Seizing sustainable growth opportunities from zero emission passenger vehicles in the UK

Special report for the

LSE Growth Commission

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This report is intended to inform decision-makers in the public, private and third sectors. It has been reviewed by internal and external referees before publication.

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Foreword by Nicholas Stern

The UK government has a long-term commitment to improving productivity and achieving sustainable and inclusive growth. Concurrently, the UK has become the first major economy to enter a commitment into law to achieve net-zero annual emissions of greenhouse gases by 2050. The combination of these long-term commitments creates a whole-economy opportunity to drive growth through sustainable investment, innovation and creativity, while demonstrating the UK's international leadership on climate change.

By orienting the economy towards zero-carbon products and services, the UK can seize economic opportunities from the global transition as demand rises for zero-carbon activities. Market forces combined with rising government and societal ambitions across the globe are unleashing demand for zero-carbon goods and services. The costs of technologies such as lithium-ion batteries has fallen by more than 75 per cent over the past 10 years. The zero-carbon transition is the growth story of the 21st century, and a race is now on between economies to become cleaner, smarter and more efficient.

The UK's commitment to sustainable and inclusive growth to date has been increasingly embedded in policies and plans through, for example, the Industrial Strategy and Clean Growth Strategy. The combination of urgency and opportunity implies that the Government should now make a step change, both in the amount of investment and in the package of policies and institutions that can achieve effective impact at scale. Strong institutions and sound policies can unlock further investments in infrastructure, innovation, skills and cities, driving productivity improvements and sustainable growth across the nation.

In many parts of the country, employment in automotive manufacturing and related sectors is interwoven with local communities and their sense of identity, and the zero-carbon transition must be carefully managed to minimise displacement and ensure its benefits are spread. Well-planned policies for sustainable investment can strengthen local cohesion and pride by building local capacity, generating economic opportunities and improving labour market resilience.

In 2018, the LSE Growth Commission released a special report on sustainable growth in the UK, setting out how the country can seize opportunities from technological change and the transition to a low-carbon economy. The report presented the institutional and policy frameworks required to stimulate investments in innovation, infrastructure, skills and cities and to return the UK to long-run and inclusive growth. These principles must underpin the Government's approach to policymaking in the coming years.

The transition towards sustainable growth needs to take place across the entire economy. The Committee on Climate Change's advice to government on net zero shows that substantial structural shifts are required simultaneously across different parts of the economy if the UK is to achieve this ambition and legislative target. These include, but are not limited to: electricity, hydrogen, buildings, road transport, industry, land use, agriculture, aviation, shipping, waste, F-gases, greenhouse gas removals and infrastructure. Road transport is just one of many parts of the economy that are undergoing a significant transition, and that could present growth opportunities for the UK. But it is one of great importance. The UK government's recent decision to move the ban on sales of internal combustion engines forward to 2035 is welcomed. Strong, long-term policy sends a clear signal to both business and consumers, thereby reducing uncertainty and the cost of capital and allowing commitment at the scale that can reduce costs. This report unpacks how the UK can derive balanced and inclusive growth opportunities from a shift towards zero emission passenger vehicles.

***Nicholas Stern**, February 2020*
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Glossary of terms

Connected and autonomous vehicles (CAVs): Vehicles that use information from on-board sensors and systems to understand their global position and local environment, enabling them to operate with little or no human input for some or all of their journey. Future CAVs are expected to have the ability to communicate with their surrounding environment (including infrastructure and other vehicles), and to provide information to the driver that informs decisions about the journey and even activities at the destination.

CAV technologies are the on-vehicle technologies that provide CAVs with their autonomous and/or connected capabilities. This includes software – such as computer imaging and safety critical systems, as well as hardware – such as radar, LIDAR and GPS receivers.

L [Level] 3–5 CAVs are CAVs in which the system performs the entire dynamic driving task while engaged, including monitoring and response as well as steering and acceleration.

Electric vehicles (EVs): Vehicles with an electric motor and battery (also referred to as Battery Electric Vehicles – BEVs).

Extended range electric vehicles (E-REVs) and plug-in hybrid electric vehicles (PHEVs): Vehicles that use an electric motor and battery but are supported by an internal combustion engine that may be used to recharge the vehicle's battery. PHEVs use their electric and ICE motor interchangeably, whereas E-REVs only use the ICE motor when the electrical charge is exhausted.

Internal combustion engines (ICEs): Conventional vehicles that produce power through the combustion of fossil fuels with air inside an engine.

ICE phase-out: The UK government has committed to phase out the sale of all new conventional (i.e. ICE) petrol and diesel cars and vans, with an end date of 2035.

Light duty vehicle (LDV): Road vehicles that include cars, vans and sport-utility vehicles.

Mobility-as-a-service: Digitally-enabled car-sharing and ride-hailing services.

Private charging points: Charging points in workplaces (including depots for fleet vehicles) and homes.

Public charging points: Include long-distance en-route charging, and parking-based charging points.

Executive summary

Key findings

- The rise of zero emission and autonomous vehicles offers a pathway to decarbonise road transport in the UK and provides growth opportunities for the country, part of the whole economy opportunity that sustainable growth presents.
- Despite the UK losing competitiveness in comparison with market leaders, our analysis suggests it could still have a manufacturing opportunity if it steps up incentives to support production in regions across the UK, spurs demand for zero emission vehicles and secures close alignment with the European Single Market and EU emissions regulations.
- The UK could sustain nearly 80,000 jobs in 2030 in the production of electric vehicle powertrain components, charge points, fuel cell powertrain components and autonomous vehicle hardware and software – if the UK is globally competitive in these technologies.
- In this scenario there would be significant additional employment upstream and downstream of component production. For instance, upstream, EV component production would likely be underpinned by a competitive domestic chemicals supply chain. Downstream, car manufacturers would likely be more inclined to assemble vehicles in the UK if the country is manufacturing high value components for zero emission vehicles.
- Related growth opportunities are diverse in nature and extend beyond the automotive supply chain as it is traditionally considered, including areas such as the testing of connected and autonomous vehicles, the production of chemical inputs for batteries, and software platforms for mobility services. Future supply chains could look very different from today's.
- In terms of innovation, the UK's competitiveness varies across technologies and supply chain stages. The UK has a comparatively lower share of global innovation in clean and autonomous car technologies relative to other countries and is lagging behind on EV component innovation; there is still innovation activity in dirty car technologies.
- However, looking at specific technologies within the clean and autonomous car category, the UK has a comparatively greater share of global innovation in connected and autonomous vehicle technologies, and regions such as the West Midlands and Eastern Scotland are hotbeds of zero emission and autonomous vehicle innovation.
- Innovation policy can also be informed by new measures of the social returns from innovation, which include private returns on innovation as well as direct and indirect knowledge spillovers. Such measures can highlight areas where the UK returns to R&D are high.
- To meet this diverse range of opportunities and given varying levels of competitiveness, the UK should adopt a portfolio approach to incentive design, targeting a wide range of goods and services that can contribute to zero emission, connected and autonomous road transport.

Seizing opportunities from goods and services related to passenger vehicles can be part of a strategic approach to achieving net-zero in the UK

The transition to a zero-carbon economy is the growth story of the 21st century. The UK's recent commitment to achieve net-zero annual emissions of greenhouse gases by 2050 presents an opportunity to drive sustainable growth in the country through investment, innovation and creativity. By being at the forefront of the development of zero-carbon products and services, the UK can seize economic opportunities from the worldwide transition that is already underway, and the markets that are growing around the world.

An economy-wide approach to supporting decarbonisation presents the UK with significant opportunities to harness and exploit innovation in transformational technologies such as digitisation, artificial intelligence (AI) and robotics. However, to realise this potential, the UK needs to adopt a strategic approach to decarbonisation and the transition to net-zero economic growth. This will require consistent and long-term policy across government, R&D funded directly by government, and incentives for businesses to invest in innovation for zero-carbon goods and services. Clear signals will also be needed to demonstrate the direction of travel to consumers, and to incentivise and accelerate the switch to zero-carbon alternatives across all sectors of the economy, including transport. This report focuses on how the UK can seize opportunities from goods and services related to passenger vehicles.[1]

Despite the UK losing competitiveness in vehicle manufacturing in comparison with market leaders such as China and Germany, our analysis suggests the country could still have a manufacturing opportunity if it steps up incentives and maintains its focus on driving domestic demand for zero emission vehicles. Furthermore, the areas related to passenger vehicle mobility in which the UK could be competitive extend beyond manufacturing of components to diverse goods and services across value chains and stages of innovation.

Passenger vehicles – an area of opportunity

The UK automotive industry, including both automotive manufacturing and jobs reliant on automotive jobs, accounts for the employment of nearly 450,000 people. In 2019, 1.3 million cars were built in the UK, 1.1 million of which were exported, according to the Society of Motor Manufacturers and Traders. What combination of passenger vehicle technologies takes root in the future remains to be seen – full deployment of individual technologies and trends such as autonomous driving are not yet guaranteed, and there are uncertainties over the speed of take-up. However, the UK government recently signalled its commitment to the domestic uptake of zero emission vehicles by moving a ban on new sales of internal combustion engine (ICE) and hybrid vehicles forward from 2040 to 2035. Furthermore, global technology trends, passenger behaviours and policy signals are gradually steering innovation away from vehicles powered by internal combustion engines, owned by individuals and driven by humans, and towards a number of cleaner and smarter technologies and innovations. Along with unanticipated future innovation related to zero emission passenger vehicles, these are the focuses of our analysis:

- Electric vehicles (EVs), charging infrastructure and supporting services
- Connected and autonomous vehicle (CAV) hardware and software
- Fuel cell vehicles and infrastructure
- Mobility-as-a-service (e.g. digitally-enabled ride-hailing)

[1] This is the first in a series of reports by the LSE's Grantham Research Institute on Climate Change and the Environment and the Centre for Economic Performance that will identify how the UK can maintain a focus on sustainable and inclusive growth in different parts of the economy as the country seeks to redefine its place in the world and achieve net-zero emissions.

Expected technology trends and drivers in road transport

The main developing technologies expected to penetrate further in the 2020s, to differing degrees, are:

- *Electric vehicles (EVs):* EV sales are expected to increase significantly through the 2020s, both domestically and globally. The 2019 Battery Price Survey by Bloomberg New Energy Finance (BNEF) predicts that EVs will start to reach price parity with internal combustion engine vehicles globally in 2024, after which sales will gather pace. This will be accompanied by improvements in performance and resultant reductions in anxiety over range.
- *Connected and autonomous vehicle (CAV) hardware and software:* Many vehicles sold today are already equipped with some autonomous functionality. Sales of CAVs with fully autonomous capabilities (e.g. L4–5) are expected to gradually increase through the 2020s but fully autonomous vehicles are not expected by BNEF to have a meaningful impact on transport patterns until the 2030s. Autonomous driving will be enabled by regulatory frameworks which allow L4–5 autonomous vehicles to drive on roads and growing consumer confidence in the technologies.
- *Fuel cell vehicles and infrastructure:* Fuel cells are not anticipated to have a material impact up to 2030 for passenger vehicles as there is not yet a supply of hydrogen available at scale or a demonstrated infrastructure network that can safely carry it to vehicles. The 2020s are likely to provide an opportunity for testing, refining and demonstrating the technology, with it being most viable for heavy goods vehicles.
- *Mobility-as-a-service*: With a proliferation of ride-sharing applications and car clubs, mobility-as-a-service is likely to increase significantly through the 2020s, driven by factors including shifts in vehicle ownership behaviours and the disrupting force of technologies such as artificial intelligence and the internet of things working together. The impact on car sales and ownership is not clear but the market for technologies which enable mobility as a service is set to increase.

Passenger vehicles (even if self-driving or under shared ownership) are expected to continue to play a role in future transport systems in 2030, alongside other mobility modes such as cycling. Therefore, opportunities in the design and manufacture of passenger vehicles as well as auxiliary services can be created by an ambitious vision for sustainable growth in the UK.

Sizing up the future growth opportunity for the UK

A broad range of growth opportunities exist for the UK in relation to passenger vehicles, from early stage innovation through to diffusion, across the value chain. Automobile value chains themselves are expected to change shape in the coming years as they are upgraded due to rising wage costs in emerging economies, the digitisation of production and the bundling of goods and services together. These factors will potentially create opportunities for advanced economies, including the UK, to regain international competitiveness in the passenger vehicle industry. Production may also become more distributed and closer to markets for consumption.

There is increasing awareness of the strong linkages between manufacturing and services, with business services able to provide inputs into manufacturing processes. The Government should think strategically about where the UK could have advantage across innovation and value chains, given the competition it faces from other economies.

Below we outline how competitive the UK is in different areas across the value chain and where employment opportunities may lie:

- *Raw material production:* The UK is exploring lithium mining opportunities in Cornwall, but this is early stage research and it is not clear whether production can be cost-competitive with imports. Currently, cobalt production is dominated by Democratic Republic of Congo while China has significant lithium production and secondary processing of cobalt. The UK has an established and mature chemical industry that could benefit from increased demand for chemical inputs from a UK-focused battery industry.
- *Manufacturing of components:* The UK's production of batteries has remained small at around 2GWh per annum (powering 60,000 vehicles) at the Nissan Leaf factory. Battery production remains dominated by China (73 per cent of global capacity), followed by the United States and many Chinese and Korean companies are siting production in Europe. It is likely that much of the CAV-related hardware (in particular, sensing and mapping hardware) would be imported to the UK from abroad. Our innovation analysis indicates the UK has a good record for vehicle-to-everything technologies and smart charging technologies.
- *Assembly of components:* The number of UK-based developers of EV charging infrastructure is growing – developing turnkey charging products, by purchasing components from overseas and then assembling them under different configurations – e.g. Jaguar Land Rover recently announced plans to assemble an EV. However, established automotive companies in countries such as China, the United States and Germany (such as Volkswagen) are dominating investment into both EV assembly and charging infrastructure. Large-scale conventional vehicle assembly in the UK is dominated by foreign companies.
- *Sale and usage (including maintenance):* The UK is one of the fastest growing markets for EVs and could be well placed to test the usage of future vehicle technologies such as CAVs – it is already one of the major global centres with four CAV testbeds and internationally active companies testing the technology e.g. Horiba Mira. China remains the world's largest market, accounting for almost half of the global stock. Norway is the global leader in terms of EV market share as a proportion of total vehicles, at 46 per cent of new sales in 2018. A recent survey by KPMG found the Netherlands to be the country most prepared for CAVs, followed by Singapore, Norway and the United States.
- *Services across the supply chain:* A wide range of services play a role in current and likely future supply chains. This includes software and computer services that enable autonomous mobility via passenger vehicles (dominated by Silicon Valley firms); and strategy, management consulting and technical services (e.g. engineering – spread throughout the world but with concentrations of revenue in the United States, China and Canada) related to production of passenger vehicles. The UK is a world-leading green finance centre and financial services continued to be the largest service exported globally by UK businesses in 2017. However, to date the UK's capabilities in, and availability of, green finance have not translated into an advantage for the country's zero emission vehicle industry. The UK has a significant number of major engineering firms, including Mott McDonald, and examples of businesses working on mobility services such as Oxbotica.

In focus: UK jobs from manufacturing of passenger vehicle components in 2030

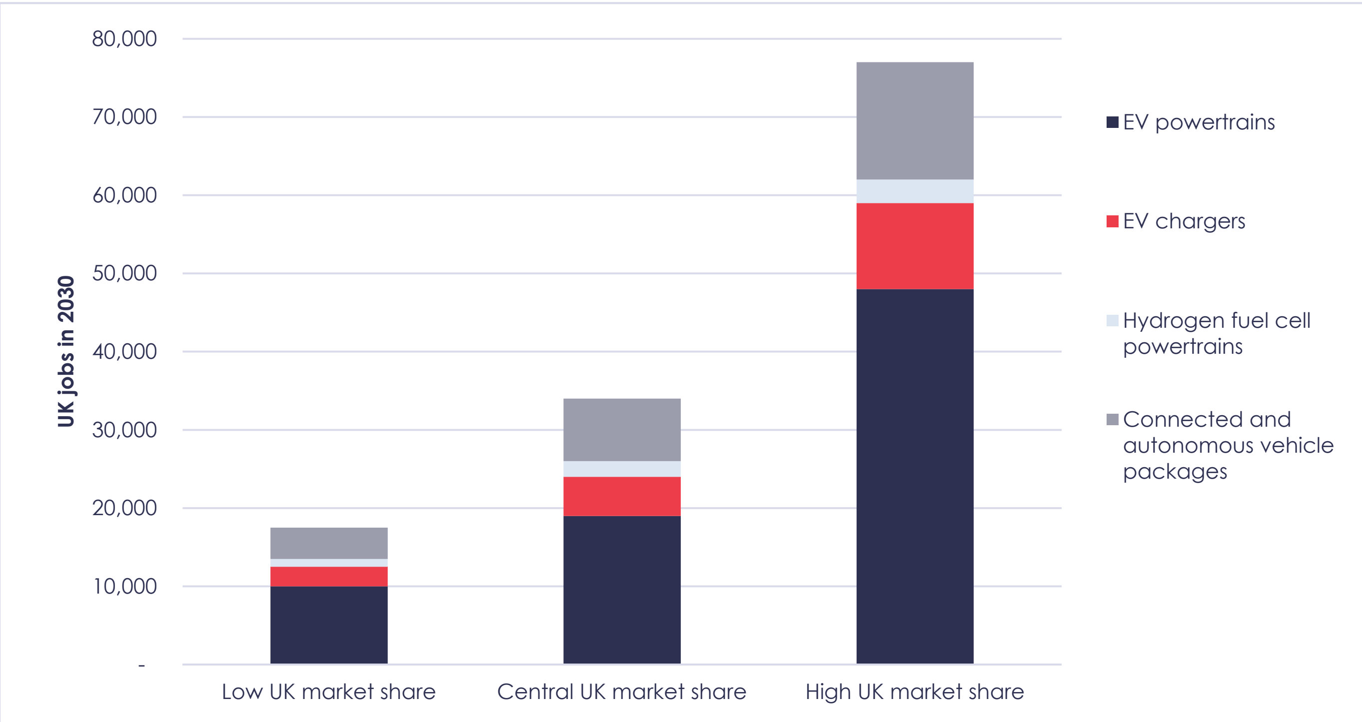
It is challenging to make accurate estimates for the number of individuals that might be employed in the future value chain for passenger vehicles. This is due both to the diverse range of potential employment opportunities as well as to uncertainties about future business models, technology penetration levels, vehicle sales and UK market share. In contrast, fewer assumptions are required to make high level estimates for the jobs that could be directly supported by the manufacture of future goods, based on the value of components if they were manufactured in the UK. We have taken the latter approach but we highlight the fact that the total numbers across the value chain would be much bigger.

To estimate the jobs directly supported by the manufacture of future goods, we project the 2030 sales for different technologies, using a range of sources including the International Energy Agency, Transport Systems Catapult and Frost & Sullivan. Figure 1 outlines the possible number of jobs in 2030 if the UK gains or loses market share relative to the status quo. If the UK can attain the 'high market share' scenario (growing its global market share from 2017 to the level of its close European competitors), the passenger vehicle industry could sustain nearly 80,000 jobs in the direct manufacture of zero emission vehicle powertrain (the mechanism that transmits the drive from the engine of a vehicle to its axle) components and connected/autonomous passenger vehicle components. This does not include broader employment opportunities in the supply chain or remaining jobs in component production for vehicles powered by internal combustion engines. The global market for selected zero emission and autonomous vehicle components made in the UK could be worth £16.8bn in 2030, with EV powertrains making up the bulk of this value, under a 'high UK market share' scenario.

There are currently 168,000 people directly employed in the manufacturing of all types of vehicle in the UK. Many of these jobs are not powertrain-specific (e.g. chassis production) and thus in theory are transferable to zero emission vehicles. However, securing UK jobs in the manufacture of zero emission and autonomous vehicle components could be particularly important to anchor the manufacture of a broader range of components in the UK. A strong backbone of next-generation component production in the UK could encourage businesses to continue – or move – production of other vehicle components and assembly to the UK.

However, it is also clear that the UK needs to improve its competitiveness in these technologies if it wants to support a number of workers in manufacturing zero emission vehicle components comparable to the amount currently employed in the manufacture of components for vehicles powered by internal combustion engines.

Figure 1. UK jobs related to selected vehicle and charger components under varied scenarios



Note: each scenario assumes consistent vehicle sales, technology deployment and a sales ban in the UK in 2030 on vehicles powered by the internal combustion engine.
Source: Authors' analysis based on multiple sources

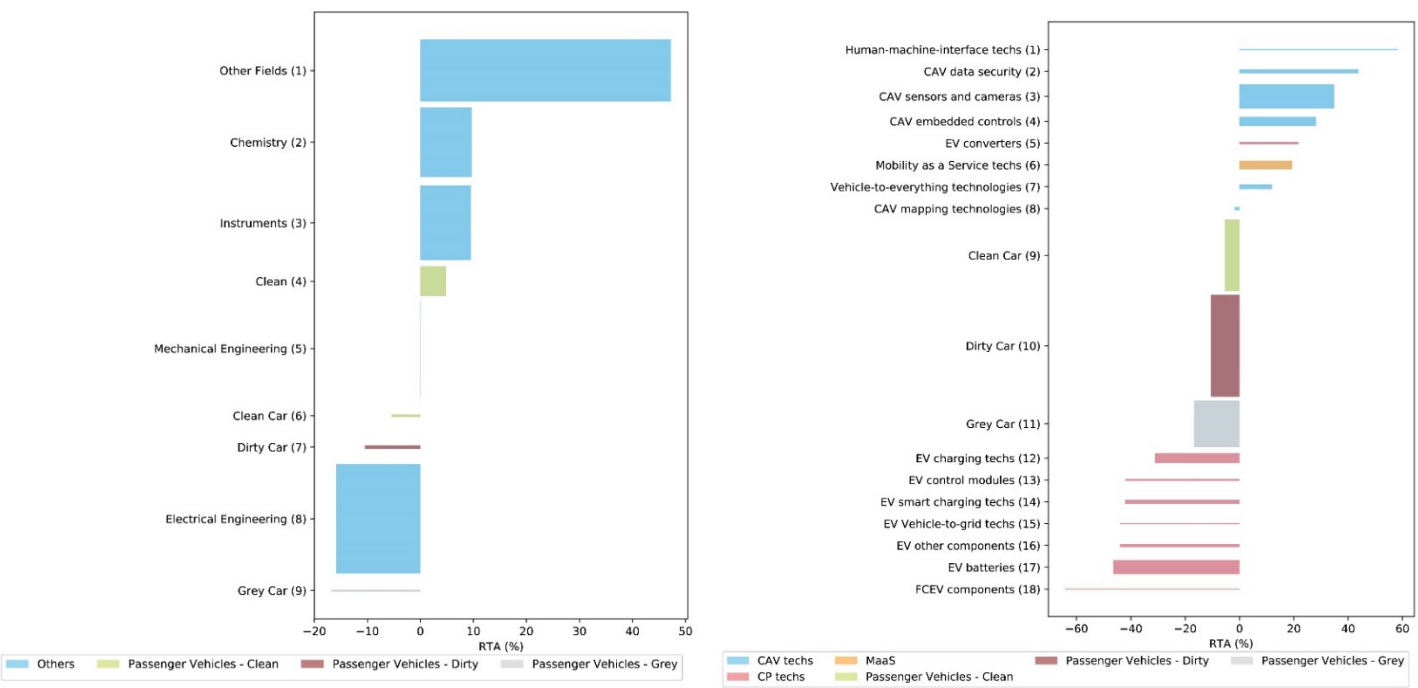
In focus: the UK's innovative strengths

While there is significant uncertainty over future UK competitiveness in goods and services related to zero emission passenger vehicles, tracking innovation activity can give an indication of areas in which the UK might enjoy comparative advantage. A useful measure to consider is Revealed Technological Advantage (RTA), which gives the share of an economy's patents in a particular technology field relative to the share of patents in that field around the world. This gives an indication of the relative specialisation of a given country in selected domains of technological innovation. Figure 2, Panel A shows the UK's RTA in clean car innovation compared with the rest of world between 2005 and 2014. This reveals that at a broad, economy-wide level, the UK is doing comparatively worse in clean car innovation compared with other countries – in contrast with other broad categories of the economy (including cleantech as a whole), in which the UK has a greater share of innovation than other countries.

Figure 2. Revealed technological advantage (RTA) of the UK in clean car innovation compared with the rest of world (2005–14)

A. Share of clean car innovations in the UK compared with rest of world

B. UK innovation in clean cars compared with broader innovation



Notes: The x-axis (width of the bar) shows the RTA; the depth of the bar on the y-axis is proportional to the number of patents in each category. Source: Authors' estimates based on PATSTAT

Panel B shows UK innovation at a more granular level within the clean car category, compared to broader categories of car innovation. This analysis suggests that within the category of clean cars, the UK is outperforming the rest of the world for CAV technologies (labelled CAV techs, coloured blue) and doing worse relative to other countries in clean powertrain technologies (labelled CP techs, coloured pink). While in absolute terms a large number of innovations related to EV batteries have been registered, the UK has a considerably lower share of total innovation than other countries.

Another significant finding is that during the period in question, the UK was still registering more 'dirty' vehicle innovations than 'clean' innovations. This piece of analysis finishes in 2014 given lags in data availability, and we note that the shares of innovation are likely to have changed since then given the significant amounts of R&D funding directed towards clean powertrain technologies (e.g. via the Advanced Propulsion Centre and the Faraday battery challenge).

