Connected Places Catapult

Market Forecast

For Connected and Autonomous Vehicles

Catapult Connected Places

Contents

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NOTES
This report has been produced by Element Energy, Cambridge Econometrics and Connected Places Catapult on behalf of the Centre for Connected and Autonomous Vehicles.

Unless explicitly stated otherwise, all costs in this report are expressed in GBP, adjusted for the 2019 average inflation.

DISCLAIMER: COVID-19 Pandemic
This Market Forecast was developed over the February 2019-February 2020 period and presents the state of the industry before the COVID-19 Pandemic. Whilst the Pandemic has had a significant impact on the automotive manufacturing sector and the wider economy, this is expected to be a short term shock. Over the period 2025-2035, the vehicle demand and key parameters used in the economic analysis (e.g. GVA to gross output ratios, labour productivity, trade and investment ratios) could return to the trends observed before the onset of the Pandemic. However, this adds another layer of uncertainty to the findings presented in this publication. Any output should thus be analysed in conjunction with any further global, market, and economic developments.

Terminology

ADAS	Advanced Driver Assistance Systems
AESIN	Automotive Electronic Systems Innovation Network
ASEAN	Association of Southeast Asian Nations
CAV	Connected and Autonomous Vehicle, for the purposes of this study, CAV refers to any vehicle considered to be in-scope, as defined in Section 2 - Scope
CAV Technologies	The technologies required by vehicles that are in-scope for this study, which are additional requirements above vehicles that do not have CAV capabilities. This excludes equipment fitted to non-CAVs which could be used as part of driver assistance functionality (e.g. reversing cameras and parking distance control).
CCAV	Centre for Connected and Autonomous Vehicles
DfT	Department for Transport
ECU	Engine Control Unit
GPS	Global Positioning System
GVA	Gross Value Added
HDV	Heavy Duty Vehicle
HMI	Human Machine Interface
ICE	Internal Combustion Engine
L3/4/5	Level of vehicle automation as defined by SAE International Standard J3016
LIDAR	Light detection and ranging
LDV	Light Duty Vehicle
MBM	Mobility Business Models
SIC	Standard Industrial Classification
TCO	Total Cost of Ownership
TSC	Transport Systems Catapult
ULEV	Ultra Low Emission Vehicle
V2X	Technology that allows vehicles to communicate with other objects, including moving parts of the traffic system around them; V2X encompasses vehicle-to-vehicle and vehicle-to-infrastructure.

This report discusses the developments in the uptake of Connected and Autonomous Vehicles (CAVs). Two markets are studied: the overall Connected and Autonomous Vehicles (CAVs) market as well as the market for CAV technologies, that enable autonomy. As explained in Chapter 2, the CAV market values include the value of the vehicle base alongside with any CAV technologies installed on the vehicle and required to provide autonomy. The report also presents the standalone value of the CAV technologies market. The CAV technologies market value is thus included in the value of the CAV market, and the two figures should not be added.

Executive summary

Context

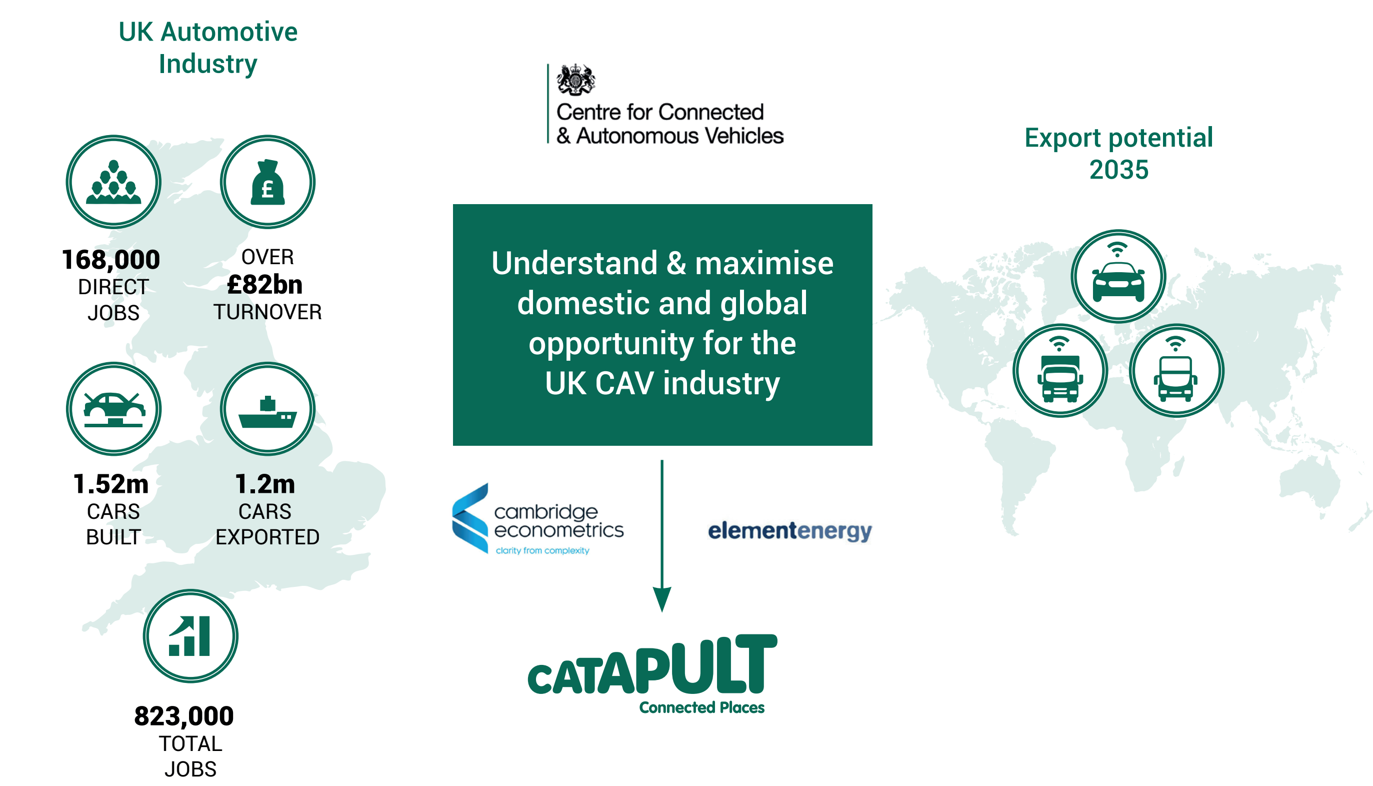
In 2017, the first revision of this Market Forecast showed the great potential that could be unlocked by the development of CAVs, helped to justify investment in the sector, and allowed the UK CAV industry to continue to develop. We have now revised our 2017 Market Forecast with a series of new assumptions and analyses to represent both the changes in the global CAV market and advances in technology.

The automotive sector is on the cusp of a revolution. The development of increasingly connected and autonomous vehicles (CAVs) brings the potential for truly transformative change in the way people and goods are transported, offering significant improvements in safety, efficiency, mobility, productivity and user experience.

This potential for transformative change creates huge opportunities for both new and existing players in the automotive sector, but for a successful transition from basic functions like cruise control, to fully autonomous driving, CAVs must overcome challenges to safety, cost, and customer perceptions. The technologies that will achieve this are yet to be fully defined, and the race to provide the winning solutions is on.

The automotive sector is a key pillar of the UK economy, employing over 823,000 people, including 168,000 specifically in motor vehicle manufacturing[1]. The CAV revolution brings with it the chance to not only maintain the UK's place in the global market, but to expand it, potentially unlocking a host of opportunities in terms of employment and wider economic benefits.

What is the opportunity for UK CAV industry?



[1] (SMMT, 2019) Available here.

Context

However, the size of the opportunity that results from this transition will depend on the extent of the changes to the automotive market overall, and the specific new technologies required for CAVs will be a fundamental part of this change. As such, capturing the maximum opportunities for the UK will require an astute understanding of which UK capabilities could be effectively harnessed to provide the technologies which will be most valuable to the burgeoning CAV market.

In this context, the Centre for Connected and Autonomous Vehicles (CCAV) has commissioned this study to quantify the industrial opportunity to the UK that could result from CAV uptake, in terms of:

- the potential value of the domestic and global markets for CAVs and CAV technologies;
- the potential GVA for UK production of CAVs and CAV technologies;
- the potential for new UK jobs relating to the production of CAVs and CAV technologies.

This work is intended to provide a greater understanding of the specific opportunities for UK industry that the transition to CAVs could bring, to inform the development of a strong Industrial Strategy which will enable the UK automotive sector to consolidate and expand on past successes, as the global market shifts.

Scope

"Autonomous Vehicles" are expected to 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. "Connected Vehicles" 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.

It is likely that autonomy and connectivity will complement and reinforce one another; the ability to receive and transmit data, for example, is already being utilised in vehicles to help achieve autonomous capabilities. It is likely that technology convergence will result in the production and uptake of intelligent vehicles that are both connected and autonomous. Such vehicles are the focus of this study, and are referred to as connected and autonomous vehicles (CAVs).

"CAV technologies" are defined as 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 and GPS receivers).

Industry considered

As shown in the diagram, the boundaries of this revision of the Market Forecast are aligned with the previous edition for consistency and comparison purposes. This study specifically considers the markets relating to uptake of connected and autonomous cars, vans, heavy goods vehicles (HGVs) and buses, with high levels of autonomy[2], and connectivity features that enable autonomy (i.e. vehicle to infrastructure/ vehicle to vehicle technology).

The focus of the economic analysis is on the gross contribution of manufacturing CAVs and CAV-enabling technologies in the UK. The wider economic impacts of a transition to CAV technologies or potential new business models are not estimated. Changes in use of vehicles, potential new services offered and productivity or welfare improvements from more efficient use of travelling time are not accounted for.

Key results

The updated and comprehensive analysis conducted in this revision of the Market Forecast is aiming to capture the latest changes in the global CAV market and advances in technology. Whilst this translates in a revision of the projections, the CAV market is expected to grow beyond previous estimates in certain regions (e.g. the UK) by 2035. The key findings of this forecast revision include:

- The market for CAVs in the UK (specifically, for road vehicles with CAV technologies) is estimated to be worth £41.7bn in 2035, capturing 6.4% of the £650bn global market under the Central scenario. This represents a 42% increase in the UK market size compared to the estimate in the 2017 edition of the Market Forecast (£29.3bn in 2019 currency), whilst the global market is lower than previously estimated (~£935bn). The difference in market size estimates is due to lower CAV penetration assumed in certain regions, such as Asia, as well as due to different cost estimates around the cost of CAV technologies and base vehicle, that included assumptions on the uptake of ultra-low emissions powertrains.
- In the same year, the market for CAV technologies in the UK (as installed in UK vehicles) is estimated to be worth £6.4bn of the £100 billion global market. This is significantly higher than previous estimates (~£2.8bn) due to updated costs for the L4/5 pack and CAV technology costs falling slower than previously estimated.
- It is estimated that UK jobs in the manufacture and assembly of CAVs would reach 49,000 in 2035 (compared to 27,400 estimated previously). This compares to around 168,000 people who are currently employed in motor vehicle manufacturing (Office for National Statistics, 2019)[3]. These jobs would effectively replace the equivalent number of jobs in the manufacture of non-CAVs, so these figures should not be considered as net additional. The increase in job estimates are due to a change in methodology and so the figures reported here are not comparable to that in the 2017 report.

[2] Specifically SAE autonomy level 3 and above. SAE has defined 6 levels of autonomy. Level 0 translates to complete control by the driver and levels 1-2 include existing “advanced driver assist” features. For level 3 and above, the full dynamic driving task can be undertaken by the vehicle, including monitoring of the environment as well as lateral and longitudinal control. Level 5 corresponds to complete autonomy, with no input required by the driver
[3] (Office for National Statistics, 2016)

- However, jobs relating to the production of CAV technologies would not replace existing jobs (they relate to the manufacture of additional components compared to those on current vehicles) and, as such, are net additional. By 2035, there would be an estimated 23,400 direct UK jobs in the production of CAV technologies, with a further 14,600 indirect jobs created in the supply chain for these technologies.
- In 2035, 80% of the UK jobs relating to CAV technology production are estimated to be in software-related industries, where UK capabilities are strong, the value of the technologies is high, and the labour intensity of production is high. The remaining 20% would be in the production of CAV hardware such as sensors.
- Over 90% of the jobs created in developing CAV software and over 80% of the jobs relating to the manufacture of CAV hardware are expected to be in professional, technical and skilled trade occupations.
- Annual GVA related to the production of CAVs is estimated to reach £6.3bn by 2035; GVA in firms that are producing CAV technologies is expected to reach £2.7bn. As with the job estimates outlined above, only the GVA for CAV technologies should be considered net additional.

The opportunity for UK CAV Industry

CAVS	£650bn GLOBAL MARKET	£41.7bn UK MARKET	49k UK JOBS
CAV TECHNOLOGIES	£100bn GLOBAL MARKET	£6.4bn UK MARKET	23k UK JOBS
GROSS VALUE ADDED	£6.3bn UK GVA from CAVs	£2.7bn UK GVA from CAV technologies	-

2019 prices

Size of the market in 2035 [4]

The 2035 CAV UK market value is higher between this edition of the Market Forecast and the 2017 edition (£41.7bn vs £29.3bn), whilst the global market was revised, with a lower uptake (£650bn vs £935bn), highlighting the observed market trends as well as the revised assumptions on uptake of CAV technologies across different vehicle types. Similar trends are also observed for the CAV technologies market.

Although the CAV market has developed since our previous edition of the Market Forecast, with several OEMs announcing CAVs, progress takes time and CAVs and CAV technologies are yet to be fully developed. Furthermore, an industry consensus around factors such as costs and consumer attitudes has yet to emerge. Therefore, the accuracy of the forecasts set out in this study revision are inevitably limited by uncertainties around adoption rates, costs and labour intensities for these technologies. It is important that the results are considered in the context of the assumptions made and the range of scenarios considered (all of which are explained in detail in the report).

[4] The CAV market value includes both the value of the vehicle base and that of the CAV technologies needed to provide autonomy

1. Introduction

Background

Connected and Autonomous Vehicle technologies herald the dawn of one of the most exciting and transformative changes since the invention of the internal combustion engine over a hundred years ago. The very paradigm of mobility is set for a radical shake up, along with the industries that serve it. Automotive executives such as GM chief executive Mary Barra believe that the industry will change more in the next few years than it has in the past fifty. As it stands on the cusp of this revolution, the industry faces both the challenges of disruption, and the chance to seize tremendous opportunities.

The UK is the fourth largest automotive producer in Europe – in 2018, it produced 1.5 million vehicles and 2.7 million engines.

The world stands to gain from CAV technology, through the quantum leaps it makes possible in safety, efficiency, mobility, productivity and user experience. The potential value for end-users and society is enormous, and generates a unique alignment of incentives between government and industry – providing fertile ground for collaboration.

As a major contributor to the UK's economic growth and prosperity, it is vital that the automotive sector adapts to this change and continues to thrive. In 2018 the sector contributed £18.6bn to the economy, 8% of manufacturing output and 0.8% of total output. It employs 168,000 people directly(Office for National Statistics, 2019), and over 800,000 jobs are dependent on it. The UK is the fourth largest automotive producer in Europe – in 2018, it produced 1.5 million vehicles and 2.7 million engines[5]. By 2020, the Society of Motor Manufacturers and Traders forecast that this will rise to 2 million vehicles.

It was in this context that the Centre for Connected and Autonomous Vehicles commissioned CPC, Element Energy and Cambridge Econometrics to quantify the industrial opportunity to the UK of CAV technologies. Understanding what CAV technologies could be worth, both in terms of the potential size and value of the domestic and global markets for CAVs and CAV technologies, is a key analytical priority for CCAV. Developing an understanding of the value of this technology and the global opportunity that the UK is competing for a share of is essential in order to build a business case for UK government support for the technology, including many of the investments CCAV is sponsoring into research, development, demonstration and deployment.

Early development and adoption of these technologies is likely to bring considerable economic benefits to the UK and position it as a market leader. Consequently, the UK would be well-placed to export these new transport solutions to the rest of the world, and exploit the considerable market for intelligent mobility: the smarter, greener and more efficient movement of goods and people.

[5] SMMT (2019)

Outputs and deliverables

This report is an update of the 2017 edition of the CAV Market Forecast, with the same approach and target outputs as in the previous edition. The objective of the study is to quantify the CAV market in 2025, 2030 and 2035 under different uptake scenarios, in terms of its size and core economic impacts (trade, gross output and investment, GVA and jobs). Recognising the uncertainty in the projections, the assumptions are transparent, and sensitivities have been explored.

Structure of the report

Chapter 2 defines the levels of vehicle autonomy relevant to this analysis, and sets out in detail the technologies within the scope of the study. Chapter 3 sets out the scenarios for CAV uptake on a global and regional level, defines the projected value of CAVs and CAV technologies, and on this basis, presents three main scenarios for the total global market value to 2035. Chapter 4 uses the market value scenarios to inform the assessment of the economic benefits to the UK. Chapter 5 estimates the market value of business models related to autonomy, and finally, Chapter 6 summarises the key insights from the study.

