innovation will be the key to success in the low carbon environment of the future. To say that is not to express a tech utopian desire for everything to be 'cured' by some ill-defined technological advance just over the horizon. It is to recognise the huge progress that has already been made in how many manufacturers operate, and the incentives, both societal and, perhaps more importantly, financial, for even more companies to do even more. Getting to that net-zero future will be done by decarbonising processes and products right along the supply chain. That is where manufacturing technologies come in – by harnessing innovative technologies, from 3D Printing to automation, we can reduce the carbon intensity of the production process and create products that are better for the environment in the long term too.

In the UK we are well placed to move into this green future. The UK has actually been a leader in moving towards a low carbon future; a 44% reduction in carbon emissions since 1990 and the first country to commit to net zero emissions. The sorts of increases in investment in green technologies that will be needed, estimated by the Commission on Climate Change and which underpinned the net-zero target, are in the order of 1 to 2 percent of GDP per year up to 2050. This paper extrapolates from that figure to estimate the value of that investment to UK manufacturing and the number of jobs that could be created as a result: up to £12bn for manufacturing and another £8bn in its supply chain; and 90,000 direct and 83,000 indirect jobs.

It is a huge prize which is available if, as a nation, we are prepared to back the rhetoric with action and investment in the technologies and the skills that we need to take UK manufacturing into the future. We already have valuable assets that can support us along the journey, not least the High Value Manufacturing Catapult which is working with companies of all sizes to drive down emissions associated with production, product use and energy generation. Now, bringing together the Industrial Strategy and the Clean Growth Strategy and putting the adoption of new technologies at their heart is the way to spur our progress, creating a virtuous circle of green growth aligned with the industries of the future.

James Selka, CEO, MTA

Executive summary

Climate change is here, now, today.
The basic consequences are known. Some, but not all, can be mitigated.

A shift to clean growth is necessary and unavoidable. And it will be revolutionary, changing fundamentally what is demanded, what is produced, how, and where.

The UK is comparatively well positioned in international comparison – green transition plays to UK strengths. The country's interest now is to capitalise on this by responding constructively, to make the transition as smooth as possible, and keep costs down.

The restructuring stands to be both manageable and affordable, and will forge a new economic backbone, based on sustainable output and quality jobs. And it will bring 'co-benefits', ranging from reducing general pollution to easing traffic congestion to reducing noise. Energy security will be enhanced, and energy price volatility reduced.

Green transition involves decarbonising processes and products all along the supply chain, as well as reducing the carbon that products require in use. How well the 7-million-job UK manufacturing sector handles this restructuring will be of significance for decades.

Human and physical capital will have to adapt continually, and faster than in the past. Intangible investments will become progressively more important. Fiduciary responsibility, disclosure, regulation, and standards will all need to evolve in response to broader (IR4.0) technology trends.

Innovation, the heart of successful green transition, is strongly path-dependent – past paths influence future directions. But they can be induced and steered. Green transition also benefits considerably from clustering, spill-over effects, and embedding of green technology.

Green growth is an important economic driver – growing around four times faster than the overall economy. Starting early gives companies the best chance of staying ahead, and diversifying into future products and markets. Already there is significant momentum: some key sectors have reached a tipping point.

Transformation that is investment-led both boosts GDP directly and adds to productive capacity.

The effect on GDP stands to be large, adding some £8bn to £20bn in output to UK manufacturing and its supply chains. The effect on jobs also stands to be substantial:

- Creating some 400,000 to 1 million jobs in the economy as a whole;
- Some 37,000 to 90,000 jobs in UK manufacturing, and
- A further 34,000 to 83,000 jobs in the supply chain.

Moreover the new jobs stand to be of high-quality, well paid, and fit for the 21st century.

Green growth thus offers considerable promise. But realising that promise is not easy: the challenge is complex. Remaining competitive and maximising potential involves 'getting a lot of things right': and one component of this is constructive government policy. Only government can provide the broad regulatory framework that industry calls for; and only government can provide 'enabling assistance', nudge the direction of change, and facilitate its pace.

Both 'macro' and non-sector-specific policies will have as great an impact on the manufacturing sector as will policies specifically aimed at it. Shifting investment, shaping expectations, and reinforcing feedback loops require that policy be joined up, credible, clear, and consistent across the entirety of its range.

The requisite full panoply of policy needs to include an Industrial Strategy, integrated with the Clean Growth Strategy.

Industry and government alike have much on their plates at present; and both Brexit and COVID-19 have a long way to run. But on the showing to date there is good reason to be optimistic about the UK's ability ultimately to effect an effective green transition – and to prosper while doing so.

Introduction

Climate change is here

The consequences of global warming – sea-level rises, water shortages, storm surges, heatwaves, flooding, hurricanes, fires, and more – are known, inevitable, and starting to be seen at scale all around the world, from Europe to Australia. And matters are set to get worse. Economic, social, and political structures will need to adapt: and fast, if the challenge is to be met successfully.

Fortunately public and corporate moods have now shifted palpably

Public mood over climate change and sustainability has shifted palpably. And at the 2020 World Economic Forum in Davos, forward-thinking big-company CEOs used the stage to elevate the issue and announce new corporate strategies that place decarbonisation firmly at the centre.

Those on the right side of the curve will do well

And understandably so. Publics typically are slow to anger, but when they do they react strongly. Meanwhile, markets anticipate, bringing future developments forward. Consequently, companies that are seen to be doing the 'right thing' may receive little direct reward, but perceived wrongdoers stand to see their businesses and reputations hammered.[1] Others will be caught in the backwash.[2]

Handled right transition is both manageable and affordable

> "Our consumers and our customers are looking for assurances that we are doing business the right way. It's becoming table stakes."
>
> **Mark Hunter, President and CEO of Molson Coors, 2019**

Handled right, the challenge is both manageable and affordable. For example, the additional investment required for the UK to attain a 'net-zero' economy[3] by 2050 is likely of the order of 1% to 2% of GDP per year. This is manageable: overall investment in the UK over the past fifty years has fluctuated between 15% and 25% of its GDP per year.[4]

Getting incentives 'right' is key

Percentages aside, the investment requirement is significant, so it is important to get incentive structures 'right' so as to stimulate effective action – from the financial sector to investors, from manufacturers to consumers. The additional costs, as new technologies and infrastructure are invested in, will be substantial, particularly initially. But these can be recouped from cost reductions over future decades.

Policy is going to get increasingly more forceful ...

Early policy efforts have already resulted in substantial technological advances that will restructure key sectors, including energy generation and transport. Policy everywhere, in most nations and certainly collectively, has however so far been inadequate. But hard policy is coming, and it stands to be not only forceful, but abrupt, and quite possibly disorderly. (For more, see Box 1: The likely evolution of the price of carbon.) The coming decades will see patterns of demand changing fundamentally, structures of production changing commensurately, and whole economies being transformed.

... fundamentally changing patterns of demand and structures of production ...

It is in the interests of the UK to respond constructively to the conditions – commercial and other – that will develop, exploit comparative advantages,[5] and decarbonise and restructure in the smoothest, most economical way possible. It is also in the UK's interests to use its influential 'soft power' to persuade big-polluting countries to act.

... offering up a huge opportunity for sustainable long term productive growth

> "The energy transition is a fantastic opportunity to grow our business, grab a tonne more market share and actually make a positive impact around the world at the same time."
>
> **Warren East, CEO of Rolls-Royce, 2020[6]**

Led by the manufacturing sector, decarbonisation offers a major opportunity for the UK economy, not only in terms of higher output, but in terms of raising long term productivity and creating sustainable long term growth and jobs. Getting more out of existing resources, while simultaneously creating new resources in the form of intangible capital, are key drivers of sustained productivity growth.

Box 1: The likely evolution of the price of carbon

Firms are increasingly being held to account for the damages that they cause outside the company's perimeter fence. Environmental, as well as social and governance, issues – ESG – are already having a discernible impact on investment and stock prices. Such pressures are set to increase.

Attempts on the policy front have so far been half-hearted. Piecemeal, regional, and a mixture of regulatory and feeble price-based measures (carbon trading and carbon taxes), they have not worked. 2019 saw the highest global levels of greenhouse gases emissions ever.

Market economies allocate resources in accordance with (relative) prices. Attempts at running economies by fiat, from the centre, do not work – as was demonstrated by the collapse of the former Soviet Union.

Ultimately, policymakers will find themselves obliged to use the price mechanism; and consistently so, both within and across countries. (Regulation and standards increase the cost of carbon implicitly, by obliging firms to incur expenditure in order to meet the mandatory reductions in emissions. Economists prefer that the price of carbon be explicit. But either way, it is to increased costs of carbon that firms will be responding.)

Not surprisingly, carbon pricing is not popular. Like any tax, a tax on carbon emissions imposes significant, and generally visible, costs up-front, especially in old, declining sectors. By contrast, the benefits accrue principally to future generations and rapidly-expanding new sectors.[7] Public resistance would likely be lessened were carbon-related revenues to be rebated by reducing other taxes. But with most governments already seriously revenue-constrained, not least as a result of the ageing of populations and, more recently, the fiscal response to the COVID-19 pandemic, many may well not regard this option as open to them.[8]

So far, carbon price action is falling far short of what is needed. Carbon pricing currently applies to only some 20%-odd of global GHG emissions. Moreover, while a carbon price consistent with the Paris Agreement goals[9] needs to be of the order of $40-80 per ton of CO_2 by 2030, and $50-100/$tCO_2$ by 2050,[10] in fewer than 5% of cases is carbon priced anywhere near these figures: the global average is only about $2 per ton, ranging from below $1 in Mexico and Poland, to $127 in Sweden.[11] The current gap between ambition and reality is thus wide.

Carbon pricing, and at appropriate levels, is coming, however. Moreover, markets bring expected developments forward: equity analysts, rating agencies, and investors are starting to assess companies in part on the basis of their likely economic and financial viability in the face of a 'polluter pays' price of carbon.

The sums involved are of macroeconomic significance. A tax of, say $75 per ton, applied to all of the world's CO_2 and CO_2-equivalent emissions – around 55 giga-tonnes in 2019 – would increase revenues from around the present $220 billion to just under $4 trillion, a 'carbon gap' of around 4% of world GDP.[12]

1. The response of UK manufacturing is key

Manufacturing is a major driver of the UK economy

UK manufacturing lies at the heart of the networked production process ...

The UK is the ninth-largest manufacturer in the world by output, and the fourth-largest industrial producer in Europe, behind Germany, Italy, and France.[13] While manufacturing is proportionately less important in the UK than once it was,[14] UK manufacturing nevertheless accounts for 42% of UK exports,[15] lies at the heart of the networked production process, and has an 'outsized' spill-over impact on the economic supply chain.[16]

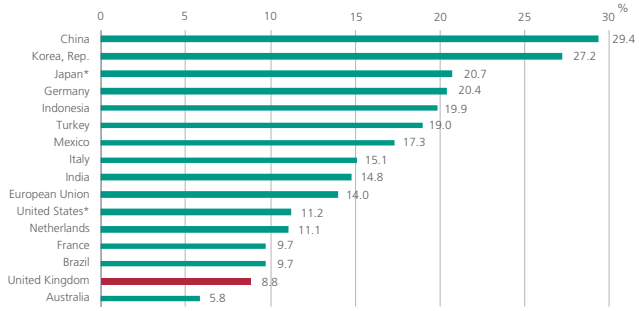
... and has an 'outsized' impact on economic supply chains

When taking into account all the direct and indirect impacts of UK manufacturing (i.e. not just the size of the manufacturing in itself, but also the wider economic 'footprint' via supply chains), the UK's manufacturing sector makes up about 15% of the UK's economy – more than is generally recognised by those who see the UK as predominantly a services economy. Estimates from Oxford Economics give the following breakdown:[17]

It accounts for about ¼ of the UK economy ...

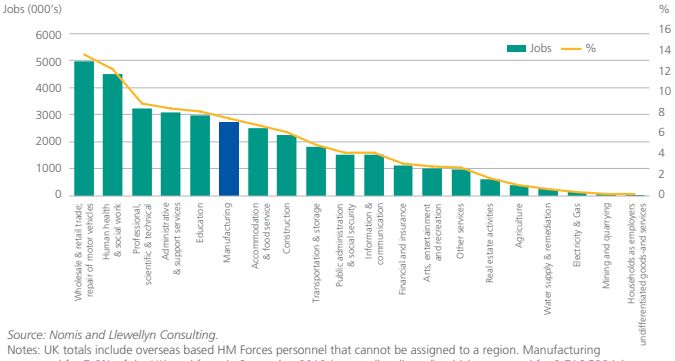
1. **The direct impact** (the value-added of the output of businesses that are typically considered as 'manufacturers') accounts for about 9% of GDP and 2.6m jobs – some 8% of total employment. (See figure 1 and figure 2).

Figure 1: Manufacturing as a percent of GDP, by country



Source: World Bank national accounts data, OECD National Accounts data files, Llewellyn Consulting.
Notes: * = 2017 data; Manufacturing refers to industries belonging to ISIC divisions 15-37.

Figure 2: UK employment by industry, 2019



Source: Nomis and Llewellyn Consulting.
Notes: UK totals include overseas based HM Forces personnel that cannot be assigned to a region. Manufacturing accounted for 7.6% of the UK workforce in September 2019 (seasonally adjusted), which accounted for 2,716,528 jobs.

2. **The indirect impact** (via supply chains of manufacturers) adds a further 6% of GDP, and an additional 2.4m jobs – many of them in 'clean' service sectors.

... some 7 million jobs

However, there is an additional effect, that also warrants being taken into account. Changes in the income of people employed by manufacturing – both directly, and indirectly in its supply chains – give rise to successive rounds of income, and thereby expenditure, throughout the economy as a whole. Oxford Economics estimates that the expenditure of (9% + 6%) = 15% of GDP gives rise ultimately to some 23% of GDP – a so-called expenditure multiplier of 1.5.

In total therefore, the UK manufacturing sector accounts for something like 7m jobs (around 22% of total employment).[18]

... and plays a key role in other parts of the economy

Manufacturing also plays an important role in other dimensions of the UK economy accounting for, for example, over two-thirds of business R&D investment; and 15% of total business investment.[19]

This systemic importance of the manufacturing sector is likely to prove important as the COVID-19 lockdown of the economy is eased progressively. To the extent that the lockdown is eased in the 'upstream' sectors (manufacturing, and also construction) the effects will ripple out to its supply chains and beyond. Likely early beneficiaries include the transport sector –

which moves materiel and goods at every stage in the supply-chain process. That would be followed by the wholesale and retail sectors once sales start to pick up. Most of the remaining service sectors (restaurants, entertainment, and the like) would follow only with a lag, as the rise in incomes filtered through the economy.[20]

How well the sector restructures will be of quantitative importance

How well manufacturing handles the decarbonisation process will therefore be of quantitative importance to the UK economy, and for decades to come. This is a challenge not only to not get wrong, but to get right, so as to harness the major opportunities successful restructuring stands to bring.[21]

> "Only the retail tradesmen, and such industries (essentially retail in character) as street railways are dealing with the final consuming public. The maker of iron and steel sells to the maker of machinery, he to the manufacturer, he to the wholesale agent or jobber, he to the retailer.
>
> Every one of these, unless possessed of almost unlimited capital or credit on his own account, necessarily depends on what others will buy of him.
>
> Whatever be his own opinion of the source or extent of ultimate demand, the direct influence on him comes from those who stand next in the long chain of apparently separate yet essentially interdependent operations."
>
> **Professor F. W. Taussig, Harvard University, 1925.**[22]

Manufacturing will bear much of the structural change

The climate challenge will change fundamentally what is demanded ...

Structural changes of fundamental form and scale are afoot, the result of cumulating forces. Five years ago there were the (2015) Paris Agreement pledges to keep global warming below 2°C and take steps to get it below 1.5° C. Then there developed an increasingly supportive public mood. And the most recent period, particularly since Davos 2020, has seen not just corporate acceptance, but also corporate drive.

... how it is produced ...

Economies are now on the cusp of radical transformation in what will be demanded and how things will be produced. Energy provision, transport, industrial processes, agriculture, and more will all change fundamentally. These shifts will filter through to businesses all along the supply chain, transforming existing industries, creating whole new industries, while wiping out old, carbon-intensive activities.

... and manufacturing is where much of the structure of production will change

This move to cleaner economic growth through low carbon technologies and the more efficient and cleverer use of existing resources is one of the greatest industrial challenges, and opportunities, of our time: indeed some would argue, given the pace at which the consequences of global warming are now emerging, arguably of all time.[23] And manufacturing will be at the epicentre because, directly or indirectly, it drives so much of the rest of the economy.

Technological advances have already achieved critical mass in key sectors

Politicians around the world have so far not done enough to enable economies collectively to meet their global commitments. That said, early policy support in some countries has resulted in important technological advances, including in key sectors, achieving a critical mass in the form of cost-competitive new processes and products,[24] all but guaranteeing the transition to low carbon forms of production.

Responding appropriately will ensure competitiveness

UK commitment to GHG reduction at top level has been bold

The UK's political commitment has been bold in international comparison, adopting the Committee on Climate Change's (CCC) recommendation to target net-zero emissions of greenhouse gases (GHGs) by 2050 (i.e. at least a 100% reduction in emissions from 1990 levels). The UK was also the first major economy to pass net-zero emissions law in June 2019.[25]

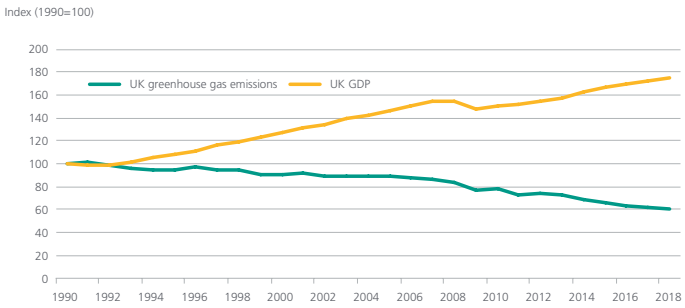
The UK, like all advanced economies, is aided in achieving its targets by a progressive trend to a 'lighter' GDP – i.e. an increasing proportion of services. This is a worldwide feature of high per capita income economies: even in those with comparatively large agricultural sectors, ranging from France to New Zealand, the proportionate size of the services sector has increased from around 50% of GDP in the 1960s to around 70% today.[26]

Reductions have not come at the expense of growth

Even allowing for that trend, however, the UK has achieved much in recent years, including a 44% reduction on 1990 levels. Likewise, the UK's emissions-intensity ratio (EIR) – the amount of greenhouse gases (tonnes of carbon dioxide equivalent) produced per unit of GDP – has fallen by more than two-thirds since 1990.[27]

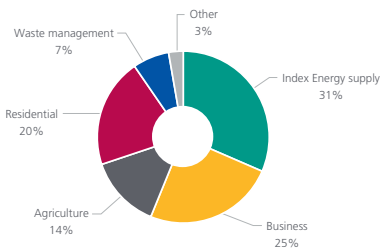
Importantly, these emission reductions have not – contrary to the fears of some – come at the expense of economic growth: the UK economy expanded by some two-thirds over the same period. (See figure 3 and figure 4a and 4b).