While RTA gives an indication of the areas in which the UK has specialised, it does not give an indication of the value that the UK – or the rest of the world – might gain from a particular type of innovation. Nor does it give an indication about the ability of governments to promote further innovation in specific areas. Innovation policy can also be informed by measures of the social returns from innovations, which vary considerably in nature and between different technologies and across countries. The 'IStra-X' industrial strategy index methodology allows for the computation of the social return on potential government R&D subsidies to different technology areas, taking into account variation in the private returns on innovation, as well as direct and indirect knowledge spillovers. It also allows for differential responses to government subsidies across technology areas.

The IStra-X analysis shows that in the UK, car related technologies as a whole tend to deliver lower social returns than most other technology fields. Furthermore, public R&D investments in clean cars appear to deliver comparatively lower social returns to the UK than 'dirty' and 'grey' car technologies, relative to the cost and likelihood of innovation. This may be explained by the enduring incumbency of the ICE vehicle and the corresponding firms innovating incrementally.

Nonetheless, as with relative technological advantage, there is a high level of heterogeneity between specific vehicle technologies. EV vehicle-to-grid technologies and vehicle-to-everything technologies are the technologies that outperform dirty and grey car technologies when considering both RTA and IStra-X as indicators; the UK outperforms the rest of the world in innovation related to these technologies, and they deliver notable innovation-related social returns for the UK (in excess of 10 per cent on average).

Given the diversity of these results, and the UK government's decision to target passenger vehicles as a strategic priority (for reasons broader than innovation spillovers), this analysis highlights the need for a portfolio approach to policymaking in this area, with incentives at the aggregated, outcome level – e.g. 'zero emission passenger vehicles'. This may help to mitigate the overall impact of certain passenger vehicle technologies receiving government support while delivering comparatively lower returns than others. More generally, this type of analysis can help highlight other clean technologies, for example in clean energy, where further support can be justified from a growth perspective.

Ensuring opportunities contribute towards regionally balanced growth

Growth opportunities related to clean and autonomous vehicles need to be understood at a regional level to ensure goods and services contribute to growth that is well distributed across the UK. Areas outside London and the South East account for a large proportion of employment in vehicle manufacture, and the industry plays a key role in defining regional identities. Motor vehicle production accounts for 18 per cent of total manufacturing jobs in the West Midlands and 15 per cent of manufacturing jobs in the North East.

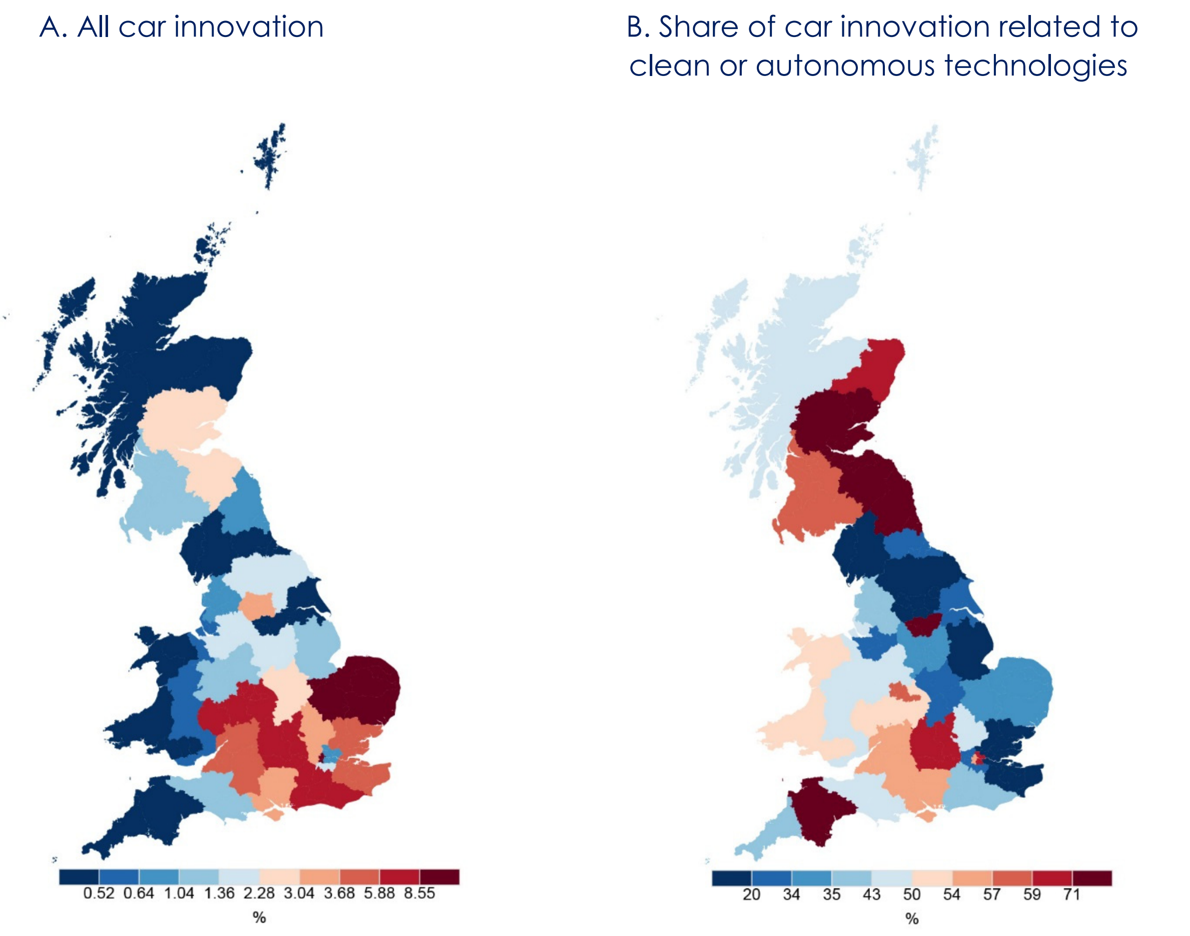
In areas with high employment in the internal combustion engine supply chain, there should be a focus on worker reskilling programmes and other programmes to attract investment and jobs in zero carbon goods and services. This must recognise that other sectors alongside vehicle production could also foster growth opportunities. Where there is regional capacity to drive growth from clean and autonomous vehicles, it should be nurtured. From a national policy perspective, it is also valuable to share best practice and build linkages between regions.

Analysing innovation activity at a regional level can shed light on which parts of the UK could be well positioned to act as R&D hubs for clean and autonomous vehicles in the coming years.

Panel A in Figure 3 maps the distribution of car innovation (patents) across Great Britain, and includes innovations classed as clean, dirty and grey (e.g. improvements to reduce the emissions of ICE vehicles). Panel B shows the share of total car innovation in each region that is related to clean or autonomous technologies. The West Midlands has a relatively high share (over 8 per cent) of total car innovation in the UK (Panel A), and more than 50 per cent of this innovation is in clean or autonomous vehicle technologies (Panel B). The statistics are similar for the nearby area encompassing Herefordshire, Worcestershire and Warwickshire. The Warwickshire and Coventry automotive sector has been praised for its investments in R&D and strong links to local universities.

In contrast, a considerably lower proportion of car innovation in East Anglia is related to clean and autonomous, despite being the location for nearly 10 per cent of total car innovations. Eastern Scotland, where just 2.5 per cent of total car innovation takes place, appears to specialise in clean vehicle technologies – more than 75 per cent of its car innovations are in clean and autonomous technologies.

Figure 3. Distribution of car innovation in Great Britain, 2005–14



Notes: The maps give innovation shares (based on patents between 2005 and 2014) at the NUTS2 level. The boundaries marked in the legend for each reflect the deciles of each measure.
Source: Authors' estimates based on PATSTAT

Recommendations for sustainable growth in the UK from passenger vehicles

Current incentive frameworks are not fully optimised to capture the opportunities for sustainable growth that the design and production of zero emission passenger vehicles could present over the next 10 years.[2] There are several gaps and limitations across supply and demand side policies for future passenger vehicles. The recommendations here are structured in response to these gaps and limitations, outlining the changes needed to overcome the barriers to realising the potential of growing demand and markets for zero emission passenger vehicles. Adopting these recommendations can indicate to business that the UK has a strategic commitment to being internationally competitive in these markets, while driving economic growth across the UK.

Issue 1. Demand-side policies are not sufficiently holistic, ambitious or long term to maximise their potential to encourage UK-based suppliers of goods and services.

Recommendations

- 1.1. Implement a non-regression clause which mandates current and future governments to either maintain demand-side vehicle incentives or revise them to be more ambitious and comprehensive, until such a time that the Committee on Climate Change deems them to be no longer necessary.
- 1.2. Explore options to move the ICE and hybrid vehicle sales ban earlier than 2035, while empowering regions to implement further incentives to make the economics of zero emission vehicle purchase more appealing.
- 1.3. Ensure all investment in road infrastructure facilitates charging infrastructure development, with public investment leveraging private investment.
- 1.4. Use demand-side policies, regulation and government procurement in larger vehicle classes to spur UK manufacturing, resulting in technology and knowledge spillovers for passenger vehicle production.
- 1.5. Consult UK businesses to gradually develop the Autonomous and Electric Vehicles Act into a clear regulatory framework while not stymying innovation while there is technological uncertainty

Issue 2. Current innovation and deployment incentives do not integrate zero-carbon systematically.

Recommendations

- 2.1. Establish a new National Investment Bank with a mandate to support zero-carbon goods and services.
- 2.2. Introduce more detailed criteria for the issue of R&D tax credits to ensure that they target R&D projects aligned with zero-carbon transport objectives.
- 2.3. Amend the General Export Facility's mandate to "ensure that no viable UK export fails for lack of finance or insurance" to review the extent to which an export can be considered part of a zero-carbon future.
- 2.4. Scale up funding and lengthen the timeframes for supply chain improvement programmes, with redesign to ensure that the productivity and competitiveness improvements are for components that are either specifically for – or are not incompatible with – usage in zero emission vehicles.

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[2] The Appendix to the full report provides a detailed overview of current supply-side incentives, supported by an assessment of their potential effectiveness, based on ex-post academic analysis of policies, observations of international best practice and consideration of their suitability in relation to the market size and innovation analysis, which is provided in Section 4 of the report. It should be emphasised that not all of these policies specifically target goods and services related to zero emission vehicles at present, and many are economy-wide.

Issue 3. The majority of incentives are finance packages – examples of dynamic policies that are responsive to changes are limited.

Recommendations

- 3.1. Implement an Annual Mobility Services Innovation Prize.
- 3.2. Amend the automotive sector deal to ensure it is a dynamic instrument that responds to changes in the sector.
- 3.3. Build in more robust evaluations of the Catapult centres.

Issue 4. There are comparatively few incentives focusing on skills.

Recommendations

- 4.1. Introduce human capital tax credits for companies that are training staff in skills considered to be of high value for zero emission goods and services including passenger vehicles.
- 4.2. Implement a future skills marketplace that establishes a direct dialogue between skills providers, e.g. further education colleges, and skills demand from companies, enabling skills needs to be tracked and addressed on an ongoing basis.

Issue 5. There are limited policy mechanisms that target balanced growth across the UK, in terms of both communities and workforces.

Recommendations

- 5.1. Ensure that local industrial strategies and long-term sectoral or missions-based policies are consistent in their drive for an inclusive management of the transition in the automotive sector.
- 5.2. Expand and deepen the programme of Science and Innovation audits, which identify areas of strength at the regional level.

Issue 6. Current policies and regulation cannot mitigate the impact of Brexit-related uncertainty for businesses in sectors related to zero emission passenger vehicles.

Recommendations

- 6.1. Secure the UK's connectedness to global automobile value chains by making frictionless trade in the sector a priority for any future UK–EU trade deal.
- 6.2. Ensure UK vehicle sales continue to contribute to EU emissions sales targets.

Issue 7. The UK does not currently have comparative advantage in some technologies receiving government support, and other countries are committing more funding.

Recommendations

- 7.1. Scale up supply-side incentives to values and timescales that are comparable with market-leaders.
- 7.2. Deliver this funding scale-up under a technology 'portfolio' approach, structuring support mechanisms to target economic growth opportunities for the UK in zero emission and autonomous vehicles as an outcome.
- 7.3. Conduct robust assessments of all recipients of the Industrial Strategy Challenge Fund's Faraday battery challenge.
- 7.4. Use the package of incentives recommended in this report as a foundation to negotiate deals with major players in the zero emission and autonomous vehicle supply chain, with a particular focus on a UK gigafactory.

Concluding points

The recommendations in this report seek to make the UK a more attractive location for major foreign companies, as well as create an enabling environment for small and medium sized enterprises (SMEs). For instance the National Investment Bank could provide high value guarantees for chemical companies interested in establishing gigafactories, while also offering smaller packages of working capital for CAV startups. Similarly, human capital tax credits could be employed on a small scale, or could be used to arrange a large, long-term tax break in exchange for a company's commitment to a 10 year programme of targeted worker upskilling. These types of incentives could be used to encourage a major player in the battery cell market to establish a gigafactory in the UK; tax breaks have played a role in incentivising Asian battery manufacturers to establish production in Eastern Europe. Policymakers should keep in mind that those businesses which could secure the future of automotive manufacturing in the UK may not fall within the commonly recognised bounds of the car industry, and will likely include chemicals (including battery cell) manufacturers, semiconductor manufacturers and software developers.

The UK needs sustained, proactive engagement with globally leading companies at the cutting edge of passenger vehicle supply chains. Moreover, it is likely that the UK will need to surpass its international peers in the provision of incentives, given its mixed record of competitiveness and uncertainties over its future trading relationships. Such engagement therefore needs to be underpinned by implementation of the full suite of recommendations in this report. This means stepping up incentives to support innovation and production in regions across the UK; spurring demand for zero emission vehicles; and securing close alignment with the European Single Market and EU emissions regulations. The companies that could anchor long-term car production in the UK may then be considerably more likely to view the country as a favourable place to do business.

1. Introduction: context, purpose and approach

The race is on between economies to become cleaner, smarter and more efficient. For the UK to be competitive in this race, it first needs to understand where the transition to net-zero greenhouse gases brings opportunities to boost resource and labour productivity and the quality of jobs. Then it must orient policies, investment and regulation to seize these opportunities across the economy in order to stimulate sustainable and inclusive growth in the UK over the coming years.

This report sets out the principles to guide these processes. It focuses on the goods and services related to passenger vehicles, identifying the multiple areas in which the UK could be competitive: opportunities lie in diverse goods and services across value chains and stages of innovation. Our objective is to provide a set of actionable recommendations to the UK government to drive sustainable growth in the context of passenger vehicles. Subsequent reports in the series will cover other areas of the economy.

The growing global market for zero-carbon goods and services

The zero-carbon transition is the growth story of the 21st century. The UK has already shown that it is possible to decouple emissions from economic growth; GDP has grown by more than 70 per cent since 1990 while annual emissions of greenhouse gases have fallen by more than 40 per cent.

The coming years will be a critical period for the UK as it seeks to redefine its place in the world while maintaining a focus on sustainable and inclusive growth. The UK's recent commitment to achieve net-zero annual emissions of greenhouse gases by 2050 presents an opportunity to drive growth through investment, innovation and creativity. This is a goal that gives a clear signal to the private sector for how it should focus its activities long-term. By being an early mover on zero-carbon products and services, the UK can seize economic opportunities from the global transition that is already underway, and from the markets that are growing around the world.

Market forces combined with rising government ambitions internationally are unleashing demand for zero-carbon goods and services. Ricardo-AEA and the UK's Committee on Climate Change have estimated that global trade in a selection of low-carbon goods and services could increase from around £150 billion in 2015 to £1.0–1.8 trillion in 2030, and to £2.8–5.1 trillion in 2050 (Ricardo-AEA, 2017). This corresponds to an annual growth rate of almost 10 per cent every year for 35 years. Furthermore, the costs of critical decarbonisation technologies have fallen significantly, not least the 79 per cent decrease seen in lithium-ion battery costs since 2010 (Henze, 2018).

Our approach

The series of reports of which this is the first builds on the messages of a previous report for the LSE Growth Commission: *Sustainable Growth in the UK: Seizing opportunities from technology and the transition to a low-carbon economy* (Rydge et al., 2018). That report emphasised the priority policy areas of innovation, infrastructure, skills and cities to deliver sustainable growth. Each of our new reports will focus on a specific aspect of sustainable growth, taking into account the effect of powerful trends that are transforming the UK economy and other advanced economies alongside decarbonisation, trends such as the rise of artificial intelligence and robotics. Together, the reports can act as a blueprint for the UK government's approach to driving sustainable growth across the economy in the coming years.

Our reports take a pragmatic view of the UK's competitiveness, acknowledging assertions that the country is "lagging behind" in the race to be competitive in the manufacture of future vehicles and components (Bedingfield, 2019). Uncertainties over the UK's future trading relationship with the EU also play into this narrative; for example, in the passenger vehicle context, Tesla recently suggested that uncertainties over Brexit currently make the UK "too risky" an option for the site of the company's first European gigafactory (McGee, 2019).

Report structure

- In Chapter 2 we review the UK's sustainable growth opportunity and where passenger vehicles fit in to this.
- In Chapter 3 we estimate the potential market size for these goods and services, as well as the UK's international competitiveness in these areas, to inform which opportunities may represent better 'value for money' if targeted by government incentives.
- Chapters 4 and 5 focus on specific aspects of this opportunity: first, the number of jobs that could be supported in component manufacturing, and second, the UK's innovative strengths in terms of competitiveness and spillovers.
- Chapter 6 identifies barriers that are restricting the UK from seizing growth opportunities, as well as gaps and weaknesses in the current policy landscape.
- Chapter 7 provides recommendations to address these barriers and gaps, underpinned by examples of best practice from other economies that have successfully driven growth from low- or zero-carbon goods and services.
- Chapter 8 concludes.
- The Appendix summarises our analysis of current policies.

2. The UK's sustainable growth opportunity and where passenger vehicles fit

The Committee on Climate Change (CCC) has set out a pathway for how the UK could reach net-zero emissions by 2050, with milestone actions for the 2020s, 30s and 40s (CCC, 2019). The pathway shows that substantial structural shifts need to occur if the UK is to achieve this legislative target. The CCC's analysis demonstrates that these shifts need to happen simultaneously across different parts of the economy: electricity, hydrogen, buildings, road transport, industry, land use, agriculture, aviation, shipping, waste, F-gases, greenhouse gas removals and infrastructure. Thus road transport is just one of many factors; this report is focused on how the UK can derive economic growth opportunities from structural shifts in this sector. Since 1990 the economy as a whole has reduced greenhouse gas emissions, by more than 40 per cent (Energy UK, 2019), but the road transport sector's emissions have remained relatively stable over this period, accounting for just over a quarter of the total, hence significant changes are needed over the next 20 years.[3]

Following the pathway to net-zero emissions will require the UK to seize opportunities for technological innovation and diffusion, as well as investing in sustainable infrastructure as opposed to high-carbon alternatives. If the UK can take a leading role in these processes, new inventions or improved products can be developed within the country. These can generate both a healthy domestic market and export opportunities, given that the UK and all countries have low-carbon commitments to fulfil in their combined efforts to meeting the Paris Agreement targets.

The UK will need to be strategic in implementing low-carbon policy to drive growth. Domestic implementation of environmental policies and targets does not necessarily lead to domestic economic benefits such as increased innovation, even if the emissions goals are met (Brunel, 2019). Thus, if decarbonisation policies were to focus purely on delivering emissions reductions (e.g. banning certain technologies without consideration of which economies have the greatest competitive advantage in innovating or diffusing replacements), the UK may increasingly act as a net importer of the relevant goods and services. This could strand workforces and communities that are currently dependent on high-carbon industries.

The aim of this report is not to set out the policies and incentives that are needed to deliver the required decarbonisation, as other cost-oriented research and analysis has already demonstrated this (Axsen and Wolinetz, 2018). Rather, the report focuses on how to seize the economic opportunities presented by the goods and services that could help to decarbonise passenger vehicles. For instance, the number of jobs may increase if the UK is globally competitive in services focused on the outcome of affordable and efficient vehicle usage (e.g. ride sharing and autonomous vehicle testing, relating to the broader trends that could reduce vehicle ownership and sales per-capita). Nonetheless, analysis covers both the demand and supply side, since domestic demand-side policies (e.g. consumer purchase incentives) can stimulate increased supply of goods and services for zero emission vehicles.

Economy-wide principles to drive zero-carbon growth

The UK has confirmed its commitment to promoting strong, sustainable, balanced and inclusive growth in recent years through flagship government strategy documents such as the Industrial Strategy and Clean Growth Strategy. This shows that the Government is recognising the need to drive improvements in labour and resource productivity through more and better

[3] The CCC's scenario shows for road transport that in the 2020s the EV market requires ramp-up and decisions made on HGVs, and in the 2030s and 40s fleets must be turned over to zero emission vehicles, starting with cars and vans, then HGVs (CCC, 2019).

investments in innovation, infrastructure and skills, from both the public and private sector. However, these strategies need to be dynamic and updated in light of the changing nature of technological change, growth opportunities, decarbonisation commitments and changes in UK competitiveness.

By taking an economy-wide approach to supporting decarbonisation, the UK could benefit from potential complementarities with innovation in general purpose technologies such as AI and robotics. However, to realise this potential, the UK will need a change of approach. It will require consistent and long-term policy across government, R&D financed directly by government, and incentives for businesses to invest in R&D for clean technologies.

The role of government is not simply to address isolated market failures or externalities, but rather to plot a course for innovation targeting economy-spanning 'missions' (Mazzucato and McPherson, 2019). The UK should adopt this approach, recognising an overarching mission of sustainable growth across the economy, and aligning policies and investment with this goal. In many cases the innovations required will involve different professions working together, e.g. data scientists, engineers and designers across diverse sectors such as automotive manufacturing, information technology and chemicals.

The policies and investment underpinning this growth should be 'predictably flexible'. Industry needs to know the direction of travel and avoid changes in direction; predictability is critical for setting a clear growth trajectory and to encourage private investment. For instance, revoking the zero-carbon homes standard in 2015 raised concerns from industry about long-term policy direction for buildings decarbonisation (Kemp, 2015). However, policy needs to be flexible and dynamic to change in response to technological and other developments, learning or economic shocks. This responsiveness can be underpinned by emphasis on an industrial policy where government works closely with industry to monitor and evaluate the success of policy, and redirects as required (Rodrik, 2004).

Constant engagement will be required between business and government. This approach can draw on the findings of Bailey and De Propis (2014), who suggest that government can most effectively bring automotive sector manufacturing back to the UK by framing the sector within broader, longer term, proactive pro-manufacturing industrial policy. Nonetheless, they caution that there are major barriers to 'reshoring' happening, most notably relating to the availability of skilled workers and access to finance (ibid.). Academics need to engage in the policymaking process by analysing the effectiveness of mechanisms to decarbonise and suggesting pathways forward. Civil society will be critical in holding business and government to account, as evidenced by the youth climate strikes and Extinction Rebellion's effectiveness in increasing public demands for decarbonisation.

Our *Sustainable Growth in the UK* report set out four priority policy areas (Rydge et al., 2018). These form the pillars of growth in this report and are summarised in Table 2.1.

Table 2.1. Pillars of sustainable growth

Innovation	**Government has a role to play in increasing the rate of investment in innovation and to direct new innovations to ensure they are consistent with sustainable growth.** ***Why is this important?*** Innovation is fundamental for productivity and growth, and for getting the most out of the UK's resources. Public support for R&D is justified due to the presence of spillovers which mean that firms do not capture the full benefits from their R&D. Research has shown that the spillovers generated by low-carbon innovation are likely to be higher than for high-carbon technologies. In addition to the importance of policies to stimulate low-carbon innovation, promoting the diffusion and uptake of low-carbon technologies also requires carefully designed policies to tackle the market failures that hold them back, including unpriced greenhouse gases, finance constraints and incomplete information. Techniques to improve demand could include corralling public support and buy-in for new products, but governments can also regulate to increase adoption. ***Issues and implications in the UK*** UK spending (public and private) on R&D as a share of GDP is consistently lower than that of its major peers. Moreover, R&D on energy technologies is particularly low by historical standards, at under 0.02 per cent of GDP today, compared with around 0.1 per cent in the early 1990s.
Infrastructure	**Infrastructure is long-lived and locks in emissions profiles and resilience patterns for decades.** ***Why is this important?*** Infrastructure for transport, water, energy, telecommunications and housing are all essential inputs for sustainable and inclusive growth. Infrastructure creates networks that spur creativity, innovation and productivity across key economic assets and systems, thereby linking cities and regions. Infrastructure is also likely to be underprovided by the private sector due to market failures around finance and coordination, in particular due to the long-term, large-scale and high-risk nature of infrastructure projects. Decisions made now on the UK's infrastructure will inform its emissions profile; in the example of passenger mobility, investing in critical infrastructure such as rail networks and charge points for EVs is essential to orient consumers towards lower emission modes of transport. ***Issues and implications in the UK*** The UK's public investment in infrastructure, as a share of GDP, is lower than in other major economies such as the United States, France, Canada and Switzerland and has been since the late 1970s. There are persistent inadequacies in all areas of UK infrastructure, leading to detrimental impacts on growth. The first National Infrastructure Assessment, published in 2018 by the then-new National Infrastructure Commission, outlines many of these inadequacies and in particular notes that the delivery of UK infrastructure projects has been slow and uncertain. For example: the Mersey Gateway Bridge was proposed in 1994, began works in 2014 and opened in October 2017; London's Crossrail project was proposed in 1974 and works which started in 2009 are still ongoing.
Skills	**Workforce skills and more broadly 'human capital' are key drivers of labour productivity and crucial for improving economic opportunities and social mobility.** ***Why is this important?*** As the low-carbon transition intertwines with emerging technologies such as AI, the nature of work and skills needed is likely to change radically and rapidly. If this transition is managed badly, there is potential for disruption and hardship for workers, and constraints on growth. Poor policy decisions will mean locking individuals and communities into outdated skills, leaving them stranded or devalued as the world moves on. A key role for government is to create a strong institutional framework and sound policies for flexible labour markets and a 'just transition' for workers. In regions with a high risk of job disruption, additional place-based policies are likely to be required to support vulnerable workers.