2. Scope

Defining Connected and Autonomous Vehicles

The scope of this edition of the Market Forecast is unchanged compared to the 2017 edition of the same study, however updated assumptions and additional levels of granularity were included in the modelling. The vehicle segments included for the uptake scenarios are cars, vans, heavy goods vehicles (HGVs) and buses, both based on internal combustion engine (ICE) technology as well as Ultra Low Emissions Vehicles (ULEVs), with levels of autonomy of Level 3 or above (levels of autonomy are defined in Section 0). In this study, the core economic impacts relate specifically to the sales of the CAV technologies, as opposed to quantifying the impacts to the wider change brought by CAVs, such as improved traffic flow, safety, or CAVs' impact over the total vehicle sales market etc. Only the technologies directly related to the vehicles themselves are considered; the supporting infrastructure outside of the vehicles, which will enable different aspects of connectivity and autonomy (e.g. telecommunications infrastructure; sensing infrastructure integrated in the environment), are not included.

For the purpose of this study, CAVs refer to connected and autonomous vehicles, which are defined as follows[6]:

- **Connected Vehicles (also known as Cooperative Intelligent Transport Systems (C-ITS)):** Connected Vehicles refer to vehicles with increasing levels of connectivity which allows them to communicate with their surrounding environment (including the infrastructure and other vehicles). This could provide information to the driver about road, traffic, and weather conditions, and on routing options and enable a wide range of connectivity services.
- **Autonomous Vehicles (AVs) (also known as automated, self-driving or driverless vehicles):** Vehicles with increasing levels of automation will use information from on-board sensors and systems so they can understand their global position and local environment and enable them to operate with little or no human input for some, or all, of the journey.

The SMMT states that

"Vehicles with some levels of automation do not necessarily need to be connected, and vice versa, although the two technologies can be complementary"[7]. It is likely that vehicles with autonomous capabilities will increasingly rely on connectivity (i.e. the ability to receive and transmit data) to achieve autonomy, and that technology convergence will result in vehicles that are both connected and autonomous (CAVs). As such, this study considers the market for vehicles that fall under this definition.

The terminology set out in Figure 2.1 is used to describe CAVs and related products. As shown in Figure 2.1, each level of autonomy defines different vehicle capabilities. Each level has an associated set of use cases, each of which defines an environment where these capabilities are applied.

[6] (Transport Systems Catapult, 2016)
[7] SMMT, February 2017, Position Paper: Connected and Autonomous Vehicles

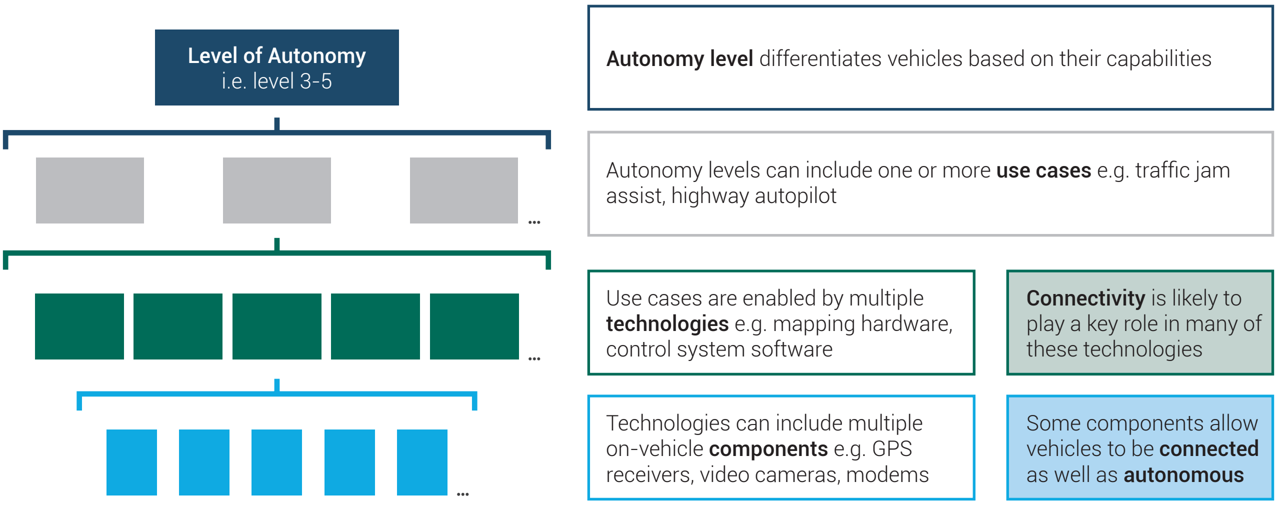


Figure 2.1 Defining technologies and components for vehicle autonomy

Different levels of autonomy and their use cases are made possible by various components such as cameras, GPS and control systems. These components (some of which enable connectivity as well as autonomy) are grouped into "technologies" for the purposes of this study, to enable comparison of the prospective market value of different types of CAV technologies and their relevance for the UK.

Technologies in scope

2.1 Levels of Autonomy in Scope

The internationally recognised standard for automated driving in on-road vehicles (SAE International Standard J3016)[8] defines six levels of driving automation, from "no automation" (Level 0) to "full automation" (Level 5), as summarised in Figure 2.2. The key distinguishing factor for levels 3 and above is that when the system is engaged, the full dynamic driving task can be undertaken by the vehicle, including the monitoring of the environment (object and event detection and response, OEDR) as well as lateral and longitudinal control. Below level 3, the driver is required to supervise the actions of the system, and may be required to control inputs in at least one plane of motion.

Vehicles at automation levels 1 and 2 are already offered by many major automakers. This study aims to assess the economic benefits to the UK that would result from uptake of CAV technologies which are defined as autonomy levels L3 and above. Therefore, **only autonomy levels 3-5 are considered in this study for the purposes of the market sizing and economic analysis.**

[8] (SAE International, 2014) – revised in January 2019

0 No automation	1 Driver assistance	2 Partial automation	3 Conditional automation	4 High automation	5 Full automation
Human driver performs part or all of the dynamic driving task; in particular, the driver is responsible for monitoring the environment and any action taken by the automation system			System performs entire dynamic driving task while engaged, including monitoring and response as well as steering and acceleration		
Human driver performs all aspects of dynamic driving tasks	System can perform either steering or acceleration	System can perform both steering and acceleration	Human driver may be requested to intervene (fall-back)	Full automation in some driving modes	Full automation in all driving modes
	e.g. Park Assist, Adaptive Cruise Control	e.g. Traffic jam assist	e.g. Intersection Pilot, Platooning	e.g. Urban automated driving	

examples of use cases

Figure 2.2 Levels of driving automation as defined by SAE International J3016. Adapted from SAE International J3016 taxonomy and definitions (full diagram shown in Appendix A)

Excluding vehicle automation technologies below level 3 allows the study to focus on CAV technologies as opposed to current vehicle technologies, as to quantify the additionality of basic cruise control (L2 technology) would be counter-intuitive.

For these higher levels of automation, the different use cases relate to the environments in which a level can be achieved. By definition, a level 5 CAV must be fully autonomous in every use case and environment. However, a level 4 CAV may be fully autonomous only within a certain environment, and similarly a CAV with level 3 functionality may only achieve level 3 in some conditions.

Table 2.1 lists the example use cases relevant to each level of autonomy, and their corresponding environments.

Environment	L3	L4	L5
Parking		Driverless valet parking	Full autonomy in all environments
Urban	Traffic jam pilot	Urban automated driving	
Highway	Highway pilot, Traffic jam pilot	Highway automated driving	
Rural		Rural automated driving	

Table 2.1 Possible use cases and environments for different levels of vehicle automation[7]

As suggested by the multiple use cases, the functionality of different L3 CAVs is likely to differ to align across vehicle brands and across demand from various customer groups. However, this study does not attempt to predict uptake at this level of detail, and therefore a "typical" L3 package of technologies is referred to, which is intended to represent the average across the market[9]. Similarly, although L4 CAVs will not be fully autonomous in every possible environment, the market sizing exercise considers L4 and L5 CAVs together, with assumptions around component technologies and value intended to represent the average package for "full autonomy". There are several reasons for this approach. Firstly, there is currently a broad consensus that the difference in hardware and software requirements between L3 and L4 will be much greater than the difference between L4 and L5[10]: the transition to L4 marks the first move to full autonomy

[9] The "typical" L3 package refers to a suite of technologies that is assumed to be representative of the average or most common suite of technologies within adopted L3 vehicles, based on the information available in the literature. For the purposes of modelling costs and economic impact, specific assumptions on technologies and their costs are made (explained in Section 3.4)
[10] (Archambault et al., 2015) – see p18. Note that the "L4" here is analogous to L4 and L5 together

(albeit in specific use cases) and therefore the requirements for system redundancy are likely to be very high to ensure safety. The transition from a range of autonomous use cases at L4, to fully autonomous vehicles at L5 is expected to be enabled by learning from the extensive experiences of CAVs at L3 and L4, and therefore the additional requirements at L5 compared to the "average" L4 vehicle are not expected to be as large. Secondly, in terms of producing uptake scenarios for CAVs at different levels of autonomy, attitudes towards adoption of highly or fully autonomous vehicles (in which the driver is not required to provide input for a particular use case, including CAVs at L4 and L5) are expected to be similar to each other, but distinctly different from attitudes towards conditional driving automation, where the human driver is expected to provide input when requested (L3). Therefore, it makes sense to consider the rate of uptake of highly and fully autonomous vehicles together. Effectively removing the distinction between L4 and L5 also reflects the high level of uncertainty around the rate at which the transition from high autonomy to full autonomy will occur. Assumptions will be discussed in detail in Section 6.

2.2 Connectivity and autonomy technologies in scope

METHOD BOX #1: CAV TECHNOLOGY SCOPING PROCESS

The process of defining the technologies required for CAV implementation involved an extensive review of the literature, including work by Transport Systems Catapult & the Centre for Connected & Autonomous Vehicles. Many of the literature sources involved interviews with vehicle manufacturers, tier 1 suppliers, and other companies seeking to enter the autonomous vehicle market.

The technologies required for CAV implementation are set out in Figure 2.3. Only the technologies exclusive to the level of capability attributed to in-scope vehicles (L3+ automation and connectivity, as defined in section 2.1) are included in the scope of this study. Therefore, the "Vehicle design" group of technologies (relating to the baseline design and functionality of on-road vehicles, and not directly affected by autonomous capabilities) are not in scope. Technologies or areas that will support CAV implementation but that do not include on-vehicle components are also out of scope, for example parking sensors and reversing cameras. This means that the development of CAV standards is not included, and that only the on-vehicle aspects of the Localisation & Mapping, and Connectivity technologies are in scope.

Industry considered

Figure 2.3 CAV technologies included in market sizing and economic analysis[11]

[11] Figure adapted from work by Transport Systems Catapult

Figure 2.4 gives some examples of components for the technologies in scope. To maximise the accuracy of the assessment of the potential economic impacts resulting from these markets, the major software and hardware components of these technologies are considered separately for the purposes of market sizing.

Technology categories	On-vehicle hardware	On-vehicle software
Control systems	**Control systems and computing** e.g. passive components, architecture	**Control systems** e.g. critical event control, decision algorithms
Sensing Localisation & mapping	**Sensor-supporting** e.g. actuators **Sensing & local mapping** e.g. cameras, LIDAR, radar, GPS receivers	**Mapping and path planning** e.g. machine vision, digital image processing
Connectivity	**Connectivity** e.g. embedded modems, DSRC module	**Connectivity** e.g. data processing, communication protocols
Cyber security	Assumed that this will not require dedicated hardware but will run on existing hardware	**Data security** e.g. encryption, intrusion prevention
Human factors	**Human-Machine Interface** relating to safety e.g. internal sensors	**Human Machine Interface** software

Figure 2.4 *Hardware and software aspects of CAV technologies defined for this study*

"Sensing" & "Localisation & Mapping" both include components that could be used to provide vehicles with information on their environment and immediate surroundings, informing the decisions made by CAV control systems. The relative requirements and corresponding value for each of these components in L3-L5 CAVs is an area of considerable uncertainty, as different approaches are already being taken by different vehicle manufacturers. The approach taken for the purposes of the market sizing and economic analysis will be explained in Section 3.4.

3. Sizing the CAV Market

Summary of findings

- Three scenarios were developed to estimate the possible size of the markets for CAVs and CAV technologies in the UK and globally. It must be noted that the CAV market includes the vehicle base and the integrated CAV technologies. The **Central case** is the main scenario used to explore the economic impacts of CAV uptake. The High case and Low case scenarios will be used to provide an indication of the possible extremes for the economic impacts. For each of these scenarios, the cost reductions for CAVs and CAV technologies are assumed to be linked to uptake.
  - **Central case:** rapid technology development and moderate global CAV uptake, reaching 15% of total annual global car sales in 2035. UK CAV uptake follows the predicted trend for Europe, which is assumed to be ahead of the global average with L3-L5 CAVs accounting for 40% of total annual cars sales in 2035 (lower for the other vehicle types). For the UK, this equates to 1.36 million CAVs sold in 2035, including 1.28 million CAV cars, with the remainder being represented by vans, HGVs and buses.
  - **High case:** rapid technology development and high global uptake of CAVs (41% of total annual global car sales in 2035). The UK is the leading global market in terms of CAV sales penetration, with L3-L5 CAVs accounting for 72% of total annual UK cars sales in 2035, and 69% of all UK vehicle sales.
  - **Low case:** remaining challenges for autonomy are not resolved quickly and many consumers remain suspicious or untrusting of the technology, leading to global uptake of CAVs reaching only 6% of annual global vehicle sales in 2035. UK CAV uptake reaches only 14% of total annual vehicle sales in 2035.
- **UK sales result in a projected total domestic market size of £41.7bn in 2035 for the central scenario** (as shown in Figure 3.2), **of which £6.4bn for CAV technologies.**
- In the central scenario, in 2035 the global market size is estimated at £650bn from CAV sales (as shown in Figure 3.3), **of which £100bn is represented by CAV technologies. The UK and Europe would lead the global market, with over 45% of the sales**.
- The 2035 CAV UK market value is higher in this edition of the Market Forecast compared to the 2017 edition (£41.7bn vs £29.3bn), whilst the global market is lower (£650bn vs £935bn), highlighting the observed market trends as well as the revised assumptions on uptake of CAV technologies across different vehicle types. For example, the absolute market size (number of vehicles) decreased due to updated CAV uptake scenarios considered the slow roll-out of CAVs observed during the past few years and a delay of CAV technologies integration in heavier vehicles. However, the cost of vehicles and technology were increased, as a result of tighter regulatory targets for ultra-low emission vehicles (ULEVs) and new cost estimates for CAV technologies. The increase in UK market value as opposed to the decrease in

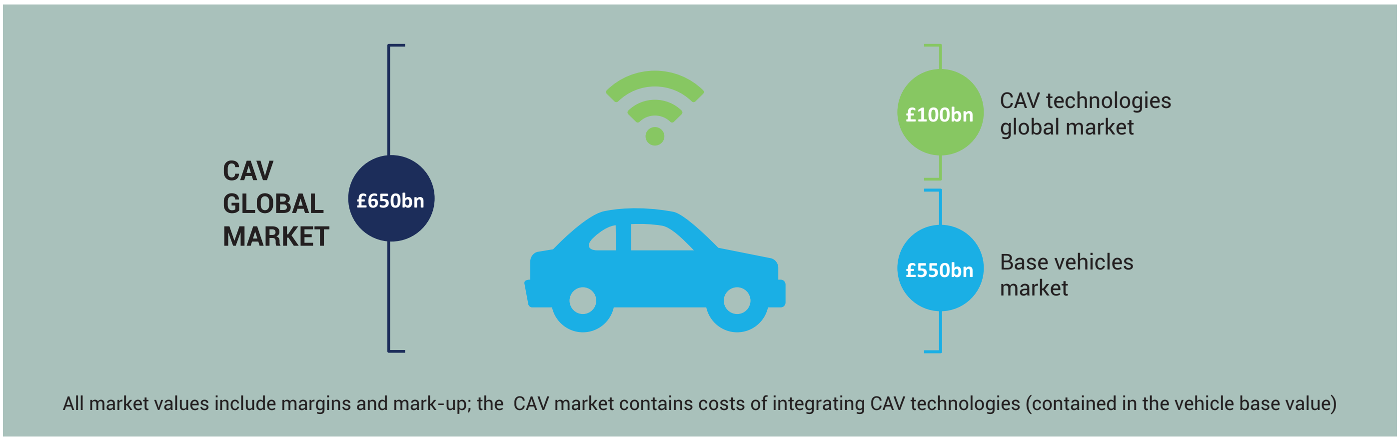


Figure 3.1 Projected market values for CAVs and CAV technologies in 2035

the overall global market (compared to the 2017 study) is driven by the leading position of the UK (alongside Europe) in adopting both CAVs (with increased technologies costs) but also ULEVs, which are considerably more expensive than the internal combustion engine counterparts. On the other hand, the much smaller global CAV market (in terms of absolute vehicle units sold) offsets the increases in CAV unit costs (as a result of more expensive CAV technologies and uptake of ULEVs), leading to a lower market value overall, compared to 2017 estimates.