Figure 3: UK greenhouse gas emissions and GDP



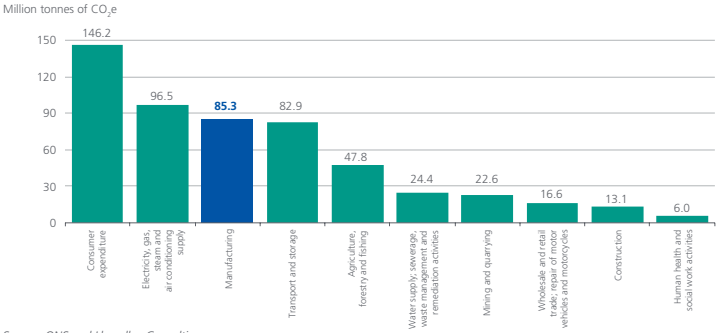
Source: BEIS, ONS and Llewellyn Consulting.
Note: Series indexed to start at 100. GHG emissions in 1990 were 818 $MtCO_2e$, including international aviation and shipping. In 2018 GHG emissions were 491 $MtCO_2e$ and UK GDP was £2.0 trillion.

Figure 4a: UK greenhouse gas emissions by sector (2018)



Source: ONS, Department for Business, Energy & Industrial Strategy and Llewellyn Consulting
Note: 'Other' includes Public, Industrial Processes and the Land Use, Land Use Change and Forestry sectors. The percentages may not sum to 100% due to rounding.

Figure 4b: Greenhouse gas emissions by industry, 2018



Source: ONS and Llewellyn Consulting.
Notes: 1. Top 10 GHG emitting industries. 2. Greenhouse gases under the Kyoto Protocol: carbon dioxide, methane, nitrous oxide, hydro-fluorocarbons, perfluorocarbons, nitrogen trifluoride, sulphur hexafluoride; 3. Activities of extra territorial organisations and bodies is assumed to be negligible; All figures are reported to 1 decimal place. 4. Total figures are based on raw data and therefore may not sum due to rounding.

The UK's low carbon economy is growing strongly

Indeed, the UK's low-carbon economy is expanding rapidly: turnover in the low-carbon sector was up 7% in 2017, growing more quickly than UK GDP.[29] And it has considerable potential: by one estimate the UK's clean economy could in future years grow at four times the rate of GDP.[30]

With clean energy expected to be one of largest markets of the 21st century,[31] and annual clean economy exports potentially worth £100bn by 2030[32] there are also substantial and growing opportunities for UK exporters – opportunities that are reckoned far to outweigh risks.[33]

Maximising potential necessitates a continued constructive response

Remaining internationally competitive, and capitalising on the UK's already-strong footing (see figure 5), will be led importantly by SMEs. This necessitates a continued, constructive, joined-up response at both the sectoral and national levels. And this means continuing to 'get a lot of things right'.

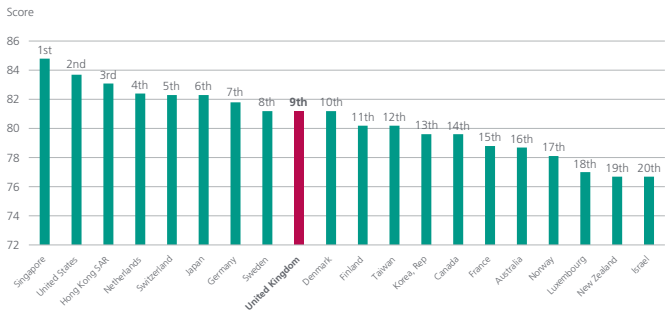
> " … 22% of SME manufacturers are true trailblazers – their leaders are actively looking for growth, have the internal capability to achieve it and are putting the creation strategies that optimise disruption opportunities at the top of the agenda.
>
> They apply the necessary time and resources to create and develop business models that look out to the next 5-15 years."
>
> **Richard Hill, Head of Automotive & Manufacturing at NatWest, 2018.[34]**

And this means getting a lot of things 'right'

Perhaps the most important conclusion is that this entire process is well manageable. Sweden is a case in point, and there is no reason in principle why the UK cannot perform equally well, and achieve at least as much. (For more on a successful economy-wide transition, *see Box 2: Sweden – an exemplar of how decarbonisation can be undertaken*.)

But the process is manageable

Figure 5: Global Competitiveness Index 4.0 2019 Rankings



Source: World Economic Forum and Llewellyn Consulting
Notes: The index is an annual yardstick for policy makers to look beyond short-term and reactionary measures and to instead assess their progress against the full set of factors that determine productivity.

It is in manufacturing's interests to respond appropriately

For the manufacturing sector, high on the agenda is to ensure response to, and increasing integration with, products-as-a-service (rather than 'own and dispose') and circular economy models. And here too, integration with complex service providers plays to UK strengths.[35]

> "Servitisation is one of the most exciting aspects of Industry 4.0 …"
>
> "The industrial business receives equipment, say a motor, for free and is charged when it's used. The 'owner' monitors the unit remotely and makes sure it runs as efficiently as possible. This can make manufacturing more efficient and cost-effective."
>
> **Nick Boughton, systems integrator at Boulting Technology, 2018.[36]**

A shifting balance of risk

Industrial sectors face three principal risks

The shifting balance of risk and uncertainty means that industrial sectors are confronted with a growing array of climate-related risks:[37]

1. **Physical risk:** including preventing and addressing potential distress such as floods, droughts, natural disasters as well as ecosystem collapse, and the costs of restoring depleted natural capital.

2. **Litigation liability risks:** people taking to the courts to seek recompense and justice against private and public organisations, which knowingly undertook activities that have undermined their livelihoods.

3. **Transition risk:** disruption and valuation losses resulting from attempts to reduce emissions at an accelerated pace.

Liability and transition risk pose the most immediate threat to UK manufacturing

Of the three risks, the most immediate for UK manufacturing probably comes from transition risks – those associated with keeping up with rapidly changing technologies, markets, policies, and social norms. These risks can quickly render physical, human, and intangible assets devalued or 'stranded' i.e. with reduced, or even zero, economic value.

Unprecedented change led by new technologies and processes

Change will be on an unprecedented scale

New technologies and processes will undercut the old and render them redundant. This has the potential to transform the competitiveness of goods and services markets, especially as significant R&D and deployment shifts to low carbon sectors. At the same time, increasingly ambitious policy action (including regulation and more stringent carbon pricing) increases the costs of high-carbon activities. The threat of litigation will increasingly undermine the future viability of laggard companies and their shareholder value.[38]

Most new fossil-fuel-related infrastructure will have to be scrapped prematurely ...

... or be subject to costly retrofitting

Carbon from fossil sources has powered most of the world's economic activity for more than two hundred years. For the world to have a 50-80% chance of keeping global warming below 2°C, probably between two-thirds and four-fifths of global proven and possible fossil fuel reserves will have to be kept in the ground (or, if they are combusted, the resulting greenhouse gases will have to be captured and stored).[39] Almost all new fossil fuel related infrastructure will need to be either scrapped prematurely or undergo costly retrofitting.[40]

Human and intangible capital will also have to adapt ...

The change will extend well beyond physical capital. Human capital (skills and training compatible with low-carbon resource-efficient production) and intangible capital (the ideas, knowledge, management, and technical processes, and institutions that must accompany a low carbon transition) will also have to adapt to the new world.

... including to new regulatory environments

This will be matched by a change fiduciary responsibility, disclosure[41] and regulation and standards. At the same time, new technological drivers and improved efficiencies will generate opportunities for early movers, although the appropriate allocation of risk capital means that not all new innovation will be scalable or profitable.

UK companies will need to deal head on with these secular shifts and the associated systemic risks, and go with the grain of change.

> "There's no question that we are in an energy transition and we are going to be decarbonising the global economy so companies looking in that field are obviously investing in the grain."
>
> **Adam Parr, former F1 chief executive, 2019.[42]**

Box 2: Sweden – an exemplar of how decarbonisation can be undertaken

The Swedish experience: it is possible to reduce emissions while maintaining economic growth

Sweden set about decarbonising its economy in 1971. Since then its economy has grown by 78% (in real terms), while carbon emissions have decreased by 26%. Today, Sweden's annual GHG emissions per head of population – 4.25 tonnes of CO_2 equivalent (tCO_2e) – are markedly lower than the 6.9 figure for Europe as a whole.

Economy-wide decarbonising via carbon pricing

Sweden's principal decarbonisation policy instrument was, and remains, a tax on carbon. The virtue of this instrument is that it works with the grain of the market economy. In particular it requires no measuring of emissions: CO_2 emissions released in burning any fossil fuel are proportional to its carbon content.

The Swedish energy taxation system has two elements: a carbon tax and an energy tax. While the energy tax has been levied on major motor fuels since the 1930s, and on heating fuels since the 1950s, the carbon tax was first introduced in 1991, as part of a major tax overhaul. This tax reform package dramatically lowered marginal income taxes on capital and labour; and offset this by broadening the value added tax and changing the system of energy taxation. The carbon tax was levied on transport, buildings (heating), industry, and agriculture.

The carbon tax rate was originally set at €24 per ton of CO_2, and thereafter increased gradually, to €88/tCO_2 in 2004 and €114 in 2019 – the highest such tax in the world. This step-by-step approach enabled households and businesses to adapt, as well as rendering implementation politically more feasible.

The evolution of the Swedish carbon pricing system was not only politically, but also economically, astute. Any tax levied in a single country raises concerns about effects on international competitiveness. In Sweden's case, concern was compounded by concerns over potential carbon 'leakage' – the risk of activities being moved abroad to regimes where carbon was not taxed.

Accordingly, for three decades Sweden effectively imposed two different carbon tax rates. The 'high' rate was levied on motor fuels and heating for households and services, while emission-intensive industries enjoyed significant exemptions, with the 'low' tax rate initially set at 25% of the general carbon tax rate. This tax was brought in line with the general level only gradually, with the two rates becoming fully harmonised in 2018.

Another change was that, as of 2005, emission-heavy industries (approximately two-thirds of total industry) became covered by the EU Emissions Trading System (EU ETS) rather than the local, much higher, carbon tax. About 95% of Swedish fossil fuel emissions are now covered either by the carbon tax or the EU ETS.

Reasons for the success of the Swedish carbon tax

- Early introduction of the tax enabled the government to take its time gradually to increase the rate. This option is not open to most governments today; but even so, where necessary and unavoidable structural change is involved, sooner is better than later.
- The introduction of the carbon tax and subsequent increases were generally part of a bigger tax reform, and accompanied by reductions in other taxes to avoid increasing the overall level of taxation and disproportionately affecting low-income households.
- Political support for environmental policy remained strong.
- Abatement opportunities that facilitated the transition were readily available, including:
  - Abundant, and thereby affordable, low-carbon electricity (nuclear, hydropower, and wind, together account for over 90% of total).
  - Biomass. A large proportion of Swedish energy use consists of bio-fuels (40%, mainly paper and pulp) and electricity (35%).[43]

2. Transition is needed across the entire economy

Resources need to move to the high productivity growth areas of the future

Maximising the advantages for UK industry from the global shift to clean growth can best be achieved by capitalising on the UK's already-strong position and leading the world in the development, manufacture, and use of low-carbon technologies, systems, and services that cost less than high carbon alternatives.

Decarbonisation has several dimensions

Decarbonisation is required throughout the entire economy and supply chain …

An effective transition involves nothing less than wholesale structural change at the level of the economy as a whole, whereby the economy's basic resources – labour, capital, and knowhow – move away from technologies and goods of the past century to the sectors that will drive the next century. Transition has a number of dimensions:

On the demand side, it involves:

- Reduction of demand for carbon-intensive products and services.
- A corresponding increase in demand for low-carbon goods, as well as for services (dematerialisation).[44]

For the manufacturing sector, this will not mean a massive decline in demand for material goods. But the sector will continue to change structurally, including in the direction of 'servitisation' – the evolution of goods-as-a-service, whereby the manufacturer retains ownership of the product through its serviceable lifetime, and is responsible for its maintenance, re-use, or disposal.

This activity is growing fast. One study found that, in 2007, around 24% of UK manufacturers with more than 100 employees derived value from services related to products. By 2013, this figure had risen to 35%. A number of British companies have transitioned particularly successfully, with Rolls-Royce one notable example, now deriving around 50% of its revenue from services.[45]

In this process, the manufacturing sector becomes progressively more 'green', and the distinction between manufacturing and services less sharp.

… and means economising on all inputs

On the supply side, it involves:

- Decarbonising individual processes and products, all along the supply chain; and
- Reducing the carbon that products require in use – i.e. efficiency in use.

This requires a multi-pronged approach, comprising importantly: design improvements; 'light-weighting'; and new efficiency-enhancing techniques, including real time digital and smarter tailored technologies, techniques, processes, including for management and demand response.

> "Technology is rapidly accelerating for manufacturers and this pace is likely to grow. The use of data analytics, robots, multi-purpose production lines and intelligent machines will change the landscape."
>
> "So it's no surprise to see technology revolutionising our manufacturing process."
>
> "Some giants, such as Ford and BAE, have already adopted VR. Rather than having to build a physical model, they build a VR model, explore it and see how changes to the model or the environment make an impact."
>
> **Dr Kevin Curran, senior member of the Institute of Electrical and Electronic Engineers (IEEE) and professor of cybersecurity at Ulster University. 2018.** [46]

Innately carbon- and energy-intensive sectors are not exempt

Innately carbon- and energy-intensive sectors face a particularly tough challenge, but they too have scope to dematerialise, reduce emissions, and will not be exempt.[47]

> "Industrial sectors like steel and cement face tough challenges to decouple emissions from production but, make no mistake, these industries must transform themselves if they are going to survive the low carbon transition."
>
> **Faith Ward, co-chair of the Transition Pathway Initiative (TPI), 2020.[48]**

Fortunately many of the positive economic effects are immediate

Economy-wide transition perforce also involves all parts of society. A helpful feature of the green transition is that a number of the effects are immediate and positive. These include co-benefits (such as improved health from reduced local pollution); growth in new 'green' sectors; improved energy security and supply; and lower energy-price volatility, due to reduced dependence on fossil fuel imports.[49]

Innovation is at the heart of sustainable transition

Innovation is the driving force ...

Innovation, and the investment to which it gives rise, lie at the heart of the transition process: it is innovation and investment that shape and develop future production processes, supply lines, and markets in new directions.

These new directions do not necessarily have to take the form of economising in the use of the input (in this case, carbon) that becomes relatively more expensive. An increase in the relative price of an input that threatens a company's profitability can be addressed by economising in the use of **any** input. The rational response is to seek the economies in the areas where the opportunities are the most cost-effective.

... and may be embedded in old as well as new products

Sometimes innovations involve new technologies and new products; but they may be embedded in products that are not wholly new – such as housing, and glass. And the gains can be staggering. New houses built by Citu, in Leeds, for example, require only about one-tenth of the energy for heating compared with the average UK house; and these heating needs are so low they can readily be met from 100% renewable energy.[50]

The NSG Group/Siemens energy optimisation programme has saved in excess of 25,000 tonnes of CO_2 to date. *For more see Box 3: The Pilkington / Siemens energy optimisation programme below.*

Box 3: The Pilkington / Siemens energy optimisation programme

Pilkington is part of the NSG Group, one of the world's leading manufacturers of glass and glazing systems in three major business areas: Architectural Glass Products, Automotive, and Technical Glass, with manufacturing operations in 28 countries, employing some 27,000 people globally.

A traditionally high-energy user, like many glass manufacturers, Pilkington faces the continual challenge of managing its energy costs. With substantial energy bills, the company worked with Siemens engineering teams to reduce these costs, and to find additional opportunities for improved efficiency and support of its drive towards a low-carbon and sustainable future.

A series of detailed energy audits and due diligence was undertaken across the company's UK-wide manufacturing sites, and an initial list of ten energy management projects identified. The projects included the installation of new drive technologies and automation controls at a Scottish production site; new pump system upgrades; and a major programme to install an intelligent lighting solution at one of the company's prime warehousing locations.[51]

The strategic partnership with Siemens also involved the sharing of risk, and an innovative tailored investment funding package. In essence, Siemens funds the initial capital expenditure required – it generally does this over a three year period, and the partner (Pilkington in this case) pays back monthly as the savings occur, and the partner keeps any benefits above that, as well as those that accrue after completion. This enabled Pilkington to support investment strategies in critical areas such as energy management, without having to tap into existing cash reserves, impair day-to-day cash flow health, or resort to traditional bank funding.

The energy optimisation programme aims to achieve a £1 million cost saving; and to date has saved in excess of 25,000 tonnes of CO_2.

Growth is increasingly being driven by intangibles

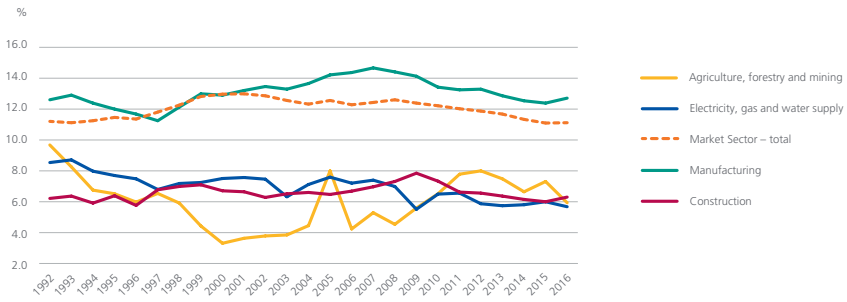
Growth in high-income economies is increasingly being driven by investment in intangible assets such as knowledge capital. Today, about four out of every five dollars spent in the leading OECD economies is on services or intangible goods.[52]

... and progressively greater integration with services

Intangibles also make up an increasing part of the capital base necessary for production. Indeed valuation of the world's largest firms is now based mostly on their intangible capital, rather than the value of their people, buildings, or capital equipment. In 1975, around 20% of the value of listed companies was intangible – the ideas, processes, and networks that companies had nurtured. By 2015, that level had risen to around 80%.[53] Today, intangible capital in most developed countries is reckoned to make up some 60% to 80% of total wealth.[54]

The UK was early in this process: it has been deindustrialising for over 100 years. This is reflected in the structure of its economy, and the increasing importance to national income of intangible, knowledge-products – software, new media, databases and libraries, creative copyright and online services etc. (See figure 6).