	Issues and implications in the UK The UK is predominantly a services economy with a declining manufacturing sector. Around 80 per cent of the UK's GDP comes from services – with many existing service jobs concentrated in major cities and surrounding urban areas, in particular London. With regard to manufacturing transitions, lessons must be learned from the coal pit closures of the 1980s, which have led to persistent high unemployment, poor health outcomes, social dislocation and a breakdown of communities. Too many young people across the country, particularly those from disadvantaged backgrounds, are emerging into a rapidly changing world of work without appropriate skills, and the UK faces skills shortages in a number of areas, including STEM (science, technology, engineering, maths).
Cities	**Cities and urban areas are central to the UK's economic and social success. They are places where physical and human capital closely interact to spur creativity and innovation, which is particularly important in the UK's service-driven 'knowledge economy'.** ***Why is this important?*** Well-planned and governed cities that are compact, efficient, interconnected and make appropriate use of technology – so-called 'smart cities' – can maximise agglomeration economies, improving the flow of people, ideas, creativity and low-carbon innovation. There is no trade-off between sustainability and growth at the urban level: polluted, congested, unattractive cities create alienation and fail to attract skilled labour and capital. The co-benefits of sustainable growth with respect to health, wellbeing and the strength of communities are now widely recognised. ***Issues and implications in the UK*** Cities are central to the UK's economic and social success. Around 55 per cent of UK residents – about 35 million people – live in cities, and the four largest UK cities (London, Birmingham, Manchester and Glasgow) are home to almost a quarter of the total UK population. The socioeconomic gap between London and the Southeast on the one hand and other UK cities on the other has widened over time and policies to narrow the gap are still to deliver meaningful results.
Source: Based on Rydge et al. (2018)	

Why focus on sustainable growth from passenger vehicles?

There are four inter-related reasons to focus on sustainable growth opportunities from zero carbon passenger vehicles:

1. The sector is significant to the UK's economy and is one that faces uncertainty
2. There are economic opportunities to be realised
3. Clean passenger vehicle growth can play a key role in the UK's decarbonisation
4. UK and global demand for emerging passenger vehicle technologies is growing, driven by powerful trends

We expand on each of these in turn.

Addressing current uncertainty in the automotive sector

Passenger vehicles – and goods and services related to them – form an important part of the UK's economy. They are a source of skilled jobs that contribute to a sense of local pride and identity in regions with significant employment in automotive supply chains. Including both automotive manufacturing and jobs reliant on automotive jobs, the sector accounts for the employment of nearly 450,000 people (SMMT, 2020). The UK's future competitiveness in these supply chains is currently uncertain. However, there are undoubtedly economic opportunities for the UK to compete in goods and services related to zero emission vehicles, driven by growing domestic and global demand. The decarbonisation of domestic road transport and growth opportunities from the sector in the UK can be mutually reinforcing.

Manufacturing of vehicle engines is the second largest value driver in the UK auto industry after final vehicle assembly (WWF and Vivid, 2018). Promisingly for the EV sector in the UK, the Society of Motor Manufacturers and Traders recently published figures showing that the production of electric, plug-in and hybrid vehicles increased in the UK by 34.7 percent in 2019 to 192,304 units, against an overall drop in car manufacturing in the UK for the third consecutive year to 1.3 million cars, of which 1.1 million were exported. The SMMT attributes the rise in EV, plug-in and hybrid production to an increasing 'global appetite' for UK-produced electric, plug-in and hybrid vehicles (SMMT, 2020).

However, a range of observers have expressed concerns over the near-term future of the industry. For instance, under certain circumstances, Holweg anticipates that the UK could lose 35 per cent of its current production volume over the next decade, slipping to below 1 million cars per year (Holweg, 2019). Regarding the current investment climate for UK automotives, UHY speaks of "an increasing degree of nervousness in the lending decisions from the mainstream banks" (UHY, 2019). In 2019, Tesla's Elon Musk indicated that the UK was never under consideration as a location for its first European gigafactory due to Brexit-related political uncertainty (McGee, 2019). Such uncertainty is underpinned by a challenging global market. Ford's CEO explained that Ford's recent closure of its Bridgend factory, with the loss of 1,700 jobs, would have happened regardless of Brexit, and was instead a result of falling global demand for the engine produced there (Jolly, 2019). There is a very clear threat to the workforces and communities that are still reliant on the automotive industry.

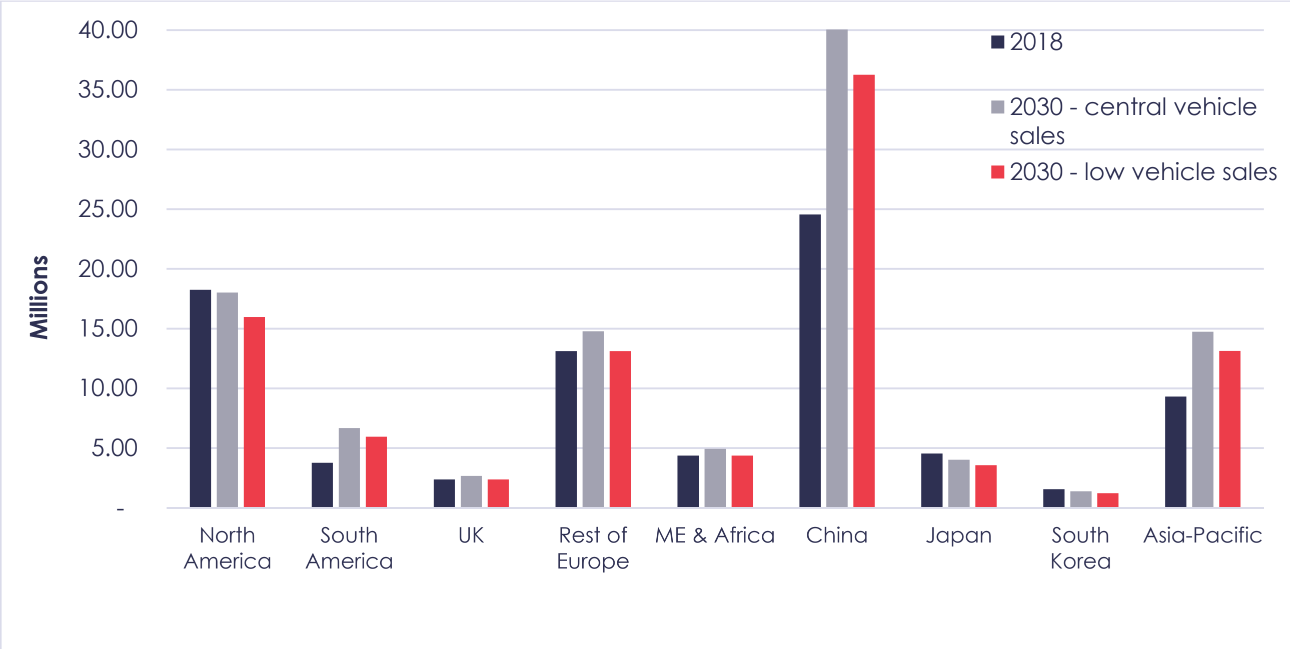
Economic opportunities from passenger vehicles

In spite of these threats, passenger vehicles are one of several opportunities across the economy that form part of a coherent sustainable growth vision for the UK. Passenger vehicles (even if self-driving and under shared ownership) are expected to play a continuing role in future transport systems. As shown in Figure 2.1, global sales are expected to grow steadily, from 86 million in 2018 to between 95 and 105 million in 2030, a macro trend outside the control of UK policymaking.

This growth is not uniform across countries, with some markets such as the United States, Korea and Japan expected to contract slightly due to market saturation. Nonetheless, passenger vehicles as a global market segment are expected to remain a growth area, with sales in the EU (the UK's principal trading partner in vehicles and components) remaining stable. There could be significant global export opportunities in areas where the UK has (or can build) comparative advantage.

If the UK were to restructure its economy to capitalise on the rising global demand for low or zero emission vehicle technologies, this could simply be seen as a story of manufacturing substitution – the UK automotive industry pivoting from producing internal combustion engines (ICEs) towards batteries for electric vehicles (EVs) and other components. However, the structural shift taking place is much broader and more complex than this. Many auto manufacturers operating in the UK are foreign-owned multinational companies, which have a range of considerations when determining manufacturing location. The supply chains for zero emission vehicles are different to those for ICE vehicles: they make use of new manufacturing techniques and systems in auto assembly plants, and manufacturers require different skills sets, raw material and component inputs, with their own complex supply chains (Fessler, 2018). The UK therefore needs to strategically consider where it may be able to establish comparative advantage across these new supply chains, and direct incentives efficiently towards these opportunities.

Figure 2.1. Projections for future passenger vehicle sales by region



Notes: Central sales scenario: 2 per cent average increase in sales per year. Low sales scenario: 1 per cent global average increase in sales per year. Source: Authors' analysis, with current vehicle sales from JATO market analysis, future sales scenarios from AlixPartners forecast

Furthermore, there are likely to be significant growth opportunities associated with decarbonising passenger vehicles in emerging sectors such as artificial intelligence. Connected and autonomous vehicle (CAV) technologies could deliver significant efficiency savings. They could also be a significant driver of profits, with Boston Consulting Group suggesting that the share of industry profits generated by new mobility technology could grow from just 1 per cent in 2017 to 40 per cent in 2035 (Anderson et al., 2018). In 2017, the Transport Systems Catapult estimated that CAVs and related technologies could deliver as much as £1.2–2.1 billion in gross value added for the UK economy and between 33,000 and 47,000 jobs by 2035 (Transport Systems Catapult, 2017; see the Appendix for details about the Catapult). Potential jobs related to CAV technologies are specified by the Transport Systems Catapult to be net additional and are mostly (70 per cent) created in the software industry. This demonstrates that growth opportunities related to passenger vehicles could accrue in a range of industries.

Passenger vehicles' role in decarbonisation: technologies and projections to 2030

A wide range of innovative goods and services are emerging that have the potential to reduce emissions from passenger vehicles. These range from EV powertrain components through to services that alter the way people use vehicles, driving them more affordably and efficiently. Markets for these goods and services are consequently growing, as nascent innovations develop into viable business propositions.

There are a number of goods and services that feature consistently in future vehicle scenarios that have the potential to reduce emissions from the transport sector – globally and domestically – and also that the UK government has indicated are strategic priorities (through the Road to Zero Strategy and automotive sector deal[4]). These technologies form the basis of the opportunities described in this report and are summarised in Table 2.2.

[4] See Appendix for details of the automotive sector deal.

Table 2.2. Key goods and services related to passenger vehicles

Goods and services	*Description and role in reducing emissions*	*Penetration trend in the 2020s*	*Drivers of trend*
Electric vehicles, charging infrastructure and supporting services	EVs are powered by electricity from charging stations, enabling them to be fuelled by renewable energy via the electricity supply. Key goods include EV components for the powertrain (e.g. batteries, electric motors, DC converters) and public and private charge points. Services such as smart charging enable EVs to recharge when demand on the grid is low.	There is consensus across a range of technology forecasts that EV sales will rise significantly through the 2020s, both domestically and globally.	The 2019 Battery Price Survey by Bloomberg New Energy Finance (BNEF) forecasts that EVs will start to reach price parity with internal combustion engine vehicles globally in 2024, after which sales will gather pace. This will be accompanied by improvements in performance and resultant reductions in range anxiety.
Connected and autonomous vehicle hardware and software	CAVs interact with their surrounding environment and use this information to drive autonomously; in this report references to CAVs refer to L3–5 CAVs, which are capable of carrying out the entire dynamic driving task while engaged. This technology has the potential to reduce emissions by improving driving efficiency (Liu et al., 2017).	Many vehicles sold today are already equipped with some autonomous functionality. Sales of CAVs with fully autonomous capabilities (e.g. L4–5) are expected to gradually increase through the 2020s. However, fully autonomous vehicles are not expected by BNEF to have a meaningful impact on transport patterns until the 2030s.	Autonomous driving will be enabled by regulatory frameworks that allow L4–5 autonomous vehicles to drive on roads and growing consumer confidence in the technologies.
Fuel cell vehicles and infrastructure	Hydrogen fuel cell vehicles represent an alternative powertrain option to battery electric vehicles, and hydrogen can be produced from renewable energy sources. They have much lower market penetration than battery EVs do currently, but may be suitable for heavy duty vehicles or for travelling longer distances since hydrogen is so energy-dense (Hydrogen Europe, 2017).	Fuel cells are not anticipated to have a material impact up to 2030 for passenger vehicles. The 2020s are likely to provide an opportunity for testing, refining and demonstrating the technology, with the technology being most viable for heavy goods vehicles.	Hydrogen fuel cells will only be used in a limited way up to 2030 as there is not yet a supply of hydrogen available at scale or a demonstrated infrastructure network that can safely carry it to vehicles.

Mobility-as-a-service	'Mobility-as-a-service' refers to digitally-enabled carsharing and ride-hailing, building on the success of companies such as Uber. This has the potential to disrupt the automotive sector significantly, with value being derived from customers using transport services efficiently and affordably as opposed to purchasing vehicles. It has the potential to reduce emissions by reducing the number of vehicles required to transport passengers (reducing emissions from across the lifecycle of vehicle production). Replacing a private car with car sharing could reduce an individual's emissions by 130–980kg of carbon dioxide equivalent a year (Laine et al., 2018).	Mobility-as-a-service is likely to increase significantly through the 2020s, with a proliferation of ride-sharing apps and car clubs as models of vehicle ownership shift. It is not clear what impact this will have on car sales and ownership, but the market for technologies that enable mobility-as-a-service is set to increase.	This technology is driven by a range of factors, including shifts in vehicle ownership behaviours and the disrupting force of technologies such as AI and the internet of things working together.
Future innovation related to zero emission passenger vehicles	In keeping with the 'missions'-led approach to growth, unanticipated future innovations are also targeted as a key potential driver of growth. By focusing innovation on zero emission passenger vehicles, new technologies may emerge with the potential to reduce emissions and create opportunities in the UK.		

The Committee on Climate Change notes that privately-owned EVs are not a perfect solution to reducing emissions from transport, but it recognises that the emissions reductions needed for the UK to reach net-zero will not be delivered solely through curbing demand for car travel, and that technologies such as EVs are the most feasible option for reducing emissions in the short to medium term (CCC, 2019). Other modes of personal mobility, such as cycling, have high potential to further decarbonise transport and have a range of other co-benefits, and may also present growth opportunities for the UK (but they are outside the scope and focus of this report).

Trends driving demand for new and developing passenger vehicle goods and services

i. Technologies are becoming commercially viable

Market forces are driving down the costs of these emerging technologies. Analysis by Goldie-Scott (2019) for BloombergNEF shows that the price of lithium-ion battery packs fell from around US$1,200 per kWh in 2010 to $200 in 2018, and further falls are expected, to $94/kWh in 2024 and $62/kWh in 2030. This is enabling battery electric vehicles to compete with petrol and diesel models, with BloombergNEF (2019) expecting price parity between EVs and internal combustion vehicles by the mid-2020s.

ii. Passenger behaviours are changing and there is growing awareness of co-benefits

The rise of ride- and car-sharing, facilitated by businesses such as Uber, Drivy and Blablacar, is underpinning a broader shift towards viewing mobility as a service. Combining this with autonomous and connected vehicles could help to address congestion issues and potentially remove the need for individual car ownership (Stewart et al., 2019). Although behaviour change is a gradual process, car purchasing habits are already changing in the United States, with consumers postponing car purchase until later in life (Wharton University, 2017). Furthermore, awareness of the co-benefits, particularly in health terms, of zero emission vehicles is increasing, driven by concerns about the impacts of air pollution. Results of a recent poll of 4,000 adults in the UK found 71 per cent were concerned about the health impacts of dirty air (Holder, 2019).

iii. There is significant policy support for future technologies

Countries around the world are implementing a wide variety of policies and regulation for zero emission vehicles. The International Council on Clean Transport notes that a combination of electric vehicle industrial policy and electric vehicle promotion policy is driving growth. For example, the major markets of China and Norway, each with EV sales accounting for more than 5 per cent of total passenger vehicle sales in 2018 (IEA, 2019), provide incentives valued at more than US$10,000 per vehicle (Lutsey et al, 2018).

Other considerations for assessing future deployment of zero emission passenger vehicles

While there is consensus among forecasters regarding the transition towards zero emission vehicles, views vary regarding the deployment levels of different zero emission vehicle technologies in 2030. Barriers such as battery costs and anxiety over vehicles' range need addressing and could significantly impact deployment levels for EVs. To account for these uncertainties between technologies, we conducted sensitivity analysis in the quantitative elements of the report, and the technology mix we assume is broadly consistent with third parties such as the International Energy Agency and BloombergNEF. In any case, regardless of the exact combination of future passenger vehicle technologies, macro-level policy signals are steering innovation away from ICE vehicles. The time lag in R&D through to sale means that new vehicles and technologies currently under development (which feature the technologies described above) will be on sale in the 2030s. This underpins the assumption in this report that EVs, CAVs and mobility-as-a-service will likely play a role in the 2030 road transport system.

In understanding where the UK can be competitive, consideration must also be given to the disruptive trends that are altering business models, and the relative strengths of different global economies. The UK is unlikely to be able to compete with countries such as China as a favoured location for original equipment manufacturers (OEMs). However, it does have a proven track record in services such as vehicle testing and engineering. Furthermore, it is building expertise in the manufacturing of specialist parts, as well as in the assembly and retail of goods such as electric vehicle chargers. The UK could also benefit from transport business model disruptions such as mobility-as-a-service, and connected vehicles as a tool to address congestion, and these shifts should also be taken into consideration in identifying opportunities.

The ambition of this report is not to suggest that passenger vehicle decarbonisation represents an unambiguous growth opportunity. In fact, LSE found in a previous report that the UK appears to be losing comparative advantage in clean automotive technologies (battery and hybrid vehicles), despite those being areas identified as strategic in the Government's Industrial Strategy and being the subject of recent funding announcements (Rydge et al., 2018). Instead our aim is to better understand where the UK may have advantage and where support can lead to positive spillovers to ensure government funds are efficiently focused.

Managing workforce transitions and the regional dimensions of growth

While seizing the economic opportunities related to passenger vehicles, policymakers also need to carefully manage the workforce transitions that are likely to take place. Within the context of large and persistent regional disparities in the UK (see, for example, Bernick et al., 2017 or Zymek and Jones, 2020), consideration needs to be given to the location of current jobs (both in the automotive sector, and jobs in other sectors with converging skills sets e.g. engineers in heavy industry/extractives) and where future jobs may be created, based on local strengths and capacity and where these can be built.

Such consideration, applied consistently across sectors experiencing transition, can help to reduce regional disparities. An example is provided in the case of Germany's successful refocusing of the Ruhr region away from coal towards technology and education, demonstrating how the economic strength of regions can be protected by strategic, regional policymaking (Sheldon et al., 2018).

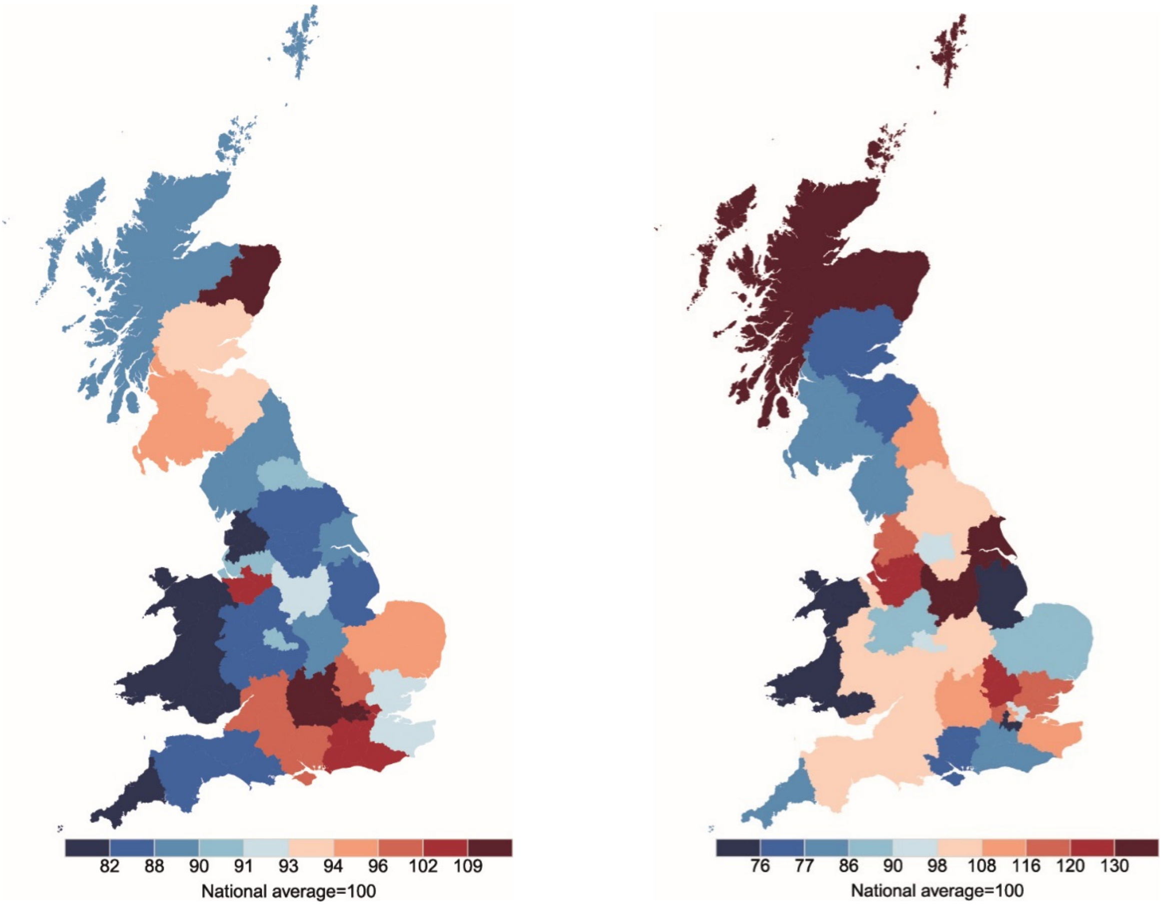
Figure 2.2 shows that in 2014[5] regions in Great Britain in the top decile for productivity, which include parts of inner London, areas around Oxford, and Edinburgh, were nearly 40 per cent more productive than those in the bottom decile, which includes Cornwall and large parts of Wales. However, as our previous report on sustainable growth in the UK pointed out, some of the areas with low productivity also had above average national spillovers (Rydge et al., 2018). These areas include the Scottish Highlands and Islands, Kent, Essex and Greater Manchester. This implies that some of the UK's lower productivity regions are actually particularly active in generating spillovers at the national level. Such linkages should be factored into consideration of the appropriate balance between regional and national policymaking.

The Industrial Strategy Council (ISC) recently recommended focusing on places whose productivity levels and growth rates are well below the national average, while also emphasising that growth strategies need to be carefully tailored to local conditions (Zymek & Jones, 2020). The automotive sector could play a role in reducing regional disparities. For instance the West Midlands region, and Hereford, Worcestershire and Warwickshire, have a large share of zero emission and autonomous car innovation, and have a number of businesses in the area which have the potential to act as productivity-enhancing cluster through knowledge spillovers. Despite this, these regions have overall productivity levels which are below the national average. This indicates potential for targeted policies to enhance productivity – and that the automotive sector could have a role to play in delivering these productivity improvements. This aligns with the recommendations of the OECD's case study of Coventry and Warwickshire (OECD, 2019). The case study explains that the local automotive industry has experienced renewal as a result of the density of companies and strong investment in R&D, but that targeted interventions are needed to address skills shortages (particularly for SMEs) and local availability of capital.

[5] Data is shown up to 2014 to be consistent with the innovation analysis in Chapter 4. Although we rely on patent applications and application dates, these are only recorded in the public patent databases once the patent application has been fully processed which can take several years. Hence there is a time lag of three to four years. Since we are using the 2018 version of PATSTAT this leaves us with 2014 as the last usable year.