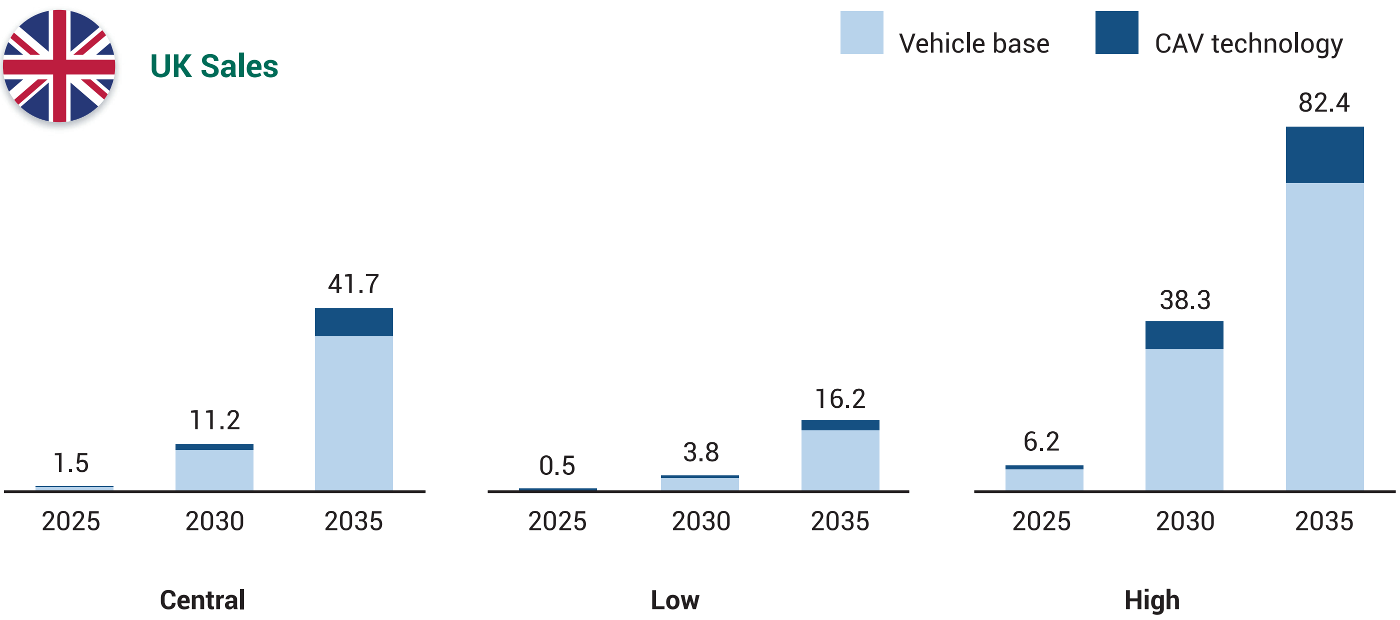


Figure 3.2 *Projected market value from CAV sales in the UK (£ billion). Values shown are based on the projected sales of L3-L5 cars, vans, HGVs, and buses in the specific years shown (i.e. not cumulative)*

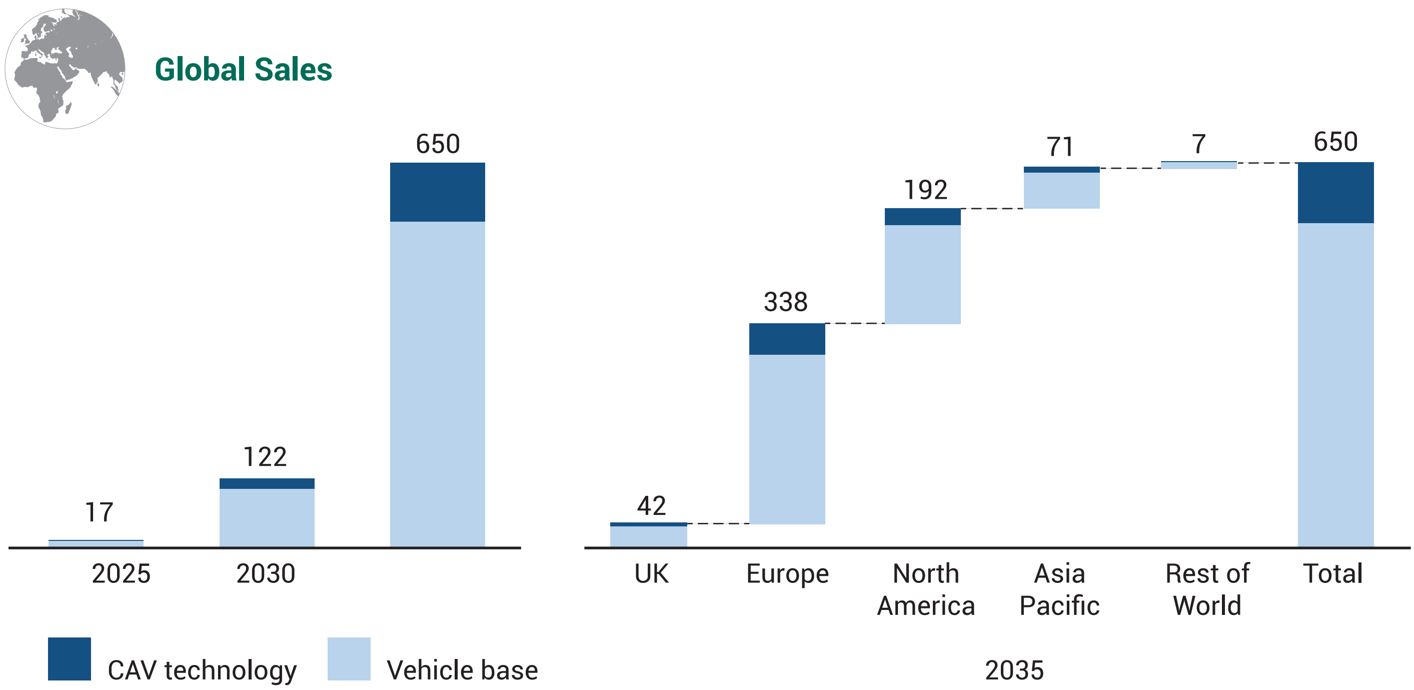


Figure 3.3 *Projected global market value from CAV and CAV technology sales. Values shown are based on the projected sales of L3-L5 cars, vans and HGVs in the specific years shown (i.e. not cumulative)*

- The uptake scenarios take account of the best available evidence, but there are inherent difficulties in predicting the future adoption of new, emerging technologies. All scenarios were revised as part of this study update. This includes an update of the High and Low scenarios, which were adjusted to reflect realistic market trends and the barriers to adoption that CAVs face. For example, the high scenario assumes that the uptake of CAV in the UK reaches a maximum of 69% of all sales in 2035, compared to the previous version of the High scenario assuming up to a 100% UK update in 2035.
- All CAV uptake scenarios assume that total car, van, and HGV sales increase over time, whilst the bus sales are kept at a constant level relative to the 2020 sales projections. In the case of low-duty vehicles (cars and vans), the sales projections were modelled based on 2020 projected values across all markets and taking into account the impact of future mobility business models (MBMs), based on the work published by PwC (PwC, 2018) as described in the next section . Overall, between 2020 and 2035, a 1.5% compound annual growth rate (CAGR) in sales is assumed in the UK, 3.7% in Europe, 2.2% in North America, 1.9% in Asia Pacific, and 3.5% in the Rest of the World.

Summary of approach

The approach taken to estimate the total market size at global and regional scale is summarised in Figure 3.4.

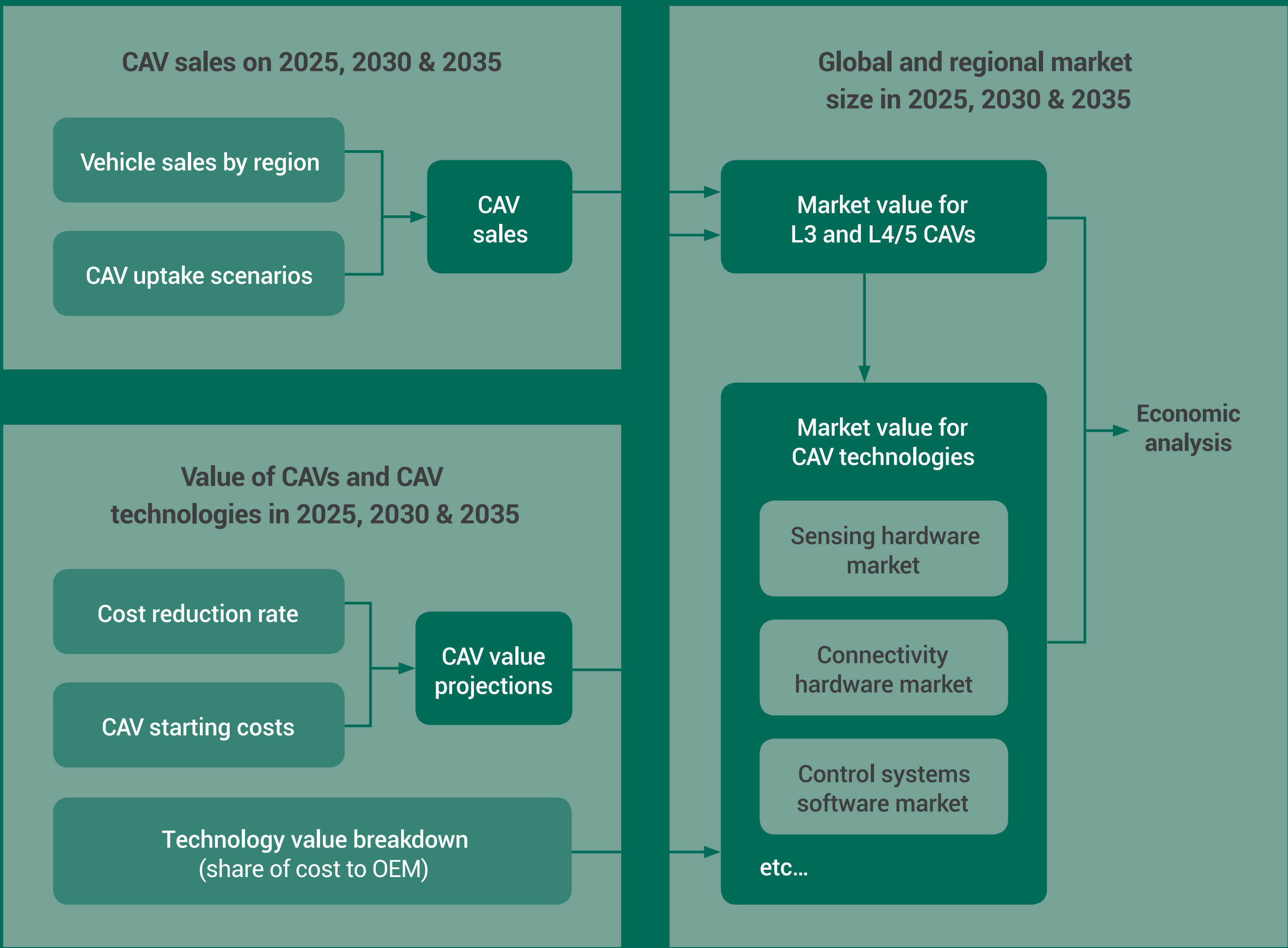


Figure 3.4 Summary of approach to finding global and regional market sizes

As shown in Figure 3.4, projections of CAV sales at a global and regional level were combined with value projections (for both CAVs as a whole, and for their technologies) to produce estimates of the total future market value for CAVs, and for CAV technologies. These estimates are used in the economic analysis, as described in Chapter 4.

This chapter of the report sets out in detail the approach taken to estimating the size of the market by 2035, and shows how results could vary depending on the rate of CAV uptake and on the costs involved.

Scenarios for future CAV sales

3.1 Projected vehicle sales by region

To estimate the market for CAVs and CAV technologies, assumptions are required around the future volume of vehicle sales, both globally and in the UK. The vehicle sales scenarios consider the disruptive impact of CAVs on future vehicle ownership and sales rates for the vehicle types in scope: all the CAV uptake scenarios assume that total car, van, and HGV sales (inclusive of CAV and non-CAV sales) increase over time, with the exception of bus sales which were kept constant.[11]

Figure 3.5 shows the assumed future vehicle sales for light duty vehicles (LDVs, i.e. cars and vans), heavy goods vehicles (HGVs), based on a range of sources.[12]

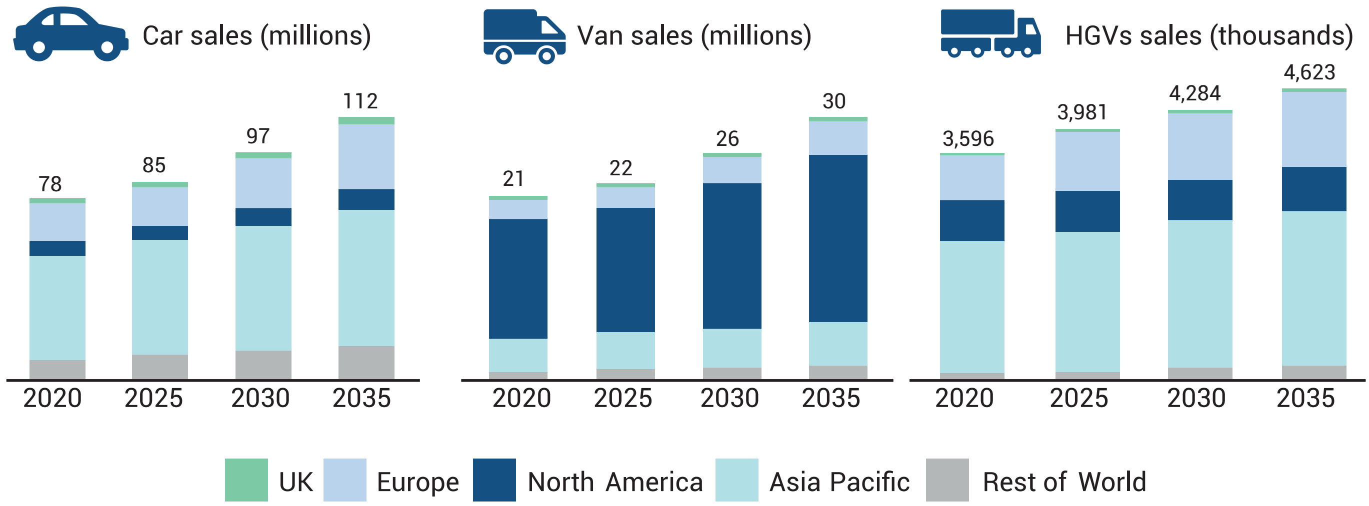


Figure 3.5 Projections of annual global sales of cars, vans, HGVs[11] – note different scale for each vehicle type

[11] The sales projections for cars and vans in 2020 are based on IHS Markit Research data (IHS Markit Global Sales and Production Outlook, Oct 2018) and are extrapolated to 2035 by using assumptions on the growth of vehicle markets across different regions based on PwC (2018). The latter trends include the impact of the uptake of Mobility Business Models (MBMs) onto the sales volumes

[12] A full description of the modelling approach used to estimate vehicle projections is provided in the appendix B. Bus sales were maintained flat due to small cycling fluctuation in the market size in line with the vehicle renewal cycles of bus fleet operators. Note that Asia Pacific includes Japan, Belarus, Kazakhstan, China, India, Korea, Taiwan, Indonesia, Australia, New Zealand and Rest of ASEAN

3.2 UK CAV uptake

A bottom-up approach was used to estimate the CAV sales in the UK, Europe, North America, Asia Pacific and the Rest of the World. This approach was key to estimate the market size in each region and subsequently, the economic impacts to the UK resulting from export of UK-made CAV components to these regions.

The starting point was the generation of three CAV uptake scenarios for each vehicle type (cars, vans, HGVs, and buses) in the UK. These scenarios were generated by the CCAV, based on market observations and literature research, and were validated by CPC and Element Energy. The diagram below shows the Central uptake of different vehicle autonomy levels across the four vehicle types in the UK. This is different compared to the 2017 edition of the Market Forecast which assumed that the CAV uptake would take place evenly across all four vehicle types.