Figure 6: UK intangible investment (production industries) % of adjusted gross value added (1992-2016)



Source: ONS and Llewellyn Consulting
Note: Gross value added (GVA) has been adjusted for the capitalisation of additional intangible assets.

The dynamics of innovation

Innovation tends to be geographically clustered ...

It is easier for an economy to become competitive in products that require similar production capabilities and concentration of research as in existing sectors.[55]

In part for this reason, innovation tends to be geographically clustered. Only around 1% of invention is related to new science; and 45% is derived from information that exists already but is new to an industry. Cross-industry and cross-value-chain collaborations are essential to solving innovation problems.[56]

Teesside, for example, hosts 58% of the UK's chemicals industry, is responsible for 20,000 jobs, and £4bn of exports per year. A cluster of leading energy-intensive industries is working together to create the *'Teesside low emissions industrial zone'*, through the development of shared emissions-reducing infrastructure. By sharing infrastructure, logistics, energy, and utilities; and by exchanging raw materials, products, and residual and waste materials, companies in the cluster operate more efficiently, enabling them to reduce costs and strengthen their competitive position.[57]

... and strongly path-dependent ...

... with firms learning by doing

Innovation is also strongly path-dependent – shaped by history and happenstance. Inertia and switching costs can make it difficult at first to shift the innovation system from dirty to clean technologies. Firms and scientists tend to direct innovation towards what they are already good at.[58] Production methods seldom jump from a to z – rather, they proceed sequentially, sweating supply lines and assets that they already have, and catering to existing consumer tastes.[59]

Production and distribution are scaled up as costs fall further

Then, as new technologies are developed and deployed, learning how best to fabricate, fit, engineer, and maintain them is achieved through experimentation (so-called 'learning by doing'). As production and distribution are scaled up, unit costs fall further, encouraging more innovation, making goods cheaper and more productive.

The process is influenced importantly by expectations:[60] the faster that innovation commitments shift at scale, the more this generates reinforcing feedbacks that further reduce the costs of the new technologies, and accelerate further deployment and investment.[61]

Dynamics of change are propelled further by positive-reinforcing feedback loops

Once a technology becomes truly competitive, it starts to change the entire environment in which it operates and interacts. New supply lines are formed, behaviours change, new physical, institutional, and societal networks are created, and old ones are repurposed. New business lobbies push for more supportive policies. Investment strengthens further, and the political and commercial barriers to transition begin to fall away.[62]

Transitions are thus subject to strategic complementarities

Transitions are thus subject to strategic complementarities whereby, through the interaction of hysteresis, the influence of history, and forward-looking expectations, the benefits of using a product rise with the number of others using it.[63] Research and development (R&D) externalities and learning spill-overs in low-carbon technologies also have these features.[64]

Knowledge spill-overs from low-carbon innovation in the energy production and transportation sectors are reckoned to be over 40% greater than in conventional technologies.[65] To the extent therefore that the UK can shift its energy and production systems to clean networks, the potential to generate positive productivity spill-overs across the economy will be considerable.

Occasionally, however, a technological change is so fundamental that it short circuits much of this process, producing an irreversible structural shift in technology networks. Historical examples include the shifts from kerosene to electricity, horses to cars, canals to rail, fixed to mobile technology, and film to digital photography. The prospect of superior technologies, and the inevitable need to decarbonise, together with increasing direct policy intervention, is likely to tip the balance between inertia and expectations in favour of new networks.

Those late stand exposed to devalued or 'stranded' assets

Whatever the process, eventually a tipping point is reached, whereby incumbent technologies, products, and networks become redundant. Those late to recognise the transition stand exposed to devalued or 'stranded' assets.

Countries that invest early have greater success

Countries, sectors, and areas that start early have the best chance of staying ahead ...

Countries that invest early and successfully in sustainable capabilities typically have greater success in diversifying into future products and markets:[66] a firm's choice whether to innovate in 'clean' or 'dirty' technologies is influenced by the know-how and production capabilities of the countries in which its researchers and inventors are located.[67] The payoff from starting early is high, even for the less dynamic sectors.

... and diversifying into future products and markets

Where clusters do not exist, there has to be 'leapfrogging' to entirely new processes and techniques and thereby network externalities. This may require strong and early policy signals. The transition to electric and other zero-emission vehicles, for example, is necessitating a major shift in both manufacturing and consumer purchasing.

For those UK manufacturers who have been behind the curve on investment in 3IR (investment in 'basic' automation), there stand to be good opportunities to leapfrog competitors by going full throttle for 4IR (digital and integrated) technologies.

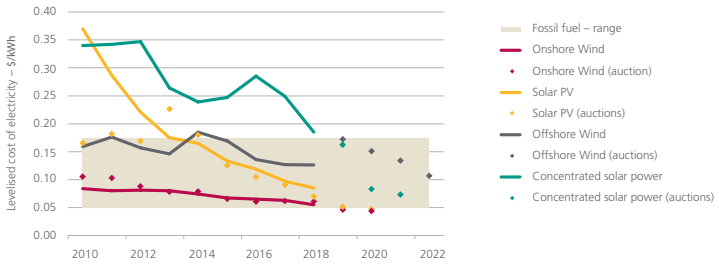
Much momentum is now already 'inbuilt'

Changes in policy and institutions tend to be accompanied by changes in social norms, which further reinforce the dynamics of change.[68] Social feedbacks help to make norms self-reinforcing and stable,[69] but social norms are also prone to tipping points. A committed minority of people amounting to as little as 25% of the total can often prove to be 'a critical mass', able to overturn established behaviour, and initiate social change.[70] The recent palpable shift in mood over climate change and sustainability, at both public and corporate levels, may be one such instance.

Key sectors have already reached a tipping point

Key sectors, including electricity and transport, have already reached a tipping point. The price of solar PV modules, for example, has fallen by at least 80% since 2006; battery prices by 80% since 2010; the cost of new offshore wind contracts by over 50% since 2017.[71] (See figure 7).

Figure 7: Global average renewable power generation costs



Source: International Renewable Energy Agency and Llewellyn Consulting
Note: Solid lines indicate global weighted-average levelised costs of energy, dots indicate global weighted-average for auction prices for projects set to start in a particular year. All costs are in 2018 US dollars.

There are of course issues to overcome. Intermittency is a problem for renewable energy: the sun does not always shine, and the wind does not always blow. However, renewable technologies are now so cheap that small and affordable investments in the grid can ensure that peak demand is met in all conditions while still keeping generation costs below those associated with fossil fuels.[72]

The costs of countering intermittency and keeping the lights on in all conditions start to rise sharply at penetration rates of around 80 percent[73] but, given that renewable power currently provides less than a quarter of UK generation,[74] this leaves ample time for technologies such as battery storage, hydrogen distillation, and synthetic methane production, as well as 'smart' demand-response capacity, to mature as the UK continues to extend its renewables capacity.

These augmentations to a renewables generation network are still likely to be cheaper than investing in fossil power generation – even in the absence of a carbon price. The transformation is extending beyond electricity generation: large auto manufacturers ,for example, are no longer committing significant proportions of their stretched R&D budget to the combustion engine.

3. The UK is well placed

> "The UK is already cutting emissions faster than any other major economy and we're the first to legislate to end our contribution to climate change entirely. Eliminating emissions from industry is key to achieving this."
>
> **UK Business, Energy and Clean Growth minister, Kwasi Kwarteng, 2019.**

Not all countries will handle the transition well

Global transition to green economies is inevitable and feasible, but the structural adjustment that that implies will be demanding – of all parts of society. Not all countries are going to handle the transition well.

The UK is comparatively well placed ...

Encouragingly, the UK is comparatively well placed. Its structural adjustment policy framework is reckoned by the OECD to be in the top echelon;[75] and transition plays to a number of the UK people's basic strengths, including all-important capabilities to innovate; be flexible, and to adapt. (For an international comparison of the UK's all-important structural settings, see 'heatmap' figure A in the Appendix.)

... with a modern, sophisticated economy ...

Moreover, the UK is starting from a relatively good place. It has a sophisticated, modern economy – a pre-requisite. Indeed, the UK already has an estimated 400,000-odd jobs in low-carbon businesses and their supply chains,[76] providing a sound base for further development. And the country has strong digital capabilities, which stand to play a central role in various dimensions of green development.

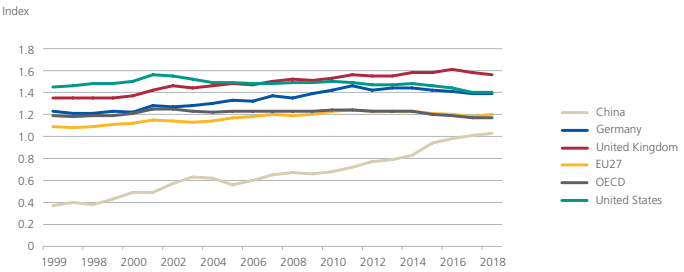
This encouraging overall situation owes to a range of interacting causes:

... well geared for adjustment to the new age

1. **A global leader in green legislation.** That the UK was early – indeed the first – to set (through the Climate Change Act of 2008) a legally-binding emissions-reduction target[77] sent early, clear signals. These provided a degree of certainty for industry decisions:

2. **A world-leading research base.** Many of the requisite technologies for the green transition will perforce be new. Economies that invent these have a potential lead-advantage. The UK ranks second, behind only the US, as the country with the highest number of universities in the top 100 of the world.[78] The UK also punches above its weight in terms of research impact. In 2018, the UK's field-weighted citation impact, an established measure of research impact, was the highest in the G7, a position the UK has held since 2007, when the UK initially overtook the US to become the highest ranked comparator.[79] (See figure 8).[80]

Figure 8: UK research base: Field-weighted citation impact



Source: Department for Business, Energy & Industrial Strategy and Llewellyn Consulting
Note: A value of 1.0 represents the world average; EU 27 entry represents all current European Union countries apart from the UK
OECD entry includes all countries on the list apart from Brazil, China, India, Japan, Russia, and South Korea

3. **Strong capacity to innovate.** Invention of new technologies, while essential, is only a first stage: invariably, extensive innovation is required to translate a new technology effectively into the workplace. Here too the UK is well placed, ranking as the fifth most innovative country in the world.[81]

It is, therefore, not surprising that the UK has developed world-leading competencies in important sectors, including offshore wind; electric vehicles; smart energy systems; sustainable construction; precision agriculture, and green finance.[82 83]

The consequences have already proved significant:

- More than half of UK electricity already comes from low-carbon sources, with a record 39% coming from renewables.[84]
- The UK has more installed offshore wind capacity than any other country – 40% of the total worldwide.[85]
- As for electric car exports, the UK was ranked number six in the world in 2018, capturing approximately 6% of the global market.[86]

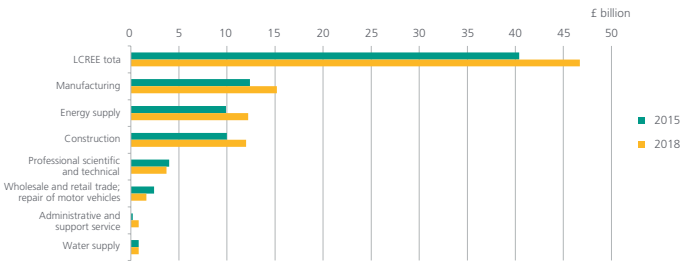
The potential to capture market share in a number of sectors which play to the UK's areas of strength is considerable (See figure 9), with substantial export potential for the green products in which it specialises. Manufacturing is the most heavily involved in new low-carbon activities, and is growing briskly. The other two important such sectors, which have also grown quickly, are energy supply and construction. (See Figure 10).

Figure 9: UK potential to capture market share and examples of current UK strengths

Low carbon economy (LCE) sector	Potential to capture market share	Examples of current UK strengths
Energy efficient products	Medium	Smart Grids, advanced building design materials and manufacturing systems
Energy from waste and biomass	Low to Medium	Biofuels, waste recycling techniques
Low carbon electricity	Medium	Off-shore wind, energy storage, solar PV
Low carbon services	High	Finance, insurance, consultancy
Low emission vehicles, infrastructure, fuel cells and energy storage	Medium to High	Power systems & transmissions, batteries, logistics, telematics
Other products and services	Medium to High	Membranes, catalysts, bioprocessing

Source: Committee on Climate Change (CCC) and Ricardo Energy.
Notes: Assesment of UK potential to capture market share and examples of current UK strengths in 2017

Figure 10: UK LCREE turnover, total and selected industries, 2015 and 2018



Source: ONS and Llewellyn Consulting
Notes: 1. Low carbon and renewable energy economy (LCREE). 2. The chart shows the seven largest industries in 2018. 3. Figures have been rounded to the nearest £0.1 billion. 4. For simplicity, the Electricity, gas, steam and air conditioning supply category is referred to as "Energy supply" and the Water supply; sewerage, waste management and remediation activities category is referred to as "Water supply".

But transition will still be challenging in many areas

Transition will in many areas, however, be particularly challenging without a step-change in technology,[87] not least in UK heavy industry (i.e. iron, steel, and cement), which is responsible for just over one-quarter of UK industry's total carbon footprint.[88] The opportunities for investors are substantial, as are the concomitant risks. The energy transition is already visibly disruptive, and in the automotive sector, which is in a scramble to reinvent itself, it is not yet clear which technologies and businesses will prosper and which will not.[89] Some opportunities, if they are to be exploited, will have to be undertaken at substantial scale – battery manufacture and the case for a UK Gigafactory, for example.[90]

The macroeconomic environment

No matter how advanced technologically a firm or a sector may be, and no matter how efficient its production methods, its performance will be determined in important part by the macroeconomic environment in which it operates.

The macroeconomic environment will determine much

Here too the UK has a number of fundamental strengths. These include:

- A world-class financial system;
- Competitive product markets (the UK ranks 9th in the world);[91]
- Flexible labour markets (4th in the world);[92]
- A world-class university system producing excellent graduates;
- A strong and functional legal system; and
- Internationally-competitive firms in both manufacturing and services.[93]

4. The nature and size of the prize

> "By 2030 the UK could have higher living standards, and better health and wellbeing, underpinned by UK businesses innovating and adopting cutting-edge zero-carbon technologies and practices fit for the mid-21st century."
>
> **Lord Nicholas Stern, 2020.**[94]

'Business as usual' has no meaning in the current context

'Business as usual' is no longer a viable concept

The consequences of the green transition for GDP growth, employment, productivity, and regional development stand to be constructive. Quantifying the likely outcome, however, is conceptually complicated.

The customary approach to such questions is to evaluate outcomes relative to some sort of 'business as usual' (BAU) scenario. However, in the case of climate change, a BAU scenario has little meaning. The present BAU path is unsustainable: were the world to try to stay on it, or something like it, the result, as the climate change effects continue to build, would be a collapse in GDP and employment. Thus the BAU path is not a viable option; and hence it cannot be a plausible baseline.

Meanwhile, and fortunately, the UK has taken the decision to start diverging from anything like a BAU path, by adopting a policy of zero emissions by 2050. Hence in assessing 'the nature and size of the prize' under the green transition, the most appropriate form of evaluation is to estimate the gross number of new jobs that are likely to result, and assess their likely quality – recognising that, were there not to have been a change in policy, GDP and thereby employment would ultimately suffer enormously.

A major impact on GDP

Transition will require investment of 1 to 2% of GDP per year to 2050

Green transition will necessitate significant investment. The Commission on Climate Change (CCC), in line with the expected cost accepted by Parliament when the current target was set, takes it that transition to net zero GHG emissions by 2050 will require sustained investment of the order of 1 to 2 per cent of GDP annually through to 2050.[95]

Aggregate demand

Green Investment expenditure will boost GDP directly ...

Initial investment expenditure almost always gives rise to successive rounds of expenditure, not only in the manufacturing sector and its supply chains, but also throughout the rest of the economy. The ultimate increase in spending in the economy is thereby almost invariably at least somewhat greater than the first-round effect.

The size of this so-called 'expenditure multiplier' depends on a number of factors, including importantly the stance of monetary policy; the degree of spare capacity in the economy's product and labour markets; and the extent to which the initial and subsequent rounds of expenditure are saved, taxed, or spill over into imports.

Estimates of the expenditure multiplier typically lie in a range of 1.0 to 1.5, depending on the assumptions made.[96] In the case of UK green investment, and given the current economic and extremely accommodating monetary conditions, a value towards the upper end of the range seems the most plausible.[97]

Productive capacity

There is however more to the story than (near-term) expenditure multipliers. An increase in investment expenditure not only boosts aggregate demand through the expenditure multiplier: it also generally adds to capacity.

The process thereby embeds the latest technologies; and may even, given the complementary nature of infrastructure services, also 'crowd in' further private investment.

In today's world, new efficiency-enhancing techniques include real-time digital and smarter tailored technologies; data analytics; intelligent machines and robots; and multi-purpose production lines.

... and the addition to productive capacity will add further to it

The size of these effects depends on a number of factors, not least the efficiency with which the investment is planned, undertaken, and utilised; and its propensity to induce productivity-enhancing innovation that might not otherwise have been undertaken, at least to the same extent.[98] This increase in capacity permits a further expansion of GDP, beyond that caused by the expansion of demand.

The two effects taken together

Given that there is no single 'correct' value either for the expenditure multiplier or for the capacity-enhancing effect of investment expenditure, there can be no uniquely correct value for the two effects taken together.

That said, various estimates, by the IMF, and by the OECD (which averaged the estimates of three models for the UK) are interestingly close, lying in a range of 2.5 to 3.0.[99] i.e. each percentage point of investment, if sustained, can be expected ultimately to increase UK GDP by around 2½ to 3 percent.

The effect on GDP stands to be large ...

On the basis that the requisite level of green investment for the UK is 1 to 2 percent of GDP, the ultimate effect on the level of GDP therefore stands to be large, in the range of 2½ to 6 percent.[100]

... adding some £8bn to £20bn in output to UK manufacturing and its supply chains

On the assumption that manufacturing and its supply chain each remain something like their present proportion of the UK economy,[101] this represents an increase of £5bn to £12bn in the value of the output of the UK manufacturing sector, and of £3bn to £8bn in the resulting output of the industries in its supply chain.[102]

A transformative future-proofing of jobs

The structure of employment will change massively

Green transition and the changing economic structure will see a jettisoning of jobs in activities that are doomed (such as those in mega fossil-fired plants); and a flow of labour and capital into new jobs that, by virtue of their low-carbon technology, and thereby their ability to meet the changing pattern of demand in the economy, stand to remain viable long term.
Ultimately, the distinction between 'green' jobs and other jobs, already blurred, will largely disappear – all jobs that survive will in some sense be 'green.' But during the period of transition the concept remains helpful.[103]

Job gains in the energy sector itself stand to be small ...