Figure 2.2. Productivity and innovation spillovers across regions of Great Britain

A. Relative regional productivity (2014) **B. Relative national spillovers (2000–14)**



Notes: Panel A reports an area's labour productivity relative to the UK-wide average level (in %). Panel B reports average national spillovers (national Patent Rank) in an area, relative to the UK average national spillover level (%). Both maps are divided into NUTS2 regions. See footnote 5 above for explanation of why 2014 data are used.
Source: Rydge et al. (2018)

3. Sizing up the future growth opportunity in passenger vehicles for the UK

Identifying opportunities across innovation and value chains

A broad range of growth opportunities exists for the UK in relation to passenger vehicles, from early stage innovation through to diffusion, and from raw materials production through to recycling and reuse. Furthermore, there is increasing awareness of the strong linkages between manufacturing and services, with business services able to act as intermediate inputs into manufacturing (ECSIP, 2014).

This chapter summarises the diversity of opportunities for the UK and draws evidence together to give an indication of the UK's competitiveness. This diversity is illustrated in Figure 3.1 below, which positions examples of current UK activities on a value chain/innovation matrix. The y-axis of the matrix sets out stages in the value chain along with services in which UK businesses could be active. The x-axis summarises stages from innovation to diffusion in which businesses could also be active. This demonstrates that a range of different opportunities exist, and the UK has varying levels of competitiveness in each, depending on its comparative advantage in relation to other economies.

The UK government should think strategically about which aspects of this broader innovation/value chain matrix it should seek to target, given the competition it faces from other economies. Furthermore, the Government must be in a constant dialogue with industry figures to understand how value chains are changing shape, and to ensure policies and investment can help incubate businesses operating at the frontiers of future value chains. These businesses and activities may not fall within the confines of the passenger vehicle supply chain as it is traditionally defined.

Additional stages in future value chains that are already beginning to play a role include:

- Operating platforms that enable the functionality of vehicles communicating with each other and self-driving, such as Waymo or Renovo.
- User experience platform providers that manage a passive passenger's experience travelling in the vehicle.
- Data services providers informing vehicles with the data they need to operate as part of a seamless CAV network, such as traffic, mapping or other vehicles.
- Bespoke vehicle design and manufacturing based on specific local demand. As cities and regions develop their own future mobility strategies, vehicles may be designed with the location's specific demands in mind, localising production. The London Electric Vehicle Company's production of London black cabs is an example of this.
- Fleet servicing and maintenance providers. As mobility-as-a-service trends deepen, individual vehicle ownership may give way to large, centrally owned fleets of vehicles that are leased, hired or treated as a robotaxi. In such a scenario, responsibility for maintenance and care for vehicles could pass into the hands of the fleet operators or separate service providers, generating new value chain steps.

Source: Adapted from Bailey (2019)

Figure 3.1. Matrix showing where UK growth opportunities may exist across innovation and today's value chain for vehicle production, with examples of current UK activities

Stages in today's value chain	Early stage research through to concept / invention	Early stage concept development through to product / service development	Production / diffusion / marketing
Services	*R&D into using AI to integrate ridesharing services with CAVs e.g. robotaxis*	**UK Power Networks 'Shift' trial offering 1,000 EV owners financial incentives to charge their vehicle off-peak**	*UK engineering services in the design of EV charging networks provided to other economies*
Recycling and reuse	**Faraday Battery Challenge's ReLiB project exploring how batteries could be recycled or reused**	*Testing centres for the production of batteries with recycled raw material inputs*	*UK battery recycling and reuse facility for nickel, cobalt and other components*
Sale and usage (including maintenance)	*R&D into typical EV usage patterns to extend lifetime and consumer acceptance*	**Zenzic's testbed for testing out new CAVs**	*UK-based dealerships for zero emission vehicles*
Component assembly	*R&D into repurposing ICE vehicle assembly factories for EV assembly*	*Testing assembly of overseas EV charging components under different configurations for UK market*	**Jaguar Land Rover decision to assemble EVs at Castle Bromwich plant**
Component manufacturing	**Granta Design's research into potential uses of AI in manufacturing EV batteries**	*Road testing new battery technologies in vehicles e.g. solid state batteries*	*Production of hydrogen fuel cells for usage in fuel cell vehicles*
Raw material production	*R&D into reducing emissions / environmental degradation from mineral extraction for batteries*	**£500k feasibility study to explore UK lithium production in Cornwall**	**Johnson Matthey's UK-based production of chemicals as inputs for batteries**

Innovation chain stage

Note: Bold text indicates examples of current UK activities related to passenger vehicles. Source: Authors

Raw material production

International leaders and examples of investment

Based on the anticipated demand and production growth in the sector as we have described, demand for lithium and cobalt will rise considerably, due to their importance in lithium-ion batteries. China has significant lithium reserves and produced 8,000 metric tons in 2018; only Australia and Chile produced more and neither of those countries has a significant stake in the global batteries market. This supply of lithium, insulated from international price volatility, acts as a critical enabler for China's dominance of the battery industry (see Chapter 7).

Cobalt production is dominated by the Democratic Republic of Congo, which has by far the world's largest reserves, but concerns abound regarding risks of child labour in the supply chain, which are encouraging other countries with reserves such as Russia to increase production. Much of the secondary processing of cobalt takes place outside the DRC, with China the leading producer of refined cobalt and the largest consumer worldwide as a result of its battery industry (Barrera, 2019).

UK activity and potential competitiveness

> The UK could enjoy opportunities from raw material production in the production of chemicals for batteries.

The UK has a mature chemicals sector which is well placed to respond to increasing demand for batteries. It is estimated that chemicals for batteries could represent a £2.7bn per year opportunity for the UK chemical industry, just for UK-built cars (University of Warwick et al., 2018) – if there is sufficient demand from local battery production. Furthermore, the UK is investigating lithium production, a key input for battery production. UK Research and Innovation's Faraday battery challenge has begun funding exploration for reserves of lithium in Cornwall (Autovista, 2019). However, this is at very early stages and it is not known whether the UK can produce lithium cost-competitively. Furthermore, the UK will remain an importer of other minerals required for the production of batteries such as nickel and cobalt.

Component manufacturing

International leaders and examples of investment

Production of batteries – which our modelling indicates is likely to be the highest value individual component in 2030 – is dominated by China. BloombergNEF estimates that in early 2019 there were 316 gigawatt-hours (GWh) of global lithium cell manufacturing capacity, with 73 per cent of that in China and the United States in second place but far behind with 12 per cent of global capacity (Rapier, 2019). While the United States has not formally adopted industrial policy to support batteries, under the Obama administration a US$2.4bn funding package was provided to establish lithium-ion battery facilities, dwarfing funding announcements in the UK and coming at a significantly earlier stage. The United States now has extensive entrepreneurial activity in the batteries sector and is home to arguably the most recognisable battery and EV producer, Tesla (8). Alliance Ventures, the strategic venture capital arm of Renault-Nissan-Mitsubishi, recently announced an investment in The Mobility House, a technology company that provides a platform for integrating vehicle batteries into power grids using intelligent charging, energy and storage solutions. The Mobility House is based in Germany, Switzerland and California's Silicon Valley (Renault-Nissan-Mitsubishi, 2019).

Significant investment is also flowing from Silicon Valley firms in the United States, with Amazon currently working on a multi-function autonomous vehicle with Toyota (CBInsights, 2019).

UK activity and potential competitiveness

> The UK may be able to be competitive in the manufacturing of some components, but it faces stiff competition.

Production of components for both EVs and CAVs predominantly takes place outside of the UK. The UK's production of batteries has remained small at around 2GWh per annum at the Nissan Leaf factory. LG Chem is planning a 45GWh p.a. factory in Poland, Samsung a 16GWh p.a. factory in Hungary and CATL a 14GWh p.a. factory in Germany – these are all Chinese and Korean companies siting production in Europe. Numerous stakeholders, including the Faraday Institution, have emphasised that establishing one or more new gigafactories in the UK will be essential to securing long-term competitiveness in battery production (Faraday Institution, 2019).

The Transport Systems Catapult observes that it is likely that much of any CAV-related hardware (in particular, sensing and mapping hardware) needed in the UK would be imported from abroad. Existing electronics and component manufacturing capabilities in other markets, and relatively high labour costs in the UK, mean that it would be very challenging for the country to gain a significant share of the global market for manufacturing CAV hardware (Transport Systems Catapult, 2017). Also, the market for EV original equipment manufacturers (OEMs) is predominantly overseas. As manufacturing moves to other countries there is a risk that this hinders innovation capabilities by reducing knowledge flows that come from firms locating near each other (Fuchs, 2014).

UK competitiveness is further challenged by the fact that both EVs and hydrogen fuel cell vehicles have considerably fewer parts than existing ICE vehicles, and powertrain production is often outsourced to a single OEM (ING, 2017). For instance, UK companies such as Johnson Mathey undertook R&D in the UK – in this case batteries for EVs – but then opted to manufacture the batteries in Poland (Lewis, 2018). Nonetheless, the UK could still produce specific components for vehicles, as London-based Arcola Energy does, for example, producing hydrogen fuel cells for transport applications.

Component assembly

International leaders and examples of investment

Established automotive companies in countries including China, the United States and Germany, are dominating investment in both electric vehicle assembly and the related charging infrastructure. For instance, Volkswagen is investing about €250 million in charging points alone at its European locations (Kilbey, 2019).

UK activity and potential competitiveness

> The UK has a long history in automotive assembly and could be competitive in the assembly of chargers and other related products.

There is a mixture of large, established car manufacturers and smaller break-out companies active in this stage of the value chain. In the former category, Jaguar Land Rover recently committed to producing its new electric Jaguar cars at the plant at Castle Bromwich, using battery packs from the company's nearby site at Ham Hall and electric components from its Wolverhampton engine plant. In the context of EV charging infrastructure, a growing number of UK-based developers and utilities are developing turnkey charging products, by purchasing components from overseas and then assembling them under differing configurations so they can be sold to consumers as a ready-to-use charging product (see, for example, Pod Point and Zenobe). Investor interest in these companies, such as the recent £25m equity injection into Zenobe, indicates their potential to be a key driver of growth in the coming years (Stoker, 2019). However, this is small in comparison to the sums of money invested by European auto manufacturers such as VW, described above.

Overall, the UK is in a significantly weaker position than its main international competitors. Since the break-up and selling off of British Leyland, large-scale car manufacturing in the UK has been dominated by foreign companies such as Nissan, which was subsidised by Margaret Thatcher's government to set up manufacturing in the UK in the 1980s. These industrial policy decisions have rendered the UK significantly less competitive in automotive assembly (Pardi, 2016).

Sale and usage (including maintenance)

International leaders and examples of investment

China remains the world's largest EV market with nearly 1.1 million EVs sold in 2018 and, with 2.3 million units, it accounted for almost half of the global EV stock that year. Europe followed with 1.2 million EVs and the United States with 1.1 million on the road by the end of 2018. Norway remained the global leader in terms of EV market share at 46 per cent of its new EV sales in 2018, more than double that of Iceland, which at 17 per cent has the second-largest market share (IEA, 2019).

A survey by KPMG found the Netherlands to be the country most prepared for autonomous vehicles, followed by Singapore, Norway and the United States. The UK is positioned seventh. This is based on an assessment of policy and legislation, domestic innovation, infrastructure and consumer acceptance. Singapore in particular is seeking to establish itself as a centre for CAV development with the deployment of a simulated urban test-bed and plans for driverless buses (KPMG, 2019).

UK activity and potential competitiveness

> The UK is one of the fastest growing markets for the sale of electric vehicles, and could be well placed to test the usage of future vehicle technologies such as CAVs.

Accenture categorises the UK as being of 'high potential' in its EV market attractiveness index, due to the speed of market growth in the country, although the UK lacks the market size of leaders like the United States (Accenture, 2016). A coherent, long-term policy framework to support EVs and charging infrastructure is essential if the UK is to remain an attractive location for selling EVs in the future.

However, there may be other opportunities for the UK in relation to usage of vehicles, such as CAV testing. The Government has made this a priority through Zenzic, its public–private partnership focused on CAVs. Autonomous driving trials are taking place in several towns and cities with four major CAV test beds. Internationally active companies such as Horiba Mira are based in the UK and new announcements are coming regularly, such as the recent opening of Autonomous Village at the Millbrook Proving Ground in Bedfordshire (Tyrell, 2019).

Services

International leaders and examples of investment

The services sector that relates to passenger vehicles is extremely diverse but core aspects include (i) software and computer services, which enable mobility via passenger vehicles; and (ii) strategy, management consulting and technical services (e.g. engineering) related to production of passenger vehicles. Regarding (i), Silicon Valley firms have dominated mobility services, such as Uber, which has invested more than US$1bn in R&D (Bergen, 2019). Regarding (ii), engineering firms are spread throughout the world: the firms with the highest revenues are based in the United States, China and Canada. The highest ranked UK firm is Mott McDonald, which has the 17th largest revenue in the world for engineering firms (ENR, 2019).

UK activity and potential competitiveness

> The UK can be competitive across the innovation chain in services, from developing new services such as smart charging software through to diffusion of engineering services.

The UK has a number of globally recognised services firms working in the automotive and mobility sector, reflecting its nature as a sophisticated services-based economy. The UK is a world-leading green finance centre, as the Government has highlighted in its Green Finance Strategy, published in July 2019. Financial services continued to be the largest service exported globally by UK businesses in 2017 (ONS, 2019), and this is where much of the country's comparative advantage with regard to the zero-carbon transition lies. London ranked top for the 'quality' ranking of its green financial products and services in the 2019 Global Green Finance index (Mava et al., 2019). The UK's competitiveness in green finance could in theory target investment at UK-based companies working on goods and services for zero emission vehicles, developing bespoke financial products adapted for the industry. However, to date, there is limited evidence that the presence of London's green finance centre is driving UK competitive advantage in zero emission vehicles.

Maximising synergies across goods, services and supply chain stages

While matrices such as Figure 3.1 above are useful for visualising different types of opportunity, the economic reality is that opportunities may straddle stages in supply chains and supply chains are expected to change shape. The UK should avoid picking one area for focus as this could risk missing opportunities elsewhere. Rather, incentives ought to be available across the spread of the matrix, enabling UK business to invest where they see opportunity.

Similarly, it is important to emphasise that the UK should not pick between manufacturing and services opportunities: the two are likely to be mutually reinforcing. Manufacturing – driven by strong domestic demand – could enable the UK to gain a level of expertise that could translate into competitiveness in related services. Bailey et al. (2014) highlight the shift towards a hybrid model where manufacturing and services are increasingly intertwined. This kind of model could provide an opportunity to bring manufacturing back to the UK through close integration with services. Services can play an important role as an intermediate input into production, such as through consultancy, design activities, marketing and repairs (ECSIP, 2014). The links between different types of opportunities in services and how they might link to manufacturing opportunities are shown in Table 3.1 below.

Table 3.1. Links between different types of service and manufacturing opportunities

Service sector opportunity	*UK examples*	*Links to manufacturing opportunities*
Software and computer services that enable mobility via passenger vehicles	**Oxbotica** is an Oxford-based company that develops software to enable autonomous vehicles to drive. It grew out of Oxford University and was named by *Wall Street Journal* as a Top 10 tech company to watch in 2015 (Oxbotica, 2020). Its main product is its **Universal Autonomy** software platform, which is modular, self-contained (e.g. does not rely on external GPS) and comes with full installation and operating support. Oxbotica expects to grow to around 200 UK employees under its current phase of expansion, and is considering opening overseas offices (Campbell, 2018). **Fleetondemand** is a Yorkshire-based company that offers **Mobilleo,** a software platform (either web or app based) to enable door-to-door journey planning for businesses. It draws on passenger vehicles (with a list of approved vehicle hire companies) along with other transport solutions. Fleetondemand has 75 employees in offices in Leeds and Shipley.	UK competitiveness in companies such as Oxbotica is strongly linked to the hardware needed to enable autonomous driving. UK-based knowledge spillovers of the technical specifications required of the hardware to support CAV software could lead to advantage for UK companies developing hardware, if spillovers are local.
Strategy, management consulting and technical services (e.g. engineering) related to production of passenger vehicles	**Ricardo-AEA**, a UK-based engineering consultancy, provides services to a range of clients internationally in the automotive sector, covering the full range of future vehicle technologies discussed in this report. It works with clients internationally but is led out of five technical centres across the UK, along with three in Europe, four in North America and one in China. Shoreham Technical Centre (STC), Ricardo's head office, is home to around 700 permanent and temporary engineers, technicians and professional support staff across a wide range of specialisms and departments. Ricardo's teams in the UK have been working on projects with BMW since 2006, exporting UK engineering skills to international automotive clients (Ricardo, 2019).	UK-based technical services can drive a more competitive manufacturing sector by facilitating knowledge spillovers and synergies between companies.

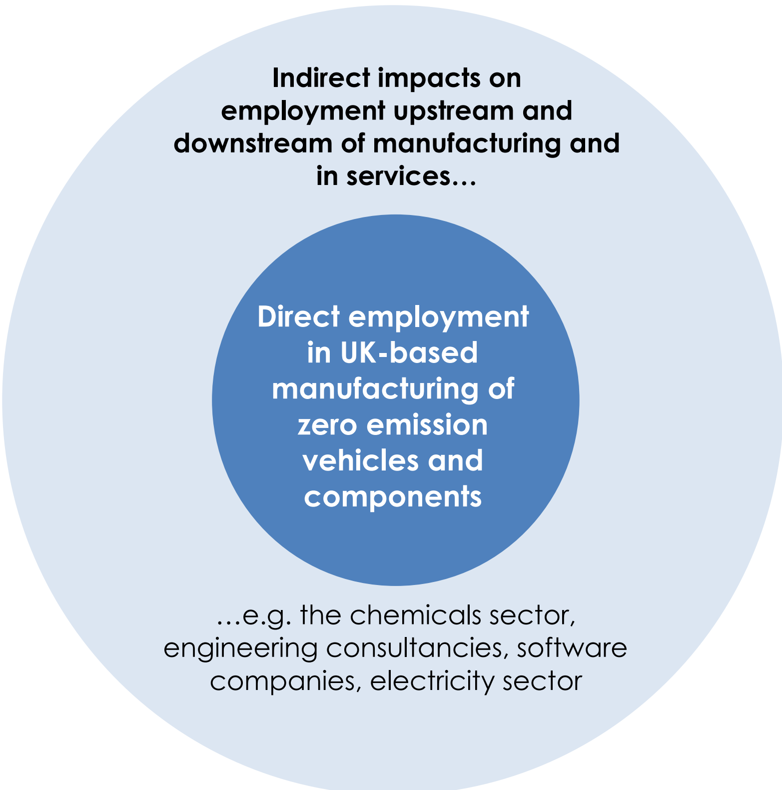
4. In focus: UK jobs in 2030 from the manufacturing of passenger vehicle components

This section sets out the potential scale of the passenger vehicle opportunity. We make high level estimations for the jobs that could be supported from some of these goods and services, based on the value of components if they were manufactured in the UK. Box 4.1 discusses the broader context for employment prospects in the manufacturing of vehicles across the EU, which is likely to be reflective of the global trends that inform this report's analysis (Cedefop Eurofound, 2018).

Quantifying direct and indirect employment from passenger vehicles

In 2030, as now, a large number of people will be employed across the full value and innovation chain related to passenger vehicles (e.g. in R&D and services). We do not quantify these jobs in this report but as an illustration, the Faraday Institution (2019) estimates that a largescale battery factory in the UK would directly support between 2,000 and 3,000 jobs, but would also indirectly support a further 7,000 to 8,000 jobs in the battery supply chain. This is illustrated in Figure 4.1, which emphasises that there are likely to be a much larger number of people employed in the supply chain of the goods and services in question than those employed directly in manufacturing. The jobs we quantify in the next subsection give an indication only of how employment levels in passenger vehicle-related manufacturing in 2030 might compare with the present day.

Figure 4.1. Illustration of job opportunities in the UK from manufacturing zero emission vehicles and components, relative to potential broader employment impact of zero emission vehicles



Note: Jobs in the inner circle are quantified in this report, jobs in the outer circle are not quantified. Size of circle gives indication of relative number of jobs.
Source: Authors

Box 4.1. The global outlook for manufacturing employment in the automotive sector

The automotive sector is undergoing significant structural changes, due in part to the transition towards clean powertrains but also due to broader automation trends in manufacturing.

The European Commission anticipates that on average EVs are likely to reduce the number of assembly line jobs, since these vehicles are less labour-intensive to produce and have fewer parts. Nonetheless, the Commission highlights that there will be creation of new jobs such as material scientists, computer analysts, and chemical, electrical, industrial, material and mechanical engineers. Furthermore, there is likely to be significant bridging between the ICT and traditional automotive sector as digital manufacturing techniques are increasingly used. This could lead to a decline in the number of low and medium skilled jobs – a decline that will need to be managed carefully – but creation of jobs elsewhere (Cedefop Eurofound, 2018).

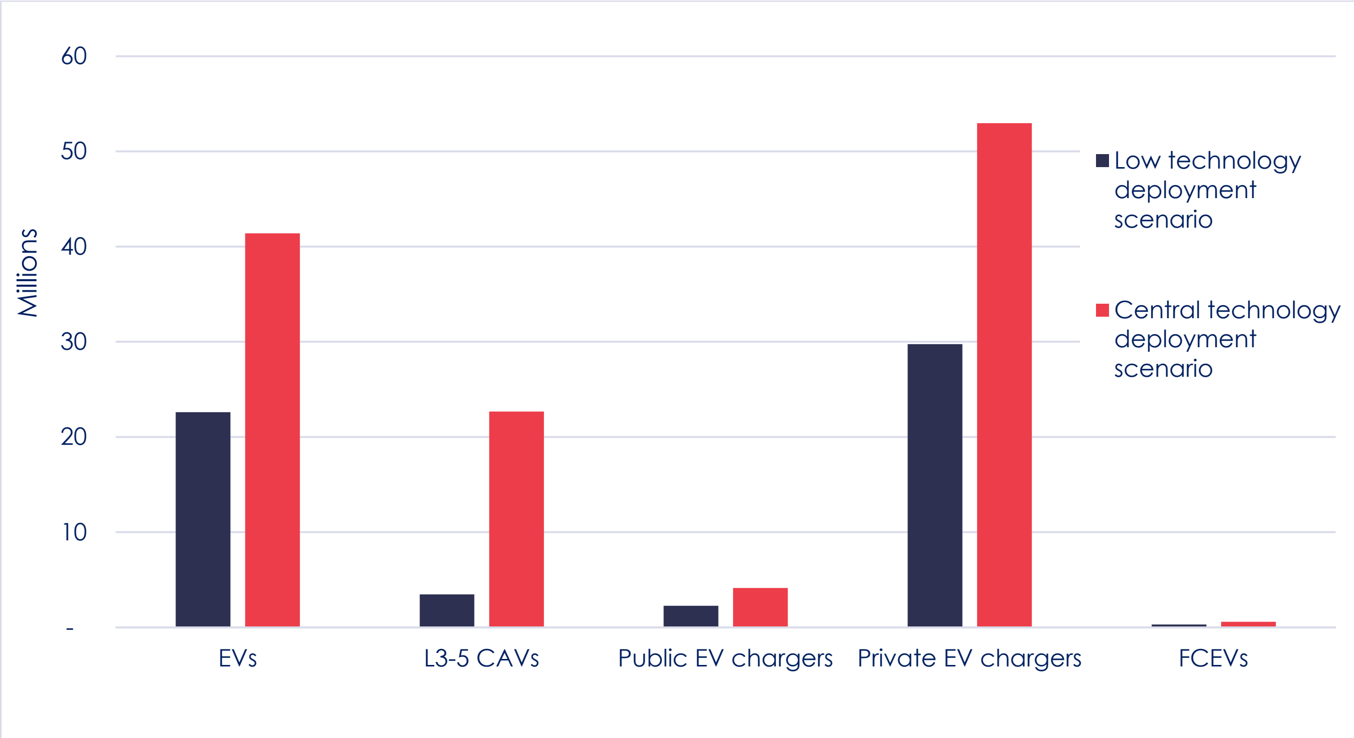
Calculating future sales for different technologies

To estimate the market size for components manufactured in the UK, we have projected the 2030 sales for different technologies, using a range of sources including the International Energy Agency (IEA), Transport Systems Catapult and Frost & Sullivan. These estimates are shown in Figure 4.2 below. The central scenario used to inform the subsequent analysis in this section is an optimistic but realistic outlook that sees electric vehicles accounting for 38 per cent of new vehicle sales worldwide in 2030 (complemented by a more conservative, 'low technology deployment' scenario).

EV sales vary by country, ranging from 22 per cent of sales in the Middle East and Africa to 50 per cent of sales in Europe. The global EV sales projection aligns with the IEA's 30@30 scenario, forecasting 43 million EV sales in 2030 (IEA, 2019). Penetration of L3–5 CAVs is somewhat lower, with these technologies installed in 21 per cent of new vehicles sold in 2030.

Sensitivity analysis was also conducted on a number of key variables. For instance, it is possible that sales of L3–5 CAVs remain extremely low in 2030 due to lack of consumer acceptance regarding safety and other considerations.