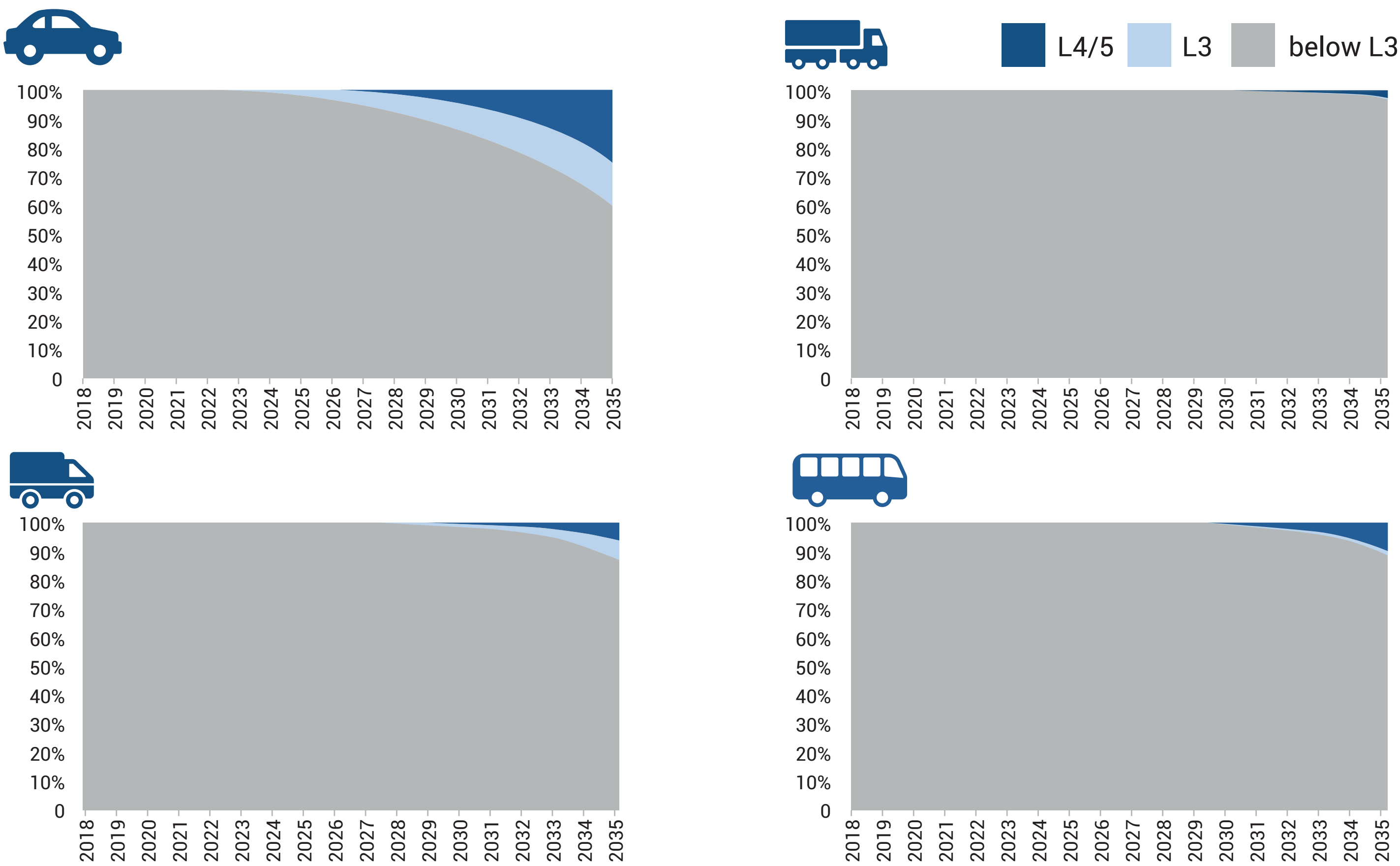


Figure 3.6 UK CAV Central uptake scenario (showing the composition of new vehicle sales by autonomy levels and vehicle types)

In this update of the Market Forecast, the uptake of CAVs within the van, heavy goods vehicle (HGV) and bus markets is assumed to occur at a different rate compared to the car market, with these three vehicle categories lagging behind cars. This assumption was made on the premise that integration of CAV technologies in heavier powertrains would require to overcome more technical barriers. This is already observed for other transformative trends in the automotive industry, such as electrification of powertrains. For example, in spite of hybrid cars being on the roads for years, the release of full hybrid vans has not been announced by OEMs. For this reason, we assume that the uptake of CAV technologies in vans could be lagging behind cars by up to 5 years. Similarly, literature sources[13] describe similar challenges for the automation of heavy duty vehicles (HGVs). Overall, a 3-year lag for buses, 5-year lag for vans and an 8-year lag for trucks is suggested by literature.

Two variations of the Central case were conducted to highlight the uncertainly regarding the uptake of CAVs and are intended to represent the boundaries of reasonable probability for global CAV adoption. The UK CAV uptake projections are shown for each of these three scenarios in Figure 3.7 and Figure 3.8.

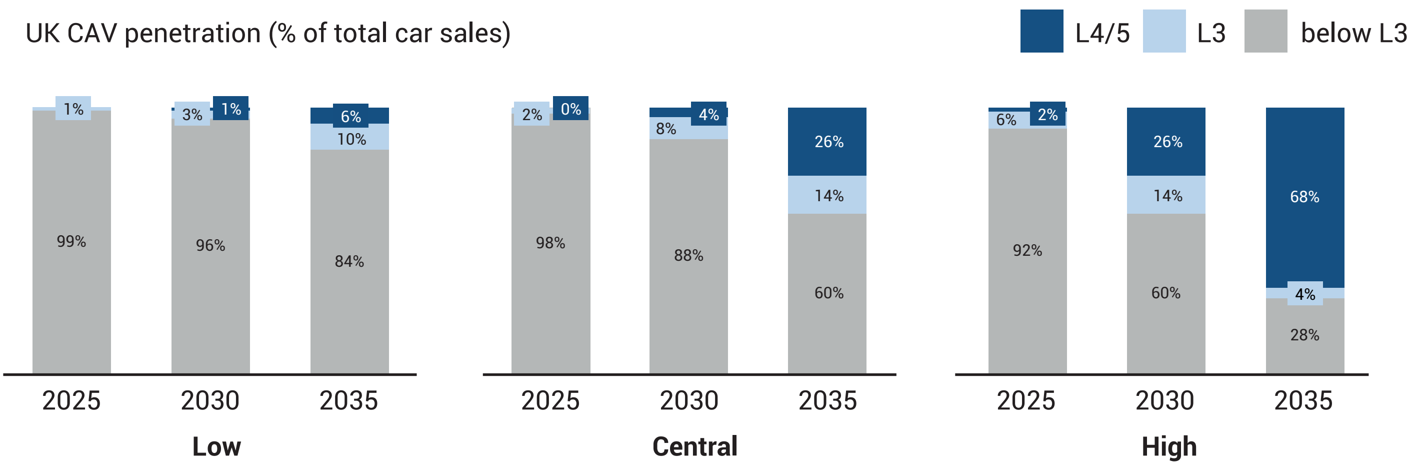


Figure 3.7 *UK uptake scenarios for L3-L5 CAV cars (as a percentage of UK cars sales)*

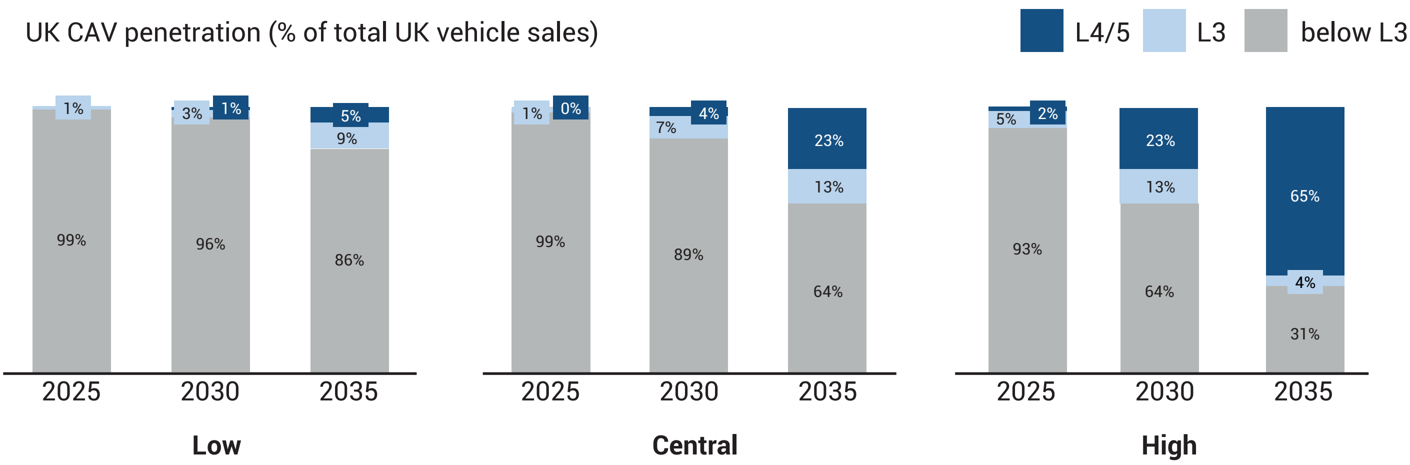


Figure 3.8 *UK uptake scenarios for L3-L5 CAV across all vehicle sectors (as a percentage of UK vehicle sales)*

[13] Distraction or disruption? Autonomous trucks gain ground in US logistics, McKinsey & Co, 2018 and ROUTE 2030 – The fast track to the future of the commercial vehicle industry, McKinsey Centre for future mobility, 2018 – estimates that the uptake of autonomous trucks in the US will start after 2022. This delay is mainly associated with the difficulty to carry-over certain autonomous technologies from passenger cars to commercial vehicles

In terms of market and technology dynamics, in the Central and High scenarios, it is assumed that uptake of L4/5 CAVs begins to replace L3 CAVs by around 2030-2035. This is most noticeable in the Central scenario where uptake of L3 CAVs reaches 8% for UK cars in 2030, whilst L4/5 represent just 4% of the total car sales. By 2035, L4/5 CAVs lead, representing 26% of the market, whilst L3 still grow but only reach 14% of new car sales. These uptake shares have been applied to projections of total vehicle sales, as shown in Figure 3.5 (in Section 3.1), in order to estimate total CAV sales in each year for the three scenarios. The table below summarising the three scenarios in terms of absolute vehicle sales.

Scenario	Cars			Vans			HGVS			Buses		
	2025	2030	2035	2025	2030	2035	2025	2030	2035	2025	2030	2035
Total (including CAVs)	2,748	3,144	3,217	413	473	484	55	58	61	9	9	9
L3-L5 CAV sales												
High	220	1,258	2,316	0	38	261	0	0	0	0	1	6
Central	44	377	1,287	0	7	58	0	2	13	0	0	1
Low	19	129	515	0	2	15	0	1	4	0	0	0

Table 3.1 Projected annual vehicle sales in the UK (thousands)

A comparison of the UK CAV sales to the global market is provided in the following section.

3.3 Regional and global uptake scenarios

Based on market observations, this study assumes that the UK represents the epicentre of CAV innovation and uptake, and that it will be leading in terms of CAV uptake compared to other markets. Thus, the UK uptake scenarios were used to inform the uptake across other regions. This was based on the relative uptake between regions aligned with that suggested by Goldman Sachs, 2015[14], the study which informed the scenarios in the 2017 edition of this Market Forecast. The diagram shows the assumed CAV uptake for cars across regions under the Central scenario. Similar scenario translations to regions were conducted for all vehicle types and for the Low and High cases.

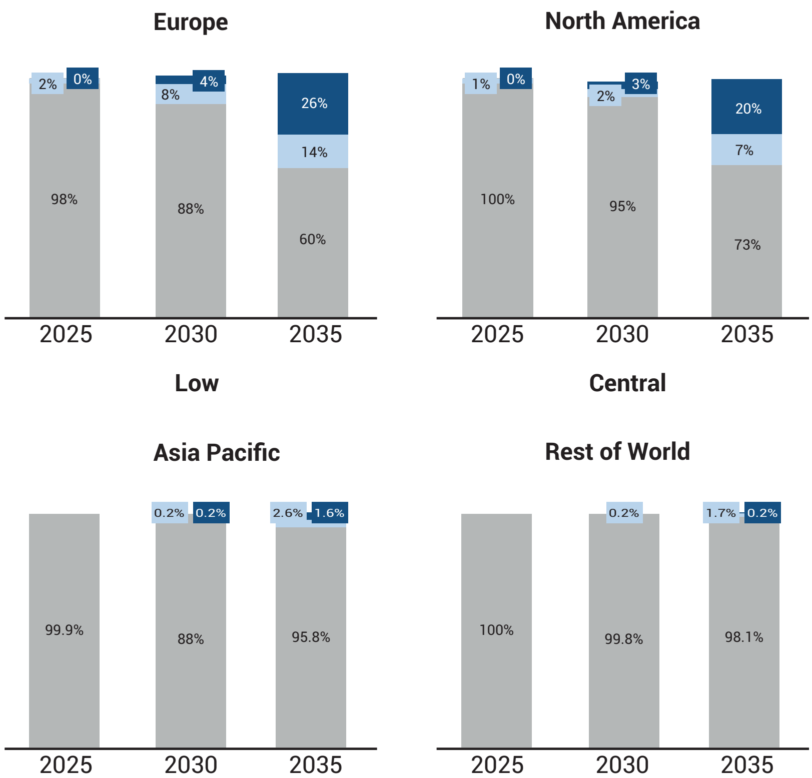


Table 3.9 Relative CAV sales penetration in different regions (shown for Central Scenario and cars only)[14]

[14] A full description of the generation of different uptake rates across markets is provided in the appendix. This was based on figures in Goldman Sachs, 2015, Monetizing the rise of autonomous vehicles

The relative uptake scenarios assume that Europe (including the UK) is the leading market for CAVs, with North America closely following, due to the early emergence of a testing and regulatory landscape for autonomous driving features (particularly in the UK) and the presence of multiple large automakers with premium vehicle offerings and links with suppliers of complex vehicle components (e.g. Bosch, Continental and Valeo). To gauge the wide uncertainty regarding the adoption of CAV across regions, a set of sensitivities assessing the potential of other markets, particularly North America leading the UK and Europe, was also conducted. The results of these sensitivity tests are described in section 3.9.

The diagram below provides a comparison of the aggregated global sales penetration of L3-5 CAVs cars in 2035 under the three scenarios are approximately 41%, 15%, and 6% in the High, Central, and Low scenarios respectively[15.] It can be noticed that the uptake of CAVs across other vehicle segments is delayed relative to cars and reaches lower levels in 2035 compared to cars.

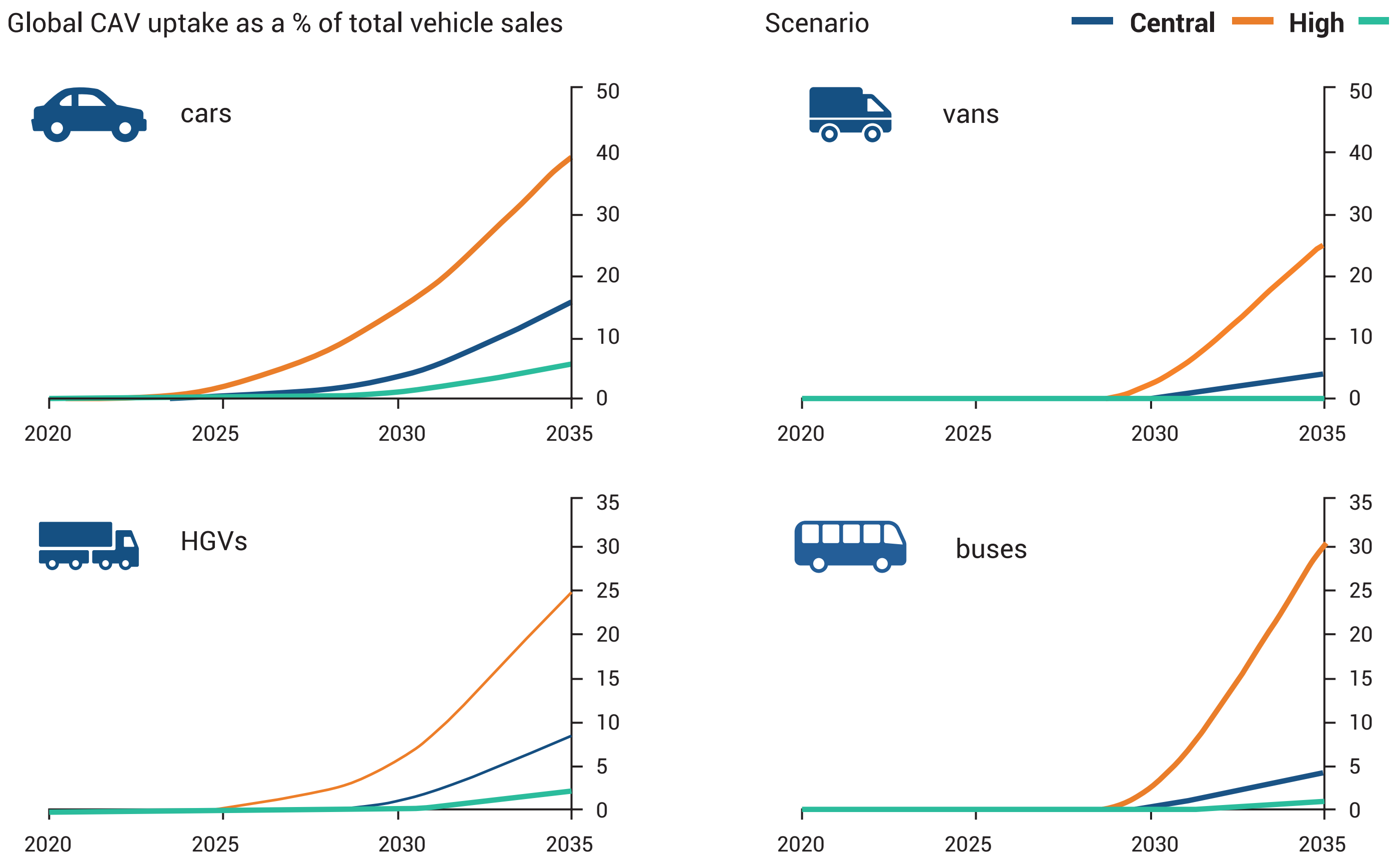


Figure 3.10 *Global uptake scenarios for L3-L5 CAVs (as a percentage of vehicle sales)*

[15] This represents a revision from the 2017 Market Forecast uptake scenarios which included an uptake of L3-5 cars of 85%, 25% and 10% in the progressive, central and obstructed scenarios respectively

Figure 3.11 shows (on the left) the global CAV sales totals in 2035 resulting from each of the global scenarios, and (on the right) the UK CAV sales totals in 2035 for each of the scenarios. This shows that, across the scenarios, the domestic CAV market is assumed to be ahead of the global market in terms of the transition to higher levels of autonomy, with a much higher share of L4/5 CAV sales relative to L3 CAV sales. Annual L3-L5 CAV sales in the UK in 2035 are predicted to be 1.4 million in the Central scenario but could range from around 0.5 million (Low case), to 2.6 million (High case)[16]. On a global level, the number of CAVs sold in 2035 varies between 8 and 60 million, with an estimated of 22 under the Central case. The UK would represent only 6% of the total sales in 2035, however this proportion would be much higher in the earlier years, when the UK would be leading in terms of CAV uptake whilst the other markets would be lagging behind.