In the energy sector itself, green transition stands to increase net employment, albeit not substantially:

- An International Labour Organization (ILO) scenario projects that "… progress towards sustainability in the energy sector will create [net] around 18 million more jobs globally by 2030 when compared to the business-as-usual path,[104] which is equivalent to a 0.3 per cent difference [in employment] between the two scenarios."[105]
- A similar percentage figure has been reached for the UK renewable energy sector, and derives in significant part from the fact that renewables and energy efficiency are in general more labour intensive than fossil-fired mega generating plants.[106]

... but in other sectors job gains stand to be considerable ...

In some individual sectors the increases stand to be considerable. The UK offshore wind sector, for example, which currently supports around 7,200 jobs, seems set to almost quadruple, to around 27,000 jobs, by 2030.[107] And these are high-skill jobs that stand to remain viable over the long term.

Such conclusions are encouraging for those who feared that green transition must inevitably lead to net job losses and rising unemployment.

It is however not sufficient to focus simply on job creation (whether gross or net), at the level of individual sectors: such calculations do not take into account the multiplier effects that ramify through the economy as a whole.

Historically, each 1% increase in UK GDP has resulted in something like a ½% increase in employment. Recently, not least because investment in the UK economy has been particularly weak, the employment response has been stronger (i.e. labour productivity growth has been unusually weak); but when looking many years ahead it is more appropriate to assume the sort of productivity growth that has been obtained over the longer term.[108]

... and substantial at the level of the economy as a whole

On such a basis, and taking the 2½% to 6% increment to GDP that stands to result from the required climate change investment, the gross increase in the number of jobs created in the economy as a whole would be around half that figure, i.e. between say 400,000 and 1 million.[109]

To the extent that manufacturing broadly maintains its current share of total employment (around 9% immediately before the COVID-19 crisis), the gross increase in the number of manufacturing jobs in the sector could be expected to be between 37,000 and 90,000,[110] with a further 34,000 to 83,000 in the supply chain.[111]

> "BP will have a very high-quality oil and gas business" that over time is likely to get smaller and be de-carbonized, he said in an interview with Bloomberg television. "At the same time, I see us building and growing new low- or zero-carbon businesses."
>
> **Bernard Looney, BP CEO, 2020.** [112]

Quality of jobs

Moreover, the new jobs stand to be good, and well paid

While job growth is clearly important, it is not the sole metric by which the labour consequences of the green transition should be judged. Even more fundamental, in some ways, is whether the green transition is efficient and fair – and that includes the extent to which the shift creates quality jobs: i.e. jobs that will be sustainable and pay well.

The prospect is encouraging: a high proportion of the new jobs will be sustainable, because the low-carbon economy will be here to stay. And they will also generally be well-paying. Those in the manufacturing sector are likely to be increasingly high skilled, requiring degree-level or similar qualification to support high-tech and professional occupations. Meanwhile, an increasing proportion of jobs will be in the services sector, and a growing proportion of these too will be high-skilled.

Siemens is a case in point. The company employs 379,000 people, of whom 14,000 are in the UK, and it has created over 1,000 new jobs directly at its Alexandra Dock site. As part of the development of its Green Port site, Siemens agreed union representation through the Union Unite, which was directly involved in the design. Both management and union representatives report very good labour relations at the site overall.[113]

5. What manufacturing needs from policy to win the prize

A market economy is best able to effect the green transition

The market economy, with its ability to mobilise all the requisite actors and finance, is the best system to effect the green transition quickly and efficiently. Ultimately, much of the economic structural adjustment that green transition requires will be carried out by the private sector, using private sector money. Helpfully, the private sector is already 'on side', with significant thinking, discussion, political pressure, and even action being led by the corporate sector.

But the private sector needs 'enabling assistance' ...

... that only a government can provide

Leading by corporates alone is not enough, however: the private sector cannot deliver the transformation all on its own. It requires 'enabling assistance' that only a government can provide, including a robust, credible, dependable, policy framework that delivers a level playing field, aligns incentives with aims, and deals with the 'free rider' problem.[114] And in policy-driven and regulated sectors, such as energy, transport, and buildings, policy risk is a primary factor limiting expected returns to private investment.[115]

These policies do not, in the main, require increased government expenditure (or reduced receipts from tax break). This is important because governments are always budgetarily constrained, and likely never more so than after the global pandemic has finally started to draw to a close.

The many needed individual policies cover a wide range: just how broad was emphasised in a 2013 report to the UK government on the long-term future of UK manufacturing.[116] One submission, which examined the impact of government policy on manufacturing since 1945, averred that 'macro' and non-sector-specific policies often had as great an impact on the manufacturing sector as did those policies that were specifically aimed at it.[117]

The green transition also carries societal requirements. In a transition as fundamental as that to a green, zero-emission, economy the policy framework has to be clearly and widely understood, and enjoy broad support, lest the UK encounter resistance, and risk losing its leadership in areas ranging from green technology to finance. People have to have clear expectations, and warranted faith that the policy framework will be maintained.[118] *(For more on this, see Policy Box 3: Promoting a supportive environment for structural reform.)*

Furthermore, policy needs to be 'joined up' and coordinated

Equally importantly, policies that relate directly to the manufacturing sector need to be 'joined up' and coordinated – in short, a full-blown industrial strategy:

> "An effective industrial strategy is central to tackling some of the deep-seated structural challenges facing the UK economy, among them the climate crisis, 'levelling-up' the regions, the skills deficit, and the productivity puzzle."
>
> **Andy Haldane, in his capacity as chair of the Industrial Strategy Council:[119]**

Many countries have industrial policies – economies as diverse as Germany (with its Industry 4.0); the US (America Makes) and China (Made in China 2026) all have 'coherent government strategies'.[120] However, the new UK government's position on industrial strategy is not yet fully clear.

Clarity and certainty are important to manufacturers. The then CEO of Siemens UK, Professor Juergen Maier, criticising the UK's adoption of digital industrial technologies (DIT) – which themselves stand to play an important role in the green transition – has observed a lack of a "clear narrative", and the need for "… cross-sector national leadership providing market-focused strategic vision, direction, and co-ordination."[121]

Overarching macro policy proposal

- **Bring together the Industrial Strategy and Clean Growth Strategy** to create one coherent strategy for low-carbon growth, infrastructure, and innovation across the economy. This would offer the opportunity for better alignment between Government Departments.

This was the essence of a principal recommendation of the *Sustainable growth in the UK* report for the LSE Growth Commission.[122] For an even more recent, thorough, and detailed rationale of the underlying case for an industrial strategy, see Professor Sir Tim Besley's *Formulating Industrial Policy,* written for the Policy Reform Group.[123]

Other policy proposals

Policy issues often straddle conventional areas of policy responsibility. And policies are needed at various levels – from high-level institutional policies to lower-level policies such as procurement, urban planning, and standards.

The authors of this paper have spoken with, or consulted, sources ranging from the manufacturing sector to the economic research community; from technologists to trade associations. And while this by no means constitutes a fully-fledged survey; it has brought out a range of points that all interlocutors consider particularly important. Broadly, these policy suggestions fall into two groups:

1. Those that influence the ability of the economy to adjust - particularly the ease with which labour and capital can move from old, declining, low productivity sectors into the newer, higher productivity, sustainable sectors; and
2. Those that affect the pace of innovation and its rate of take-up.

Proposed broad lines for policy are presented below, starting with policies at the macro end of the spectrum, and proceeding to those that are more sector-specific.

Active Labour Market policies (ALMPs)

People have to be able to move r eadily between jobs

It is always important, in any economy at any time, that people be able to move smoothly between jobs and tasks. Basic education and training provides for this, up to a point: but further education and retraining becomes increasingly necessary as working lives get longer, and as technological progress changes the nature of so many jobs. And it becomes crucial when an economy undergoes fundamental structural transformation.

Around one-fifth of jobs in the UK today use skills that are likely to be affected by the green transition. Approximately half of these – one in 10 overall – use skills that are likely to be needed more in the green economy: for example, over one-third of marine engineers are now working in the offshore renewables sector, having transitioned from the oil and gas sector. However, around one in 10 use skills that are likely to be needed less.[124]

Jobs in construction, transport, and manufacturing are particularly likely to need re-skilling, with transition impacts likely to be felt especially in the East Midlands, the West Midlands and Yorkshire, and the Humber region.

Active Labour Market Policies have a large and growing role

Active Labour Market Policies (ALMPs) provide people who have become, or risk becoming unemployed, with new skills that help them remain in the workforce, and find alternative employment. Advanced manufactures – robotics, aerospace, satellites etc. – rely heavily on high proficiency digital skills.

They are expensive, at least in the near term: there is no escaping that, and they are the one area in this report that recommends that government expenditure be increased, notwithstanding post-pandemic budget constraints. But this is **investment** expenditure – ALMPs more than pay for themselves over the long term by raising per capita income and reducing structural unemployment. (For job vacancy statistics in UK manufacturing, see figure B in the Appendix).

There is no person to whom we have spoken who does not accord this issue extremely high priority – and often the highest. It is a vast area, on which much has been written, both as regards the UK itself and other comparable countries.

An authoritative overview, together with detailed pointers to the evidence in many studies, has recently been provided by John Martin, writing for the Policy Reform Group.[125]

- **Move progressively to the OECD average expenditure level on Active Labour Market Policies,** especially for 16-24-year olds and low-educated/low-skilled job seekers.
- **Remedy the weaknesses with the apprenticeship levy.** The take-up has been widely recognised as disappointing.
- **Invest more in lifelong learning initiatives,** with a special focus on upskilling needs for low-skilled workers.

Product market and competition policies

Competition plays an essential part in the system's functioning

These are judged by the OECD to be the most important element of structural policy after those relating to the labour market. Competition raises product awareness, keeps prices down, raises real incomes, encourages differentiation, stimulates efficient use of resources, and increases consumer satisfaction. And competition promotes productivity, for firms both far from, as well as close to, the technological frontier.

The UK is overall the most lightly regulated of all OECD economies, and scores well in almost all of the individual categories established by the OECD.[126] This is a feature of the energy, transport, and e-communications sectors, and of retail and especially professional services.

Although the response to the pandemic may change matters, at least for a period, to date public ownership is extremely limited in the UK, and there have generally been few distortions to the private sector induced by state involvement. Moreover, barriers to domestic and foreign entry into UK industry and entrepreneurship have been low.[127]

It will not be easy to resist pressures to intervene

It is in the UK's interest to sustain its toothsome competition policy. This may be easier said than done, however. The disruptive implications of technological progress, Brexit, climate change, and COVID-19, together with the world-wide threats of protectionism and bilateralism, suggest that there will be strong pressures for greater levels of intervention.

- **Align with best-practice policies of OECD countries,** except where the UK has a good case for a (generally stronger) alternative.

Incentives

Carbon emissions have to be priced correctly ...

Greenhouse gas emission is a clear case of market failure: emitters do not pay for the damage they cause. (For more on market failure, and 'externalities' that lead to them, see Policy Box 1: *The rationale for policy intervention: correction of market failure*.) That so many emissions occur reflects the fact that most emitters are not incentivised to behave otherwise.

A core component of any serious emissions policy has to be a tax on the price of emitted carbon. The rate will probably have to rise ultimately to around £80 ($100) per tonne of CO_2 emitted.[128] But in the UK at present emissions from different sources are taxed at widely different, and generally far lower, rates: from around £109 per tonne for motoring, down to around £7 for home-heating oil.[129]

... in markets, regulations, and standards

While a carbon price is necessarily a centrepiece of any rational, efficient green transition policy, support from regulations and standards[130] can be, and often is, an effective addition.[131] However, efficiency requires that the implicit cost of saving carbon be not too seriously out of line with the £80 ($100) or so optimal price for the economy as a whole. Calculating the implicit cost of carbon should be a standard part of the overall procedure when formulating regulations and standards.

- **Implement a "coherent tax and spending strategy"[132]** that:
  - Sets the price of carbon at an appropriate level; and

– Broadly equalises the cost of carbon emissions, both across sectors and across regulations and standards.

Innovation

Innovation often does not happen fast enough by itself ...

Innovation and transition seldom just happen; or at least not fast enough. And urgency has been recognised by the UK government: the UK is just one of five countries (along with France, Sweden, Scotland, and New Zealand) so far to have set by law a date by which to achieve carbon neutrality.[133]

While a uniform, rising, global carbon price is central to any economically-efficient transition, this 'slow policy ramp' approach[134] can usefully be augmented. Carbon abatement cost schedules are dynamic and endogenous: once industries or sectors are set off on a path, that path can become self-sustaining.

Subsidies for solar photovoltaics have enabled significant cost reductions. Crucially, this does not imply a need, or make a case, for open-ended financial support. In many parts of the world, unsubsidised solar photovoltaics can now produce electricity cheaper than that generated by fossil fuels. In the UK, onshore wind farms and new-generation off-shore wind farms may now be able to achieve this too.[135] Subsidies, even if less targeted than policies that specifically tackle market failures, have proven successful in addressing dynamic market failures to the point where, once the new energy technologies compete unsubsidised with fossil fuels, the latter can be phased out.

... but barriers can be addressed ...

Subsidies alone cannot however offer a long-term solution. For emission-reducing innovation to flourish – whether in energy generation, manufacturing processes, or product use – a key challenge is to enable the more effective translation of research into commercial offerings and to reduce the perceived risks of trying something new.

The Catapult Network, established in 2011, was created to do this. In reducing emissions, the High Value Manufacturing (HVM) Catapult is a key force for innovation, helping to pull through latest research into manufacturing technologies into the innovative goods and processes that will drive down the cost of low-carbon transport, low-carbon production processes and, crucially, low carbon energy generation. Its approach ensures an effective route from research to application, and strips away some of the risks of innovation for firms of any size, encouraging the risk averse to take the first step towards change.

In addition to a supply of renewable energy, the UK will need a supply of reliable energy, generated when the sun does not shine nor the wind blow. Nuclear power offers the solution, but has long proved uncompetitive when pitched against traditional fossil fuels. For more see Box 4: *New generation Small Modular Reactors (SMRs)*.

Box 4: New generation Small Modular Reactors (SMRs)

Today, a new generation of Small Modular Reactors (SMRs), similar in technology to current reactor designs, but at a smaller scale, offers the potential for much more affordable nuclear power generation, avoiding the huge upfront costs and decade-long development times of current reactors.

An initial SMR power station would be a fraction of the cost of a gigawatt-scale new build, could be built in four or five years and, once operational, would generate revenue to help finance additional units.

Beyond SMRs, the government has also set out support for the next generation of nuclear technology including salt- and lead-cooled reactors, small high-temperature reactors for off-grid and industrial co-generation, and small tokamaks for nuclear fusion.

All these new modular designs are designed to be made largely in factories, creating opportunities for manufacturers who can use lessons from other sectors, such as aerospace, to drive down costs, and put innovative manufacturing techniques into production.

Reactor developers are now looking to work with manufacturers, technology providers, and researchers to prove innovative processes for new nuclear applications, and use techniques such as design for manufacturing and modularisation to build in production efficiencies. Many of these innovative technologies are already being developed for nuclear applications by the Nuclear Advanced Manufacturing Research Centre, part of the UK's High Value Manufacturing Catapult, making the cost of nuclear power generation more cost competitive.

Once the 'clean innovation machine' has been 'switched on and is running', low-carbon and climate change adaptation can become in large part self-sustaining. This is key to embedding real change into the economy for the long term.

... and often it can be nudged, and at no great cost

The primary constraint is often politics, rather than economics.[136] Emphasis warrants being directed at the most ambitious and credible policy that is politically tractable in order to engender an early transition.[137] One area that would seem ripe for such a policy would be smart grid and battery technology.

- **Combine R&D in smart grid and battery technologies with support for renewable energy.**
  - This could achieve multiple objectives: by increasing the efficacy of electricity production and storage, it would also have benefits in terms of energy security, innovation, lower costs, and lower emissions; as well as exploiting 'home market effects'to increase competitiveness in the global marketplace.

Infrastructure

Poor infrastructure is holding the UK economy back

The UK's infrastructure is in many areas inadequate, with significant parts of its energy, water, transport, and communications networks in need of upgrading or replacement. This situation creates bottlenecks, crimps productivity, discourages potential foreign investors, undermines the economy's competitiveness, increases inequality, and leaves the economy under-equipped to face the challenges of climate change.

The government has recently announced a set of priorities that include transport projects, energy projects, and regional spending. However, it is going to find itself particularly cash-strapped once the COVID-19 crisis has passed.

A National Investment Bank could really help ahead

An ambitious, but feasible, proposal would be to establish a National Investment Bank. This could offer project guarantees, recommend user fees, lend to projects with the proceeds of National Investment Bonds, and simplify planning. By raising capital from the private sector, it could provide at least some welcome relief from pressure on the government's budget, which will be severe once the pandemic has passed.

A detailed analysis of the UK's infrastructure issues, and a range of policy proposals for addressing them, has been offered by the Policy Reform Group.[138] Some of the most important proposals are as follows.

- **Accord precedence to the recommendations of the National Infrastructure Commission,** especially as regards energy.[139]
- **Reduce the skew of infrastructure spending towards London.**[140]
- **Increase efforts to achieve cross-party consistency on regulatory frameworks,** so as to temper perceived political risk.
- **Broaden the UK Guarantee Schemes.**[141]
- **Improve the coordination and prioritisation of infrastructure investments** across the economy, especially given the government's focus on greater devolution of decision-making to local governments.[142]
- **Create a National Infrastructure Bank (NIB).**[143]

Inequalities

Many benefit from change; but some lose

While transition stands to bring considerable benefits at the whole-economy level, and to many people individually, in some areas – Northeast England and South Wales, for example, which are at high risk of disruption – it will inevitably also impose costs.

Just as there has been a sea-change in respect of the perceived importance of climate change, so too – in many countries, and certainly in the UK – has there been a sea-change concerning inequalities. The phrases 'a just transition' and 'a fair transition' have entered the lexicon.