Figure 4.2. Global sales of passenger vehicles and related components in 2030, under central assumptions for vehicle sales



Note: Assumes central vehicle sales scenario. 100 per cent of UK vehicle sales are assumed to be electric by 2030, in line with the suggestion by the Committee on Climate Change to consider moving the ICE sales ban forward to this date. FCEV=fuel cell electric vehicle. Source: Authors' analysis based on IEA, BNEF, Goldman Sachs, Frost & Sullivan

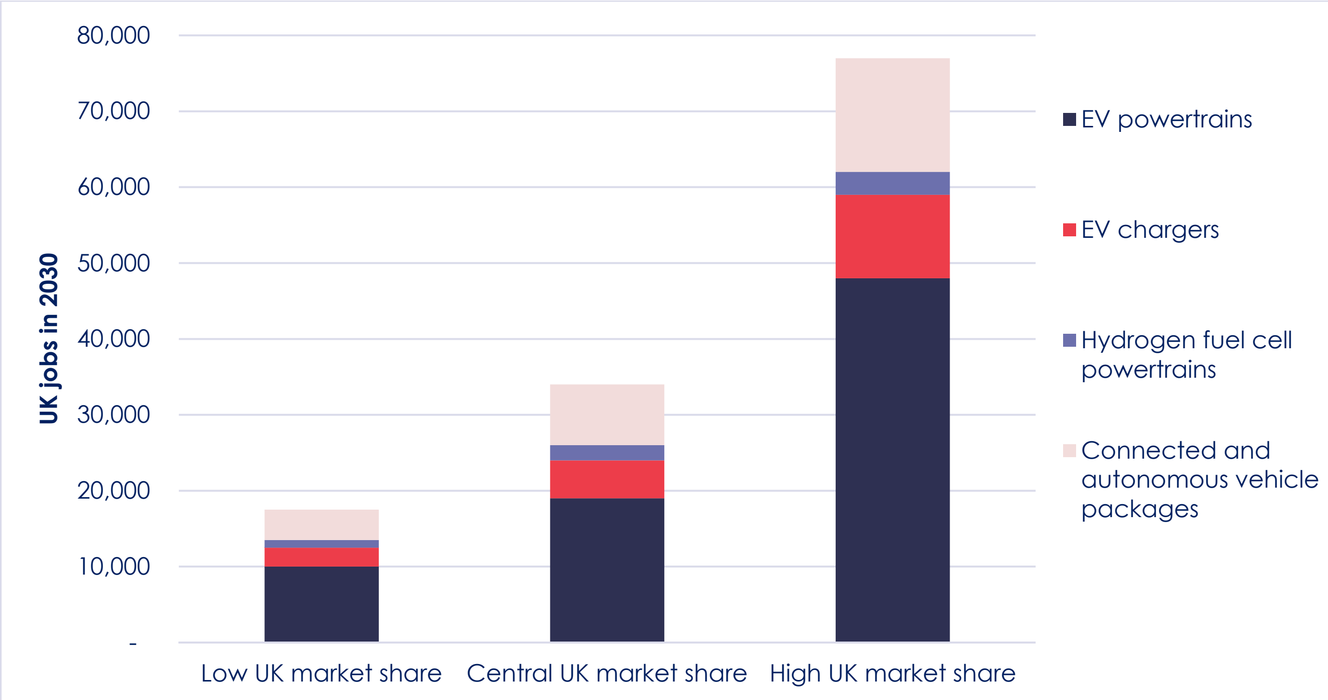
Calculating jobs from manufacturing

This analysis was conducted under three key scenarios: 'central', 'low' and 'high' UK market share:

- 'Central' assumes the UK maintains its current share of the market.
- The upper and lower bounds assume that the UK attains the market share of its more or less competitive neighbours in Europe.
- Proxies used for 'high' and 'low' estimates vary by component. For instance, in the context of EVs, France is taken as a reasonable 'high' estimate, attaining a 5 per cent share of the global market for EVs from 2010–17 compared with the UK's share of 2 per cent. These scenarios act as a proxy for the possible impact of more or less enabling policies.

Figure 4.3 outlines the possible number of jobs in 2030 if the UK gains or loses market share. If the UK maintains its current share of the market for each component, the country could sustain around 35,000 jobs. However, if the UK can attain the 'high market share' scenario it could sustain nearly 80,000 jobs in the direct manufacture of these components, not including broader employment opportunities in the supply chain or remaining jobs in ICE vehicle component production. This demonstrates the scale of the employment opportunity in zero emission and autonomous vehicle components, given there are currently 168,000 people employed in automotive manufacturing across both component production and vehicle assembly. However, it also shows that the UK needs to grow its competitiveness in these key technologies.

Figure 4.3. UK jobs related to clean passenger vehicle and CAV components (varied scenarios)



Note: Each scenario assumes consistent vehicle sales, technology deployment and a 2030 ICE vehicle ban in the UK. Source: Authors' analysis based on multiple sources

Table 4.1 demonstrates the potential UK market value under the 'high UK market share scenario', again assuming central vehicle sales and technology deployment scenarios. This suggests the market for UK components could be worth £16.8bn in 2030, with EV powertrains making up the bulk of this value.

Table 4.1. Market value of zero emission vehicle components in 2030 in the UK (high market share scenario)

Component	*Global market value (£, millions)*	*UK market value (£, millions)*
EV powertrains	241,000	12,000
Public EV chargers	11,000	600
Private EV chargers	44,000	2,000
Hydrogen fuel cell powertrains	4,000	200
Connected and autonomous vehicle packages	44,000	2,000
Totals	*344,000*	*16,800*

Source: Authors

5. In focus: the UK's innovative strengths

In integrating zero-carbon goods and services as a priority into growth plans related to passenger vehicles, the UK government faces challenges in policy design. It must decide on the areas to target, and the form that policy interventions should take. The UK's automotive sector deal formalises the Government's commitment to the sector as a strategic priority.[6] However, as we have demonstrated, the UK is presented with a wide range of potential opportunities for growth, with varying levels of current activity and possible competitiveness, purely within the category of passenger vehicles.

Analysing patent data and its contribution to policymaking

While there is significant uncertainty over future UK competitiveness, tracking innovation can give an indication of the areas in which the UK might enjoy future advantage. This section analyses patent data to explore revealed technological advantage in technologies for passenger vehicles, and to understand which technologies currently represent the most compelling opportunity for creating knowledge spillovers. We also carry out analysis to examine best 'value for money' from a UK policy perspective, based on the spillovers the technologies generate, and highlight where innovation on clean and autonomous vehicle technology is taking place in the UK.

The insight this analysis provides can assist policymaking on a number of levels:

- At an economy-wide level, patent analysis enables policymakers to take a strategic view of the UK's record of innovation in passenger vehicles in relation to other broad segments of the economy such as chemicals and information technology. This is important for assessing how clean passenger vehicle technologies fit into the wider industrial strategy context.
- By narrowing the focus to specific technologies as opposed to broader analysis (e.g. 'vehicles' as a broad category), insight is provided into the UK's track record in 'clean' car innovation that is compatible with zero emission vehicles, as opposed to 'grey' (e.g. ICE efficiency improvements) or 'dirty' (e.g. ICE component design) innovation.
- Finally, by focusing on innovation in different technologies compatible with zero emission vehicles, the analysis can provide insight into which specific technologies the UK may be well positioned to innovate in and inform the design of incentive packages for the sector.

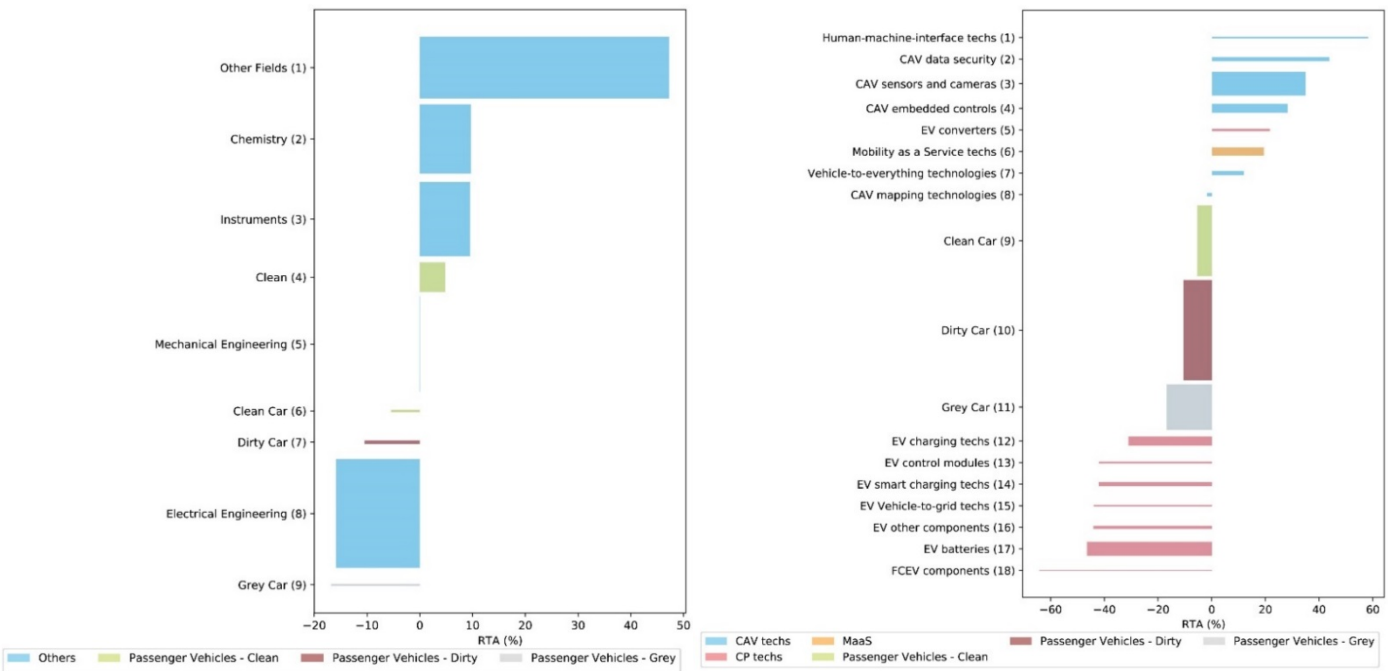
Revealed technological advantage

Figure 5.1 shows the revealed technological advantage (RTA) of the UK in clean car innovation compared with the rest of world from 2005 to 2014. RTA is defined as the share of an economy's patents in a particular technology field relative to the share of patents around the world. This gives an indication of the relative specialisation of a given country in selected technological domains. An RTA of 0 per cent would indicate that the UK's share of innovations in the category is aligned with the global average.

[6] See Appendix for more details about the automotive sector deal.

Figure 5.1. Revealed technological advantage (RTA) of the UK in clean car innovation compared with the rest of world (2005–14)

A. Share of clean car innovations in the UK compared with rest of world | **B. UK innovation in clean cars compared with broader innovation**



Note: The width of each bar on the x-axis shows the RTA; the depth of each bar on the y-axis shows the number of patents in each category. Source: Authors' estimates based on PATSTAT

Panel A shows the share of clean car innovations in the UK compared with the rest of the world. This reveals that on a broad, economy-wide level, the UK is doing comparatively worse in clean car innovation compared with other countries. However, in other broad categories of the economy such as chemistry, instruments and other clean innovation (e.g. incorporating other sectors and technologies such as renewable power generation) the UK has a comparatively greater share of innovation than other countries. This indicates that the UK has already lost some ground relative to other countries in the field of clean car innovation.

However, this analysis aggregates innovation in various technologies compatible with zero emission vehicles together as a broad 'clean car' category. Panel B shows UK innovation for specific technologies within the clean car category in comparison with broader categories of car innovation and shows that the RTAs of the technologies within clean cars are highly heterogeneous. Interestingly, the UK is outperforming the rest of the world for CAV technologies (labelled CAV techs, coloured blue), with CAV sensors and cameras standing out as a category with a comparatively high number of innovations and high technological advantage. In contrast, the UK is doing relatively worse in clean powertrain technologies (labelled CP techs, coloured pink) – primarily related to EVs and charging infrastructure. The notable exception to this is EV converters. While a relatively large number of innovations have been registered related to EV batteries, the UK has a considerably lower share of total innovation than other countries.

Another significant finding is that during the period in question, the UK was still registering a greater number of 'dirty' vehicle innovations than 'clean' innovations. This indicates that a significant number of UK businesses are continuing to register patents for ICE-related innovation. The shares of innovation are likely to have changed since 2014[7], given the significant amounts of R&D funding directed towards clean powertrain technologies (e.g. via the Advanced Propulsion Centre and the Faraday battery challenge). Nonetheless, there is considerable path dependence in both country economies and automotive companies: economies tend to innovate in line with national spillovers and companies tend to innovate in the direction of their own innovation history (Aghion et al., 2012, 2016).

Estimating the value and cost of spillovers for different technologies

While relative technological advantage gives an indication of the areas in which the UK has specialised, it does not give an indication of the value that the UK – or the rest of the world – might gain from a particular type of innovation. Nor does it give an indication about the ability of governments to promote further innovation in specific areas.

The 'IStra-X' industrial strategy index methodology, developed by Martin et al. (2020), provides a framework to take these issues into account. It allows for the computation of the social return on potential government R&D subsidies to different technology areas, and takes into account variation in the private returns on innovation in different sectors, as well as direct and indirect knowledge spillovers. It also allows for differential responses to government subsidies across technology areas.

IStra-X measures can differentiate between 'national' and 'global' spillovers; this is particularly relevant in the context of a national industrial strategy. For example, from the perspective of the UK government, a technology that generates more knowledge spillovers for inventors and firms operating within the UK will be more valuable than a technology that predominantly generates knowledge spillovers in other countries, even if the same value of global spillovers is generated.

Knowledge spillovers are measured using citations in patent data. Private values are then inferred from the short-term response of the stock market price of innovating companies when a patent is granted (private values of patenting for non-stock-listed companies are based on the most similar stock-listed companies). We infer the average R&D investment required to generate an innovation from the observed shape of the private value distribution in a particular technology area. If we observe relatively few low value innovations, it is a sign that the costs of R&D projects in that area are higher; i.e. innovators will ensure that they can recover those higher costs – on average – by only pursuing the most promising ideas. If average R&D costs in a technology area are high, it will require more government funding to increase innovation. Another consideration is the availability of marginal ideas that inventors have not pursued but could do with some government help. This basic idea generation could vary across technologies and we try to guess it by looking at the curvature of the existing value distribution across realised projects.

This is an emerging methodology, and there are other benefits and costs that may not be captured, for example innovations that are not patented, or patents that are not perceived by the stock market to deliver value at the point of filing. Moreover, it may be that market valuations are clearer in more distinct areas of innovation (e.g. pharmaceuticals) than in incremental advances in inter-related technologies where the full market potential is not yet understood (e.g. mobility-as-a-service technology). Nonetheless, the methodology provides new insights into the possible returns of different types of innovation.

[7] Although we rely on patent applications and application dates, these are only recorded in the public patent databases once the patent application has been fully processed which can take several years. Hence there is a time-lag of three to four years. Since we are using the 2018 version of PATSTAT this leaves us with 2014 as the last usable year.

Results: innovation values in the UK

Panel A in Figure 5.2 below demonstrates that public R&D investments in clean cars deliver comparatively lower social returns to the UK than 'dirty' and 'grey' car technologies, relative to the cost and likelihood of innovation. This may be explained by the enduring incumbency of the ICE vehicle and the corresponding firms innovating incrementally.

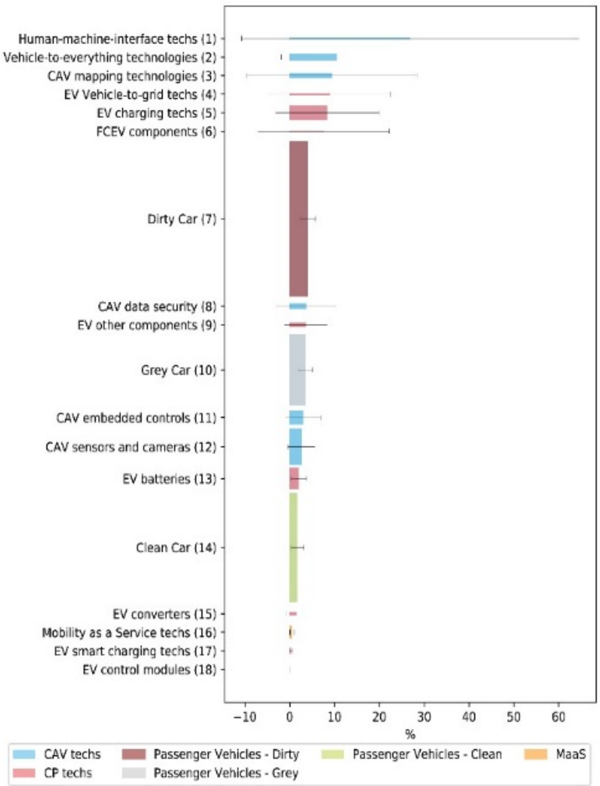
Nonetheless, as with relative technological advantage, there is a high level of heterogeneity between specific vehicle technologies. EV vehicle-to-grid technologies and vehicle-to-everything technologies are the technologies that outperform dirty and grey car technologies when considering both RTA and IStra-X as indicators; the UK outperforms the rest of the world in innovation related to these technologies, and they deliver notable innovation-related social returns for the UK (in excess of 10 per cent on average). However, our results also show that there is a high level of heterogeneity within the categories (as indicated by the wide 95 per cent confidence interval bands). This could imply that targeting specific technologies such as EV charging technologies with incentives may come with a level of risk concerning social returns.

A comparison can be drawn with equivalent results for Germany, shown in Panel B. By far the largest volume of innovation and the best returns for Germany are in the category of 'grey cars'. This is also likely explained by the role of incremental innovation, given Germany's sizeable ICE vehicle sector, and raises questions about the extent to which Germany should 'sweat' its existing assets by continuing to innovate in ICE vehicle efficiency improvements as opposed to directing industry purely towards clean powertrain technologies. However, beyond this, it is notable that innovation in a number of clean powertrain technologies such as EV batteries, charging technologies and control modules are delivering substantial returns, with a relatively low level of uncertainty, in contrast with the UK. It is also of interest that Germany's clean car innovations as a broad category deliver better societal returns (as defined by IStra-X) than dirty innovations, whereas in the UK clean car innovation returns continue to lag behind dirty and grey.

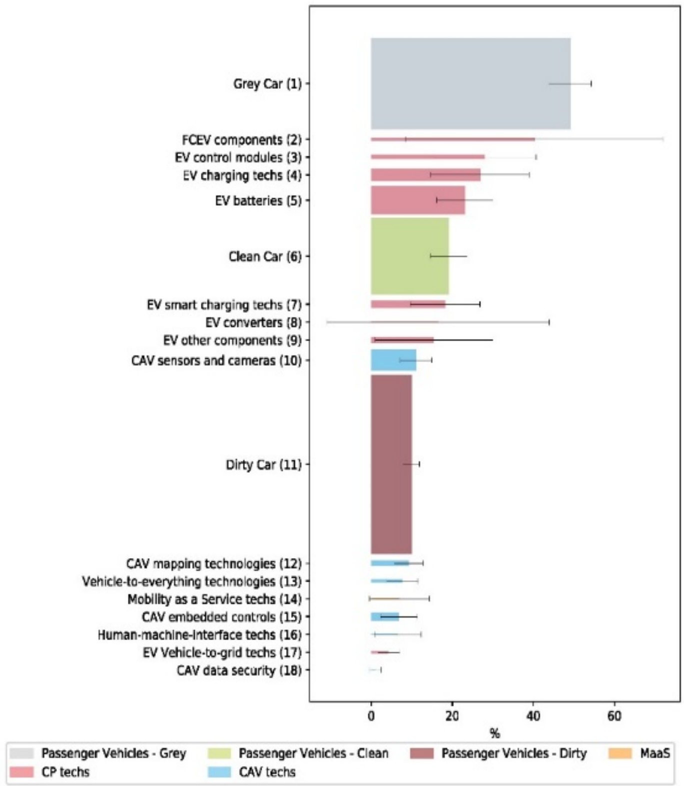
Given the diversity of these results, and the UK government's decision to target passenger vehicles as a strategic priority (for reasons broader than innovation spillovers), this analysis highlights the need for a portfolio approach to policymaking in this area, with incentives at the aggregated, outcome level – e.g. 'zero emission passenger vehicles'. This may help to mitigate the overall impact of certain passenger vehicle technologies receiving government support while delivering comparatively lower returns than others. More generally, this type of analysis can help highlight other clean technologies, for example in clean energy, where further support can be justified from a growth perspective. To illustrate this point, Panel C in Figure 5.2 shows IStrax-X for broader categories of technology innovation in the UK, in comparison with returns from clean, dirty and grey car innovation. It shows that clean innovations as a broad category deliver better returns than other broad categories such as instruments, chemistry and electrical engineering. However, car technology innovation – whether clean, dirty or grey – delivers lower returns than these other broad categories.

Figure 5.2. IStra-X results considering national spillover benefits from clean cars in comparison with dirty and grey car innovation, 2005–14

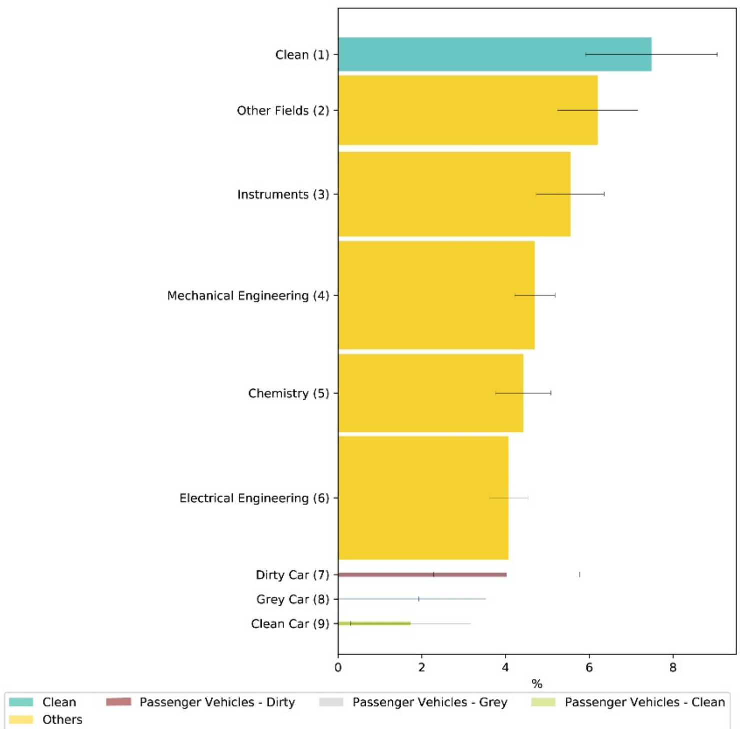
A. UK – clean and dirty car



B. Germany clean and dirty car



C. UK – broad technology fields



Note: This indicator takes into account – along with the average private returns and external value – the cost of the average innovation, as well as the probability that an innovation will be achieved given a certain subsidy. This is based on the structural estimates derived in the report by Martin et al. (2020) and can be read as a Return on Investment of a subsidy.

Source: Authors' estimates based on PATSTAT

Ensuring opportunities contribute towards regionally balanced growth

Growth opportunities related to clean and autonomous vehicles need to be understood at a regional level to ensure goods and services contribute to growth that is well distributed across the UK. Areas outside London and the South East account for a large proportion of employment in vehicle manufacture and the industry plays a key role in defining regional identities. Motor vehicle production accounts for 18 per cent of total manufacturing jobs in the West Midlands and 15 per cent of manufacturing jobs in the North East.

In areas with high employment in the internal combustion engine supply chain, there should be a focus on worker reskilling programmes and other programmes to attract investment and jobs in zero carbon goods and services. This must recognise that other sectors alongside vehicle production could also foster growth opportunities. Where there is regional capacity to drive growth from clean and autonomous vehicles, it should be nurtured. From a national policy perspective, it is also valuable to share best practice and build linkages between regions.

Analysing innovation activity at a regional level can shed light on which parts of the UK could be well positioned to act as R&D hubs for clean and autonomous vehicles in the coming years.

Figure 5.3 shows the distribution of car innovation (as measured by patents) in the UK. Panel A shows the distribution of total car innovation across Great Britain, including clean, grey and dirty. Panel B then gives the share of total car innovation in each region related to clean or autonomous technologies.