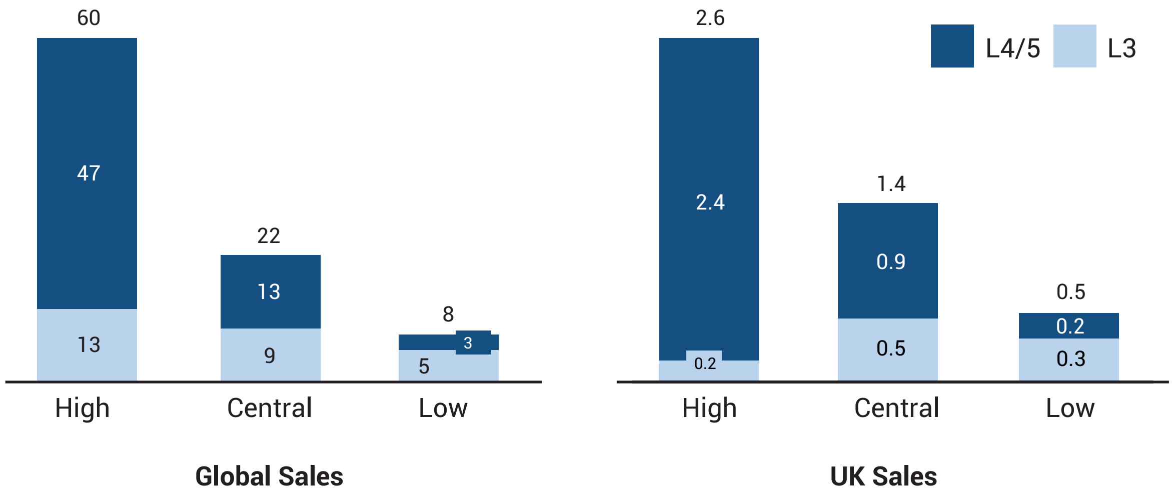


Figure 3.11 Global and UK CAV sales (millions) scenarios in 2035 across all vehicle types – note different plot scales

The resulting CAV sales projections for each scenario in 2025, 2030 and 2035 are shown by vehicle type in Table 3.2.

Scenario	Cars			Vans			HGVs			Buses		
	2025	2030	2035	2025	2030	2035	2025	2030	2035	2025	2030	2035
Total (including CAVs)	85,100	97,500	112,200	22,100	25,500	29,600	4,000	4,300	4,600	450	450	450
L3-L5 CAV sales												
High	1,844	14,045	44,226	0	605	7,525	24	263	1,168	0	12	136
Central	355	3,501	17,226	0	48	1,095	7	61	404	0	2	19
Low	155	1,178	6,457	0	14	139	0	17	113	0	0	4

Table 3.2 Projected global annual vehicle sales (thousands, rounded)

[16] This is a more conservative estimate compared to the 2017 edition of the Market Forecast - 1.16 million in the Central scenario but could range from around 0.2 million (Obstructed case), to 3.74 million (Progressive case). This is mainly a result of the revision of the CAV uptake scenarios as well as the use of different uptake rates across different vehicle types

Value of CAV components and technologies

METHOD BOX #2: VALUE OF CAVS AND CAV TECHNOLOGIES

Approach:

1) Estimate overall costs of autonomy on a per vehicle basis (i.e. cost of autonomy package). Project these costs over time in accordance with different uptake scenarios.
2) Identify components and the share of the overall package value that is allocated to each component and each CAV technology.

3.4 Cost of base vehicles

The economic impact assessment of the potential of CAV technologies included an analysis of the industrial activities undertaken for building both the vehicle base, as well as the CAV technologies included in the autonomy package installed on this vehicle. This assessment began by understanding the expected future costs of vehicles. At this point, market trends in this sector, such as the uptake of ultra-low emission powertrains were also considered. We assume that that the uptake of electric mobility is independent of the uptake of CAVs, and that is driven by policy, environmental concerns, and economies of scale. The uptake of ultra-low emission vehicles (ULEVs) was based on the latest literature data, including Element Energy ECCo's modelling and IEAs EV outlook (IEA, 2018) and were applied to both cars and vans, the most representative vehicles in terms of sales volumes. This modelling considered geographic differences and is summarised in the diagram below:

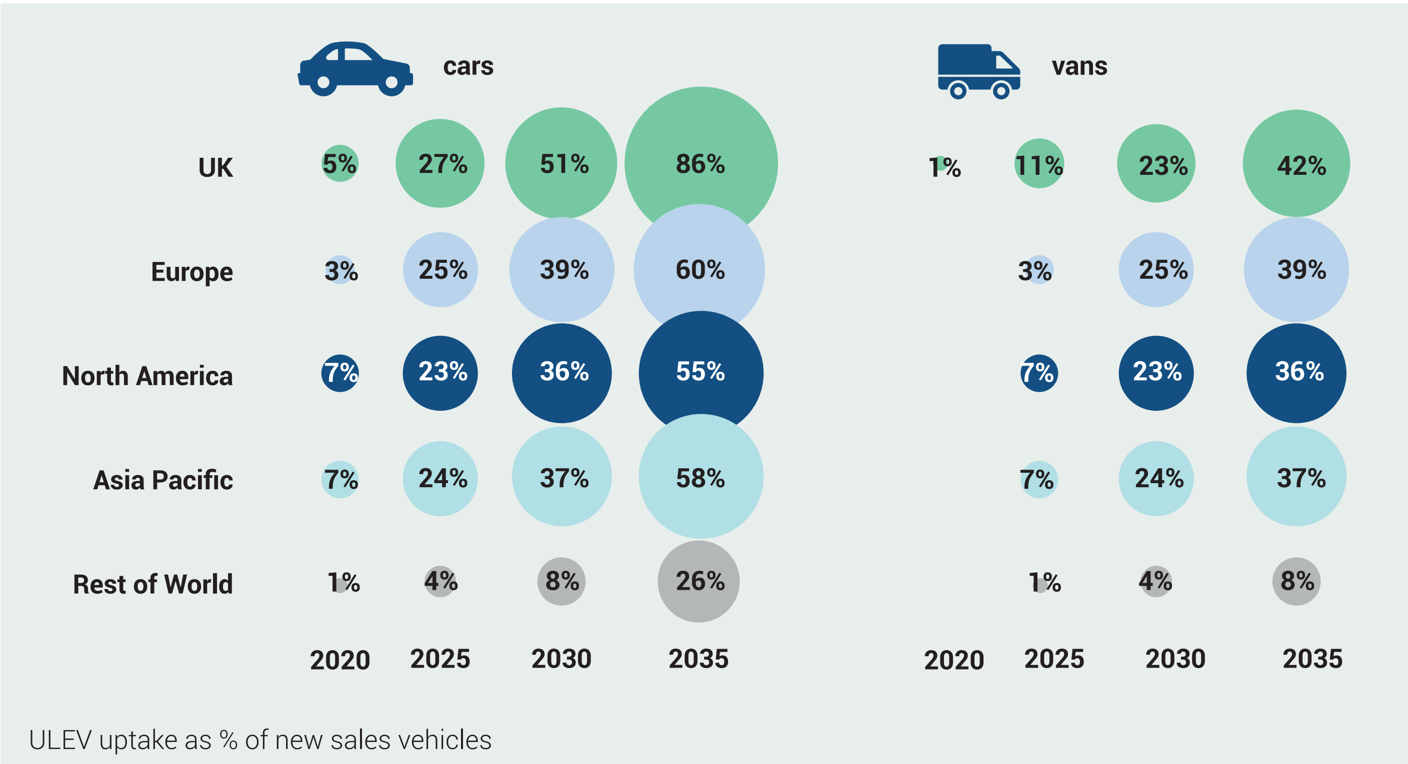


Figure 3.12 Uptake of ULEV cars and vans across different markets (as a % of new vehicle sales)[17]

[17] The ULEV uptake rates for the UK were developed in line with the Road to Zero policy, before the announcement of the UK Government to bring forward ban on ICE vehicles sales to 2035 from 2040

For cars and vans, the base vehicle costs are assumed to follow the trajectories for representative internal combustion engine (ICE) and electric vehicles within each category. The cost of ICE vehicles is observed to have a nearly flat trajectory, whilst the cost of ULEV is decreasing over time in line with cost reduction in batteries and streamlining of the manufacturing[18]. In the case of trucks and buses, only the diesel powertrains were considered, with an estimated average price of £92,800 for HGVs and £175,500 for a typical single deck bus[19] in 2035.

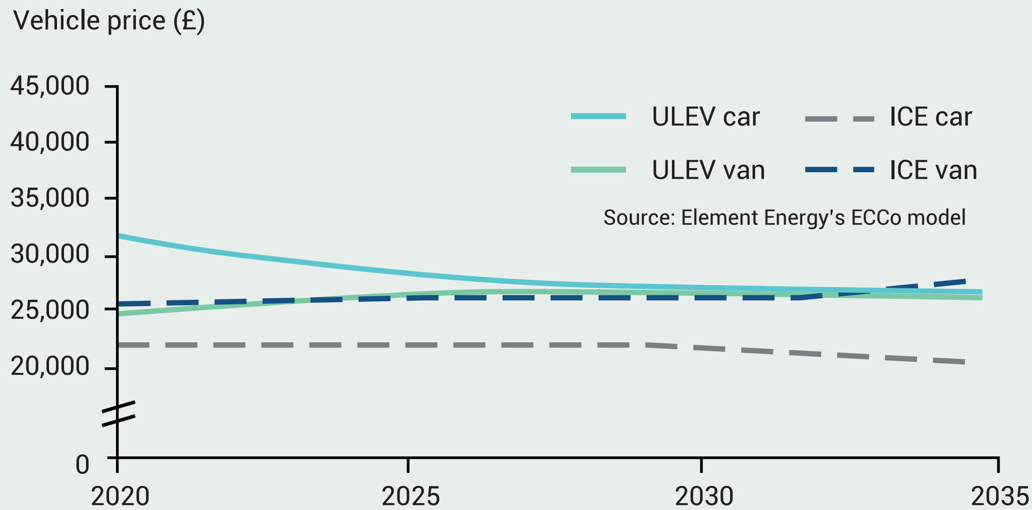


Figure 3.13 *Vehicle cost projections for different powertrains*

Following the costs of the base vehicles, the costs of autonomy packs were investigated as described in the following section.

3.5 Cost of autonomy packages over time

There is likely to be significant variation in the cost of autonomy packages, even at specific levels of autonomy. Therefore, in order to estimate the overall market size, this study aims to use projections of costs and uptake that represent the average or "typical" packages of technologies at L3 and L4/5. These are defined in terms of function and cost below, and in terms of the required components in Section 3.6. Further to this, the same autonomy package costs are assumed to apply to all vehicle types (implications are discussed in Section 3.7).

In the 2017 edition of the Market Forecast, costs at the point of introduction have been taken from Boston Consulting Group's 2015 study: Revolution in the Driver's Seat: The Road to Autonomous Vehicles, which also provides the basis for the Central global uptake scenario. The study and the estimated costs are informed by a review of the technologies required, interviews with OEMs, suppliers and researchers, and a survey of 1,500 US consumers to identify willingness to pay for various autonomous driving features. While the survey is not necessarily representative of the global market, in the absence of wider-reaching surveys it is a valuable contributing factor to the introductory costs.

The introductory costs of the "typical" L3 package are assumed to correspond to those of one of a specific L3 feature discussed in the Boston Consulting Group (BCG) study, "Highway autopilot with lane changing". This is likely to be one of the most commonly adopted L3 functions due to its high potential to improve comfort, convenience and safety for drivers. The total cost to the OEM at the point of introduction was estimated at **$3,800** in 2015, corresponding to £3,076 in 2020. This figure was used in the previous version of this study, and was re-examined by industry, being deemed still appropriate for the cost of the L3 autonomy pack.

[18] Element Energy vehicle cost modelling (ECCo), as used for DfT . Quoted baseline costs based on C segment diesel cars
[19] Element Energy for TSC (2018) Hydrogen to Smart Mobility: Current and Future Hydrogen Use Technologies for Transport; large data for rigid diesel trucks and single deck diesel buses, respectively

The costs of a typical L4/L5 package was derived based on more recent literature, such as the BCG's 2017 "The Reimagined Car" study (The Boston Consulting Group, 2017), estimating a price of $7,100 (in 2017 currency) for the autonomy pack installed on a vehicle in 2030. Using this as a base, the figure was segmented into different components. By assuming that the L4/5 package will require 5 LIDAR sensors per vehicle, and considering the learning curve advances, we estimate an introductory price of £5,417 for the L4/5 package in 2025. This is intended to encompass the average autonomy package costs per vehicle for the range of autonomous use cases at L4, as well as for fully autonomous vehicles at L5. The evolution of the autonomy pack costs is shown in the diagram below. The cost decline is a combination of economies of scales driven by both technological learnings and cumulated technology adoption. For this reason, the costs vary depending on the CAV uptake scenario and are summarised below. The cost reduction associated with technical learnings is discussed in the following section.

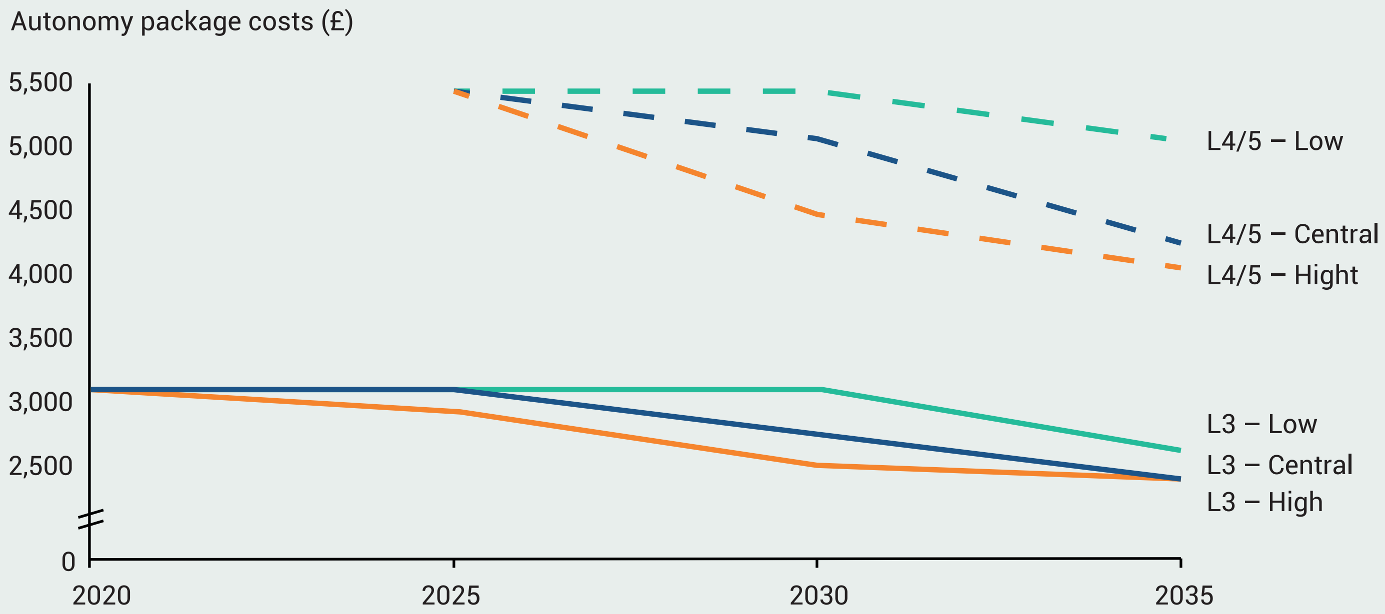


***Figure 3.14** Estimated costs of autonomy packages under different CAV uptake scenarios*

The autonomy package costs are assumed to apply to all vehicle types in scope. In order to estimate the total turnover from CAVs in each year, further assumptions are needed around the cost trajectories for the vehicles themselves, and also to account for the OEM mark-up on the technology. To translate OEM costs to consumer prices, this study assumes a 50% mark-up on the autonomy packages[20].

3.6 Relative value of components for autonomy packages

To estimate the market size and economic impacts relating to the various CAV technologies, the package costs shown in Figure 3.14 are split according to the relative values of the components needed to achieve each level of autonomy. Figure 3.15 shows the estimated breakdown, based on the primary research conducted by Goldman Sachs Global Investment Research study back in 2015, and validated and revised by Element Energy through consultation with over 10 industrial players in 2019Q1. Figure 3.15 displays the estimated value of each component in terms of the percentage share of the total aggregated value, which are expected once autonomy package production reaches scale. LIDAR is predicted to be by far the most expensive component, and V2X (vehicle connectivity) and cameras account for the second and third largest share of the total value at both L3 and L4/5.