Above all, decision makers crave consistency

The lesson from globalisation needs to be heeded: if the benefits of transition are not used to compensate the losers, the process will be perceived by some as unfair, and generate a backlash of political opposition and disruption of the transition. The 'just' or 'fair' transition, involving as it necessarily does all regions and groups in society, needs to become a core part of overall decarbonising strategy.[144]

Inequalities have many dimensions: in addition to inequality of income, they also include inequalities of access to education; training; healthcare; infrastructure, including importantly transport; and more.[145]

- **Integrate the issue of inequalities not only into climate change policy per se, but nto all areas of provision of government services,** including urban planning; and public procurement.

Consistency, consistency, and consistency

> "The UK has rightly been seen as a world leader on climate change since the Climate Change Act. However, the lack of a stable policy environment in the UK has made it challenging for business to plan and take decisive action with certainty."
>
> **Gudrun Cartwright, environment director at Business in the Community 2019.**[146]

Public acceptance requires that gains be shared fairly

Perhaps the single most important overall requirement of policy that our interlocutors stressed is consistency. Switching to lower-carbon forms of production requires investment in heavily regulated and policy-driven markets, including energy and transport. Businesses and investors have to be sure that the policy framework will be implemented and sustained.

Policy uncertainty is damaging, both at the firm level, in terms of lower investment and hiring, and at the country level, in terms of lost GDP and unemployment.[147] Recent UK Governments have a record of sudden or unpredictable changes in support for electricity generation by onshore wind, solar photovoltaics, and carbon capture and storage.[148]

- **Set clear goals, and remain steadfast** when temporary political resistance is encountered, while being proactive in steering political economy realities.

If the full panoply of policy can be used, of which the heads for policy summarised in this paper are merely a starting point, there is every reason to be optimistic about the United Kingdom's ability to effect a green transition – and to prosper while doing so.■

Policy Box 1: The rationale for policy intervention: correction of market failure

It is in general appropriate for government to intervene only in cases of clear 'market failure' – the situation where market prices fail to represent true costs. In the case of climate change, five forms of such intervention are warranted.

1. **Dealing with externalities: pricing environmental damage** from emissions, whether though a carbon tax or some sort of emissions trading scheme (the 'polluter pays' principle). Pricing needs to be non-discriminatory and transparent, leaving consumers and producers to choose how to respond. (For more see Box 1: *The likely evolution of the price of carbon*).

2. **Promoting innovation.** Those who innovate do not capture the full value of the knowledge spill-overs that they generate: that is why policies that promote low carbon innovation to kick-start the green innovation machine are so important.[149] The U.S. government, undeniably a keen believer in the private market economy, nevertheless has not infrequently judged it appropriate for it to bear the risk of investing in longer-term projects that are important but whose future returns are initially uncertain. Cases include the Global Positioning System (GPS), the internet, and touchscreen technology. These now underpin successful American companies.[150]

3. **Providing information where demand is price insensitive.** Lack of information can lead to waste and inefficiencies that can be overcome by creating awareness of the different carbon contents of energy sources, and the options available for emission reductions, for example by stating energy ratings on domestic appliances. In others, it may require the creation of instruments such as energy service companies (ESCOs).[151]

4. **Overcoming capital market limitations in the financing of new energy technologies.** The scale and long-term nature of much of the requisite investment, and that it takes place in heavily regulated policy-driven markets, including energy, buildings, and transport, may scare private capital away. There may also be scepticism about the likely duration and credibility of policies to support decarbonisation. Publicly-funded institutions such as infrastructure investment banks can, by having public sector 'skin in the game', promote risk sharing and risk reduction, whether through guarantees, publicly backed equity stakes, feed-in tariffs, or carbon price floors.

5. **Realising network externalities.** Networks such as grids, or public transport, are prone to natural monopoly, because infrastructural costs and other barriers to entry generate scale economies. Public subsidies, planning, and regulation may be required to roll out new infrastructure while seeking to minimise rent, maintain investment, and promote consumer surplus. ■

Policy box 2: Promoting a supportive environment – labour market and product market flexibility

The pace of change in the structure of the economy will extend beyond decarbonisation. New technologies such as artificial intelligence (AI), machine learning, biotechnologies, big data and automation create both opportunities and challenges.[152] New sectors exploiting opportunities will replace declining less productive and slow growing sectors. This crucial political economy aspect requires responsive institutions and policies.

- The UK's relatively flexible job and investment markets provide a good foundation for managing the impacts of change allowing the economy to take full advantage of the whole-economy Schumpeterian benefits of creative destruction and innovation.
- Good policies are flexible enough to enable diversification from old unsustainable assets to new higher productivity assets with stronger growth potential in a resource- and carbon-constrained century, while addressing interrelated market failures (see Policy Box 1: *The rationale for policy intervention: correction of market failure*).
- The UK has a complex and diverse economy. Its network of universities and urban knowledge centres puts it in good stead to maximise the capacity to diffuse and absorb knowledge and innovation, while incentivising the diversification of a broad portfolio of national assets -natural, produced, and intangible assets.

Change is inevitable. The coming economic transition, which will see the low-carbon transition intertwine with the Fourth Industrial Revolution, could lead to even larger displacement of high-carbon jobs as new technologies such as artificial intelligence go beyond replacing manual tasks to replacing some cognitive workers too.[153]

- Areas at high risk of disruption include Northeast England and South Wales and are most in need of targeted employment transition policies.[154]
- Social cohesion and economic justice require that such transitions are managed. This puts investment in adaptive and flexible human capital at the fore, including the training and re-training of current workers and the provision of continuing education.
- The strength of existing institutions, including trade unions, social housing, healthcare systems and educations system will also play a crucial role in cushioning the impacts of job losses.

Managing these changes will require a degree of government intervention to retool and reskill workers. This will create the skills necessary to install, operate and maintain new technologies while compensating some of the losers.[155]

- There is a central role for institutions in enabling the development of the different types of capital (human, social, infrastructure, intellectual) that are essential pre-conditions for growth, and in cushioning the damaging effects of recessions and transitions on human capital.[156]
- Policy should ensure education institutions are responsive and flexible as the low-carbon transition accelerates and the demand for skills shifts, by working closely with other economic, environmental, technological and social institutions. This will require better data and metrics for assessing employment changes and shifting demand for skills.
- Policy should support firms to overcome barriers to in-house training through tax credits and partnerships with education providers.[157]
- Awareness of distributional impacts and building institutions which insure (compensate) and enable (retool and reskill) those negatively impacted, recognising that the biggest barriers to adjustment are not economic or technological but political, institutional, and cultural (see Policy Box 1: *The rationale for policy intervention: correction of market failure*).

Policy box 2: Continued

Incumbents often claim, in particular, that stronger climate policy will put them at a competitive disadvantage relative to those in other countries, or even cause them to relocate elsewhere, outsourcing emissions to less strongly regulated economies. With very few exceptions, the evidence does not support these fears.

- Recent studies of European climate policy, particularly of the EU emissions trading system, suggest that the impacts have thus far been small, whether in terms of carbon offshoring, economic growth, employment or consumer prices, with only a few energy-intensive sectors (such as steel and cement) at risk of significant adverse effects even if policy is strengthened.[158]
- Even those who perceive themselves as losers may in fact be acting against their own interests by opposing or delaying change. Policies, regulations, and standards that affected firms complain will damage them can turn out to incentivise innovation once implemented.[159]
- For example, EU fuel efficiency targets for cars helped induce technological improvements which have improved the global competitiveness of European cars. In 2009 the EU introduced a fleet average target of 130 g/km by 2015. This was widely opposed by the motor industry, but it was met two years early. In the US, by contrast, car and consumer-industry pressures kept gasoline taxation low such that improvements in fuel efficiency have been slower. As a consequence, the US car industry was much less prepared for higher oil prices and the global financial crisis, an important but largely unheralded factor in the bankruptcies of Chrysler and General Motors in 2009.[160]
- The pace of change and the need for extensive public Intervention to promote the transition underlines the importance of transparent regulatory institutions to limit rent-seeking, protect consumers and promote competition. ■

Policy box 3: Promoting a supportive environment for structural reform

Every economic reform is conducted in a particular social and political context. Political economy is intrinsic to addressing issues of change; and particularly in cases of major structural reform such as green transition, which are complex and challenging. There have been many successes, but also many failures, with structural reform. Experience not only in the UK but also in other advanced countries too, suggests a number of considerations that, duly taken into account, can contribute importantly to success.[161]

Broad support of the people. Successful policy reform requires that there be at least tacit acceptance of it by a majority of the people; and in some cases it needs to be driven by the public will.[162]

Concrete and feasible. The reform agenda has to be easily understandable to the public. Widely accepted definitions and metrics that enable key stakeholders to monitor progress can be extremely constructive.

Wide political constituency. In addition to support from the populace, successful reform requires broad-based political support, preferably cross-party, and from the top of government down. Disunity breeds incoherence; and compromises to appease disparate stakeholders usually complicate reform.

Good reform, good politics. While there have been important exceptions, many governments that successfully implemented reforms for which they had prior electoral mandates went on to win re-election.[163]

Policies inter-relate. It is often counterproductive to consider individual elements of policy separately, in isolation from one another. Generally, all major areas of policy are best considered and implemented together.

Institutions. Change is generally unsettling. So while institutions can be changed in the pursuit of reform, due account has to be taken of a country's history: the issue of 'how to get from here to there' is real.

Strong leadership. Successful implementation of policy reform requires leadership by a well-trained, respected, committed, and cohesive team, which includes technocrats and 'technopols'.[164]

Anchor institutions. The ability, credibility, cohesion, and firmness of purpose of those impelling reform has to be emulated throughout the country's legislative, operational, and informational institutions – from local authorities, leading businesses, and business associations to trade unions, universities, and investors.

Agents of change at all levels. It helps considerably if there are agents of change – 'points of light' – throughout society, ranging from business people to journalists to NGOs. These people provide vocal, local, and credible support, which aids the communications process.

Early winners. Initial successes can boost expectations and generate momentum for continuing reform. That said, 'low-hanging-fruit' strategies can also pose problems of their own: actions that start with certain sectors, and are seen as a harbinger of deeper reforms, may lead opponents to adopt an intransigent position to stall the process, even over relatively minor measures.

Maintaining momentum. Gradualism seldom succeeds. And while there can often in theory be an optimal sequence for a range of reforms, in the real world this is often impractical.[165]

Assessing and demonstrating progress. Maintaining policy momentum is aided considerably if the public see progress being made. Making this visible, qualitatively and quantitatively, may require institutional change – including perhaps creation of independent bodies with power of oversight.

Equity and fairness. Change, and certainly structural change, creates both winners and losers. It is necessary to compensate losers, while at the same time not eliminating the gains from change.

Positive structural adjustment. It is in the interests of all that compensation for those disadvantaged by structural change should be constructive, equipping them to work in new jobs, often using new skills. These policies can be expensive; and take time to come to fruition, but the payoff is considerable.[166] ■

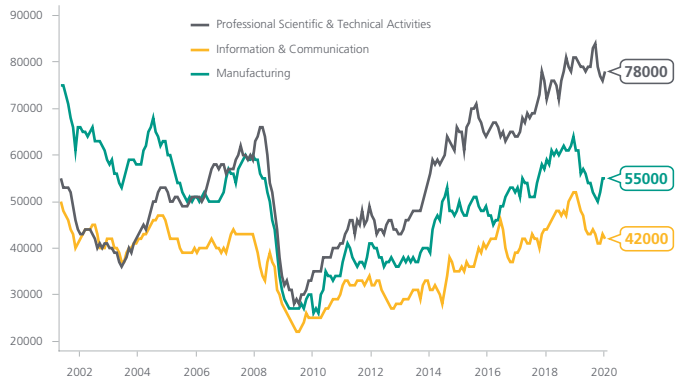
Appendix

Figure A: Structural policies heatmap, selected countries

	Weights	Finland	Switzerland	Netherlands	New Zealand	Japan	United Kingdom	Denmark	Sweden	Norway	Luxembourg	Australia	Canada	Germany	United States	Austria	Estonia	Belgium	France	Ireland	Korea	Czech Republic	Israel	Lithuania	Chile	Portugal	Slovak Republic	Spain	Slovenia	Latvia	Poland	Hungary	Italy	Greece	Turkey	Mexico
1. Institutions	14%	1.5	1.3	1.0	1.4	0.7	0.9	0.8	1.3	1.3	1.1	0.6	0.7	0.4	0.2	0.5	0.4	0.5	0.1	0.9	-0.9	-0.7	0.0	-0.7	-0.3	-0.6	-1.5	-0.8	-0.8	-0.9	-0.9	-1.7	-1.6	-1.2	-1.1	-1.7
2. Infrastructure	14%																																			
Public investment	0.33	0.4	-0.7	0.2	0.3	0.2	-0.9	0.0	0.9	0.8	0.5	-0.2	0.5	-1.8	0.2	-0.6	2.7	-1.4	0.3	-1.5	1.3	0.9	-1.7	0.6	-1.7	-0.8	0.5	-0.7	1.1	1.2	1.5	1.1	-1.2	0.1	-0.3	-1.2
Quality of transport infrastructure	0.33	1.5	2.0	1.6	-0.5	1.8	0.0	1.0	0.5	-0.5	0.6	-0.5	0.1	0.8	0.8	1.1	0.1	-0.1	1.3	-0.7	0.6	-0.6	-0.7	-0.1	-0.9	0.6	-1.1	0.5	-0.8	-1.1	-1.5	-1.0	-1.3	-1.5	-0.3	-1.6
ICT infrastructure	0.33	0.5	1.2	0.8	0.8	0.3	1.1	0.9	1.0	0.7	1.3	0.2	0.3	0.8	0.4	0.3	-0.5	0.6	0.7	0.5	0.1	0.0	-0.2	0.0	-1.1	-0.1	-1.6	0.4	-0.3	-0.2	-1.1	-1.4	-0.3	-0.3	-2.5	-1.6
3. Human capital	14%																																			
Educational achievement																																				
Secondary education	0.17	0.5	0.6	0.1	-0.3	1.0	0.1	-0.1	-0.2	-0.3	0.0	0.3	0.8	0.3	0.5	0.5	0.4	-0.2	0.2	0.6	1.2	0.8	0.6	0.5	-0.4	-1.3	0.7	-1.6	0.9	0.0	0.8	0.1	-0.9	-0.1	-2.8	-3.4
Tertiary education	0.17	-0.2	0.6	0.3	-0.3	1.7	0.7	0.2	0.4	0.6	0.7	0.6	1.6	-1.2	0.4	-0.3	-0.2	0.1	0.2	0.9	2.6	-1.1	0.4	1.2	-1.4	-0.9	-1.0	-0.1	-0.1	-0.2	0.1	-1.0	-1.6	-0.2	-1.4	-2.0
PISA scores	0.33	1.2	0.6	0.6	0.5	1.4	0.3	0.5	0.2	0.5	-0.3	0.4	1.2	0.6	-0.2	0.0	1.2	0.4	0.1	0.7	1.0	0.0	-0.8	-0.6	-1.2	0.2	-1.1	0.0	0.7	-0.2	0.5	-0.7	-0.3	-1.3	-2.6	-2.9
On-the-job training	0.33	1.2	1.8	1.2	0.7	0.6	0.7	0.9	1.0	1.1	0.5	0.6	0.4	0.8	0.7	1.0	0.0	1.1	0.3	0.5	-0.7	-0.1	-0.1	-0.3	-0.6	-1.0	-1.3	-1.4	-0.7	-1.0	-0.7	-1.8	-1.1	-1.6	-1.7	-1.2
4. Market regulation	14%	-0.6	0.1	-1.9	-0.7	-0.2	-1.3	-0.9	0.1	0.0	-0.1	-0.7	-0.2	-0.7	0.4	-1.0	-0.6	-0.3	0.0	-0.1	1.4	-0.2	2.3	0.1	0.1	-0.6	-0.6	-0.1	0.8	0.5	0.6	-0.5	-0.6	0.9	2.4	1.5
5. Labour market efficiency	14%																																			
Employment protection	0.33	-0.3	-0.4	1.4	-2.7	-0.4	-1.5	0.1	0.5	0.0	0.9	-0.7	-1.7	1.2	-2.4	0.3	-0.5	1.5	1.1	-0.5	-0.3	0.8	-0.2	0.3	-1.0	0.8	-0.1	0.1	0.2	1.3	0.2	-0.5	1.3	0.3	0.1	0.7
Average tax wedge	0.33	0.5	-1.2	-0.2	-1.8	-0.2	-0.6	0.2	0.8	0.1	-0.1	-0.9	-0.6	1.2	-0.3	1.2	0.5	1.4	1.0	-1.0	-1.3	0.7	-1.7	0.6	-2.4	0.3	0.6	0.3	0.6	0.9	0.1	1.6	0.8	0.2	0.3	-1.7
ALMP expenditure per unemployed	0.33	1.0	0.7	0.6	-0.2	-0.4	-0.7	1.6	1.5	1.2	0.5	-0.5	-0.7	1.0	-0.9	1.2	-0.7	0.5	0.7	0.0	0.9	-0.2	-0.7	-0.8	-0.9	-0.5	-0.9	-0.8	-0.5	-0.9	-0.3	0.9	-0.6	-1.0	-1.1	-1.1
6. Innovation	14%																																			
Gross R&D expenditure	0.33	0.9	1.0	0.1	-0.8	1.5	-0.2	1.0	1.3	0.0	-0.6	0.2	-0.3	0.9	0.8	1.1	-0.4	0.5	0.3	-0.4	2.2	0.0	2.3	-1.3	-1.6	-0.7	-0.7	-0.7	0.3	-1.3	-0.9	-0.6	-0.6	-1.0	0.9	-1.4
Technological adoption	0.33	0.7	1.3	1.0	0.3	0.4	1.0	0.4	1.1	1.2	1.1	-0.1	0.3	0.7	1.1	0.1	-0.1	0.7	0.1	1.1	-0.4	-0.2	1.1	0.0	-0.1	0.3	-0.3	-0.6	-1.2	-1.3	-1.3	-2.0	-1.8	-2.1	-1.4	-1.0
Digital skills	0.33	1.1	1.8	1.0	1.2	-0.3	0.6	1.1	0.9	1.4	1.5	0.6	0.6	0.5	0.4	0.4	0.4	0.1	-0.1	-1.0	0.1	-0.1	-0.5	-0.5	-1.4	-0.7	-0.4	-0.3	-0.5	-0.6	-1.2	-0.6	-1.0	-1.0	-2.3	-1.9
7. Financial market efficiency	14%	1.2	1.4	0.3	1.1	1.0	0.8	-0.2	1.1	1.2	1.1	0.4	0.4	0.8	1.4	0.5	0.2	0.8	0.2	-0.9	-0.8	-0.1	0.5	-0.5	0.4	-0.9	-0.3	-0.8	-1.5	-1.0	-0.6	-0.8	-1.8	-2.1	-0.8	-0.8
Total score (higher = better)		3.9	3.9	3.8	3.7	3.6	3.6	3.6	3.6	3.6	3.5	3.5	3.5	3.5	3.4	3.2	3.2	3.1	3.0	3.0	2.9	2.8	2.7	2.7	2.6	2.6	2.6	2.5	2.5	2.4	2.4	2.3	2.0	2.0	1.8	1.8
Standardised total score		1.4	1.4	1.2	1.2	1.0	1.0	1.0	1.0	1.0	0.9	0.7	0.7	0.7	0.7	0.4	0.3	0.2	0.1	0.1	-0.1	-0.4	-0.4	-0.4	-0.6	-0.6	-0.8	-0.8	-0.9	-1.0	-1.0	-1.2	-1.6	-1.6	-1.9	-2.0

Source: Llewellyn Consulting

Figure B: Unfilled vacancies, selected sectors, UK



Source: ONS and Llewellyn Consulting
Notes: Seasonally adjusted monthly numbers of unfilled vacancies.