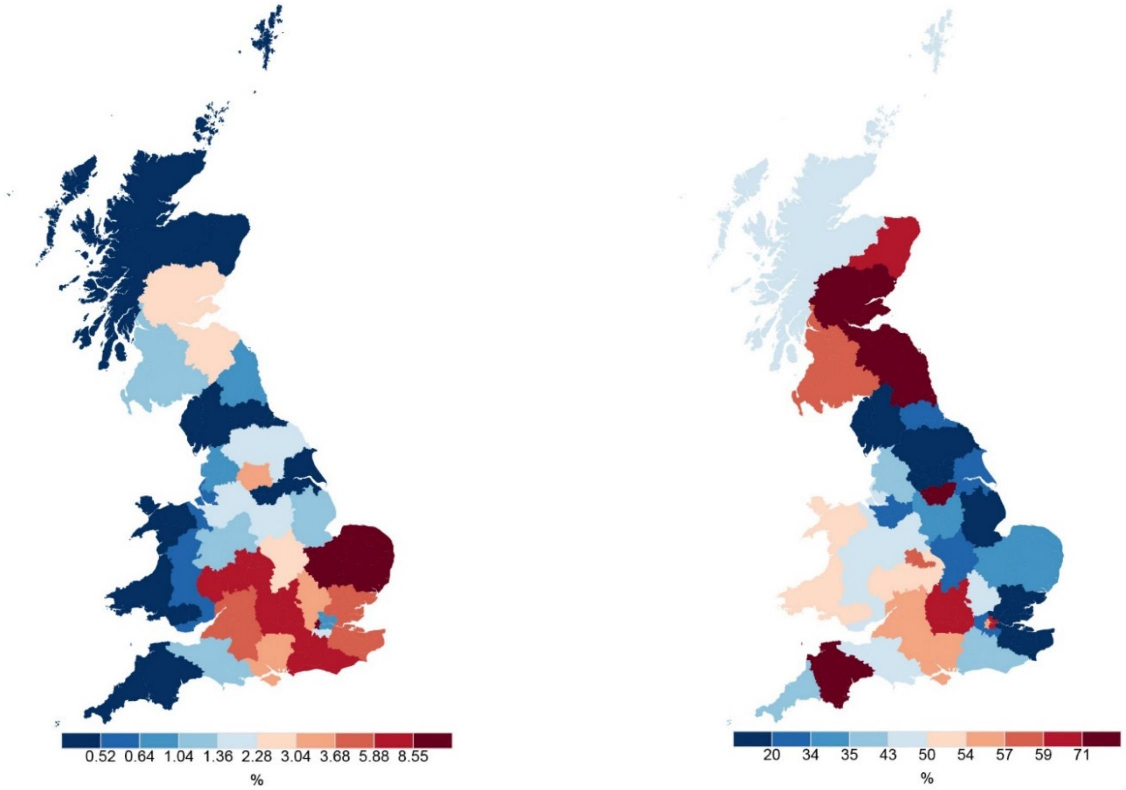
The scatter plot that follows in Figure 5.4 highlights the relationship between these two metrics. The West Midlands region has a relatively high share (more than 8 per cent) of total car innovation, and more than 50 per cent of this innovation is in clean or autonomous vehicle technologies. The area encompassing the counties of Herefordshire, Worcestershire and Warwickshire also stands out as a high performer. These patterns are likely driven by the Coventry and Warwickshire automotive sector which has been recognised for its investments in R&D and strong links to local universities (OECD, 2019).

In contrast, a lower proportion of car innovation located in East Anglia is related to clean and autonomous vehicles, despite the region being home to nearly 10 per cent of total car innovations. Kent and Essex are also areas of significant total car innovation but limited activity related to zero emission and autonomous technologies. Eastern Scotland is home to just 2.5 per cent of total car innovations but more than 75 per cent of these are in clean and autonomous technologies.

Figure 5.3. Distribution of car innovation in Great Britain, 2005–14

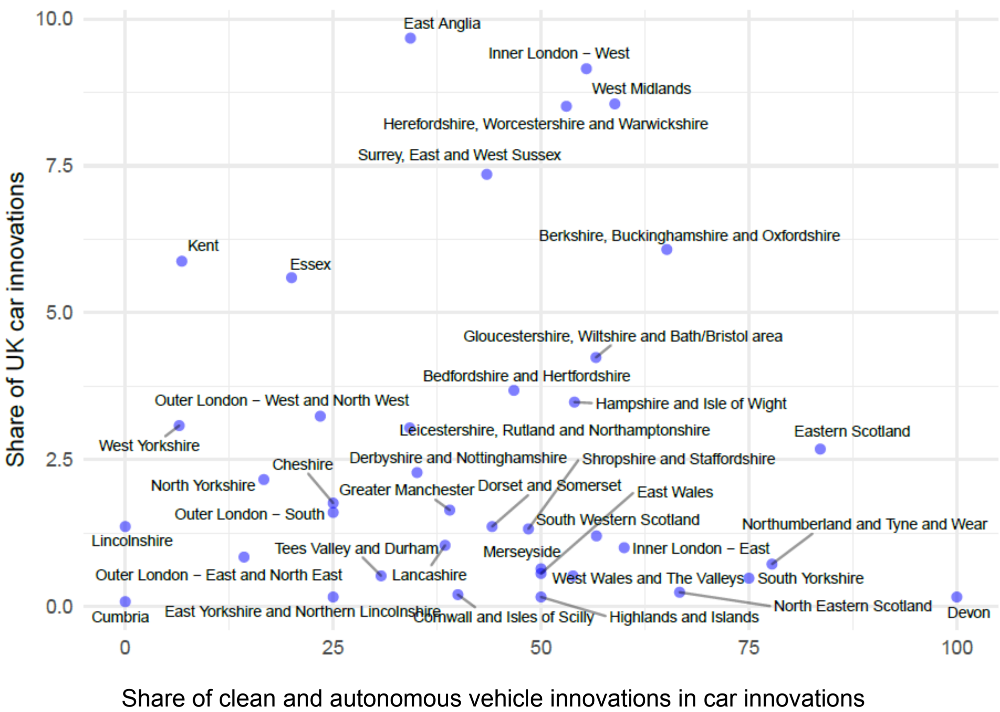
A. All car innovation

B. Share of car innovation related to clean or autonomous technologies



Source: The maps give innovation shares (based on patents between 2005 and 2014) at the NUTS2 level. The boundaries marked in the legend for each reflect the deciles of each measure. Source: Authors' estimates based on PATSTAT.

Figure 5.4. All car innovation versus clean car innovation in Great Britain, 2005–14



Note: Innovation shares (based on patents between 2005 and 2014) at the NUTS2 level.
Source: Authors' estimates based on PATSTAT

The incentives created by government policy can play a critical role in driving innovation and growth in goods and services related to passenger vehicles. The UK government has already made this a strategic priority: the Industrial Strategy's automotive sector deal sets ambitions to "mass [produce] electric batteries and vehicles here in the UK" and for raising "the competitiveness of UK suppliers to match the best in Europe" (BEIS, 2018). Incentives need to be designed carefully to ensure the UK plays to its innovative strengths across different goods and services. It is also necessary that related regional policy builds on local capacity, and does not perversely incentivise high-carbon goods and services. Consistency of incentives across innovation, infrastructure and skills policy is also critical.

6. Barriers and incentives to driving growth in the UK from passenger vehicles

In this chapter we first set out the barriers to the UK in capturing the growth opportunities from electric vehicles. We then explain the current policies that seek to address these barriers, and the gaps and limitations in these policies.

Barriers inhibiting growth

Barriers in three broad categories inhibit the UK's ability to drive sustainable growth from passenger vehicles:

- **Economic barriers** arise from general market characteristics, which are broadly applicable to other countries and segments of the economy too.
- **Technology barriers** relate specifically to the technologies underpinning goods and services related to passenger vehicles. For instance, the incumbency of carbon-intensive ICE technology in the vehicle market inhibits the ability of competing clean technologies to get a foothold.
- **UK country barriers** are specific to the UK's circumstances. For instance, skills shortages in the country have already been recognised as an inhibitor to growth in the sector based on its current composition. The Automotive Council UK found in 2016 that 2,500 vacancies were highlighted by automotive sector employers as being 'difficult to fill' or 'challenging', with a quarter of these vacancies actively impacting on business productivity and output (Bettsworth and Davies, 2016). As new technologies become more embedded in business models and without targeted skills programmes, skills shortages may deepen. Arun Srinivasan, executive vice-president and head of mobility solutions at Bosch UK and Ireland, has said that "the need for good, qualified engineers with skills that bridge the traditional and digital worlds has never been greater" (Fowler, 2017).

Actions to address all three types of barrier could help to improve the UK's comparative advantage relative to other economies, as well as potentially increasing uptake of clean vehicle technologies if economic and technology barriers are addressed (e.g. the maturity of technologies).

Table 6.1 summarises the barriers preventing growth from passenger vehicles, which both existing policy and our recommendations seek to address.

Table 6.1. Barriers inhibiting sustainable growth in the UK from passenger vehicles

Economic barriers	
R&D market failure	Due to the existence of spillovers, businesses capture only part of the benefits generated by R&D, reducing their incentive to invest money in such activities
Regulatory inconsistency	A lack of consistency in regulation and standards for the future vehicles under development
Skills training market failure	Businesses capture only part of the benefits generated by training and upskilling staff (staff may leave), reducing their incentive to invest money in such activities
Innovation to diffusion	Innovations do not always translate into commercial diffusion of technologies
Cross-sectoral collaboration	Future goods and services will likely rely on collaboration between sectors, particularly automotive and digital, but in practice this can be difficult to facilitate
Technology barriers	
Technology maturity challenges	Questions regarding the technical viability of new technologies mean technical improvements or initial stimulus from government are needed before widespread deployment of zero emission vehicles (and associated employment) can take place
ICE vehicle market strength	ICE engines' position as the incumbent car technology is inhibiting demand for sales and production of alternatives
Uncertainty over future markets	Not yet clear which technologies will have the largest future markets, and therefore which the UK should orient its resources towards. The UK faces a conundrum between remaining technology-agnostic and missing potential areas of competitive advantage, and betting heavily on specific technologies and risking path dependence/inefficient use of public funds
Unproven business models for new goods and services	Business models for new goods and services are still being defined, with implications for where there may be opportunities for revenue streams and value-add. For instance, defining a viable business model for EV charging infrastructure has proved to be challenging (PwC, 2018). Similarly, BEV powertrains have completely different supply chains to ICE vehicles and it is not yet clear if a wide range of component manufacturers will be able to be sustained (as in the current ICE supply chain) or if production will be dominated by a small number of OEMs producing the entire powertrain
UK country barriers	
Competitiveness	The UK struggles to be competitive with countries such as China who are leading in the development and diffusion of zero emission vehicle technologies such as batteries. New powertrains are simple in terms of parts, and therefore extremely margin driven, so competitiveness matters
Political uncertainty	The UK is currently facing considerable uncertainty over its future trading relationship with the EU (its largest current trading partner), stymying investment
Skills shortages	The UK faces a major shortage of skills in science, technology, engineering and maths, skills that will be necessary for new jobs in the sector
Regional disparity in growth and jobs	Benefits from future transport solutions risk accruing in areas that already have high productivity (e.g. London and the South East), as opposed to contributing to the productivity of regions that have a greater need for improvements

How incentives can impact markets for UK goods and services related to passenger vehicles

There are two main types of incentive in this context:

1) Incentives focused on stimulating demand in the UK for goods and services (e.g. market development policy)
2) Incentives focused on increasing the UK's share of the total market supplying these goods and services (e.g. industrial policy)

While these can be defined as supply- and demand-side incentives, the two are closely linked, as demonstrated by the case study of Korea (see Box 6.1). Demand-focused incentives such as grants to assist with EV purchase can appeal to consumers while sending a strong positive signal to industry in terms of market potential.

Box 6.1. Lessons from the Republic of Korea in linking supply- and demand-side policies for success in automotive manufacturing

Korea's highly planned approach to industrial strategy in the second half of the 20th century has been recognised as an example of how to build robust growth driven by sequenced and coherent planning and strong and joined-up institutions (LSE Growth Commission, 2017).

A particular area of success was the automobile sector. The Government used a range of tools such as restricted imports of cars, subsidised loans and tax incentives to ensure stable demand for domestic auto manufacturers. Import restrictions were gradually removed and replaced with domestic demand stimulation policies such as vehicle-related tax credits as Korea gained competitiveness. More recently, industrial policy has focused on driving innovation, although the Government continues to use demand-side policies to spur development of both green technologies and domestic sale of clean cars (UNIDO, 2020).

The UK has a complex policy and regulatory landscape in relation to zero emission vehicles. The country has comparatively high coverage across supply and demand compared with its international competitors, with incentives supporting both the production of zero emission vehicles (such as R&D support) and customer purchases (such as 'plug-in' grants).

Incentives focused on stimulating demand in the UK for zero emission vehicles

One of the challenges for the UK in decarbonising its transport sector is how to make all remaining passenger vehicles zero-carbon. There is widespread public support for achieving the co-benefit of reducing air pollution by shifting towards zero tailpipe emission vehicles (Holder, 2019) and there is already a complex array of investment, policies, regulation and campaigns targeting increased sales of zero emission vehicles in the UK. These are summarised in Table 6.2.

Table 6.2. Incentives focused on increasing domestic sales of zero emission vehicles in the UK

Name of incentive	***Type of incentive***	***Description***	***Current status of policy and perceived credibility***	***Goods/services that may benefit from increased demand***
ICE phase-out	Regulation	Year-based regulation in which new sales of ICE vehicles and hybrids will no longer be allowed, paving the way for zero emission vehicles to dominate	Active, 2035 phase-out date. The CCC asserts that 2035 is the earliest possible date compatible with 2050 net-zero ambition, and advise exploring an earlier date	All goods and services related to zero emission passenger vehicles
Go Ultra Low campaign	Awareness campaign	Marketing campaign launched to increase uptake of ultra-low emission vehicles by demonstrating their viability and addressing the public's concerns	Active since 2014. The International Council on Clean Transportation (ICCT) describes it as "an example of a successful multi-media campaign… the market in the United Kingdom has grown in step with the Go Ultra Low campaign" (Jin and Slowik, 2017)	All goods and services related to zero emission passenger vehicles
Electric Vehicle Home-charge scheme	Grant funding	Grant funding provided directly to the supplier to cover the upfront cost of charging units and accounted for in the cost to consumers	Active. Environmental Defense Fund Europe recommends extending support, indicating that it is perceived to be credible	EV charging infrastructure
Mandatory charge-points in new homes	Regulation	All new-build homes to be fitted with an electric car chargepoint. Government is also considering mandating that all new charge points use smart technology	Proposed by government; under public consultation. If implemented, would ensure consistency with other government commitments supporting a shift towards EVs (e.g. avoiding new homes being built that cannot support EV charging without retrofits and additional investment)	Smart charging services, EV charging infrastructure
Vehicle excise duty	Tax	Zero emission vehicles exempt from road tax as well as most congestion charges and low emission zone taxes in big cities	Active. Electric company car fleets also to be exempt from 2021. The impact of stronger differentiation between zero emission vehicles and ICE vehicles is discussed in recent analysis at LSE (Burke, 2019)	All goods and services related to zero emission passenger vehicles
Fuel duty	Tax	Levy applied to petrol for vehicles, at 58p per litre. No equivalent for hydrogen or EVs	Active. Maintaining current approach to fuel duty not seen as credible. A range of actors e.g. the IFS advise reform to fuel duty to avoid government losing revenues as fleets switch to electric (Emmerson et al., 2019). Research at LSE has investigated the impact of reinstating the escalator (Finnegan, 2018)	All goods and services related to zero emission passenger vehicles

Name of incentive	*Type of incentive*	*Description*	*Current status of policy and perceived credibility*	*Goods/services that may benefit from increased demand*
Life cycle emissions vehicle tax	Tax	Tax applied to the life cycle emissions of a vehicle, including the emissions intensity of the electricity used to power it in the case of EVs	Concept stage – policy option to replace taxes such as vehicle excise duty into the longer term. If this were implemented across the EU – and the UK remained part of the EU's CO_2 reduction standards – the UK's rapidly decarbonising power sector could make the country a particularly attractive selling market for EU car manufacturers seeking to comply with EU emissions regulations	All goods and services related to zero emission passenger vehicles
Plug-in electric car grant	Grant funding	Discount on the price of new low-emission vehicles through a grant the government gives to vehicle dealerships and manufacturers	Active. Environmental Defense Fund Europe recommends extending support, indicating that it is perceived to be credible (Koehler et al., 2019)	EV components, FCEV components
Charging Infra-structure Investment Fund	Investment vehicle	£200m of public money – to be matched by private investment – available for all aspects of the charging infrastructure, including charge point equipment and grid enhancements	Active since October 2019. £62m of private investment from Masdar Capital has claimed matched funding to date, indicating a willingness from the private sector to invest under the scheme. However, not yet mobilising finance at scale	EV charging infrastructure
Automated and Electric Vehicles Act 2018	Regulation	New legislation providing route to compensation for damage from automated vehicles, through insurance rather than via a product liability claim. Also pushes for standardisation in EV charging infrastructure	Active, although technical specification of legislation not yet confirmed, thus not yet having impact beyond sending a high-level signal of commitment to these technologies	CAV components, EV components, EV charging infrastructure

Around 2.5 per cent of UK car sales in 2018 were EVs, broadly in line with the European average. This is significantly less than in Norway, which has by far the highest market share at 46 per cent, and less than Sweden and China (IEA, 2019). Box 6.2 explains the factors behind Norway's success. There is extensive policy discussion currently taking place on how best to improve and build on the demand-focused incentives described in Table 6.2, centred on whether or not to move the date for phasing out ICE vehicles forward from 2040 (see Kumar, 2019 and Koehler et al., 2019).

Spurring increased demand for zero emission vehicles will be a key means of achieving the Government's ambitions to decarbonise the UK's transport system. Increased demand is also a central driver of sustainable growth in the UK, provided the UK's businesses are able to secure a substantial share of the market for related goods and services.

Increased demand from the UK for zero emission vehicles could give a boost to UK manufacturing by providing a domestic incubator market for goods and services. In Norway this has been the case: the country is a hotbed of innovation in EV smart charging (see for instance Fortum Charge & Drive). A comparable trend can be seen in the number of Chinese and Korean battery companies that are seeking to establish gigafactories in Europe, in close proximity to perceived future EU demand for EVs (Faraday Institution, 2019). Table 6.2 above demonstrates that the framework of demand-side policies currently in place is broadly recognised as credible. However, in comparison with Norway's comprehensive framework of support, there is more that could be done if the UK has aspirations to be a leader in EV deployment.

Box 6.2. Norway as the gold standard for stimulating electric vehicle demand

Norway has had a long-term commitment to stimulating demand for EVs, with many incentives dating back to the 1990s, and this has proven to be popular with the public (Lorentzen et al., 2017). In 2009, the Norwegian government funded a nationwide build-out of EV charging infrastructure via Transnova, a public agency set up to demonstrate and build clean transport projects. Ten years on, Norway has the most extensive charging infrastructure network in the world, installed through a series of public procurement rounds, which has largely eliminated anxiety over the range of EVs (Philips, 2015). Norway's policy is focused on a target of 100 per cent market share for zero emission vehicle sales by 2025.

A comprehensive set of incentives are in place to stimulate vehicle sales, the majority of which are tax breaks or avoided payment mechanisms. These include no tax on new EVs, exemption from company car tax alongside free access to municipal charging, ferries, parking and toll roads. City and regional governments have complied with government incentive programmes, exempting electric cars from fees and tolls, even though this cuts their revenue. This reflects the broad-based support for EV incentives and a willingness from multiple actors to sacrifice revenue to increase deployment (Centre for Public Impact, 2016). Incentive frameworks have been long-term and stable, remaining in place (and expanding) through successive social democratic and then conservative governments (Philips, 2015).

The media's portrayal of EVs, and communication of information about the benefits and ease of use, also appear to have played important roles in Norway's success. Research has indicated the media (inclusive of all types) was the most highly regarded information source, followed by family and friends. Social influence is another relevant driver for sales. The caveat to these social dimensions is that Norway's strong EV sales are underpinned by sales to wealthier households (Broadbent et al., 2019). Because Norway's used car market remains dominated by petrol cars, those who cannot afford to buy a new electric car cannot take advantage of the lower cost of driving (Nikel, 2019). It remains to be seen whether EV market share growth will begin to slow down as sales reach saturation level in the demographic groups that have driven sales to date.

The recommendations in this report focus primarily on supply-side incentives seeking to increase the UK's share of markets, but recognise the critical importance of strong demand-side incentives to create the markets for innovation. Box 6.3 provides evidence of how domestic demand incentives complemented domestic production in the Chinese wind turbine industry, with lessons for the UK.

Box 6.3. Using domestic demand to drive domestic production: lessons from the Chinese wind turbine industry

China has demonstrated the potential of domestic demand to drive production and economic growth, in the context of wind turbine manufacture. Domestic demand continued to account for around 80 per cent of total demand for production during the 1990s, even as export markets for Chinese products grew dramatically (Wong and Chan, 2003). More than half of the top 15 turbine manufacturers are based in China, accounting for 29 per cent of global market share in 2018 (REN21, 2019). China's domestic market has grown concurrently, with 23GW of new wind capacity installed in 2018 – over three times more than any other country (ibid.).

Renewable energy policy and industrial policy for renewable energy have a general tendency to be intimately linked, which China has effectively exploited (Zhang et al., 2013). For instance, China's National Development and Reform Commission stated in 2007 that "sustainable and stable market demand can create conditions beneficial to the development of the renewable energy industry" (ibid.). Thanks mainly to its local content requirement policy, the foreign share of China's annual imports of wind power equipment fell from 75 per cent in 2004 to 24 per cent in 2008 and 12 per cent in 2010 (ibid.).

To achieve a similar trend in the passenger vehicle sector, the UK would need to secure a much higher share of domestic production in future sales of vehicles than its current share.

China's successes in wind have not been without their challenges, typified by a heavy focus on industrial policy over demand-side policy. By 2011 China's wind power generation capacity had exceeded 30GW while the domestic market demand was less than 18GW. This led to more than 40 per cent of China's wind turbines standing idle (Zhang et al., 2013). If the UK is to consider using interventionist supply-side policies, they need to be designed carefully in integration with demand-side policies to ensure there is demand – whether domestic or global – for the goods being supplied by British companies.

Incentives focused on stimulating UK supply of zero emission vehicles

The Appendix provides a detailed overview of current supply-side incentives, supported by an assessment of their potential effectiveness, based on ex-post academic analysis of policies, observations of international best practice and consideration of their suitability in relation to the analysis of market size and innovation, as reported in Chapter 5.[8] Broadly, such incentives can be summarised into the following categories: overarching strategies, funding packages, concessional lending products, tax relief and capacity and capability-building programmes.

Gaps in or limitations of supply and demand incentives seeking to increase the UK's share of the total market for zero emission and autonomous vehicles demand

The UK's competitiveness in comparison with rival economies will inform the extent to which it can seize sustainable growth opportunities. Even if global markets for zero emission vehicles grow as expected, the UK could receive minimal economic benefits from the transition if it falls behind in competitiveness.

The market share analysis in Chapter 4 shows that more than 50,000 jobs in component manufacturing are at stake between the low and high market share projections, depending on whether the UK's economy takes the shape of its more or less competitive neighbouring economies in Europe in 2030. Across the full future passenger vehicle supply chain, the number of jobs at stake is likely to be significantly larger. This emphasises the importance of getting

[8] We note that not all of these policies specifically target goods and services related to zero emission vehicles at present, and many are economy-wide.

incentives right. Current incentive frameworks are not fully optimised to capture the sustainable growth opportunities that passenger vehicles could present up to 2030.

The gaps and limitations we have identified include:

1. Demand-side policies could be more ambitious and long term in order to maximise their potential to encourage UK-based suppliers of goods and services.
2. Current incentives do not integrate zero carbon goals systematically.
3. The majority of incentives are finance packages of limited duration and are subject to short-term changes – there are limited examples of long-term but dynamic policies that are responsive to changes.
4. There are comparatively fewer incentives focusing on skills.
5. There are limited policy mechanisms that target balanced growth across the UK, regarding both workforces and their communities.
6. Current policies and regulation cannot mitigate the impact of Brexit-related uncertainty for businesses working on goods and services related to passenger vehicles.
7. The UK does not currently have comparative advantage in some technologies receiving government support, and other countries are committing more funding.

In the next chapter we build our recommendations around these points.

7. Recommendations for sustainable growth in the UK from passenger vehicles

The high-level gaps and limitations revealed by our analysis provide the structure for the recommendations we make in this section. We highlight demand-side policies because they also act indirectly as supply-side incentives by increasing the UK market size, therefore making UK-based innovation and investment more attractive for the private sector.

We also highlight comparable case studies of effective policymaking from around the world to demonstrate options for the UK to address these challenges.

A series of changes are needed in order to address these issues and tackle the barriers we have identified. These may be either changes to existing incentives (amending, scrapping or replacing them) or new incentives to address identified gaps. While many of these changes seek to deliver benefits in relation to passenger vehicles, many of them have economy-wide applicability (e.g. revising R&D tax credits). Amendments could therefore be tested in the automotive sector, before a wider rollout.

The recommendations below can act as flagship policies and approaches, indicating to business that the UK has a strategic commitment to being internationally competitive in these markets, and driving inclusive growth at home. The recommendations seek to address the gaps or limitations in current policies we listed at the end of Chapter 6 and thus are grouped by these themes.

Recommendation 1. Make demand-side policies more holistic, ambitious and long term to maximise their potential to encourage UK-based suppliers of goods and services

1.1. Implement a non-regression clause that mandates current and future governments to either maintain demand-side vehicle incentives or revise them to be more ambitious and comprehensive, until such a time that the Committee on Climate Change deems them to no longer be necessary

The UK's domestic market for passenger vehicles and related products is tiny compared with the global market. However, given that many of the goods and services under discussion are still at a nascent stage of commercialisation, the domestic market can act as an incubator for UK products and services. This can help drive down costs by stabilising demand and developing globally competitive products. The UK has already demonstrated comparable successes in driving down the cost of offshore wind by assuring developers of stable market demand through Contracts for Difference. The UK should therefore maintain a comprehensive set of policies to increase uptake of zero emission vehicles over the coming years. The demand-side policies in place are broadly seen as credible and should have funding secured for them long-term. A non-regression clause is a means of formalising long-term commitment to demand-side incentives. This could be revoked once the CCC agrees with government that emissions reductions from road transport no longer need to rely on the incentives in question.