[20] 30% mark-up follows assumptions in *The Reimagined Car, BCG, 2017*

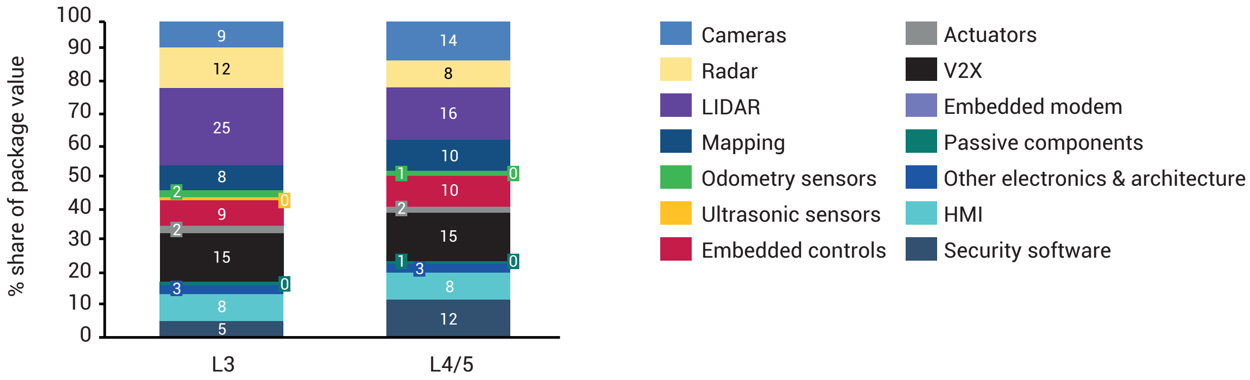


***Figure 3.15** Estimated breakdown of autonomy package costs at the component level. Note that Autonomous Control Systems are assumed to be included within "Embedded controls"*[21]

This cost structure is different compared to the previous study and was updated in light of industry consultation findings. Overall, industry believes that the L3 cost structure previously used is reasonable. However, it is believed that L3 vehicles will represent only a small share of CAVs, with the dominant technology being L4/5 as it provides a better answer to safety concerns.

Indeed, the requirements for conditional autonomy and full autonomy have different implications for each of the components identified in Figure 3.15. In some cases, greater complexity or simply a higher number of units will be required for full autonomy, leading to higher costs, but for other components there will be little change in requirements. For example, based on our industry survey, we estimate that L3 vehicles will utilise in average four LIDAR sensors, whilst L4/5 packages, which must provide increased reliability, would use five sensors. In addition to LIDAR sensors, L4/5 technology is expected to rely heavily on the following technologies: high-resolution cameras, video cards and processors, and extensive mapping software.

For the purposes of the economic impacts assessment, each component must be assigned to one or more Standard Industrial Classification (SIC) codes. SIC codes denote the type of economic activity that particular businesses relate to, and data on economic indicators such as labour intensity tends to be differentiated using SIC codes. Therefore, by relating each component to a SIC code, the estimated turnover associated with that component can be translated into various economic metrics (this will be discussed in Chapter 4).

Most of the components listed in Figure 3.15 can be clearly mapped to one SIC code (see Appendix C, Table 6.2 and Table 6.3, for the full list). However, some components cannot necessarily be classified under one SIC code, as they are likely to involve significant software aspects as well as the various on-vehicle hardware items, and the existing SIC codes and associated data do not account for this.

For example, the "Mapping" component (as shown in Figure 3.15) will provide the vehicle with geographic positioning data for path planning at a range of distances, and is likely to work alongside sensing suites. In addition to GPS receivers and other hardware, "mapping" is assumed to require on-vehicle software and data processing requirements (e.g. for "machine vision"). Therefore, part of the component value must be allocated to relevant software-related SIC codes, as well as relevant hardware-related SIC codes. This is also assumed to be the case for "embedded controls", "V2X", and "HMI" (human machine interface) components. However, the proportions for splitting of value for these components between hardware and software is a key area of uncertainty, as discussed in Section 3.7.

[21] (Archambault et al., 2015). Values for ultrasonic and odometry sensors are estimated from the BCG study (Mosquet et al., 2015)

It must be noted that autonomy packs combine both hardware components (e.g. cameras, LIDAR sensors, and actuators), as well as software. However, one great area of uncertainty is the spit between hardware and software when the autonomy pack is introduced to the market. The assumptions used in the 2017 study were reviewed validated by industry to represent any market changes. The implications of this (when considering the estimated overall value for the autonomy packages, as set out in Section 3.4) are as follows:

- For L3 CAV autonomy packages (assumed to have lower software requirements), the overall share of value for software has been set to 35%, resulting in a total **"introductory"** software value of £1,077 (in 2020).
- For L4/5 CAV autonomy packages (assumed to have higher software requirements) the overall share of value for software has been set to 50%, resulting in a total **"introductory"** software value of £2,708 (in 2025).

In addition, industry consultation pointed out that whilst the cost of autonomy packs is expected to drop in time thanks to technological learnings and economies of scale driven by cumulative uptake, a true learning curve would only apply to the hardware components. It is expected that the software costs would remain flat as the software itself would be licensed and would require continuous development under the form of new features, updates, validation, and fixes. This non-linear correlation between the costs of hardware and software is represented in our modelling, which considers that the costs of hardware drops in time whilst software costs remain constant. A learning curve of 90-95%[22] was applied to represent the relationship between cumulative uptake and cost reduction rates for the hardware components of the autonomy packages. The diagram below shows the resulting cost trends at the package level under the Central scenario.

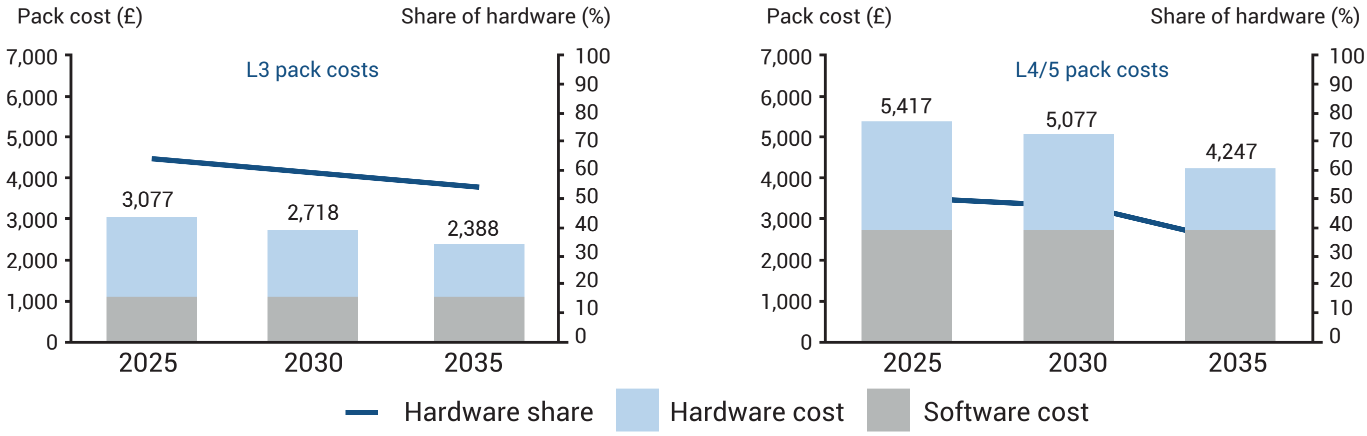


***Figure 3.16** Cost projections for autonomy packages under the Central uptake scenarios*

[22] Learning curve effect: the cumulative average cost per unit decreases by a fixed percentage each time the cumulative production volume doubles. The percentage cost reduction is (1 – x), where x is the "learning rate".

The implications of these assumptions on the value of individual components are summarised in Table 3.3 and Figure 3.17. Table 3.3 shows the assumed share of the total package value by component, at L3 and L4/5. Figure 3.17 shows the implied component costs at the point of introduction and in 2035.

The breakdown at L3 and L4/5 is informed by: a) the component costs quoted by the Goldman Sachs study (see Figure 3.15); b) assumptions around the overall split of hardware and software (see Figure 3.16 and discussion), and c) the estimated relative value of software and hardware for individual components. A full breakdown of these assumptions, and the details of the specific SIC codes allocated to each component, can be found in Appendix C).

Due to the uncertainty in the value ratio for software and hardware, the economic impacts associated with these assumptions are tested as a sensitivity to the central scenario, in Section 4.10. This sensitivity compares the economic impacts resulting from the values used in the main scenarios, to the impacts when a lower total value for software technologies is assumed.

Component	Percentage of value at L3	Percentage of value at L4/5
Actuators	2%	2%
Cameras	9%	14%
Embedded controls hardware	2%	1%
Embedded controls software	7%	9%
Embedded modem	0%	0%
HMI Hardware	2%	2%
HMI software	6%	6%
LIDAR	25%	16%
Mapping hardware	2%	1%
Mapping software	6%	9%
Odometry sensors	2%	1%
Other electronics & architecture	3%	3%
Passive components	0%	1%
Radar	12%	8%
Security software	3%	7%
Ultrasonic sensors	0.3%	0.1%
V2X hardware	3%	1%
V2X software	14%	18%

Table 3.3 Assumed share of autonomy package value by component. At L3, 35% of the total value is assumed to be software, and at L4/5 this is assumed to rise to 50%. Assumptions are described in full in Appendix B

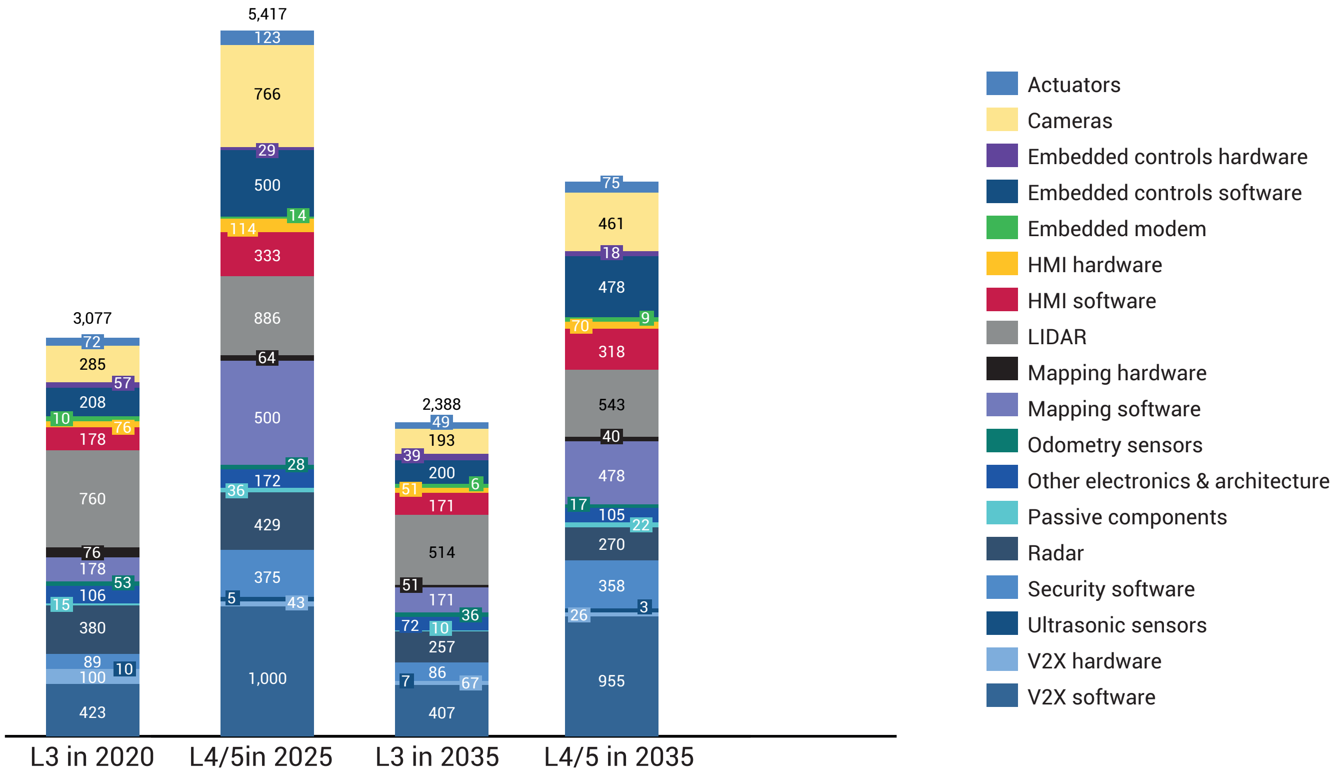


Figure 3.17 Projected costs (£) of autonomy packages by component in year of introduction and in 2035

Figure 3.18 shows the resulting aggregated value for each of the CAV technologies (as defined in Section 2) in 2035. Sensing and mapping hardware, which includes LIDAR, radar and cameras (amongst others) accounts for the largest value from a single technology.

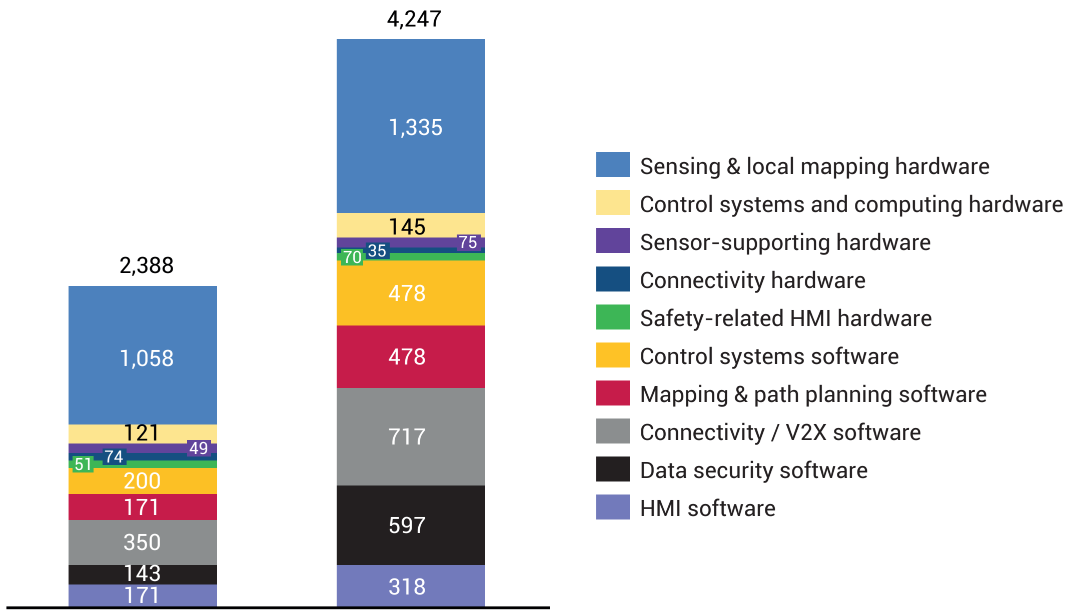


Figure 3.18 Projected costs (£) of autonomy packages by technology in 2035

3.7 Key areas of uncertainty in cost projections

The projected values for vehicle, autonomy packages, and components presented in this chapter represent the aggregation of data from numerous previous studies of the CAV market, which in turn have involved extensive consultation with industry experts. The values have also been reviewed and approved by several UK experts in this field (including members of CCAV, CPC, and industry leaders). However, it is important to note that the assumptions made for sizing the market are by nature uncertain, which have implications for the results of the economic analysis presented in Chapter 4.

- **A high share of the value of CAV autonomy packages is assumed to be attributable to software and associated economic activities.** There is currently a lack of transparent data on the value per vehicle for CAV software (in terms of how it is priced for OEMs and for vehicle users, as well as much it costs to develop). The assumptions made for the *introductory* cost segmentation reflect a range of available evidence assessed previously, including: the price of software upgrades in Tesla vehicles (enabling certain autonomous capabilities)[23]; the cost of aviation autopilot systems[24]; and the software development costs associated with existing premium cars[25]. These are consistent with the assumptions used in the 2017 study and were validated by industry to ensure accuracy. However, industry consultation points out that the cost of software will likely remain constant as this would be licensed. In light of this, the split of costs between hardware and software is modelled dynamically, in time. The cost of hardware manufacturing is assumed to follow a decreasing trend in line with a learning curve, whilst the cost of software is maintained constant (at introductory costs). For the purposes of the study, we also assume that users will only pay for a one off at the start, rather than paying for safety improvement upgrades; it remains unknown whether this will reflect actual future payment models.
- **Cost reductions applied at the package level are assumed to be applicable for different components.** It is possible that different hardware components reduce in cost at different rates, e.g. due to their parallel use in other industries, or due to different inherent learning rates in manufacture or production. Given the different UK capabilities for the technologies, such differences could have implications for the value of imports and exports, and therefore affect the economic impacts for the UK. However, future work could consider exploring different cost reduction rates for CAV technologies, and the implications for the UK.
- **The cost of autonomy packages is assumed to be the same for cars, vans, trucks and buses.** IIt is likely that the software and hardware requirements will differ between different vehicle types, according to their different use cases and business models. For example, commercial vehicles (i.e. vans and HGVs) are typically driven on motorways for a much higher proportion of their annual mileage, compared to passenger cars (DfT, 2015). As a result, L3 and L4 autonomy packages for commercial vehicles may be particularly targeted towards motorway driving, and the relative simplicity of motorway driving may mean that sensor and software requirements for "average" autonomy packages for these vehicles could be lower than those for cars. However, there is currently little evidence available for direct comparison of these requirements between different vehicle types. Fortunately, the impact of differentiating the associated costs is likely to be low, due to the market dominance of car sales compared to other vehicle types (in 2035, of the 22 million projected CAVs global sales in the Central case, 17 million are cars).