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Endnotes

[1] Millennials and Gen Z in particular want the companies they work for and buy from to stand for something. As Patrick Decker, President and Chief Executive of Xylem, put it in 2019, *"The younger generation is drawn to higher purpose and mission – 'why are we doing this?' It's not purely the profit motive."* And these demands increasingly seem non-negotiable.

For more, see Winston, A., 2019. *What 1,000 CEOs Really Think About Climate Change and Inequality.* [online] Available at: <https://andrewwinston.com/what-1000-ceos-really-think-about-climate-change-and-inequality/> [Accessed 20 January 2020].

[2] De Beers CEO Bruce Cleaver painted an even clearer picture: *"The time will come when there will be a threshold question that consumers will ask which is 'can I trust this brand?', and if the answer is 'no' they won't buy anything. It will become a binary question."*

For more, see: ibid.

[3] 'Net zero' refers to achieving an overall balance between emissions produced and emissions taken out of the atmosphere. For more, see: Grantham Institute on Climate Change, 2019. *What is net zero?* [online] Available at: <http://www.lse.ac.uk/GranthamInstitute/news/what-is-net-zero/> [Accessed: 7 February 2020]

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[5] By, for example, avoiding lock in to high carbon infrastructure, institutions and behaviours, and diversifying investment into key assets necessary to build a competitive, resource- and carbon-efficient economy.

[6] During an interview with newspaper City A.M, published 3 February 2020.

[7] See Storrow, B., 2019. Hopes for Cutting Carbon Do Not Yet Match Reality. *Scientific American,* [online]. Available at: <https://www.scientificamerican.com/article/hopes-for-cutting-carbon-do-not-yet-match-reality/> [Accessed 25 January 2020]

[8] The latest World Bank report highlights that carbon tax and trading schemes generated some $44 billion in revenues for governments across the world – funds which could, in turn, be used for re-investment in green projects, lowering overall tax burden, etc. For more, see World Bank Group. 2019. *State and Trends of Carbon Pricing 2019.* [online] Washington, DC: World Bank.
Available at: https://openknowledge.worldbank.org/handle/10986/31755 [Accessed 6 February 2020]

[9] The Paris Agreement, concluded within the United Nations Framework Convention on Climate Change (UNFCCC) and signed in December 2015, deals with greenhouse-gas-emissions mitigation, adaptation, and finance. The stated central aim is to strengthen the global response to the climate change threat by keeping a global temperature rise this century well below 2°C above pre-industrial levels, and to pursue efforts to limit the temperature increase even further to 1.5°C.

For more, see United Nations, 2015. *Paris Agreement.* [pdf] United Nations. Available at: https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf [Accessed 4 February 2020]

[10] High-Level Commission on Carbon Prices, 2017. *Report of the High-Level Commission on Carbon Prices.* [pdf] Washington, DC: World Bank. Available at <https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59b7f2409f8dce5316811916/1505227332748/CarbonPricing_FullReport.pdf> [Accessed 4 February 2020]

[11] For reference, the EU ETS prices carbon at around $25 per tonne, and the carbon price floor in the UK is $24 per tonne.

[12] Refinitiv's forecast carbon gap is based on the following: That global emissions of CO_2 + CO^2 equivalents were 55 giga-tonnes in 2019 (World Economic Forum, 2019). Today, the capitalization of the 'priced' market for CO_2e (via ETS and tax schemes globally) comes in at $216 billion (for more, see Refinitiv, 2018. *Review of carbon markets in 2018.* [pdf] Refinitiv. Available at: <https://www.refinitiv.com/en/resources/special-report/review-of-carbon-markets-in-2018> [Accessed 4 February 2020]. This factors in the sum totals of every known jurisdiction globally with a structured ETS / tax scheme, leveraging their 'price' multiplied by the emissions they cover. Due to there being no "set" cost for a tonne of CO_2e (it ranges from $1-2 in some jurisdictions to $150+ in others), we have taken the most widely traded 'price' from the EU ETS (Emissions Trading Scheme), where the average traded price was $28/tonne in 2019 (for more, see Refinitiv, 2020. *Point Carbon.* [online] Available at: <https://www.refinitiv.com/en/products/point-carbon-prices> [Accessed 4 February 2020]. Once we multiply by total global output (our 55Gt) this gives an estimated global 'cost' for CO_2e of $1.4 trillion in 2019, which means, if the price rises to $75 then this global cost grows to >$4T, leaving the world with a 'CARBON GAP' of $3.9 trillion, (even before we start to factor in potential expansion in annual emissions over the coming years which could take this figure even higher if we fail to act).

[13] Williamson, J., 2019. *UK manufacturing output now worth £192bn – world's ninth largest manufacturer.* [online] Available at: <https://www.themanufacturer.com/articles/uk-manufacturing-output-now-worth-192bn-worlds-ninth-largest-manufacturer/> [Accessed 30 March 2020]

[14] Note that the relative size of the manufacturing sector is falling in all advanced economies. And in some ways this is a bit of a statistical illusion: services that in past epochs used to be produced within the manufacturing sector are now 'bought in' – part of the increasing sophistication and complexity of modern market economies. Services in the UK currently make up some 80% of the UK's economy on a Gross Value Added (GVA) basis.

[15] The data are for 2018. For more, see Rhodes, C., 2020. *Manufacturing: statistics and policy.* [pdf] London: House of Commons Library. Available at: https://researchbriefings.files.parliament.uk/documents/SN01942/SN01942.pdf [Accessed 29 March 2020]

[16] Drawing on the ground-breaking work of Wassily Leontief (1941, p. 3), Carvalho et. al. (2019) find that manufacturing is at the heart of a networked production process, such that disturbances at certain firms or industries may have outsized spill overs to other parts of the economy over input linkages. For more, see Carvalho et. al., 2019. Production Networks: *A Primer*. [pdf] Annual Reviews. University of Cambridge. Available at <http://www.econ.cam.ac.uk/research/pub-abstracts?pub=1410> [Accessed 13 February 2020]

[17] Oxford Economics, 2018. *The true impact of UK manufacturing.* [online] Available at https://www.oxfordeconomics.com/recent-releases/bd178a1a-dbb9-4651-9b0c-4aac020e109f [Accessed 11 March 2020]

[18] For more see, *Make UK, 2019. Make UK/Santander analysis shows Europe remains dominant market for UK goods.* [online] Available at: <https://www.makeuk.org/insights/publications/2019/09/13/uk-manufacturing-the-facts-2019-20> [Accessed 7 February 2020]

[19] For more detail see Oxford Economics, 2018. Op. cit..

[20] For more, see the May 2020 Review of the National Institute of Social and Economic Research, forthcoming.

[21] Economists' Input-Output tables show that the most well connected general purpose suppliers in production across the economy are refineries, energy supplies, and core manufacturers. The currently-low elasticity of substitution among those reliant on these sectors means that when they are blockaded or damaged by natural events, the shock is propagated across GDP even though they account for a tiny fraction of gross value added. Think of the impact of refinery blockages or hurricane impacts on the Gulf.

[22] From Marshall, A., 1890. *Principles of Economics*. The Macmillan Company, New York.

[23] Except perhaps wartime.

[24] For example: on- and off-shore wind and solar pv, battery storage, and electric vehicle technologies. Other costs such as the costs of producing hydrogen through electrolysis (BNEF estimate this will become cost competitive after 2030), and synthetic fuels are also coming down fast, as is the cost of handling data to improve efficiency and demand response, but these technologies are still relatively pricey and have yet to reach a critical mass.

[25] HM Government, 2019. *The UK becomes first major economy to pass net zero emissions law.* [online] Available at: <https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law> [Accessed 10 February 2020]

[26] For more detailed data on individual countries, see the World Bank, 2020. *Services, value added (% of GDP).* [online] Available through: <https://data.worldbank.org/indicator/NV.SRV.TOTL.ZS?locations=GB-DE-US-JP-CN-OE> [Accessed 10 February 2020]

[27] ONS, 2019. *Greenhouse gas emissions intensity, UK: 2018 provisional estimates* [online Available at: <https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/greenhousegasintensityprovisionalestimatesuk/2018provisionalestimates> [Accessed 17 February 2020]

[28] The one well-documented caveat to these 'progress' numbers is the fact that the UK reporting does not include emissions from the manufacture of imported goods, which are instead reported in the country of manufacture. Consumption-based emissions rose then fell since financial crisis and are at best trending flat at 56% above territorial emissions.

For more, see Committee on Climate Change, 2019. *Reducing UK emissions 2019:* Progress Report to Parliament. [pdf] Available at: <https://www.theccc.org.uk/wp-content/uploads/2019/07/CCC-2019-Progress-in-reducing-UK-emissions.pdf> [Accessed 17 February 2020]

[29] Committee on Climate Change, 2017. *UK business opportunities of moving to a low-carbon economy.* [online] Available at: <https://www.theccc.org.uk/publication/uk-energy-prices-and-bills-2017-report-supporting-research/> [Accessed 17 February 2020]

[30] HM Government, 2019. *Leading on Clean Growth:* The Government Response to the Committee on Climate Change's 2019 Progress Report to Parliament – Reducing UK emissions. [pdf] Available at: <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/839555/CCS0819884374-001_Government_Response_to_the_CCC_Progress_Report_2019_Web_Accessible.pdf> [Accessed 10 February 2020]

[31] According to Bloomberg New Energy Finance (BNEF), global clean energy investment in 2017 was $333.5 billion globally, 3% above 2016's total, and the second highest investment year on record. With countries around the world racing to develop, deploy, and export these technologies, US manufacturers face serious competition for these lucrative markets. China was home to the largest sum of clean energy investment in 2017 at $132.6 billion, while the US came in a distant second with $56.9 billion.

For more, see Third Way, 2018. *Industry Matters: Smarter Energy Use is Key for US Competitiveness, Jobs, and Climate Efforts.* [online] Available at: <https://www.thirdway.org/report/industry-matters-smarter-energy-use-is-key-for-us-competitiveness-jobs-and-climate-effort> [Accessed 10 February 2020]

[32] See Strauss, D., 2020. UK's industrial strategy criticised by independent body. *Financial Times,* [online], 19 February. Available at: <https://www.ft.com/content/8fc12094-52f7-11ea-90ad-25e377c0ee1f> [Accessed 11 February 2020]

[33] Companies have reported opportunities arising from the low-carbon transition to be worth $2.1 trillion compared to around $1 trillion of downside risk. New and expanded product and market opportunities will be created.

Some will be oriented to specific areas, such as renewable energy, regenerative growing practices in agriculture, or sustainability-linked financing. Many more companies have the opportunity for climate risk-related product, service, and supply chain innovations that will attract customers, investors, and employees with a heightened sensitivity to the issue.

For more, see:

CDP, 2019. *Major risk or a rosy opportunity: Are companies ready for climate change?* [pdf] Available at: <https://6fefcbb86e61af1b2fc4-c70d8ead6ced550b4d987d7c03fcdd1d.ssl.cf3.rackcdn.com/cms/reports/documents/000/004/588/original/CDP_Climate_Change_report_2019.pdf> [Accessed 1 February 2020]

World Economic Forum, 2020. *The heat is on businesses to respond to climate change.* [online] Available at: <https://www.weforum.org/agenda/2020/01/climate-change-business-response-risks/> [Accessed 6 February 2020]

[34] As shown by their Future Fit research. Available at: https://www.telegraph.co.uk/business/tips-for-the-future/future-of-manufacturing/ [Accessed 10 January 2020]

[35] 'Servitisation' describes the addition of services to manufacturers' core product offerings to create additional customer value.

[36] As quoted in the Telegraph's The future of Manufacturing, https://www.telegraph.co.uk/business/tips-for-the-future/future-of-manufacturing/ [Accessed 7 April 2020]

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

[38] For more see Selzer, J. and Byrnes, R., 2019.

[39] For more see McGlade, C. and Ekins, P., 2015.

[40] For more see Pfeiffer, A, Millar R, Hepburn C and Beinhocker E, 2016. The '2°C capital stock' for electricity generation: Committed cumulative carbon emissions from the electricity generation sector and the transition to a green economy, Applied Energy, Available online 24 March, ISSN 0306-2619, http://dx.doi.org/10.1016/j.apenergy.2016.02.093 http://www.sciencedirect.com/science/article/pii/S0306261916302495 Available at: https://iopscience.iop.org/article/10.1088/1748-9326/aabc5f

[41] For more on disclosure and its implications, see TCFD, 2019. *Task Force on Climate-related Financial Disclosures Overview.* [online] Available at: https://www.fsb-tcfd.org/ [Accessed 6 January 2020]

[42] Ross, A., 2019. Tackling climate change — an investor's guide. *Financial Times,* [online], 20 September. Available at: <https://www.ft.com/content/fa7a4400-d940-11e9-8f9b-77216ebe1f17 [Accessed 11 February 2020]

[43] The information is this Box is drawn primarily from the following sources:

Ministry of Finance Sweden, 2018. *Lessons Learned from 25 Years of Carbon Taxation in Sweden.* [online] Available at: <https://www.government.se/48e9fb/contentassets/18ed243e60ca4b7fa05b36804ec64beb/lessons-learned-from-25-years-of-carbon-taxation-in-sweden.pdf#mce_temp_url#> [Accessed 6 January 2020]

Government Offices of Sweden, 2020. *Sweden's carbon tax.* [online] Available at: <https://www.government.se/government-policy/taxes-and-tariffs/swedens-carbon-tax/> [Accessed 6 January 2020]

Fossil Free Sweden, 2020. *Roadmaps for fossil free competitiveness.* [online] Available at: <http://fossilfritt-sverige.se/in-english/> [Accessed 6 January 2020]

European Climate Initiative, 2018. *The Carbon Tax in Sweden.* [pdf] Available at: <https://www.euki.de/wp-content/uploads/2018/11/fact-sheet-carbontax-se.pdf> [Accessed 6 January 2020]

[44] Among the first to recognise that even if the material economy attained a stationary state, our intellectual development would increase indefinitely was John Stuart Mill. (Mill, 1848). See also Bowen, A. and Hepburn, C., 2012, *Prosperity with Growth: Economic Growth, Climate Change and Environmental Limits.* [pdf] Available at: <https://www.semanticscholar.org/paper/Prosperity-with-Growth%3A-Economic-Growth%2C-Climate-Hepburn-Bowen/681f78e7bbf5777fc6a5a94c918b3fed88dbcf56> [Accessed 16 January 2020]

[45] According to research by Cambridge Service Alliance (CSA). See Powley, T., 2015. UK manufacturers turn to after-market services in hunt for value. Financial Times, [online] 7 June. Available at: <https://www.ft.com/content/e0aa4a06-053d-11e5-8612-00144feabdc0> [Accessed 29 April 2020]

[46] As shown by their Future Fit research. Available at: https://www.telegraph.co.uk/business/tips-for-the-future/future-of-manufacturing/ [Accessed 10 January 2020]

[47] These include metals, ceramics, chemicals cement and plastics. Demand for these sectors is unlikely to shift to ready substitutes in the near term but production process, technologies, and the efficient use and re-use of materials will allow some firms to outcompete less efficient rivals. For more, see Energy Transitions Commission, 2019. *Reaching net zero emissions: mission possible.* [pdf] Available at: <http://www.energy-transitions.org/mission-possiblehttp://www.energy-transitions.org/sites/default/files/ETC_MissionPossible_FullReport.pdf> [Accessed 18 January 2020]

[48] Hodgson, C., 2020. Industrial Companies fall behind on global warming plans. *Financial Times,* [online], 2 February. Available at: <https://www.ft.com/content/d94aa146-445a-11ea-a43a-c4b328d9061c> [Accessed 8 February 2020]

[49] More than 50%, and as much as 90%, of the global emissions reductions required to meet ambitious climate targets could generate net benefits to the economy. For more, see The Global Commission on the Economy and Climate (2014). See also Hallegatte et al. (2012).

[50] Large triple glazed windows and light wells flood large, open plan spaces with natural light. Bamboo floors and high ceilings; recycled glass wool is used to minimise its environmental impact, timber housing panels achieve high levels of insulation; retaining heat so effectively that heating needs can be met with 100% renewable energy – preventing the emission of over two tonnes of CO_2 per year. A mechanical ventilation heat recovery (MVHR) system brings a constant flow of fresh air into the home, and warms it using the heat from exiting warm stale air. Over 90% of heat is transferred from exiting stale air to incoming fresh air. Solar arrays co-owned by all the residents, provide a source of clean, renewable energy. For more, see <https://citu.co.uk/citu-home>

[51] For more on the strategic partnership, see https://new.siemens.com/uk/en/company/topic-areas/ingenuity-for-life/pilkington-glass.html [accessed 13 July 2020]

[52] For more, see OECD Data, 2020. *Value added by activity*.
Accessible through: <https://data.oecd.org/natincome/value-added-by-activity.htm> [Accessed 16 January 2020]

[53] The industry's first index based on the value of intellectual property is The Ocean Tomo 300® Patent Index (OT300). For more, see Ocean Tomo, [online] Available at: https://www.oceantomo.com/ocean-tomo-300/ [Accessed 9 March 2020]

[54] From measures of the World Bank's 'true wealth' of nations. World Bank, 2011. *The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium.* Environment and Development. World Bank. Available at: <https://openknowledge.worldbank.org/handle/10986/2252 License: CC BY 3.0 IGO.> [Accessed 19 March 2020] And Lange, Glenn-Marie; Wodon, Quentin; Carey, Kevin, 2018. *The Changing Wealth of Nations 2018: Building a Sustainable Future.* Washington, DC: World Bank. Available at: https://openknowledge.worldbank.org/handle/10986/29001 License: CC BY 3.0 IGO. [Accessed 19 March 2020]

[55] For more on these dynamics, see Hidalgo et al., 2007 and Mealy, P. and Hepburn, C., 2017.