1.2. Explore options to move the ICE and hybrid vehicle sales ban earlier than 2035, while empowering regions to implement further incentives to make the economics of vehicle purchase more appealing

The UK's recent decision to move the ICE and hybrid vehicle sales ban forward to 2035 is welcomed and sends a clear signal to consumers and business regarding the direction of policy. Now, if the UK's ambition is to break away from EU average EV deployment rates and move closer to Norway's levels of deployment, it is likely to require altogether more comprehensive and concessional support for EVs. As a headline measure, exploring options to move the ICE vehicle ban to an earlier date could further encourage manufacturing and innovation to take place in the UK, given the advantages of being sited close to markets. Beyond Norway's 2025 phase-out target, EV deployment in the country has been driven in large part by stripping away as many taxes and costs associated with EVs as is feasible, as well as developing comprehensive charging infrastructure. This requires a range of stakeholders – primarily national government and local government – to recognise that revenue streams typically generated by road transport may be temporarily or permanently eroded. Norway's national circumstances are different to the UK's; in the UK, this process could be regionally driven. Local governments in regions with high support for zero emission vehicles can go further in adapting taxation and other frameworks such as bus lane access and parking and public procurement schemes for charging infrastructure.

1.3. Ensure all investment in road infrastructure facilitates charging infrastructure development, with public investment leveraging private investment

Highways England has committed to the availability of charge points every 20 miles on 90 per cent of the strategic road network. Concurrently, substantial levels of investment have been committed by government to road infrastructure improvements, a proportion of which is allocated for charging infrastructure. These commitments need to be aligned, with *all* road infrastructure funding decisions considering how public investment can most effectively leverage private investment into the UK's charging infrastructure. Norway's approach of using public procurement rounds to contract the private sector to install charge points could be considered in areas of the UK with a low density of EVs and charging infrastructure. In areas with higher densities of EVs today, and thus a clearer business case, public investment can be channelled through the Charging Infrastructure Investment Fund. There should be constant dialogue with industry to ensure that interest rates offered by the fund have a suitable level of concessionality.

1.4. Use demand-side policies, regulation and government procurement in larger vehicle classes to spur UK manufacturing, resulting in technology and knowledge spillovers for passenger vehicle production

It can be challenging to attract jobs and investment to passenger vehicle manufacturing via demand-side policies due to the complex and international nature of fleets and markets for passenger vehicles. However, policies focused on increasing domestic demand for zero carbon medium and heavy duty vehicles (MDVs and HDVs) such as taxis and vans may be more effective as large fleets often have a single owner and/or manufacturer. For instance, the London Electric Vehicle Company (LEVC) now manufactures electric taxis in Coventry; the decision to locate there appears to have been spurred by demand-side policies and regulation focused on taxis in London. This approach could be replicated by targeting incentives at other fleets such as government vehicle fleets, public buses, company transit vans and taxis in other cities. Increasing UK-based innovation and production of zero emission MDVs and HDVs via demand-side policies could lead to knowledge and technology spillovers that increase the UK's competitiveness in the production of passenger vehicles.

1.5. Consult UK businesses to gradually develop the Autonomous and Electric Vehicles Act into a clear regulatory framework while not stymying innovation where there is technological uncertainty

This would likely ensure that the specifications agreed are well suited to the products and capabilities on offer from UK firms. Technical specifications need to be agreed on for EV chargers, a process that should be led by government but in close consultation with industry. Regarding CAVs, the law needs additional provisions to judge vehicles that are approved as being capable of 'safely driving themselves'. The UK's launch of CAV PASS as a new safety standard is a step in the right direction (Department for Transport, 2019). Lessons could also be learned from the Netherlands' Driving License for a Vehicle, which is expected to focus on the extent to which a vehicle can produce safe and predictable automated driving behaviour that aligns as closely as possible with human performance in an open traffic system (KPMG, 2019).

Provisions should also be included for sharing of data from companies providing autonomous vehicle driving services. This type of transparent disclosure (e.g. miles travelled by CAVs) has effectively driven competition between the two main CAV providers in California, Alphabet's Waymo and the GM Cruise (Hawkins, 2019). By mandating this type of disclosure in the AEV Act, government could also have the chance to identify the key performance indicators to be disclosed by companies, to ensure they can usefully inform policy design. Nonetheless, standards should be agreed to safeguard cybersecurity, in line with the Electric Vehicle Energy Taskforce's recommendations (Electric Vehicle Energy Taskforce, 2020).

As new innovations emerge from UK businesses, for instance in relation to new payment technologies, the AEV Act should be revisited on a regular basis to ensure that the UK can act as an incubator market for promising new British technologies.

Recommendation 2. Systemically integrate zero carbon goods and services as a priority into incentives

2.1. Establish a new National Investment Bank with a mandate to support zero carbon goods and services

Establishing a National Investment Bank with an explicit sustainability mandate would help bridge finance gaps for UK businesses working on zero emission vehicles. For instance, lack of working capital is likely to be a significant constraint for SMEs in emerging areas such as EV charging infrastructure, whose accounts may not be large enough to make tax credit-style incentives appealing. A National Investment Bank could help plug these gaps and make UK businesses more competitive by providing concessional lending rates. Similarly, a Bank could develop financial products to support the commercialisation of government-supported R&D projects, such as projects funded under the Faraday battery challenge (within the Industrial Strategy Challenge Fund). Channelling funding through this type of investment vehicle would send a strong signal to the private sector and would also ensure government finance is used efficiently – learning lessons from previous investments, revising priorities and reallocating capital accordingly. While this intervention would benefit goods and services related to zero emission passenger vehicles, it could also be a critical tool for supporting sustainable growth across the economy.

2.2. Introduce more detailed criteria for the issue of R&D tax credits to ensure that they target R&D projects aligned with zero carbon transport objectives

The automotive sector could be an appropriate area to trial this approach as it is relatively straightforward to specify whether or not R&D is working towards 'dirty' innovations such as ICE engines. In time, this amendment to R&D credits could be made more sophisticated, by including criteria for the extent to which the advance is likely to lead to spillovers in other industries for low-carbon goods and services as opposed to narrow benefits in the specified area. If proven to be successful after trialling in relation to passenger vehicles, the approach could be extended to other aspects of the economy.

2.3. Amend the General Export Facility's mandate to "ensure that no viable UK export fails for lack of finance or insurance"

The definition of 'viable' used by UK Export Finance's General Export Facility (GEF) should be broadened to also consider the extent to which the export can be considered part of a zero carbon future, first trialling this in the context of zero emission passenger vehicles. This could then be disseminated through UK Export Finance's network of regional export finance managers to enable these managers to seek out companies exporting products that align with a region's particular growth prospects.

The GEF should be redesigned to offer preferential support (e.g. more concessional lending rates) to UK-based businesses seeking to export products with clear sustainable growth credentials. Care should be taken in defining the criteria for this concessionality – the individual companies requesting the benefit should be considered carefully, and a cap established for the scale of tax relief permitted. The relief should also be monitored in relation to ongoing UK investment in R&D to ensure additionality. Within the area of light road transport, investment and support guidelines could specify that goods and services that can deliver zero carbon transport options will receive these benefits. The GEF should also introduce a deadline by which to phase out support to UK businesses producing ICE vehicle-related goods and services.

2.4. Scale up funding and lengthen the timeframes for supply chain improvement programmes and redesign them to ensure that the productivity and competitiveness improvements are for components that are either specifically for – or are not incompatible with – usage in zero emission vehicles

The National Manufacturing Competitiveness Levels (NMCL) is a £16m supply chain competitiveness and productivity improvement programme under the Industrial Strategy that measures competitiveness. Its aim is to help UK businesses in benchmarking their activity against the best in Europe to identify the areas in which they need to improve their operations. In contrast, the Advanced Manufacturing Supply Chain Initiative (AMSCI), which ran from 2012, made £345m available. There has therefore been a reduction in funding available for supply chain competitiveness at a time when the UK's automotive sector needs significant support in transitioning towards future supply chains. The size of the NMCL should be scaled up significantly, with a long-term time horizon and funding levels at least comparable with the AMSCI programme. It should also have a specific focus on competitiveness in zero emission vehicle technologies. Examples of businesses receiving support from the NMCL should be recorded and publicised, to promote goods and services for zero emission vehicles. The Government should consider indicating a long-term plan to phase support away from businesses producing components that are ICE-vehicle specific. Lessons can be drawn from the long-term policy signals deployed by the Republic of Korea to give a clear direction to industry, described in the box below.

Republic of Korea: using incentives to provide a long-term direction of travel

From the latter half of the 20th century, Korea demonstrated the growth potential of policy pointing coherently in a unified direction, as envisioned by government. While aspects of Korean industrial strategy were protectionist and unsuitable for the UK, the country's experiences provide lessons on the potential effectiveness of strong and joined-up institutions and a long-term strategy that is consistent across a variety of different policy levers.

Industrialisation was meticulously planned by the Economic Planning Board (EPB), a government department that coordinated policy across different levels of government. The EPB created a series of rolling five-year plans from 1962 to 1992, which worked down from overriding objectives, to targets, to proposed policy interventions and business actions, to allocation of resources. Korea's policies were sequenced and coherent: long-term plans provided a policy road map that business leaders understood. Coordination was also enabled by 'deliberation councils' in key industries, which consisted of government officials, industry representatives and more 'objective' observers such as academics or journalists (LSE Growth Commission, 2017).

While Korea in this period was targeting catch-up growth as opposed to decarbonisation, lessons can be drawn from how it aligned policies under long-term plans. In the UK the automotive sector deal could learn how to adjust incentives that may be economy-wide to favour production of zero emission vehicles under an overall strategy.

Recommendation 3. Move beyond finance packages as incentives to create more examples of dynamic policies that are responsive to changes

3.1. Implement an Annual Mobility Services Innovation Prize

A critical challenge for the UK's automotive sector is to move away from the traditional business model in which value is drawn from production and sales of cars, to a business model that offers value in facilitating efficient and affordable car usage. However, such a challenge also suits the UK's nature as a service-based economy. The UK does use competitions to fund innovation – for example, there is currently a £30m open funding competition named 'Driving the electric revolution: building regional centres of excellence' (Innovate UK, 2019) – but as yet there have been no competitions that steer innovation in services related to passenger vehicles.

Our proposed annual prize would challenge companies to innovate services to tackle different aspects of innovation for cleaner passenger vehicles. The annual frequency of the prize would mean the focus could change each year in response to emerging technologies and challenges. Key services that could be focuses could include smart EV charging, connected home-related innovations or new models for mobility-as-a-service. An annual prize could help address the fact that there is not yet a single clear, established services model, as there are a wide range of actors, from multiple sectors, who might be able to provide solutions and see these areas as being of strategic interest (Mitchell et al., 2014). Care should be taken in the design of any prize to ensure it achieves the desired effects and limits market distortion, which has been highlighted to be a potential unintended consequence of competitions (Gök, 2013).

Lessons in the use of competitions to spur innovation, from NESTA's Open Up Challenge

NESTA, a British foundation focused on encouraging innovation, launched the Open Up Challenge in 2017. The Challenge seeks to stimulate the UK retail banking market with a competition for innovative products and services. It has successfully stimulated the supply of fintech [financial technology] solutions and has increased demand for these solutions by improving the quality and usefulness of the products available for small businesses. Innovations developed under the Challenge include 'credit passports' which are updated in real time, and automated completion of tax returns (NESTA, 2018).

The UK government could learn lessons from this by targeting supply-side incentives in areas that are known to be barriers to demand, e.g. improving EV charging services. This can support both demand for zero emission vehicles in the UK (by improving the products and services available) and the UK-based businesses supplying them.

3.2. Amend the automotive sector deal to ensure it is a dynamic instrument that responds to changes in the sector

The sector deal process must begin with a formal review, as committed in the original deal document, and then become an annual occurrence, supported by a schedule of consultations with industry. This should be underpinned by a monitoring scheme that sets out key indicators of success (e.g. announcements that secure jobs), highlights risks that need to be monitored (e.g. rent-seeking resulting from the private sector relying on funding under the sector deal) and agree a set of guidelines for how to respond to monitored changes.

These updates should be reflected in a more active website[9] for the automotive sector deal that is updated more regularly than currently, and that has a more user-friendly interface, so that industry can see what funding packages and other incentives are available at any point in time, closing dates for incentives, and a long-term timeline including key dates (e.g. future

[9] The current website can be found at www.gov.uk/government/publications/automotive-sector-deal

mechanisms in the pipeline, dates when regulations come into force). Lessons for the design of longer-term, responsive incentives can be drawn from the government-funded Advanced Propulsion Centre, which has successfully built its profile over 10 years.

The sector deal should highlight when programmes funded by the Deal are brought to a close. Where appropriate or politically feasible, it should be made clear if the decision was made because the desired outcomes were not achieved, or if the issue was addressed (with evidence of this provided) so that funding can now be directed elsewhere.

3.3. Build in more robust evaluations of projects supported by the Catapult centres

The Catapult network was established by Innovate UK to connect businesses with the UK's research and academic communities, in order to transform the UK's capability for innovation in specific areas and help drive future economic growth.[10] A number of these specialise in areas relevant for zero-carbon passenger vehicles: Connected Places, Energy Systems, Digital and High Value Manufacturing. More robust evaluation can help Catapult centres to contribute more effectively to the body of evidence of what works in terms of stimulating collaboration between industry and the research community. A clearly defined purpose, mobilisation of investment, strong governance and effective collaboration between Catapults are other performance criteria on which they should be judged.

Recommendation 4. Focus more incentives on skills

4.1. Implement a future skills marketplace

Current assessments of skills needs in the automotive sector are static, taken at a point in time. The most recent detailed assessment took place in 2016 (Bettsworth and Davis, 2016). The Automotive Apprenticeship could be relaunched as a broader 'skills marketplace', using the Automotive Council's Automotive Industry Job Framework and hosted as part of the overall sector deal (ibid.). This will enable skills needs to be tracked and addressed on an ongoing basis, which would help to inform dialogue with the education sector.

An online platform could be used for industry representatives to regularly update their immediate skills gaps and needs, and also the skills gaps they envisage having one to three years on. The platform could be led by the Department for Education as its focus is broader than that of the current Apprenticeship Service, which is hosted by the social enterprise Getmyfirstjob. The focus would be primarily on STEM skills, acknowledging the finding of the Augar Review on post-18 education and funding that there is a relative lack of provision of courses in subjects such as engineering compared with the over-supply of business, creative arts and social studies courses (Department for Education, 2019). Lessons could be learned from other labour market supply/demand programmes, such as the European Commission's EURES jobs network, which has been found to be broadly effective in improving labour market transparency and linking workers with jobs (European Commission, 2015). The International Labour Organization also provides guidance on how to anticipate skills needs (ILO, 2015), which could inform the design of the platform.

The skills marketplace could pool demand for skills, which could then be supplied from a range of sources. It could be matched by a mix of other workforces requiring redeployment (e.g. from high-carbon manufacturing or extractive industry), university curricula and apprenticeship schemes. For instance, it could link directly to one of the Augar Review's headline recommendations: to create a coherent national network of further education colleges that deliver in-demand skills needs focused on England's qualification levels 3 to 5 (these include vocational qualifications such as BTECs, trade diplomas, technician qualifications and Foundational degrees) (Department for Education, 2019). The marketplace could also input skills demands to the apprenticeship programmes on offer under the Apprenticeship Levy. In the first year of its operation, the Levy raised £2.01bn, but had a £400m

[10] See Appendix for more analysis of Catapult centres.

underspend (City & Guilds, 2019). In the context of passenger vehicles, the future skills marketplace could provide the demand-side link to these supply-side skills initiatives.

4.2. Introduce human capital tax credits

R&D tax credits are one of the Government's principal tools for boosting innovation in private companies and have been found to be effective (Dechezleprêtre et al., 2019). The externality problems that lead to underinvestment in R&D (i.e. firms do not capture the full social benefits of innovation) also apply to human capital (firms might train workers who subsequently leave), therefore there is a case for more support to incentivise firms to invest in their workers. Human capital tax credits could function in a similar way to R&D tax credits (Costa et al., 2018). There is a case that the goods and services associated with zero emission passenger vehicles in the car industry and related industries would be a good context in which to pilot this type of policy – it is a large 'sector', with change underway and where technical skill requirements can be identified over time (see recommendation 4.1).

Human capital tax credits should be targeted in particular at low or middle skill workers, and can vary by firm size or other factors. In contrast to the Apprenticeship Levy (which applies only to larger firms), a human capital tax credit could cover firms of all sizes, and not be limited to types of training that can be classified as 'apprenticeships'. This type of tax credit could help to address the current skills shortages related to passenger vehicles, and if found to be successful could be rolled out to other parts of the economy.

Recommendation 5. Strengthen and align policy mechanisms that target balanced growth across the UK's regions

5.1. Ensure that local industrial strategies and long-term sectoral or missions-based policies are consistent in their drive for inclusive management of the transition in the automotive sector

Managing industrial transition and realising the opportunities it brings requires a balance between national policies that consider the economic system, and more localised industrial policy rooted in the specific needs and capacities of local areas, and formed via effective collaboration between local policymakers, industry, universities and other stakeholders. Lessons can be drawn from Hull City Council's experiences in driving sustainable growth opportunities based on local competitiveness, described in the box below.

The incentives recommended in this report should be tailored to facilitate opportunities in areas where productivity would be most responsive to higher capital intensity and support and that may be well suited to the opportunity in question based on their pre-existing or potential industrial and workforce capacity. For instance, Coventry and Warwickshire, located in the heart of the UK's conventional vehicle production region, are developing capabilities in CAV testing, applying existing expertise in vehicle testing to this growing area. Mealey and Teytelboym (2018) have developed a measure which they call the 'Green Adjacent Possible', which shows the set of green products and industrial opportunities that are likely to be the easiest to transition into given a country's existing capabilities. This type of measure could be employed at the regional and local level.

Heavy handed policy measures that immediately put the livelihoods of businesses and workforces working on 'dirty' car technologies at risk – such as levying taxes on ICE vehicles made in the UK – should be avoided. In the immediate term, government should ensure that taxpayers' money is not actively encouraging investment in ICE vehicle manufacture. This sends a signal to the private sector regarding the direction of travel. Into the longer term, policymakers should work together with businesses producing goods and services related to ICE vehicles and related components to look at the alternative goods and services that best match their workforce and supply chain capabilities. Determining future regulation in close

Green Port Hull: securing manufacturing jobs in Northeast England

The City of Hull has secured high quality jobs in wind power, a rapidly growing sector, through a collaboration between local authorities, higher education and the private sector. This is routed in long-term planning and a recognition of Hull's regional competitiveness and strengths.

Hull City Council commissioned work in 2006 to identify the potential differentiators of competitive advantage for Hull, which included the port and its logistics capabilities and the potential to develop greenfield renewable energy sites close to the port area. Siemens, a major international turbine manufacturer, recognised the long-term opportunity in wind power in the UK and was considering where to site production. Partly in response to this interest, Hull City Council formed the Green Port Hull entity in 2009 with the University of Hull and other local actors. This set the vision for Hull becoming a centre for renewable energy, with particular focus placed on training and upskilling, as a lack of skills were identified as a major local barrier to attracting businesses to invest in the area. In 2013 Siemens approved plans to manufacture in Hull and today there are around 1,000 people employed at the facility, 97 per cent of whom live within 30 miles of the city centre.

Green Port Hull demonstrates the importance of strong regionally led action in identifying competitiveness opportunities and strategically addressing barriers. It also shows the need for a strong national policy framework that assures the private sector of demand for the goods being manufactured.

Within the same region, Sheffield's Advanced Manufacturing Park is another successful example of regional collaboration between universities and the private sector to secure quality jobs (Breach, 2019). Further details on both of these examples can be found in the report by Robins et al. (2019) on the role of investors in facilitating a just transition in the UK.

collaboration with the private sector – and ensuring that the enforcement date is well communicated (e.g. a 2030 ICE ban) – can ensure business has time to prepare.

The local industrial strategies offer an entry point to embed this process in multi-level governance processes. However, they need to be evaluated to check that they are fit for purpose and reflect the current and future state of the local economy in question (WWCLEG, 2018). Zymek and Jones (2020) expand on this by emphasising that local strategies need to present a long-term and continuous policy direction and avoid the temptation of focusing on existing regional strengths. They highlight that a major pitfall of regional policymaking in recent years has been a tendency to remove and then recreate policies.

Consideration must be given to how local industrial strategies will be financed, and more decentralisation of fiscal powers is desirable. The Institute for Fiscal Studies has suggested that local income tax should be collected by local councils, accompanied by redistribution from richer to poorer areas (Harris et al., 2019). Governance processes need to draw on a combination of local knowledge of local problems/opportunities, a better understanding of where meaningful economic boundaries lie – including benchmarking and assessment of where strong clusters are located and what factors determine their success – in order that local industrial strategies can be updated continually.

Investors can also play a role in this process by shifting their allocation of capital towards assets that are aligned to a just transition. For instance, investors could ensure any capital removed from ICE-related assets is reallocated to zero carbon assets in the same region (Robins et al., 2019). Government can contribute by ensuring public investment is disbursed in a balanced manner throughout the UK, in way that is designed to leverage private investment into these areas.

5.2. Expand and deepen the programme of Science and Innovation audits, which identify areas of strength at the regional level.

Science and innovation audits are an established mechanism for bringing together local policymakers, universities and industry in order to help regions to map their research and innovation strengths and identify areas of potential global competitive advantage (BEIS, 2019). Expanding and deepening this programme could ensure local industrial strategies are well informed in areas of local strength and where there are gaps that need filling to gain competitiveness. More emphasis should be placed on identifying weaknesses and barriers to growth in particular regions, the extent to which these can be addressed via policies and incentives, and in what time frame.

Recommendation 6. Address uncertainty for businesses working on goods and services related to passenger vehicles

6.1. Secure the UK's connectedness to global automotive value chains by making frictionless trade in the sector a priority for any future UK–EU trade deal

The UK's automotive sector is deeply embedded within global value chains, with the UK both importing and exporting a wide range of components. The EU is particularly important in this respect, so the UK's trading relationship with the EU must be secured in any future trade deal. According to the Society of Motor Manufacturers and Traders, 80 per cent of components are imported from the EU and 69 per cent of components made in the UK are exported to the EU (SMMT, 2019). Furthermore, firms make decisions on where to site manufacturing based on a rich set of criteria, due to the complex structure of multinational production in the automotive sector.

An assessment of EU competitiveness in future supply chains for EVs by Bruegel concludes that, while starting late, the EU could still be a global leader in EV production (Frederiksson et al., 2018). The UK should therefore come to an agreement with the EU that safeguards the country's role in these complex supply chains, particularly tariff-free access to the EU, so that it can benefit from the trade bloc's international competitiveness. Head and Mayer (2018) model the potential impacts of Brexit on the UK car industry and predict a significant contraction (which is larger under a harder form of Brexit). Current uncertainty is already weakening the UK's position, as evidenced by Tesla's announcements over the decision not to locate its European gigafactory in the UK (McGee, 2019). Given the EU is the UK's primary trade partner and is likely to be a key market for zero emission vehicles, ensuring frictionless movement of auto sector goods is critical to maintaining UK competitiveness. The importance of this has been recognised in previous UK government strategies, with the example of 'Driving Success' outlined in the box.

Recognising the value of EU trade: the UK's Driving Success strategy

UK support for future passenger vehicle technologies such as EVs increased significantly with the 2013 Driving Success strategy. This set the foundations for the Government's commitment to making the UK competitive in zero emission vehicles and included establishing the Advanced Propulsion Centre.

The strategy places heavy emphasis on connectedness to the EU and global supply chains as being critical to success. For instance, it explains that government and industry identified "Maintaining proactive engagement with the European Union so that the UK has continued access to the Single Market and an influential voice in the development of Regulations" as being "key to the attractiveness of the UK" (Department for Business, Innovation and Skills, 2013).

6.2. Ensure UK vehicle sales continue to contribute to EU emissions reduction targets

The EU has introduced stringent regulations to ensure EU car manufacturers begin transitioning towards zero emission vehicles. Under the new rules, manufacturers must lower the CO_2 output of their fleet to an average of 95g per kilometre. They risk fines of €95 for every gram they go over the target, multiplied by the number of cars they sell in the EU (European Commission, 2020). This robust regulation has been cited as a key driver in increasing EV sales; an increase to one million sales in the EU is anticipated in 2020, up substantially from 250,000 sold in 2018 (Muzi, 2019). As car manufacturers seek to increase their sales of EVs within the EU, they will target key markets that have enabling policies, which may also influence investment decisions to site production facilities near target markets. The UK should ensure that its vehicle sales continue to contribute to these targets; if they do not, there is a risk that the UK market may decrease in appeal as a destination for the retail of zero emission vehicles. The 2013 Driving the Future Today strategy anchored the UK's ambition in producing zero emission vehicles in its contribution to EU-wide CO_2 standards, which will apply to automakers (Department for Transport, 2013). Dismantling these close associations would be highly damaging to the UK's long-term growth strategy in relation to automotives.

Recommendation 7. Recognise and address the UK's current lack of comparative advantage in some technologies receiving government support, and the higher funding commitments of other countries

7.1. Scale up supply-side incentives to values and timescales that are comparable with market-leaders

The sizeable funding the UK government has already committed towards the development of future zero emission passenger vehicles should be recognised. However, it is operating in a highly competitive market, and the majority of announcements to date (with notable exceptions such as the 10-year, £1bn Advanced Propulsion Centre) appear to be too small scale and short term to compete with the activities of countries such as Germany and China. Bolder funding commitments aligned with five-year-plus timeframes and evaluation processes are necessary to avoid the risk that the funding committed is too small scale to drive UK advantage. These scale-ups in funding should take into careful consideration the UK's trading relationship with the EU. If the UK loses tariff-free access to the EU market, this may alter the volume of funding and support needed to make the country an attractive location for investment in these technologies.