[23] Customers will pay around $3,000 for Tesla "Full Self-driving Capability" software to calibrate hardware and activate software. These costs are speculated to cover some hardware costs as well. This is in addition to the $5,000 option payable for the Enhanced Autopilot system, which is required for anyone wishing to upgrade to "Full Self-driving Capability" at a later date. See http://www.theverge.com/2016/10/20/13346512/tesla-self-driving-autonomous-enhanced-autopilot-cost

[24] Aviation is not a perfect comparison point, but could provide a proxy; upgrade costs for autopilot systems are in the region of $5,000, and systems can cost in excess of $15,000. Much of this could be software costs. See: https://buy.garmin.com/en-US/US/p/67886 and http://www.avweb.com/news/features/Retrofit-Autopilots-Youll-Pay-For-Precision-225693-1.html

[25] Up to 6% of the cost of premium cars is accounted for by software development costs (Charette, 2009)

- **By the time L3 CAVs are introduced, LIDAR costs are assumed to have dramatically reduced compared to current costs.** LIDAR is still developing as a technology, and costs would need to reduce to fractions of most current industry estimates, by the time L3 CAVs are introduced, in order to reflect the LIDAR costs used in this study. These assumptions are mirrored in previous studies; the implied position is that although LIDAR is likely to be a requirement for high levels of autonomy, costs must be sufficiently reduced to enable the cost of autonomy to be palatable to customers. LIDAR costs are the largest single contribution to the autonomy package costs, for both L3 and L4/5. Based on historic expertise, the UK has relatively weak capabilities in this area of manufacture, and therefore a higher LIDAR cost could reduce the economic benefits of the CAV sectors for the UK, assuming that UK capabilities are not strengthened, relative to those of other regions. However, it should also be noted that there is still some debate amongst CAV developers as to whether LIDAR will definitely be required for all CAV use cases (e.g. it may not be essential for motorway driving). If cheaper alternatives to LIDAR are proven to be effective, this could have implications for overall costs and the rate of CAV uptake; however, the current consensus seems to be that LIDAR is likely to be required for the majority of use cases and vehicle types.
- **There is a possibility that OEM's may provide significant discounts to vehicle fleet operators.** To assess this uncertainty, a sensitivity was designed to reflect a situation in which case OEMs mark-up (including profit margin) was decreased. Overall, the value paid by fleet operators to OEMs decreases, leading to a decrease in the CAV market value, however this value is transferred from the OEM market (which this Market Forecast is examining) to the fleet operator market. As part of this sensitivity, successive reductions of 10% to 30% of the OEM's mark-up were applied, leading to lower CAV prices, below catalogue prices. The outputs of this sensitivity analysis are explained in the Section 3.10.

Projected market size for CAVs and CAV technologies

Total market values for CAVs and CAV technologies were calculated as follows:

CAV market value = Sum across vehicle types: ***(CAV sales x CAV cost to consumer)***

CAV technology market value = Sum across vehicle types: ***(CAV sales x technology cost to OEM)***

The vehicle types included are cars and vans, HGVs, and buses (L3 and L4/5). In each case, the market value figures shown represent the value based on sales in a particular year (i.e. the results shown do not represent cumulative value).

3.8 Size of the market

The size of the UK and global CAV and CAV technologies markets is shown in Figure 3.19 below for the three scenarios modelled. In the central scenario, the UK CAV market is worth **£41.7 billion in 2035, of which the UK CAV technology market is worth £6.4 billion in 2035.** This value varies between **£16.2 billion and £82.4 billion in 2035 for the Low and High scenarios** respectively. In addition, the global overall market is estimated at between £234 billion and £1,763 billion in 2035, with a central estimated of £650 billion in 2035.

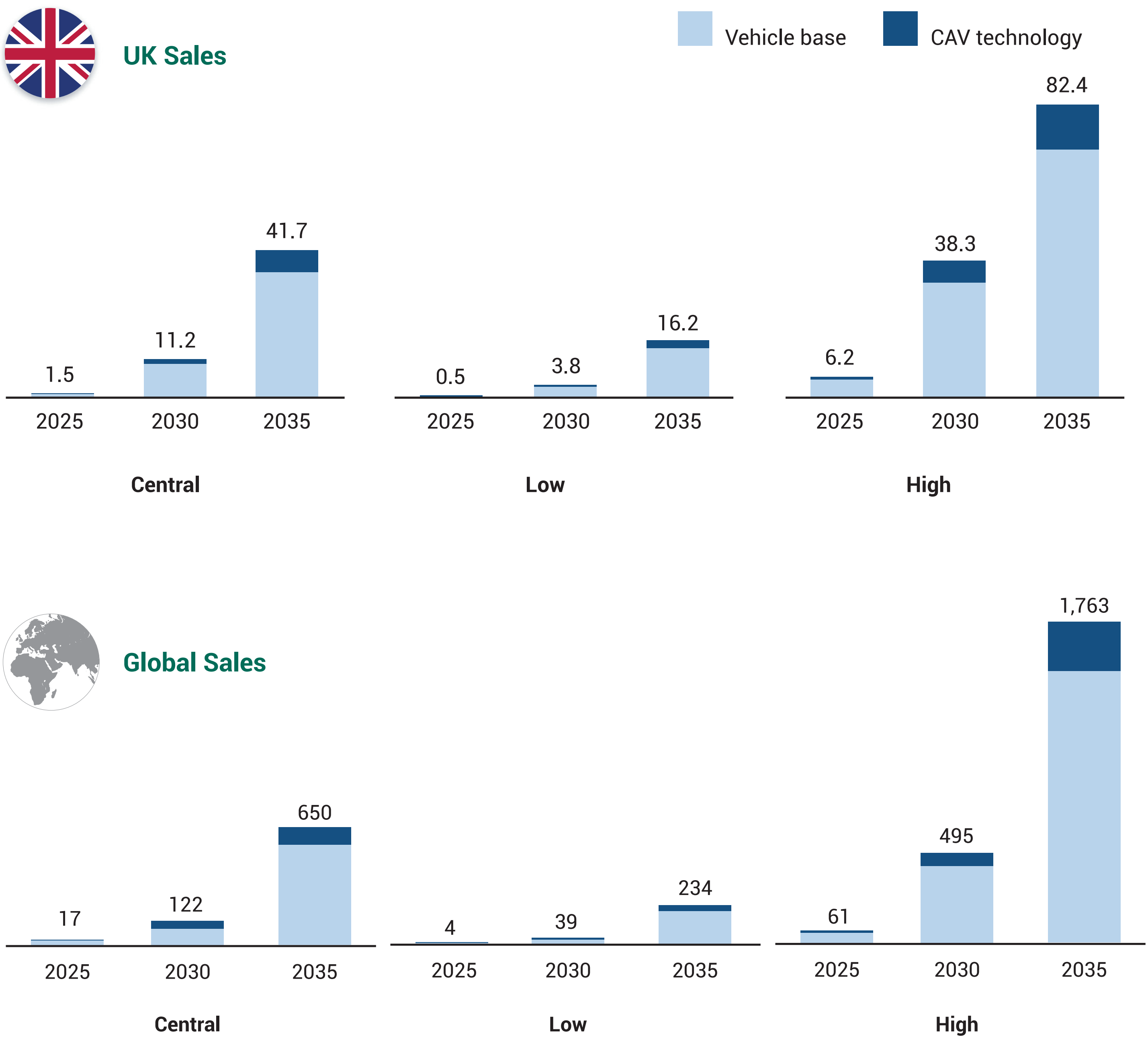


Figure 3.19 *Projected market value (£ billions) from CAVs and CAV technology sales across different scenarios. Values shown are based on the projected sales of L3-L5 cars, vans, HGVs, and buses in the specific years shown (i.e. not cumulative)*

The diagram below takes a better look at the global CAV market in 2035. It can be noticed that UK and Europe represent 58% of the total £650 billion global market of CAVs, whilst North America represents 30%. A very limited number of sales are represented by Asia Pacific and Rest of World. In terms of vehicle types, over 75% of all CAVs sold (by volume) are represented by cars. Vans represent the second largest vehicle sector, corresponding of ~20% of all CAVs sold in 2035. The number of autonomous HGVs and buses is rather limited and represents less than 3.5% of the total CAV sales.

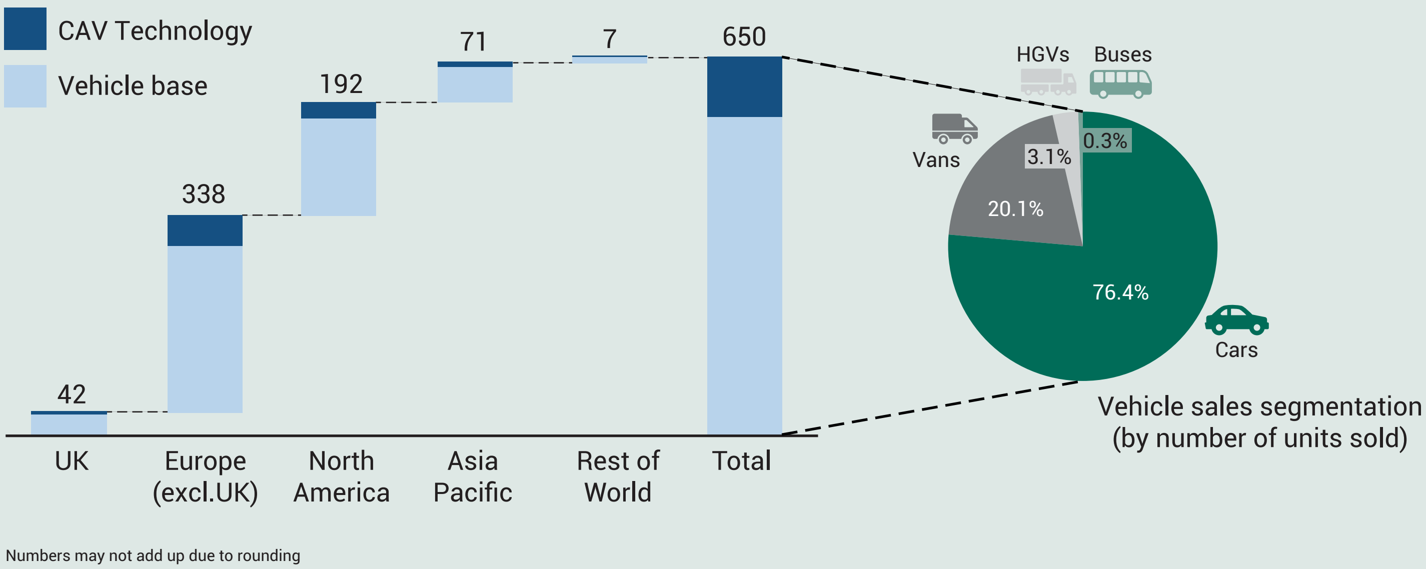


Figure 3.20 Summary of the CAV market size projections in 2035 (£ billions)

Figure 3.21 shows the breakdown of the CAV technology market by individual technologies in the central case, and indicates that the overall share of the market value coming from software technologies increases over time, reaching 44% in 2035. This reflects the increased uptake of L4/5 CAVs over time, for which software is assumed to account for a larger share of the total per-vehicle value of autonomy packages, compared to L3 CAVs.

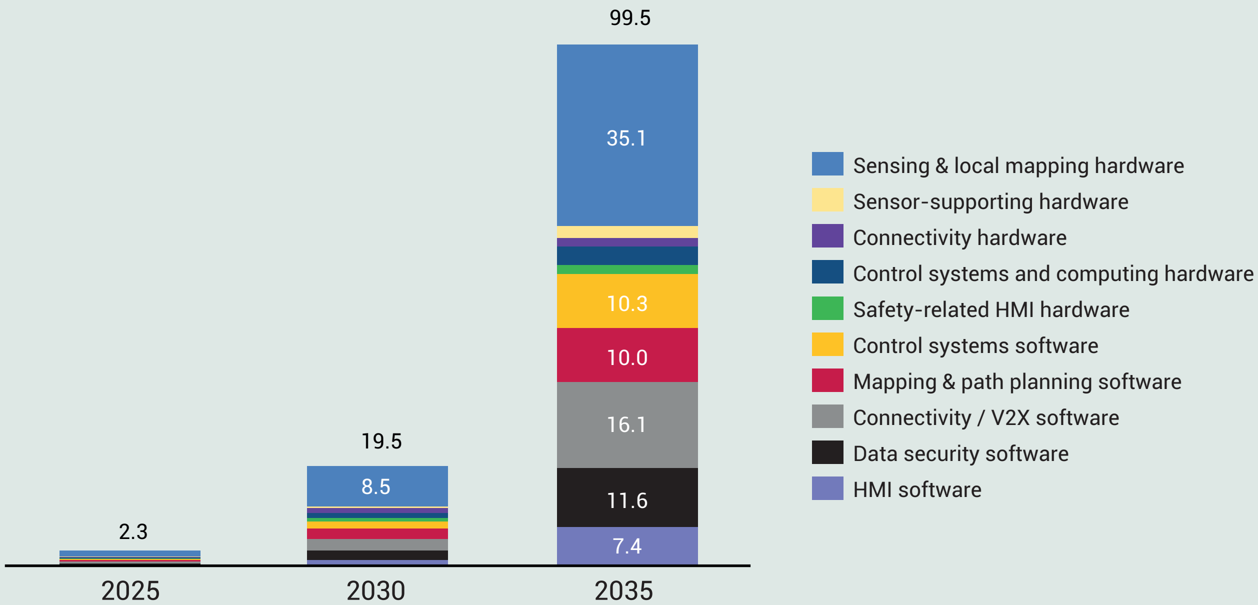


Figure 3.21 Projected global market value (£ billions) from CAV technology sales, by technology (Central case). Values shown are based on the projected sales of L3-L5 vehicles in the specific years shown (i.e. not cumulative)

The high and low bounds for the size of these markets are shown in Table 3.4, alongside the central and central UK lead scenarios. Note that the increase for the central UK lead scenarios.

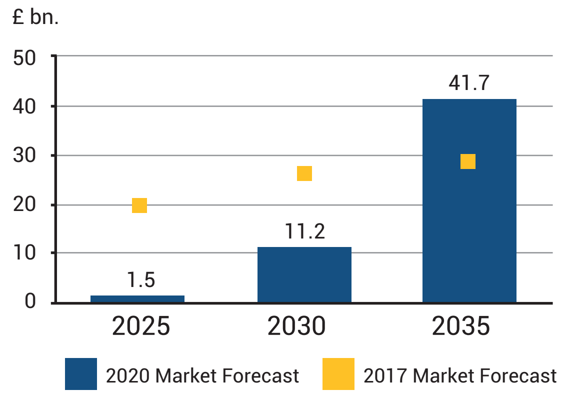
£bn.		2025	2030	2035
CAVs	High	61	496	1,764
	Central	16	123	650
	Low	5	39	233
£bn.		2025	2030	2035
CAV technologies	High	0.6	77.7	272.7
	Central	2.3	19.5	99.5
	Low	0.6	6.4	35.2

Table 3.4 Projected market value from CAV and CAV technology sales, based on global CAV demand. Values shown are based on the projected sales of L3-L5 cars, vans and HGVs in the specific years shown (i.e. not cumulative). Based on uptake scenarios set out in Section 3.3, p10

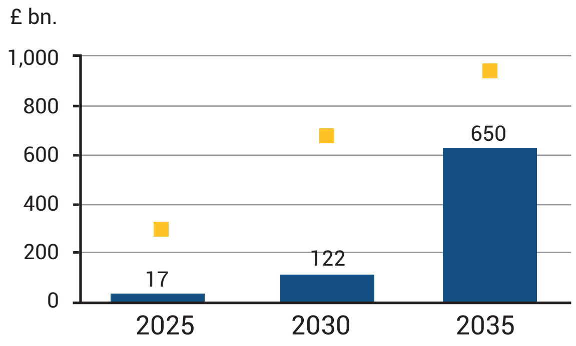
Compared to the 2017 edition of this Market forecast, this edition brings a revised short-term projection, with a lower sales value estimate (due to slow progression of the market) and a higher long-term projection in terms of sales value for the UK market. The long-term difference is also attributed to the slow development of the market, with a reduced uptake of CAVs than thought before. However, the market trends also highlight that the CAV technology package costs will remain higher than previously predicted, counterbalancing the lower number of vehicles sold.

The sluggish uptake of CAVs in developed economies during the first half of the 2020s compared with the assumptions for the same timeframe made in the previous edition, would have a global knock-on effect on the uptake across other markets. As a result, the total global market projected in this edition of the Market Forecast is smaller than previously estimated.

UK CAV and CAV technologies market value



Global CAV and CAV technologies market value



*2017 Market Forecast study outputs were adjusted for inflation

Figure 3.22 Comparison of the projected UK and global market value (£ billions) from CAVs and CAV technology sales across two editions of the Market Forecast (Central case). Values for L3-L5 vehicles sales in the specific years shown (i.e. not cumulative)

Putting these projections for the global CAV market in context, recent reports estimate the global autonomous vehicle market expected to reach over USD 550 billion by 2026[26] (~£445bn considering the CAV and CAV technology markets alone), several times higher than our estimate of £16.3bn in 2025. In the long term, there are limited projections available. Estimates by Intel indicated that "the driverless market" could be worth as much as USD70bn (around £57bn) by 2030[27]. This estimate is assumed to represent the market associated with CAV technologies (rather than the total CAV market, which inherently overlaps with the existing automotive market) and is well positioned between the Central and High case results presented in this report.