[56] For more on the importance of cross-sector collaboration, see Hytch, D., 2017. Cross sector collaboration is essential to solving innovation problems, *Innovate UK blog,* [blog] 10 July. Available at: https://innovateuk.blog.gov.uk/2017/07/10/cross-sector-collaboration-is-essential-to-solving-innovation-problems/ [Accessed 19 January 2020]

[57] Similarly, in the Humber area, rather than simply drawing on existing suppliers for its wind operations in Denmark and Germany, Siemens chose to build up a local supply chain in the area. Siemens Gamesa and Ørsted and were thereby been pivotal in growing the Humber offshore wind cluster, which includes education and training facilities; easy transfer between roles – for example, developing the 'Offshore Energy Passport' that will enable offshore workers to transfer between the renewable and extraction industries.

For more, see Robins, N., Gouldson, A., Irwin, W., Sudmant A., and Rydge, J., 2019. *Financing inclusive climate action in the UK – An investor roadmap for the just transition,* [online] LSE, October. Available at: <http://www.lse.ac.uk/GranthamInstitute/publication/financing-inclusive-climate-action-in-the-uk-an-investor-roadmap-for-the-just-transition/> [Accessed 10 January 2020]

[58] This is consistent with early slow progress in deployment of decarbonisation technologies. For more see Aghion et al. (2014).

[59] For more on path dependency, see Aghion, P., Dechezleprêtre, A., Hemous, D., Martin, R. and J. Van Reenen (2012), *"Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry",* NBER Working Paper No. 18596, December.

[60] Social psychologists have long understood that solving coordination problems requires building expectations into models and generating 'common knowledge.' (Thomas et al., 2014). Tipping dynamics can apply to social norms, opinion dynamics, and cascades of belief updating. (2019, for example, saw Greta Thunberg and Extinction Rebellion on climate, and Sir David Attenborough on plastic pollution. Social feedbacks then help reinforce policies which help induce new technologies and grow new industrial lobbies, self-reinforcing and accelerating broader structural change.)

For more on how opinion cascades are caused when private beliefs which are not expressed are authenticated when someone significant expresses them in public causing a cascade of 'belief updating', see Kuran, Timur & Sunstein, C., 2007. Availability Cascades and Risk Regulation. [online] *Stanford Law Review.* Available at: <https://www.researchgate.net/publication/228607880_Availability_Cascades_and_Risk_Regulation> [Accessed 9 January 2020]

[61] Once electric vehicle infrastructure is rolled out, for example, the incentives to conduct R&D on electric cars increase relative to combustion engine, or fuel cell, vehicles. Volvo's 2018 generation of turbocharged internal combustion engines are to be its last, as revealed by Hakan Samuelsson, the brand's CEO, during the presentation of the new V60 car in Stockholm. Focus has moved to R&D on its electric vehicles; others are sure to continue following.

[62] There is reluctance to move early into new technologies when they are expensive, subject to expensive niche financing, and the market has yet to evolve, let alone mature; and where risks are high and profitable opportunities few. But if whole markets are expected to move at scale, then technology and financing costs will be expected to fall, and profits rise. Investment will breed investment and expectations will become self-fulfilling.

[63] For seminal expositions of the tension between history and expectations in driving innovation, see Krugman (1991) and Matsuyama (1991).

[64] Romer, P., 1990. "Endogenous technological change." Journal of Political Economy, 98(5), pp. S71–S102. And Arrow, K. J., 1962. "The economic implications of learning by doing". Review of Economic Studies, 29(3), 155–73.

[65] From a study of over a million patents and 3 million citations. See Dechezlepretre, A., Martin, R. and Mohnen, M. 2014. *"Knowledge spillovers from clean and dirty technologies."* Centre for Economic Performance, London School of Economics and Political Science.

[66] This is demonstrated by Hidalgo et al. (2007) and Mealy and Teytelboym (2017) through use of network analysis.

[67] For more see Aghion et al, (2012), and Braun et al., (2010).

[68] Social norms can be defined as the predominant behaviour within a society, supported by a shared understanding of acceptable actions and sustained through social interactions. As 'better' ways of consuming, producing, and living are found, there stands

to be complementary changes in behaviour, institutions and, social norms. Increasing doubt is being cast on the assumption that sustainability must be traded off against growth. Policymakers, businesses and consumers are discovering that living in sprawling, congested, polluted environments with leaky buildings, outmoded energy technologies and wasteful use of resources is not good for GDP, let alone wellbeing. The economy is simultaneously transferring around and driving these changing expectations. For more on this, see Ostrom (2000).

[69] Formal institutions struggle to enforce collectively desirable outcomes without popular support. Acceptable standards of behaviour and social norms are the sources of law and ultimate drivers of legislative change. Social norms are the sources of law, and recognising the appropriateness or immorality of behaviour is a driver of legislative change. For more, see Posner (1997).

[70] See Centola, D., Becker, J., Brackbill, D., and Baronchelli, A., 2018. Experimental evidence for tipping points in social convention. *Science,* 08 Jun 2018, Vol. 360, Issue 6393, pp. 1116-1119. DOI: 10.1126/science.aas8827. Available at: <https://science.sciencemag.org/content/360/6393/1116> [Accessed 6 April 2020].

[71] HM Government, 2019. *Offshore wind energy revolution to provide a third of all UK electricity by 2030,* [online] Available at: <https://www.gov.uk/government/news/offshore-wind-energy-revolution-to-provide-a-third-of-all-uk-electricity-by-2030> [Accessed 7 April 2020].

[72] These include investment in better grid interconnection, to tap supply from regions further afield.

[73] Two decades ago most assumed that the cost of managing intermittency would soar after the first 5% of wind and solar entered the power mix; a decade ago the thinking was that the inflection was 20%; now it is known that it is not this side of 40%. Modelling exercises around the world suggest that it is not until 80% or more is reached that, in any decently-connected grid, that the cost of managing intermittency really starts to go vertical. For more, see Liebreich, M., 2019. Liebreich: Peak Emissions Are Closer Than You Think – and Here's Why, [online] *Bloomberg* NEF, 17 December. Available at: <https://about.bnef.com/blog/peak-emissions-are-closer-than-you-think-and-heres-why/> [Accessed 7 April 2020]

[74] Committee on Climate Change, 2019. T*echnical Annex: Integrating variable renewables into the UK electricity system,* [pdf], London, Available at: <https://www.theccc.org.uk/wp-content/uploads/2019/04/Technical-Annex-Integrating-variable-renewables-into-the-UK-electricity-system.pdf> [Accessed 6 April 2020].

[75] For an international comparison of the UK's all-important structural settings, see the 'heatmap' in the Appendix.

[76] Department for Environment, Food & Rural Affairs, 2019. *Leading the charge for the environment.* [online] Available at: <https://www.gov.uk/government/speeches/leading-the-charge-for-the-environment> [Accessed 2 January 2020]

[77] For more detail and coverage, see HM Government, 2018. *The Clean Growth Strategy: Leading the way to a low carbon future.* [online] Available at: <https://www.gov.uk/government/publications/clean-growth-strategy> [Accessed 7 April 2020]

[78] For more, see Webometrics, 2020. *Countries arranged by Number of Universities in Top Ranks,* [online]. Available at: <http://webometrics.info/en/node/54> [Accessed 1 March 2020]

[79] Department for Business, Energy & Industrial Strategy (2019). *International comparison of the UK research base, 2019.* Available at: https://www.gov.uk/government/publications/international-comparison-of-the-uk-research-base-2019 [Accessed 1 March 2020]

[80] Field-weighted citation impact (FWCI) is a measure of how much impact a set of publications have had. It compares the actual number of citations received by publications with the average number of citations a publication published in the same year, discipline, and format (book, article, review, conference paper) receives. A value of 1.0 represents the world average. The overall FWCI for a set of publications, in this case all of the UK's 2018 publications, is therefore the average of the FWCI for each specific UK publication; For a comprehensive explanation of all technical terms see the Glossary tab within the statistical release: https://www.gov.uk/government/publications/international-comparison-of-the-uk-research-base-2019

[81] World Intellectual Property Organisation, 2019. *Global Innovation Index 2019,* [online]. Available at: <https://www.wipo.int/publications/en/details.jsp?id=4434> [Accessed 11 February 2020]

[82] Department for Business, Energy & Industrial Strategy, 2019. *International comparison of the UK research base, 2019,* [online] Available at: https://www.gov.uk/government/publications/international-comparison-of-the-uk-research-base-2019 [Accessed 1 March 2020]

Department for Business, Energy & Industrial Strategy, 2019. *The Grand Challenges,* [online]. Available at: <https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges#clean-growth> [Accessed 1 February 2020]

[83] HM Government, 2017. *Industrial Strategy: Building a Britain fit for the future,* [pdf]. Available at: <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/664563/industrial-strategy-white-paper-web-ready-version.pdf> [Accessed 3 February 2020]

[84] Low carbon and renewable energy economy has been defined as: "Economic activities that deliver goods and services that are likely to help the UK generate lower emissions of greenhouse gases, predominantly carbon dioxide." For more, see ONS, 2020. *Low carbon and renewable energy economy, UK: 2018,* [online] Available at: <https://www.ons.gov.uk/releases/lowcarbonandrenewableenergyeconomyuk2018> [Accessed 10February 2020]

[85] For more detail, see HM Government, 2018. *The Clean Growth Strategy: Leading the way to a low carbon future.* Available at: <https://www.gov.uk/government/publications/clean-growth-strategy> [Accessed 7 April 2020]

[86] Workman, D., 2020. *Electric Cars Exports by Country,* World's Top Exports, [online]
Available at: <http://www.worldstopexports.com/electric-cars-exports-by-country/> [Accessed 1 April 2020]

[87] See, Ambrose, J., 2019. UK launches £315m new tech fund to help industry cut emissions, *The Guardian,* [online] 5 November. Available at: <https://www.theguardian.com/environment/2019/nov/05/uk-tech-fund-industry-emissions-energy-bills> [Accessed 6 April 2020]

[88] Source: Committee on Climate Change, 2018. Reducing UK emissions 2018 Progress Report to Parliament [online]. Available at: <https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf> [Accessed 29 April 2020]

[89] For more, see Cooper, D., 2019, Low rates provide a historic opportunity to tackle climate change, *Financial Times,* [online], 9 December. Available at: <https://www.ft.com/content/c752698c-200c-11ea-92da-f0c92e957a96> [Accessed 6 April 2020]

[90] Vehicles are becoming more complex, resulting in an ever expanding supply chain and entering new markets beyond more traditional, established routes. As a result, the whole industry is working together to ensure that the materials that go into vehicles have been sourced responsibly … A transition to an electrified powertrain presents opportunities in a number of commodity areas with no established supply base. With the opportunities around battery manufacture has come a business case for a UK gigafactory.
For more see https://www.smmt.co.uk/reports/sustainability/ [Accessed 5 April 2020]

[91] For more see World Economic Forum, 2019. *The Global Competitiveness Report 2019,* [pdf]. Available at: <http://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2019.pdf> [Accessed 1 April 2020]

[92] For more see Lithuanian Free Market Institute, 2018. *Employment Flexibility Index 2019: EU and OECD countries,* [pdf]. Available at: <http://www.epicenternetwork.eu/wp-content/uploads/2019/01/Employment-flexibility-index-2019.pdf> [Accessed 1 April 2020]

[93] Ibid.

[94] See press release for LSE Growth Commission, 2020. *UK Budget needs to include major zero-carbon investments to reposition its economy in next decade,* [online]. Available at: <http://www.lse.ac.uk/GranthamInstitute/news/uk-budget-needs-to-include-major-zero-carbon-investments-to-reposition-its-economy-in-next-decade/>
[Accessed 3 April 2020]

For the full report, see LSE Growth Commission, 2020. *Delivering strong and sustainable growth in the UK: a special decade for innovation and investment,* [pdf]. Available at: http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2020/03/Delivering-strong-and-sustainable-growth-in-the-UK_A-special-decade-for-innovation-and-investment.pdf [Accessed 3 April 2020]

[95] Committee on Climate Change [CCC], 2019a. *Net Zero – The UK's contribution to stopping global warming,* p. 213., [online]. Available at: <https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/> [Accessed 31 January 2020]

[96] Estimates of expenditure multipliers have to be interpreted with care. Basic estimates allow the full set of expenditure iterations to run their course. Other estimates, however, and particularly those applied to public sector expenditure, may incorporate some form of policy reaction – an offsetting tax, for example, to reduce or eliminate the effect of public sector investment on the public sector deficit; or a change in the stance of monetary policy so as to leave the inflation rate unchanged. Such adjustments, which reduce the estimated value of the multiplier, are however scarcely relevant in the current situation. To begin with, a good part of the UK's green transition investment expenditure will be undertaken by the private sector, not by government, so there is most unlikely to be any offsetting government fiscal action. And with the prospect of inflation and interest rates staying low for many years yet, any monetary tightening targeted at inflation is an equally distant prospect. For more, see Barrell, R., Holland, D., and Hurst, I., 2013. *Fiscal multipliers and prospects for consolidation.* [pdf], OECD Journal: Economic Studies, Vol. 2012/1. Available at: <https://www.oecd.org/economy/growth/fiscal-multipliers-and-prospects-for-consolidation.pdf> [Accessed 26 March 2020]

[97] The IMF, in 2010, reported values for US and euro-area multipliers in the range of 1.0 to 1.5. See IMF, 2010. *Effects of Fiscal Stimulus in Structural Models.* [pdf], Research Department Working Paper WP/10/73. Available at: <https://www.imf.org/external/pubs/ft/wp/2010/wp1073.pdf> [Accessed 12 March 2020] The Oxford Economics paper for the 2019 MTA conference implies a value of 1.5. See Oxford Economics, 2018, op. cit.. Similarly, it has been suggested that, in the context of green investment in the UK, the multiplier may be higher than for many other forms of investment: the environmentally-linked sectors in the UK have greater links to other sectors than is the case in other European countries. Estimates by the University of Hull in 2017 suggest that recent supply-chain investment by Siemens in the Humber region had an economic multiplier of 1.47, generating gross value added of £71.3 million. See Blyth, W. et al, 2014. *Low carbon jobs: The evidence for net job creation from policy support for energy efficiency and renewable energy.* [online] Available at: <http://www.ukerc.ac.uk/publications/low-carbon-jobs-the-evidence-for-net-job-creation-from-policy-support-for-energy-efficiency-and-renewable-energy.html>
[Accessed 2 February 2020]

[98] IMF, 2014. World Economic Outlook October 2014. Chapter 3. 'Is it time for an infrastructure push? T*he macroeconomic effects of public investment',* p. 82. [online]
Available at: <https://www.imf.org/external/pubs/ft/weo/2014/02/> [Accessed 25 March 2020]

[99] The OECD, averaging across three different model estimates, has estimated that a sustained increase in public investment in the UK of ½ percentage point of GDP leads to a long-term output gain (potential GDP) of around 1½ % of GDP (i.e. a 3% increase for a 1% increase in investment). See Mourougane, A., Botev, J., Fournier, J-M., Pain, N., and Rusticelli, E., 2016. *Can an increase in public investment sustainably lift economic growth?* OECD Economics

Department Working paper, 24 November, paragraphs 26 – 31, and Figure 8. Available at: <http://www.oecd.org/economy/public-finance/Can-an-increase-in-public-investment-sustainably-lift-economic-growth.pdf> [Accessed 12 March 2020.]

The IMF has estimated similar figures, with the caveat that underlying economic conditions affect the value importantly: "The macroeconomic effects of public investment shocks are very different across economic regimes (Figure 3.6, panels 1 through 4). During periods of low growth, a public investment spending shock increases the level of output by about 1½ percent in the same year and by 3 percent in the medium term, but during periods of high growth the long-term effect is not statistically significantly different from zero." See IMF, 2014. *World Economic Outlook October 2014.* Chapter 3. *'Is it time for an infrastructure push? The macroeconomic effects of public investment'*, p. 82. [online] Available at: <https://www.imf.org/external/pubs/ft/weo/2014/02/> [Accessed 25 March 2020]

Elsewhere the IMF has found statistical evidence for a value of 2.5: see Abiad, A., Furceri, D., and Tapalova, P., 2015. *The Macroeconomic Effects of Public Investment: Evidence from Advanced Economies.* [online], IMF Working Paper WP/15/95, especially p. 19. Available at: <https://www.imf.org/en/Publications/WP/Issues/2016/12/31/The-Macroeconomic-Effects-of-Public-Investment-Evidence-from-Advanced-Economies-42892> [Accessed 12 March 2020]

[100] Note that this is a gross figure: the net increment to GDP would not be that high, because an unknowable amount of GDP will be lost from declining sectors. But the key point is that the increment to GDP that stands to be created by green investment is large.

[101] The gross value added (GVA) of the UK economy in 2019 in current prices was £1,985,613. Manufacturing (GVA) was £m 190,994. Source: ONS.

[102] It has been estimated by Oxford Economics that the gross value added of the manufacturing sector's supply chain is about two-thirds the size of that of the manufacturing sector itself (viz. 6% of GDP in the supply chain v. 9% in manufacturing). See Oxford Economics, 2018, op. cit..

[103] For more on this point, see Robins, N., Gouldson, A., Irwin, W., Sudmant A., and Rydge, J., 2019. *Financing inclusive climate action in the UK – An investor roadmap for the just transition.* [pdf] LSE, October, p. 48 Available at: <http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2019/09/Financing-inclusive-climate-action-in-the-UK_An-investor-roadmap-for-the-just-transition_POLICY-REPORT_56PP.pdf> [Accessed 26 March 2020]

[104] Note however that, as argued earlier, the concept of a 'business as usual' path (also often termed a baseline projection), has to be handled with care. As its name implies, it is essentially an extrapolation of a present configuration. But if the present configuration is unsustainable, then a 'business as usual' baseline projection has no meaning. In that sense the 18 million figure is an underestimate, because it does not include the (presumably significantly lower) level of employment that would result were the economy not to adapt.