7.2. Deliver this funding scale-up under a technology 'portfolio' approach, structuring support mechanisms to target UK economic growth opportunities in zero emission and autonomous vehicles as an outcome

There is significant uncertainty over the UK's competitiveness in innovation and manufacturing for specific goods and services, as we demonstrated in Chapters 4 and 5. To effectively manage the risk of inefficient usage of public funding, the scaled-up funding recommended above should – as much as possible – be available for the full range of goods and service technologies discussed in this report. Technology-specific incentives such as the Faraday battery challenge should be carefully monitored to ensure the UK is both within reach of competitiveness and in need of support (see recommendation 7.3).

The analysis of patents, spillovers and social returns that we set out in Chapter 5 can provide valuable insights to help understand the UK's innovation strengths, informing dynamic policymaking by continually reviewing where innovation is taking place and the extent to which it generates value in the UK. This type of evidence forms one part of a holistic understanding of the UK's innovative competitiveness as not all innovation is patented – indeed, the measurement and analysis of innovation is in itself an innovative area in the research, business and policy communities, and government should stay closely engaged with academics and the private sector to inform them of the type of analysis most useful for its policymaking.

A portfolio approach can ensure that government incentives help UK businesses to gain a foothold in the stages of innovation and the supply chain in which they feel they can be competitive and where value can be generated in the UK. These types of opportunity ultimately may be more effective in driving growth long term than largescale manufacturing, for reasons that apply beyond the automotive sector.

7.3. Conduct robust assessment of all recipients of the Industrial Strategy Challenge Fund's Faraday battery challenge

The Faraday battery challenge is a government package that invests in research, development and scale-up facilities. It seeks to accelerate the UK into becoming 'world-class' in battery technology. Funding decisions are made via competitive tenders from the Challenge. It was announced in 2017, with funding being disbursed over four years. Robust assessment will be necessary to ensure that batteries as a technology category continue to represent a strategic opportunity for the UK, and that the technology still requires support to address market failures (e.g. because of a demonstrable investment gap). This should be coupled with review of the return on investment to date for existing projects, to judge whether the Challenge should be extended for another four years or whether funding should be reallocated to a different strategic priority within the sector deal. Rigorous evaluation criteria are necessary, particularly to determine if the Faraday battery challenge is expected to make the UK competitive in largescale battery manufacture, or if success can also be defined as the UK acting as a successful R&D hub.

China: leading the global market in battery production

China had the highest national electric vehicle battery production in the world in 2017. It has achieved this through promotion of domestic production facilities using a variety of policies and tax incentives. Incentives are now shifting towards only subsidising larger battery production facilities, in effect 'picking winners', but also enabling leading facilities to grow even more rapidly.

Battery suppliers have been the beneficiaries of government subsidies. China's Vehicle Power Battery Industry Standards specify that, in order to qualify for subsidies, lithium-ion battery manufacturers need to have at least 8GWh of production capacity (Lutsey et al., 2018). By comparison, the only largescale facility in the UK producing batteries has a production capacity of 2GWh (Faraday Institution, 2019). China's scale of investment also dwarfs the UK's, with the Chinese company Evergrande recently investing US$23bn into three EV factories in China (Lambert, 2019).

7.4. Use the package of incentives recommended in this report as a foundation to negotiate deals with major players in the zero emission and autonomous vehicle supply chain, with a particular focus on a UK gigafactory

The recommendations made in this report seek to make the UK a more attractive location for major foreign companies, as well as creating an enabling environment for SMEs. For instance, the National Investment Bank could provide high value guarantees for chemical companies interested in establishing gigafactories, while also offering smaller packages of working capital for CAV startups. Similarly, human capital tax credits could be employed on a small scale, or could be used to arrange a large, long-term tax break in exchange for a company's commitment to a 10 year programme of targeted worker upskilling. These types of incentives could also be used to encourage a major player in the battery cell market to establish a gigafactory in the UK; tax breaks have played a role in incentivising Asian battery manufacturers to establish production in Eastern Europe. Policymakers should keep in mind that those businesses that could secure the future of automotive manufacturing in the UK may not fall within the commonly recognised bounds of the car industry, and will likely include chemicals (including battery cell) manufacturers, semiconductor manufacturers and software developers.

The UK needs sustained, proactive engagement with globally leading companies at the cutting edge of passenger vehicle supply chains. Furthermore, the UK will likely need to surpass its international peers in the provision of incentives, given its mixed record of competitiveness and uncertainties over its future trading relationships. These negotiations therefore need to be underpinned by implementation of the full suite of recommendations in this report. This means stepping up incentives to support innovation and production in regions across the UK; spurring demand for zero emission vehicles; and securing close alignment with the European Single Market and EU emissions regulations. The companies that could anchor long-term car production in the UK may then be considerably more likely to view the country as a favourable place to do business.

8. Conclusions

The UK has the potential to become a critical market for zero emission passenger vehicles as technologies mature and sales increase in the coming years. The UK has established a framework of demand-side policies addressing financing barriers, consumer awareness and long-term signals to industry, underpinned by an economy-wide target to reach net-zero emissions by 2050. This makes the UK a potentially attractive early market for retailers of zero emission goods and services. However, the UK does not yet have the comprehensive framework of policies and regulation, across supply and demand, which it needs in order to make the most of this opportunity.

The growth in demand combined with the UK's incumbent position as a centre of passenger vehicle manufacturing, its innovative capabilities in a number of areas and strong service sector, creates a basis on which the UK can build international competitiveness in the goods and services associated with zero emission vehicles. Significant opportunities based on the UK's innovative strengths include connected and autonomous vehicle technologies and electric vehicle smart charging. If the UK manages to secure around 5 per cent of the global market for EVs, charging infrastructure and CAVs, it could secure employment for nearly 80,000 people in 2030 in the manufacturing of zero emission vehicle components alone, not including the broader supply chains associated with these technologies.

Current policies are a step in the right direction. The UK's decisions to date in supporting goods and services related to zero emission vehicles have provided a robust foundation for growth. Furthermore, there appears to be consensus from across the political spectrum about the importance of targeting sustainable growth opportunities – including in passenger vehicles. This can build the confidence of the private sector to make long-term investment decisions.

Significantly more needs to be done if the UK is to be competitive in the long term. The innovation analysis in Chapter 5 demonstrates that the UK has a lower share of innovation in critical zero emission vehicle technologies such as batteries – comparative to the size of its economy – than the rest of the world. The UK thus faces an uphill struggle to catch up with other companies and countries that have invested earlier in clean car capabilities. All of this occurs in the context of increased trade barriers with Europe, the UK's largest current trading partner – a particular issue for sectors relying on internationally integrated value chains such as the car industry. This increases the need for coordinated, ambitious and long-term policies if the UK is to "match the best in Europe", as mandated by the automotive sector deal.

The recommendations in this report provide steps to improve this competitiveness, with a focus on measures that could incentivise the development of a strong portfolio of zero emission vehicle goods and services. Furthermore, the importance of having flexible and dynamic policy incentives will be critical given uncertainties regarding future markets and the UK's role in them.

The evidence suggests that a more sustainable and inclusive growth path is likely to bring opportunity to the country in the medium to longer term (Rydge et al., 2018). Conversely, if the UK fails to direct incentives away from high-carbon goods and services, it faces causing harm to its economy and citizens. The prospects for achieving growth by developing the clean passenger vehicle industry are affected by this possibility. If the UK can pivot towards zero emission vehicle goods and services while securing a strong long-term trading relationship with the EU, the future will be bright. Consistent funnelling of innovation, investment and skills development towards zero emission vehicles must start now, as part of a broader approach to sustainable growth across the economy.

Appendix: Analysis of current policies

In this appendix we sum up the main details of significant existing policies for the UK's passenger vehicle sector and rate them according to their potential – given their current form – to drive sustainable growth in the UK from passenger vehicles, either amber, indicating strong potential, or red, indicating weak potential.

Automotive sector deal

Incentive type:	**Relevant growth pillars:**	**Goods/services:**	**Barriers addressed:**
Funding package and strategy	Cities, infrastructure, skills, cities	Those in the automotive sector	Various

Incentive description: Component of UK's Industrial Strategy, focused specifically on automotives, published by the Department for Business, Energy and Industrial Strategy (BEIS) and the Department for Transport (DfT)

Current status: Active, policies and programmes at various stages of completion

Geographic focus: National

Key features of policy:

- £225m from 2023 to 2026 to support R&D in the sector
- EVs backed via Faraday Battery Challenge, a funding package for batteries
- £250m to position the UK as a global leader in the development and deployment of connected and autonomous vehicles (CAVs). This includes £150m for collaborative R&D projects and £100m for CAV testing infrastructure
- £500m over 10 years up to 2023 through the Advanced Propulsion Centre to research and industrialise new low-carbon automotive technologies in the UK
- £23m hydrogen transport programme to increase the number of publicly accessible refuelling stations and increase the uptake of fuel cell vehicles
- £16m for supply chains through the National Manufacturing Competitiveness Levels programme (also covered separately below)

Potential to drive sustainable growth in the UK from passenger vehicles: AMBER

The automotive sector deal provides a solid foundation upon which to target incentives and direct the private sector's investment and innovation. However the Business, Energy and Industrial Strategy Committee calls into question the deal's ability to turn around the fortunes of the UK automotive sector, given that the deal "has not prevented Honda, Nissan and Dyson cancelling projects or taking jobs elsewhere" (BEIS Committee, 2019).

The total funding channelled through the sector deal amounts to around £1bn. This is comparable with the €1bn investment made in battery technologies by Volkswagen alone (Miller, 2019). Given much larger sums of money are being spent worldwide in other companies and countries, and the demonstrated heterogeneity of UK innovation's competitiveness in clean car technologies, funding needs to be targeted carefully in order to avoid inefficient usage of public funds. Furthermore, the £16m that is available for supply chain competitiveness appears to be in effect a reduction in funding, compared with the Advanced Manufacturing Supply Chain Initiative programme, which made £345m available from 2012–20.

The process of industrial policymaking is important, not just the desired outcome (Rodrik, 2004). In the case of the automotive sector deal, modalities need to be in place to engage with industry on an ongoing basis to revise, learn from and refocus policies (ibid.). It is not currently clear what these modalities are for keeping the sector deal up to date and responsive to changes. The risk is to keep funding companies even if they are not successful, leading to rent-seeking.

There is not yet clear evidence that the sector deal is 'learning by doing', evaluating and discussing the impact of funding and reallocating funds accordingly. The automotive sector deal has now passed its first anniversary but is yet to have an annual review or report published by the Government, despite a commitment to a first annual review in January 2019 in the original deal document. Furthermore, no criteria have been published that would enable an analysis of how this sector deal (or others) is performing (BEIS Committee, 2019).

UK Export Finance's General Export Facility

Incentive type:	**Relevant growth pillars:**	**Goods/services:**	**Barriers addressed:**
Finance	Infrastructure	Any	UK competitiveness

Incentive description: A range of credit facility products are on offer from UKEF's General Export Facility (GEF) to support capital requirements for exporters that aim to "ensure that no viable UK export fails for lack of finance or insurance"

Current status: Active, open for applications

Geographic focus: National, but UKEF has a regional network of Export Finance Managers to seek out and support export opportunities in particular regions

Products on offer include:

- Letters of credit guarantee
- Bond insurance policy
- Bond support scheme
- Buyer and supplier credit financing facility
- Direct lending facility
- Export insurance policy
- Export refinancing facility
- Export working capital scheme

Potential to drive sustainable growth in the UK from passenger vehicles: AMBER

The highest profile example to date related to zero emission vehicles has been the GEF's provision of a £500m guarantee to Jaguar Land Rover, which will underwrite a £625m loan facility from commercial banks. The loan guarantee will be used to finance the plant at Castle Bromwich, which will make electric Jaguar cars using battery packs from the company's nearby site at Hams Hall and electric components from its Wolverhampton engine plant. It will still rely on battery cells imported from Asia.

The Jaguar Land Rover deal is clearly an effective way to secure real jobs and signal to the market that the UK is a serious player in the EV manufacturing market. However, it currently appears to be a one-off within the context of UKEF's support for zero emission vehicles. It is not clear that UKEF has a strategic mandate to support businesses that are offering goods and services related to zero emission vehicles and other approaches to reduce emissions.

£246 million investment in the Faraday Battery Challenge – part of the Industrial Strategy Challenge Fund

Incentive type:	Relevant growth pillars:	Goods/services:	Barriers addressed:
Finance package	Innovation, infrastructure, skills	EV components	R&D market failure

Incentive description: Government investment package, which is investing £246m in research, development and scale-up facilities to accelerate the UK to being world-class in battery technology. Funding decisions made via competitive tenders announced by the Challenge.

Current status: Active – announced in 2017 and funding currently being disbursed for projects to be completed by March 2021.

Geographic focus: R&D projects can be nationwide; Battery industrialisation centre based in Coventry (West Midlands), Faraday Institution based at Harwell Science Campus (Oxfordshire)

Main tools within the package:

- £65m Faraday Institution, a charitable trust to invest in the skills and research to invest in the skills needed for battery science
- £88m to invest in R&D competitions for exciting innovations in battery technology from UK companies
- £80m National Battery Facility to allow companies to scale up and prototype new battery technologies, and aid diffusion

Potential to drive UK sustainable growth from passenger vehicles: AMBER

The Faraday Battery Challenge has disbursed significant funds already: across the three rounds of funding competitions £82.6m has been awarded to 63 projects (UKRI, 2019). In this respect, the Challenge has been effective in funding UK-based innovation and increasing the number of skilled experts in the area. However, it is not yet clear the extent to which the Faraday Battery Challenge is boosting UK competitiveness and securing permanent, skilled jobs that are not directly funded by the Challenge.

Our analysis in Chapter 5 of the UK's revealed technological advantage and spillover benefits derived from batteries, as opposed to other clean car technologies, indicates that allowing a broader range of technologies to benefit from funding programmes (while not excluding those companies working on batteries) may play more to current and future UK strengths in relation to zero emission vehicles. This may help to mitigate the risk that after funding has expired, UK-based research conducted into batteries will not commercialise, or that this will take place in other economies with greater competitiveness. By way of comparison, the German government announced the award of €1bn to three consortiums for battery cell production, more than four times the value of the Faraday Battery Challenge (Nienaber, 2019). In the United States, Panasonic has committed to investing up to $1.6bn in Tesla's gigafactory (Higgins and Mochizuki, 2019).

R&D tax credits			
Incentive type: Corporation tax relief	**Relevant growth pillars:** Innovation	**Goods/services:** Any	**Barriers addressed:** R&D market failure

Incentive description: Tax credits provided to businesses that can demonstrate that they have undertaken R&D leading to advances in knowledge to the benefit of whole sectors (as opposed to individual businesses)

Current status: Active

Geographic focus: National

Key features of policy:

- Two main forms are available – small and medium sized enterprises (SME) R&D relief for companies with fewer than 500 staff, and R&D expenditure credit for larger companies
- The relief is offered as a percentage tax deduction to the costs incurred in said R&D activity
- The main qualifying terms are demonstrating that professionals could not easily work out the problem the R&D is seeking to solve; that there is scientific or technological uncertainty and showing how this uncertainty will be addressed; and stating the nature of the advance in the overall field the research is seeking to achieve

Potential to drive sustainable growth in the UK from passenger vehicles: AMBER

This is an established mechanism which is effective in spurring private sector investment in R&D. A study of UK firms has shown R&D tax incentives to have a significant positive effect on innovation as an outcome (as opposed to activities merely described as R&D) (Dechezleprêtre et al., 2019). The same research finds that investment in R&D as a result of tax credits leads to significant spillovers. Every £1m increase in R&D on all technology-connected firms' patenting is about 1.7 times the direct effect on the patenting that takes place in-house in the firm in question (ibid.).

However, the Government's guidance materials on the relief do not make any specific requirements that R&D be directed towards clean as opposed to dirty innovation. Dechezleprêtre et al. (2016) argue that a crucial role for climate change policies is to make sure that low-carbon innovation activity displaces innovation in polluting technologies. The tax relief policy's current design does not facilitate this.

Automotive Industrial Partnership (AIP) for Skills, part of a broader focus on skills in the Industrial Strategy			
Incentive type: Funding package	**Relevant growth pillars:** Skills	**Goods/services:** Not specified	**Barriers addressed:** Skills shortages

Incentive description: The Automotive Council, a government–industry initiative to promote and expand the UK automotive industry, has a skills working group, which has established the

Automotive Industrial Partnership for Skills. This is a package of support mechanisms aiming to tackle skills shortages as the sector grows and evolves.
Current status: Active
Geographic focus: National, but skilled workforces are typically grouped in certain regions
Key features of policy: • Development of an industry-approved jobs framework • Publication of two automotive skills reports to identify current skills provisions and requirements to meet the needs of a growing automotive industry • Development of the Automotive Apprenticeship Matching Service
Potential to drive sustainable growth in the UK from passenger vehicles: RED There has been comparatively little attention paid to the skills needed to be internationally competitive in future automotive technologies, barring investments made through the Faraday Battery Challenge. The February 2016 AIP for Skills roadmap identified establishing new frameworks/programmes, qualifications developed with employers to industry standards specifically for new growth technologies as a priority, but this has not been implemented. It also emphasised the broad need for engineering skills and a strong awareness of emerging technologies (e.g. CAVs, EVs). The top two in-demand roles are listed as being design engineers and production engineers. The knock-on effect, according to the report, is that companies are hiring temporary contractors and increasingly recruiting from abroad. There is also an enduring gender imbalance in those employed in the UK car industry (Bettsworth and Davies, 2016). The skills requirements in automotives are typical of broader skills needs – heavily focused on advanced materials and manufacturing, robotics, mechatronics, welding, computer-aided engineering, and so on. The AIP for Skills 2016 report recommends a specific focus on attracting qualified talent from other industries and countries and on retaining the current workforce – this is paramount to the automotive industry's future. However, there is little transparency regarding how these recommendations have been acted on. Finally, the Automotive Apprentice Matching Service, while credible in principle, appears to be inactive, with the most recent ambitions stated in 2017 (Automotive Apprentice Matching Service, 2020).

Local Industrial Strategies			
Incentive type: Strategy document	**Relevant growth pillars:** Cities, infrastructure, innovation, skills	**Goods/services:** All	**Barriers addressed:** Regional disparity in growth and jobs
Incentive description: Local strategies for particular cities and regions throughout the UK, building on the principles of the nationwide industrial strategy			
Current status: 41 local industrial strategy summaries are included on the Industrial Strategy portal, with varying levels of detail. To date, detailed strategies have been published by			

Greater Manchester, West Midlands, the Oxford-Cambridge Arc and the West of England. Some of the summaries mention future passenger vehicle technologies, but this is generally in the context of highlighting local successes as opposed to locally specific incentives. For instance, the Buckinghamshire Thames Valley local summary highlights the 5G testbed at Westcott for a test site to develop unmanned automated vehicles.

Geographic focus: Regional – each strategy is regionally specific

Key features of policy:

- Strategies take the same format as the national Industrial Strategy, but with regionally-specific priorities
- For instance, the main references to innovating and diffusing transport solutions in the Manchester Strategy is in relation to 1) digital mobility solutions, tapping into Manchester's strong digital capabilities, and 2) production of lightweight and specialist materials for the transport sector
- The West of England Strategy explains that it is "exploring options for a local Mobility as a Service Living Lab that will co-design and test replicable transport innovations" and highlights the Institute for Advanced Automotive Propulsion Systems as a potential research base at the University of Bath, once it is opened in 2020
- The Oxford-Cambridge Arc strategies highlight that there are more than 4,000 businesses operating in 'Motorsport Valley' across automotive, motorsport and advanced manufacturing companies, emphasising opportunities in R&D and commercialisation of CAVs
- The West Midlands strategy places a strong emphasis on spurring foreign direct investment in EV manufacturing and CAV testing, reflecting significant current levels of employment in the automotive sector

Potential to drive sustainable growth in the UK from passenger vehicles: AMBER

This initiative of local industrial strategies is still under development and their ability to deliver impact is not yet proven. In principle, they are an effective way of identifying and highlighting perceived local barriers to growth and comparative advantage in specific areas, and finding appropriate local solutions. Strategies published to date include extensive consideration of goods and services related to future passenger vehicles, particularly CAVs and EVs, and describe an optimistic picture for UK growth prospects in these areas. However, the processes used in local strategies to robustly assess and identify local strengths and therefore comparative advantage may not be consistent. To date, the local industrial strategies appear to be limited in scope and resources, considering the potentially transformative role they could play if properly empowered.

The Institute for Fiscal Studies notes that funding channelled through local government has fallen significantly, limiting local government's ability to lead regionally-specific initiatives; since 2009–10, spending per person on planning and development is down around 60 per cent (Harris et al., 2019).

National Manufacturing Competitiveness Levels (NMCL), part of the SC21 Competitiveness & Growth (C&G) programme under the Industrial Strategy (along with its predecessors the Long Term Automotive Supply Chain Competitiveness programme and the Advanced Manufacturing Supply Chain Initiative)			
Incentive type: Provision of technical assistance	**Relevant growth pillars:** innovation	**Goods/services:** In the automotive, aviation and defence industries	**Barriers addressed:** UK competitiveness
Incentive description: £16m supply chain competitiveness and productivity improvement programme: it helps UK businesses in benchmarking their activity against international best practice to identify the areas in which they need to improve their operations. Part of the Industrial Strategy's automotive sector deal to improve competitiveness and productivity in supply chains, focused primarily on auto and aviation sectors, but other sectors can also benefit. It is also mentioned as a flagship policy in the Office for Low Emission Vehicles' 'Road to Zero' strategy			
Current status: Started in 2019, active and seeking Expressions of Interest. Chosen by BEIS as a successor to the Long Term Automotive Supply Chain Competitiveness (LTASC) programme, which had a similar structure and ran from 2014–18. There was also an Advanced Manufacturing Supply Chain Initiative (AMSCI), which ran from 2012–20 and is now closed for applications. The AMSCI was a funding competition designed to improve the global competitiveness of UK advanced manufacturing supply chains. Funding was available to support R&D, skills training and capital investment to help UK supply chains achieve world-class standards and encourage major new suppliers to locate in the UK.			
Geographic focus: National			

Key features of policy:
• It identifies the following 'themes' on which companies may want to compete:
    o Improving capabilities across competitive strategy and management systems
    o New product introduction and lifecycle management
    o Manufacturing operations
    o Supply chain management
• This identification then informs where improvement is required. The aim is to establish what types of investments within a company will provide the greatest return, depending on the stage that a business is at.			

Potential to drive sustainable growth in the UK from passenger vehicles: RED Compared with the AMSCI and LTASC programmes, which have come to a conclusion in the last two years (with combined funding available of nearly £300m), the NMCL programme on its own represents a considerable reduction in funding available for supply chain competitiveness at a time when UK business needs significant support in reshaping automotive sector supply chains. Furthermore, while the programme has a strong focus on UK competitiveness, its focus is primarily on keeping the UK competitive in whatever is currently being manufactured, as opposed to steering manufacturing towards a future vision of the auto industry which is leading in goods and services for zero emission vehicles. The areas in which it seeks to encourage the UK to become competitive are not clear, with an agnostic approach as to whether or not the technologies and supply chains are clean. The fact that			

some recipients of support from the programme's predecessors were working on ICE engine components indicates that there is a continuing risk that the programme will facilitate greater competitiveness in the manufacturing of ICE vehicle-related products.

Catapult centres			
Incentive type: Provision of technical assistance, funding	**Relevant growth pillars:** Innovation, infrastructure, skills	**Goods/services:** EVs, their components and infrastructure, and related services	**Barriers addressed:** Innovation to diffusion, R&D market failure
Incentive description: Centres of excellence focused on promoting R&D in priority areas, and working with business to convert this into commercial opportunities. The Catapult network was created in 2010 by Innovate UK as a cluster of technology centres designed to foster innovation in local businesses. They are all expected to receive funding from a combination of industry and government sources. So far, 10 centres have been established (recently the Transport Systems and Future Cities catapults combined to create the Connected Places Catapult), and many of these have multiple sites (for example the High Value Manufacturing Catapult has seven sites).			
Current status: Active			
Geographic focus: National			
Key features of policy: • Funding and infrastructure to bring together industry with the research community, split into themes • Network of centres located throughout the UK in areas of strategic importance			
Potential to drive UK sustainable growth from passenger vehicles: AMBER Considered to be an effective model, but could have had greater impact through a clearer statement of purpose and more robust governance. In a 2017 assessment, EY found that Catapult centres, despite aiming to receive funding from industry as well as government, are almost wholly reliant on UK government funding. Similarly to concerns highlighted above about the automotive sector deal, the Catapult centres model shows that UK government funding is not necessarily catalysing private sector investment and creation of good jobs. The EY assessment specifically highlighted the Transport Systems Catapult as being in need of reform. Another critical issue identified is the lack of a single, consistent statement of purpose across the catapults (EY, 2017). In the context of future passenger vehicles, it is not clear how the effort of different catapults mesh together and can contribute to future UK competitiveness in this area.			

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