[105] The ILO notes that "Employment creation is driven by the higher labour demand of renewable energy sources in comparison with electricity produced from fossil fuel sources, and the employment demand of the entire value chain associated with renewable energy and electric vehicles and construction." See International Labour Organization [ILO], 2018. *World Employment Social Outlook: Greening with jobs,* [pdf], p. 42. Available at: <https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_628654.pdf> [Accessed 31 January 2020]

[106] UKERC Technology & Policy Assessment Function, 2014. *Low carbon jobs: The evidence for net job creation from policy support for energy efficiency and renewable energy.* [online] Available at: <http://www.ukerc.ac.uk/publications/low-carbon-jobs-the-evidence-for-net-job-creation-from-policy-support-for-energy-efficiency-and-renewable-energy.html> [Accessed 3 April 2020]. That said, the net impact on jobs in the long run could well be lower, to the extent that the operation and maintenance of more productive renewable technologies becomes less labour intensive.

[107] HM Government, 2019. *Green collar jobs in offshore wind set to triple by 2030.* Press release, [online], 6 March, Department for Business, Energy and Industrial Strategy. Available at: <https://www.gov.uk/government/news/green-collar-jobs-in-offshore-wind-set-to-triple-by-2030> [Accessed 30 January 2020]

[108] There could be other issues too: while the economy was weak, even pre-COVID-19, employment was strong, a reflection in part of the tendency of the UK's flexible labour force to price itself into employment. In recoveries, the uptick in productivity could exceed that of employment. Thus there are many uncertainties: the figure of 0.5 has been selected essentially only to establish a plausible order of magnitude.

[109] This is not to say that net job growth would be that high: an unknowable number of jobs will be lost from declining sectors. But the key point is that the number of new jobs that stand to be created if green investment is undertaken on an appropriate scale is high. (Employment in the UK was approximately 33 million. Source: ONS.)

[110] Employment in UK manufacturing immediately pre the COVID-19 crisis stood at 2.9 million. Source: ONS.

[111] It has been estimated by Oxford Economics that employment in the manufacturing sector's supply chain (2.4 million at the time their report was written) is almost as large as in the manufacturing sector itself (then 2.6 million.) See Oxford Economics, 2018, op. cit.

[112] As cited in Hurt, L., 2020. Less Oil, No Carbon, Few Answers: BP CEO's Hazy Vision of Future, Bloomberg, [online] 12 February. Available at: <https://www.bloomberg.com/news/articles/2020-02-12/less-oil-no-carbon-few-answers-bp-ceo-s-hazy-vision-of-future> [Accessed 7 April 2020]

[113] See Robins, N., Gouldson, A., Irwin, W., Sudmant A., and Rydge, J., 2019. *Financing inclusive climate action in the UK – An investor roadmap for the just transition.* [pdf] LSE, October, p. 30. Available at: <http://www.lse.ac.uk/

GranthamInstitute/wp-content/uploads/2019/09/Financing-inclusive-climate-action-in-the-UK_An-investor-roadmap-for-the-just-transition_POLICY-REPORT_56PP.pdf> [Accessed 7 February 2020]

[114] For more, see Robins et. al, 2019, op. cit..

[115] For more, see International Renewable Energy Agency [IRENA], 2016. *Unlocking renewable energy investment: the role of risk mitigation and structured finance.* [pdf] Available at: <https://www.irena.org/documentdownloads/publications/irena_risk_mitigation_and_structured_finance_2016.pdf> [Accessed 5 April 2020]

[116] For a summary, see BIS and Government Office for Science, 2013. *Foresight report: The future of manufacturing: a new era of opportunity and challenge for the UK.* Summary Report. [pdf] The Government Office for Science, London. Available at: <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/255923/13-810-future-manufacturing-summary-report.pdf> [Accessed 5 March 2020]

[117] Policies reckoned to have a particularly important impact include: funding for further and higher education; corporation tax; and integration with European markets. For more, see House of Commons Library, 2020. *Manufacturing: statistics and policy.* [online] Briefing paper 01942, 10 January, p. 25.
Available at: <https://commonslibrary.parliament.uk/research-briefings/sn01942/> [Accessed 3 April 2020]

[118] Rydge, J. et al., 2018. *Sustainable growth in the UK. Seizing opportunities from technological change and the transition to a low-carbon economy,* [pdf], LSE Growth Commission. Available at: <http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2018/12/Sustainable-Growth-in-the-UK_Full-Report_78pp.pdf>
[Accessed 3 April 2020]

[119] (Haldane is also Chief Economist of the Bank of England). See Strauss, D., 2020. UK's industrial strategy criticised by independent body. *Financial Times,* [online] 19 February.
Available at: <https://www.ft.com/content/8fc12094-52f7-11ea-90ad-25e377c0ee1f> [Accessed 3 April 2020]

[120] This judgement was reached following a review led by Professor Juergen Maier, the then CEO of Siemens UK, of how UK manufacturing can maximise benefits from increasing adoption of digital technology. See Maier, J., 2017. *Made smarter: Review 2017.* [pdf] Assets.publishing.service.gov.uk., p. 9.
Available at: <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/655570/20171027_MadeSmarter_FINAL_DIGITAL.pdf> P. 9 [Accessed 3 April 2020]

[121] See Maier, 2017. Op. cit..

[122] See LSE Growth Commission, 2018. *Sustainable growth in the UK: Seizing opportunities from technological change and the transition to a low-carbon economy.* [pdf] Available at: <http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2018/12/Sustainable-Growth-in-the-UK_Full-Report_78pp.pdf> [Accessed 5 April 2020]

[123] Besley, T., and Davies, R., 2019. *Beyond Brexit: A programme for UK reform.* Chapter 7, Formulating Industrial Policy. Policy Reform Group <https://www.policyreformgroup.org/> Available on request.

[124] See Robins, N., Gouldson, A., Irwin, W., Sudmant A., and Rydge, J., 2019. *Financing inclusive climate action in the UK – An investor roadmap for the just transition.* [pdf], LSE, October. Available at: <http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2019/09/Financing-inclusive-climate-action-in-the-UK_An-investor-roadmap-for-the-just-transition_POLICY-REPORT_56PP.pdf> [Accessed 31 January 2020]

[125] See Martin, J., 2019. *Beyond Brexit: A programme for UK reform. Chapter 2, Supporting dynamic economic adjustment.* Policy Reform Group <https://www.policyreformgroup.org/> Available on request.

[126] See OECD, *Indicators of Product Market Regulation,* and the link to the Excel table. [online] Available at: <https://www.oecd.org/economy/reform/indicators-of-product-market-regulation/> [Accessed 3 April 2020]

[127] The only areas where the UK scores below the OECD average are: the complexity of some regulatory procedures (although this has declined significantly over the past decade); and the governance of the residual state owned enterprises.

[128] This rate has been estimated and promulgated by economists ranging from Nicholas Stern to those in the International Financial Institutions (the IMF, OECD, World Bank) to the UK Department for Business, Energy and Industrial Strategy.

[129] See Giles, C. and Hook, L., 2020. Zero emissions goal: the mess of Britain's carbon taxes. *Financial Times,* [online] 10 March. Available at: <https://www.ft.com/content/c4e7cf36-61f5-11ea-a6cd-df28cc3c6a68> [Accessed 12 March 2020]. The authors note that "If residents of the UK emit a tonne of carbon driving their cars, they face a steep bill of £109, according to Energy Systems Catapult, an independent think-tank. If they use the lights and computers in their homes, they pay an effective tax of £41, while the same damage to the climate from heating their homes with heating oil comes with a charge of only £7. Gas-fired heating comes with an effective subsidy of £14 a tonne of carbon and if people fly, the government offers a juicy subsidy of £26 because no value added tax is charged."

[130] An interesting practical example of how effective standards-setting can be is offered by BREEAM "… the world's leading sustainability assessment method for master planning projects, infrastructure and buildings." BREEAM assesses a number of lifecycle stages including New Construction, Refurbishment, and In-Use. Globally there are more than 562,500 BREEAM-certified developments, and almost 2,266,400 buildings have registered for assessment since it was first launched in 1990. For more, see <http://www.c80solutions.co.uk/service/breeam/?gclid=EAIaIQobChMI8Me-lqyr5wIVhrHtCh1WvgjyEAAYASAAEgIRGfD_BwE>

Another example of what can be achieved is afforded by Yorkshire Water, which has developed a Total Impact and Value Assessment) (TIVA) framework to guide its strategic direction. It uses the so-called 'Six Capitals' model, as developed in the Integrated Reporting Framework by the International Integrated Reporting Council: human

capital (e.g. the workforce's capabilities and wellbeing); social capital (e.g. community relationships and customer trust); intellectual capital (e.g. knowledge and technical processes); manufactured capital (e.g. infrastructure and technology); financial capital (e.g. financial health and efficiency); and natural capital (e.g. the services provided by the environment). Based on the TIVA model, Yorkshire Water released a Sustainable Finance Framework in 2019 to align its bond-raising strategy with both social and environmental priorities. This moved beyond the standard 'green bond' approach to include social priorities, including access to services and socioeconomic advancement, as well as environmental priorities (such as renewable energy, sustainable water management and biodiversity). Its first sustainability bond was issued in April 2019, raising £350 million with a 22-year maturity. For more on these two initiatives, see Robins et. al., 2019, op. cit..

[131] Ecodesign and Energy labelling standards and minimum UK Energy Labelling standards are for example being planned to be introduced from Jan 2021. For more, see HM Government, 2019. *Meeting climate change requirements from 1 January 2021,* [online] Available at: <https://www.gov.uk/government/publications/meeting-climate-change-requirements-if-theres-no-brexit-deal/meeting-climate-change-requirements-if-theres-no-brexit-deal> [Accessed 3 April 2020]

[132] Andrew Sentance, former member of the UK Monetary Policy Committee, quoted in Giles, C., and Hook, L., 2020. Zero emissions goal: the mess of Britain's carbon taxes. *Financial Times,* [online] 12 March 2020. Available at: <https://www.ft.com/content/c4e7cf36-61f5-11ea-a6cd-df28cc3c6a68> [Accessed 12 March 2020]. This article also usefully reviews in greater detail the current range of tax rates on carbon in the UK.

[133] See Fleming S., 2019. *These are the countries that have made their climate commitments law.* World Economic Forum. Available at: <https://www.weforum.org/agenda/2019/11/new-zealand-net-zero-2050/> [Accessed 3 April 2020]

[134] An early, and intellectually important, proponent was Nordhaus, W., 2008. *A Question of Balance: Weighing the Options on Global Warming Policies.* Yale University Press.

[135] See Bowen et al 2017. *Consultation response: Building our Industrial Strategy.* [online] Grantham Research Institute, London School of Economics. Available at: http://www.lse.ac.uk/GranthamInstitute/publication/consultation-response-building-our-industrial-strategy/ [Accessed 3 April 2020]

[136] The primary constraint thereby becomes politics not economics: if the policy shock is socially as well as innovatively disruptive, it could meet resistance that sets back policy progress (as recent examples in France for example testify). The fact that key barriers to early and ambitious action are behavioural and political, rather than technological and economic, offers a guide to policymakers. Understanding where policy impact will be felt is a central pillar of climate strategy. It explains why much of the recent focus has been on a 'just transition'. Such a transition must not only be effective but be, and be seen to be, fair. This is not just politically expedient; it is practically necessary if climate policies are to be enacted at sufficient scale and speed. (For more on the political economy of structural reform see Policy Box 3: Promoting a supportive environment for structural reform.)

[137] This will of course differ from country to country, and inevitably imply a policy landscape that is patchy, lumpy and – from a static perspective – less than perfectly efficient. Moreover, the fact that dynamic pathways deal with future uncertainty means taking calculated risks. Some policies will come right, others will, ex post, turn out to have been wasteful, while still justifiable ex ante.

[138] See Jones, R., and Llewellyn, J., 2019. *Beyond Brexit: A programme for UK reform.* Chapter 9: Improving infrastructure. Policy Reform Group <https://www.policyreformgroup.org/> Available on request.

[139] Britain has become increasingly reliant on energy imports from Europe, at a time when existing coal and nuclear reactors are being phased out. This begs the question of whether the rapidly falling cost of renewables means that there is no longer an economic case for nuclear power. It would also make sense to include more small-scale, less complex, local non-energy sector projects in the infrastructure pipeline: these would have risk profiles that appeal more to the private sector. Where these projects address particular bottlenecks, the rates of return can be especially high.

[140] This would assist in easing regional imbalances in productivity, job creation, wage levels, and community cohesion. Prioritising HS2 and Northern Powerhouse Rail would be important statements in this regard.

[141] This would help to draw more private sector investors into large-scale Greenfield projects. Directing financial incentives to private sector involvement in infrastructure more at the higher end of the risk and deal-size spectrum would help to avoid 'crowding out'. Giving greater impetus to institutional investment pooling, the provision of tax incentives for utility, project, and local government bond issues, and the creation of Infrastructure Individual Savings Accounts (IISAs) to raise the level of retail investment in infrastructure and utilities, could also help attract more private capital.

[142] Importantly, this should also extend to the linking of infrastructure plans to the government's strategies for skills, housing, industrial policy, and innovation.

[143] For a full discussion of the reason for this proposal, the way that it might operate, and the advantages that it could bring, see Jones, R., and Llewellyn., J., 2013. *UK Infrastructure: the challenges for investors and policymakers.* Pension Insurance Corporation and Llewellyn Consulting. Available at: <https://e2f546e7-c864-404c-b79b-99a12b16f765.filesusr.com/ugd/264e4c_7dba93bb076e481c8355ab8aac3a2311.pdf>

[144] The importance of this point has been emphasised by Robins et. al., 2019, op. cit., who note that:

- **"For workers,** it means anticipating employment shifts, enabling them to contribute their own ideas and experience to the transition, respecting rights at work, developing the skills that will be needed, ensuring decent pay and conditions, protecting health and safety, and delivering social protection (including benefits and pensions).

- **For communities,** it means understanding the spillover effects of the transition for affected places, respecting communities' rights to be consulted about how to manage climate impacts, and their involvement in new decision-making mechanisms, and supporting community empowerment in the transition (for example through new ownership models).
- **For consumers,** it means giving priority focus to supporting those with inadequate access to sustainable goods and services (notably those living in fuel poverty, without access to transport or unable to pay their water bills). It also means removing barriers to consumers taking an active part in the transition, not least in the world of finance and investment.
- **For citizens** overall, it means creating effective frameworks for participation in the transition, building on traditional mechanisms to include new tools (such as Citizens' Assemblies) so that both the procedural and distributional aspects of the transition are dealt with openly and fairly."

[145] For more, see Jones, R., and Llewellyn, J., 2019. *Beyond Brexit: A programme for UK reform.* Chapter 11: Reducing inequalities. Policy Reform Group. <https://www.policyreformgroup.org/> Available on request.

[146] Quoted in *The Telegraph Business,* 2019. How UK businesses can be ready for climate change. [online] 6 June Available at <https://www.telegraph.co.uk/business/tips-for-the-future/ready-for-climate-change/> [Accessed 3 April 2020]

[147] For more on this, see for example Baker, S. R., Bloom, N. and Davis, S. J., 2012. *Measuring Economic Policy Uncertainty.* [pdf] Available at: <https://web.stanford.edu/~srbaker/Papers/BakerBloomDavis_PolicyUncertainty.pdf> [Accessed 3 April 2020] See also Etsy, D. C. and Porter, M. E. 2005. *National Environmental Performance: An Empirical Analysis of Policy Results and Determinants.* Cambridge: Cambridge University Press.

[148] See Bowen et al 2017, op. cit..

[149] Veugelers et al., 2009

[150] Mazzucato, M. The Entrepreneurial State, 2014. Anthem Press.

[151] Such institutions help to overcome principle-agent problems, such as in the case where tenants pay heating bills giving landlords little incentive to invest in home insulation which would curb costs.

[152] For more see Susskind and Susskind, 2018; and Adams, 2018.

[153] Ahmed K., 2018. *Bank of England chief economist warns on AI jobs threat.* BBC News, [online] 20 August. Available at: <https://www.bbc.co.uk/news/business-45240758> [Accessed 1 February 2020]

[154] Ibid.

[155] For more see Zenghelis, D. et al., 2018.

[156] See Haldane, A., 2018. I*deas and Institutions – A Growth Story.* [pdf] Speech to the Guild Society, University of Oxford. 23 May. Available at: <https://www.bankofengland.co.uk/-/media/boe/files/speech/2018/ideas-and-institutions-a-growth-story-speech-by-andy-haldane.pdf [Accessed 10 January 2020]

[157] LSE Growth Commission, 2018. Op cit..

[158] For more see Bassi, S. and Zenghelis, D., 2014. *Burden or opportunity? How UK emissions reductions policies affect the competitiveness of businesses* [pdf] Policy paper, Centre for Climate Change Economics and Policy Grantham Research Institute on Climate Change and the Environment, LSE. Available at: http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2014/07/Bassi-and-Zenghelis-policy-paper-July-2014.pdf [Accessed 2 April 2020]

[159] Combes B. and Zenghelis D. 2014. Tough Love. [pdf] MacroPlus Comment, Llewellyn Consulting. Available at: <http://media.wix.com/ugd/264e4c_b24f1969bc844dc1840b7152e5ab0f04.pdf> [Accessed 10 February 2020]

[160] For more see Bassi and Zenghelis, 2014. Op cit..

[161] See for example de Serres, A., Llewellyn, J., and Llewellyn, P., 2011. The Political Economy of Climate Change Mitigation Policies: How to Build a Constituency to Address Global Warming?, *OECD Economics Department Working Papers,* No. 887, [online] OECD Publishing, Paris.
Available at: <https://doi.org/10.1787/5kg5d5nhcnkb-en> [Accessed 22 February 2020]

[162] The classic historical example is the development of the UK welfare state during and after the Second World War. At that time, popular support for a concerted effort to slay the 'five giants' of squalor, ignorance, want, idleness, and disease was sufficient to overcome government misgivings about cost and broader feasibility.

[163] For more, see for example Serres, A., Llewellyn, J., and Llewellyn, P., 2011, op. cit., and the references contained therein.

[164] See for example de Serres, A., J. Llewellyn, J., and Llewellyn, P., 2011, op. cit., and the references contained therein.

[165] OECD and IMF econometric evidence supports the view that the most promising time for reform is immediately after a recession or election. In reality, however, there is rarely a good time to implement reform, and economies often have to live with the consequences that emerge from sub-optimal policy sequencing.

[166] The highly successful 'active labour market' policies of the Scandinavian and Nordic countries are a case in point. Much has been written about them. A useful high-level political economy overview can be found in, for example, Martin, J., 2019. Op. cit.

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The Manufacturing Technologies Association

www.mta.org.uk

The Manufacturing Technologies Association
62 Bayswater Road London W2 3PS

T: +44 (0)20 7298 6400 | F: +44 (0)20 7298 6430 | E: info@mta.org.uk