There is still uncertainty regarding the real market size of CAV technologies and the uptake rates across different markets. These uncertainties are examined in the next section. The projected market values, both at the global and regional level, inform the assessment of the economic impacts of CAV market for the UK economy. These impacts are presented and discussed in Chapter 4.

3.9 Sensitivities on the size of the global market

The three main scenarios examined in this study (Low, Central, High) consider that the UK and Europe lead in terms of adoption of CAVs. This is based on the work published by Goldman Sachs and consistent with several other sources, however the wide range of literature available contains publications pointing out that the North American market may take over the European one in the future. To account for these uncertainties, three sensitivities on the uptake rates of CAVs across various global markets were modelled. These three sensitivities assess the position of the UK and Europe compared to North America, as described below:

- **Reverted:** in this sensitivity the North American market follows the trajectory that the UK and Europe follows in the Central case. Conversely, the uptake of CAVs in the UK and Europe is modelled lower than in the Central scenarios, and follows the trajectory assumed for North America under the Central case.
- **Aligned:** assumes similarities between the North American and the European markets, with the CAVs uptake rates in these markets following an identical trajectory in time. This means that the uptake in North America is higher in this case compared to the Central scenario.
- **Accelerated North America uptake:** in this sensitivity, it is assumed that the CAV uptake across the European and North American markets commences at the same rate up until 2025, after which the North American uptake accelerates whilst the UK/Europe continues to grow at a lower rate and fall behinds North America.

The full details of the uptake curves for these sensitivities are included in Appendix B. The resulting CAV market values of under these alternative uptake scenarios is summarised in the table below.

£bn.		2025	2030	2035
UK market	Reverted	0.5	5.6	29.9
	Aligned	1.5	11.2	41.7
	Accelerated North America	1.5	5.6	17.8
	Central	1.5	11.2	41.7
£bn		2025	2030	2035
North American market	Reverted	9.4	69.5	289
	Aligned	9.4	68.9	289
	Accelerated North America	9.4	69.1	289
	Central	5.1	31.4	192

***Table 3.5** Comparison of market size of UK and North America across different sensitivities*

[26] Allied Market Research (2018) - https://www.alliedmarketresearch.com/autonomous-vehicle-market
[27] http://www.bbc.co.uk/news/business-39253422; Accessed 30th March 2017

It can be noted that under all three sensitivities the North American market is leading, with an estimated market size of £289 billion in 2035, 50% higher compared to the Central scenario. The size of the UK market ranges between £17.8 billion and £41.7 billion under these sensitivities. Under the extreme scenario of an accelerated CAV uptake in North America and a lag in Europe and the UK, the British market would be 42% of the Central case estimate.

3.10 The impact of discounts to fleet operators

It is envisaged that connected and autonomous vehicles will revolutionise mobility and would be adopted both by private and commercial customers. Autonomous vehicles may be used for Mobility as a Service (MaaS) applications such as ride sharing, car-pooling, or autonomous taxis. It is also expected that vehicle utilised for these purposes would be purchased in bulk by fleet operators (e.g. UBER). Bulk purchases are usually accompanied with a significant discount provided by the vehicle OEMs, leading to below market prices for the fleet operator. Whilst the total value of the vehicle sold decreases as a result of reduced prices, this value is in fact transferred from the automotive market to fleet operators. However, given the scope of quantifying the impacts of CAV uptake to the automotive market, a sensitivity considering such discounts was conducted. Given that the scale of discounts given to fleet operator is usually maintained confidential, this sensitivity relies on a series of assumptions as highlighted in the appendix D. Overall, we assume that L4/5 CAV cars, those truly "autonomous" and suitable for mobility applications in fleets, would be subject discounts ranging between 10% and 20% of the vehicle base catalogue price. Such discounts, whilst leading to a reduction of only 4-5% of the overall market value for the automotive industry relative to the central case[28], could bring significant savings to fleet operators, ranging between £2.1 billion in the UK and £25 billion globally in 2035, as shown in the diagram below.

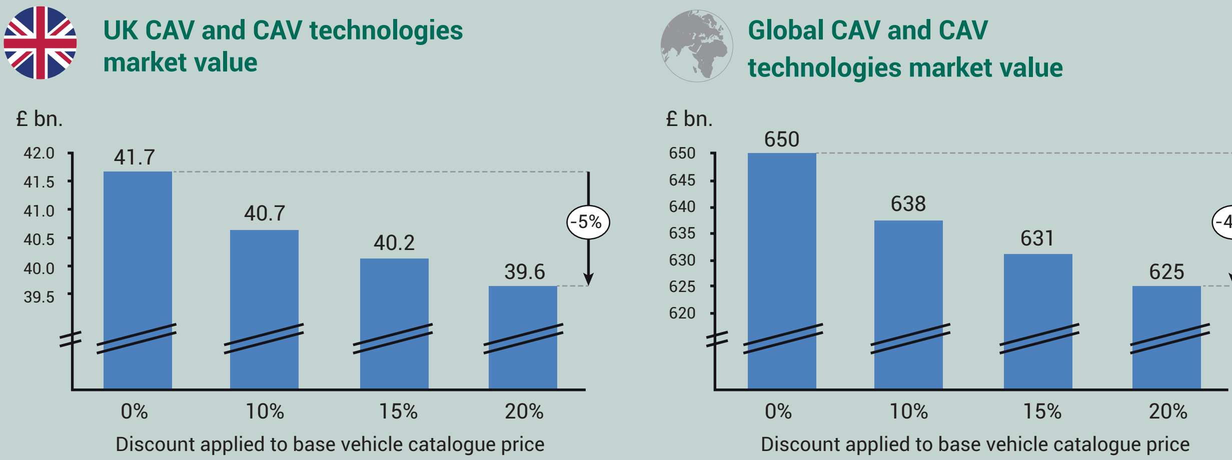


Figure 3.23 *Impacts of the discounts on L4/5 CAV cars given to fleet operators in 2035*

[28] Whilst the case of the discount ranges between 10% and 20% of the vehicle base catalogue price and applies to L4/5 cars only, the reduction in the total market value reaches only 7% as this includes other vehicle types, such as vans, HGVs, and buses, as well as L3 cars, which are not in the scope of this sensitivity

4. Economic Impacts for the UK

Summary of findings

- The objective of the analysis presented in this chapter is to estimate the gross contribution of CAVs and CAV technologies to key economic indicators for the UK. The focus is on the gross contribution to GVA and jobs, but estimates of the contribution to gross output, trade and investment are also included. Whilst jobs relating to the manufacture of CAVs will displace jobs in the manufacture of conventional cars, jobs relating to the production of CAV technologies are net additional. All results are presented as annual figures, providing a snapshot in selected years.
- Estimates were carried out across the full range of scenarios. The Central scenario assumes moderate CAV uptake and is the main scenario used to explore the economic impacts. The High scenario and Low scenario provide an indication of the economic impacts under alternative CAV uptake scenarios. The High scenario with high UK capabilities is the most optimistic variant, where it is assumed that UK and global markets grow rapidly and that UK firms are highly competitive in the manufacture of CAVs and CAV technologies.
- In the central scenario, it is estimated that the **gross direct contribution of CAV and CAV technologies to UK GVA would reach £6.3bn and £2.7bn, respectively, by 2035. In this scenario, it is estimated that jobs in the manufacture and assembly of CAVs would reach 1,600 people in 2025 and 49,000 by 2035.** This compares to around 168,000 people who are currently employed in the UK automotive sector (Office for National Statistics, 2019). **There would be 23,400 net additional direct jobs in the production of CAV technologies in the UK by 2035, with a further 14,600 indirect jobs created in the supply chain for these technologies.**

Economic impacts for CAVs		2025	2030	2035
Low scenario	Direct GVA (£bn)	0.1	0.5	2.4
	Direct Jobs	600	3,900	18,800
Central scenario	Direct GVA (£bn)	0.2	1.5	6.3
	Direct Jobs	1,600	11,500	49,000
High scenario	Direct GVA (£bn)	0.8	5.3	14.0
	Direct Jobs	6,100	41,000	108,100

Table 4.1 Key economic results for each scenario, relating to the manufacture of CAVs

Economic impacts for CAV technologies		2025	2030	2035
Low scenario	Direct GVA (£bn)	0.0	0.2	0.9
	Direct Jobs	200	1,900	8,000
Central scenario	Direct GVA (£bn)	0.1	0.6	2.7
	Direct Jobs	700	5,800	23,400
High scenario	Direct GVA (£bn)	0.3	2.5	6.3
	Direct Jobs	3,300	23,800	53,800

Table 4.2 Key economic results for each scenario relating to the manufacture of CAV technologies

- The results presented in this chapter are dependent on the assumptions underpinning the market forecasts (as described in Chapter 3). In addition, it is assumed that the trade intensity for CAVs and CAV technologies are the same as those observed in the historical data for similar technologies. This implies that the UK manufacturing sector maintains its current position in terms of relative global capabilities in the automotive sector and in component manufacturing.
- **The UK's strengths and competitiveness in software design and development puts UK firms in a strong position to capture a large share of the domestic (and global) market for high value-added CAV-related software.** However, **it is likely that much of the CAV-related hardware (in particular, sensing and mapping hardware) 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 UK to gain a significant share of the global market for manufacturing CAV hardware.
- **There is considerable uncertainty in the gross economic contribution of CAV and CAV technologies over the period to 2035,** primarily due to uncertainty in growth in the market for CAVs in the UK. In the high scenario, where it is assumed that both the UK and global market grows rapidly (with UK CAV market growth of around 38% pa over the period 2025-2035), **the contribution to GVA of activities relating to CAV and CAV technologies could be as much as £14bn, with a further £6.3bn contribution to GVA from the manufacture of CAV technologies.** In a more pessimistic, low scenario, where the UK and global market for CAVs remain small (<£21bn in the UK and <£300bn globally by 2035), the gross economic contribution of CAV and CAV technologies would be much lower, with an estimated £2.4bn gross contribution to GVA from CAV assembly and £0.9bn contribution to GVA from the manufacture of CAV technologies by 2035.
- **The economic impact is also highly dependent on the UK's capabilities in producing CAVs and CAV-enabling technologies.** If the UK market grows quickly and if UK-based firms are well-supported (for example, with access to skilled labour), this could incentivise firms to locate production in the UK (close to expected markets and where business conditions are favourable). In this case, CAV-related gross output and jobs in the UK would grow at a faster rate and dependency on imports would be reduced. A high UK capabilities sensitivity was introduced to test how the economic results would be affected if it was assumed that the UK was more competitive in CAV-related industries than is implied by historical trade shares for similar technologies). **In the most optimistic scenario and sensitivity combination for the UK,** the high scenario with high UK capabilities, by 2035, as well as an expected 179,000 direct jobs in the automotive sector for CAV assembly and manufacture, **there is estimated to be 73,000 net additional CAV technology jobs created in the UK.**
- The robustness of the results to differences in assumptions about the relative share of hardware and software requirements for CAV technologies were also tested. If the software share of CAV technologies remain fixed at 35% from 2025 onwards rather than increasing to 57% by 2035 used in the central scenario, this would result in around 25% reduction in the GVA and number of jobs in the UK from CAV technologies, compared to the results for the central scenario.

Scope of economic impact analysis

The purpose of the economic analysis was to estimate the gross contribution of CAVs and CAV-related technologies to key economic indicators in the UK, including:

- Gross output (the total value of production of CAVs and CAV technologies in the UK).
- Gross Value Added (GVA, the net contribution of CAV-related industries to the UK economy).
- Direct and indirect employment (the total number of jobs in manufacturing CAVs, CAV technologies and associated supply chains).
- Trade (the value of imports and exports of CAVs and CAV technologies).
- Investment (the value of domestic and foreign investment in fixed capital assets to support the production of CAVs and CAV technologies).

The economic analysis is informed by the market forecasts that were presented in Chapter 3. The focus of the economic analysis is on the gross contribution of manufacturing CAVs and CAV-enabling technologies in the UK, i.e. displaced activities in vehicle manufacturing are not measured. The wider economic impacts of a transition to CAV technologies or potential new business models are not estimated. Changes in use of vehicles, potential new services offered and productivity or welfare improvements from more efficient use of travelling time are not accounted for. Furthermore, the estimates do not include the effect of the transition to CAVs in potentially reducing demand for other technologies and services, such as conventional vehicles, conventional taxi services or vehicle insurance. The results from our analysis differ to those presented in other studies such as KPMG (2015)(KPMG, 2015) because wider economic impacts, including the value of time savings, are not estimated for the purposes of this report, which focuses solely on the potential economic contribution of CAV-related manufacturing industries.

All results presented in this chapter show the annual contribution of CAV-related industries to the UK economy in selected 'snapshot' years: 2025, 2030 and 2035 (although this is cumulative, in that jobs created in each year are assumed to exist in later years as part of the total). In all scenarios, the size of CAV-related industries and their contribution to the economy increases over the period to 2035, reflecting expected growth in the market for CAVs.

The diagram below provides an overview of the key economic impacts that are within scope and beyond the scope of the economic analysis presented in this chapter.

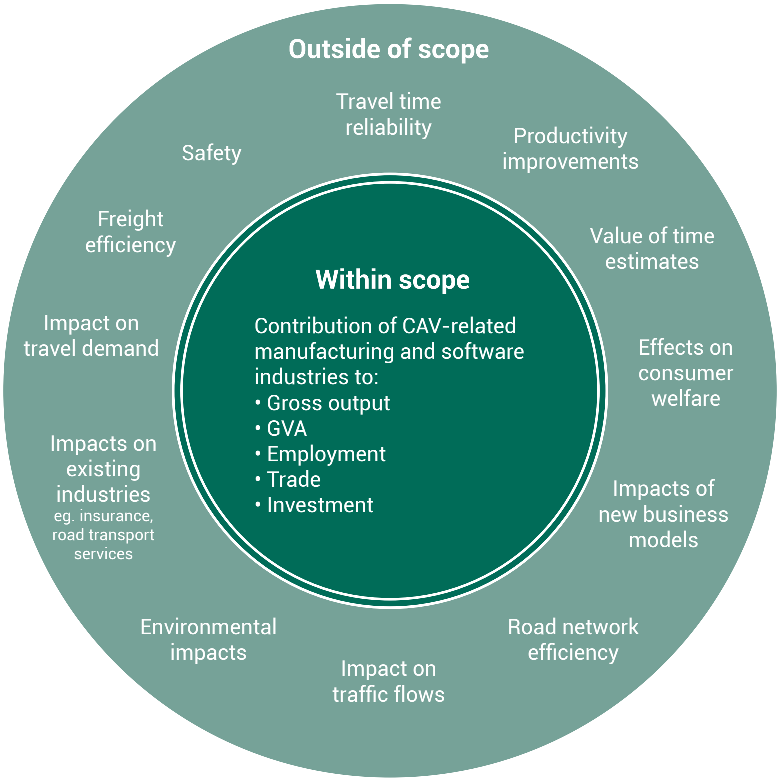


Table 4.1 Scope of the economic analysis

The economic assessment involved both qualitative and quantitative analysis. A literature and data review was undertaken to identify key characteristics of CAV technologies and services, to assess the UK's likely competitiveness in this sector and to consider how increased demand for these products and services could develop UK-based supply chains. This information was used to estimate the impacts of each of the CAV scenarios on key economic indicators.

The predominantly data-driven approach involved mapping the production of CAV-enabling technologies to relevant economic activities, as represented in the UK Standard Industrial Classification (SIC) 2007 codes (SIC07). The technology mapping is described in Appendix E.

Overview of economic method

To ensure consistency in our estimates of the gross economic effects, a systematic method to quantify each economic indicator has been applied. Starting with the UK and global market forecasts, future trade in CAV technologies are next estimated, then gross output and investment, then Gross Value Added (GVA) and jobs. Finally, GVA and employment multipliers were applied to estimate indirect GVA and employment effects.

Figure 4.2 *Summary of approach to economic analysis*

The estimates of the potential size of the UK and global market for CAVs and CAV technologies provided the starting point for the economic analysis. The UK's likely competitive advantage was then considered, to assess the extent to which the UK could produce CAVs and CAV technologies domestically and the extent to which the UK would rely on imports. An assessment of the UK's ability to capture the export market for CAVs and CAV technologies was based on historic export shares for similar products, using data for the relevant UK SIC (2007) codes.

UK gross output was estimated based on the expected size of the domestic market for CAVs, after accounting for international trade. Investment shares (i.e. the ratio of investment to gross output) for relevant UK SIC (2007) codes were used to estimate total investment in CAVs and CAV technologies. GVA was calculated as gross output net of estimated intermediate consumption in each sector (based on an adjusted input-output table). Finally, direct and indirect jobs were estimated. Direct jobs were estimated by applying estimates of labour intensity at the UK SIC (2007) four-digit class level and multiplying by estimates of gross output in the sector. Indirect jobs were calculated by multiplying these values by employment multipliers from the ONS at the UK SIC (2007) two-digit class.

The approaches taken for each economic indicator are explained in more detail in Appendix C.

The diagram below shows how the key economic indicators were estimated, and how they are inter-related. A bottom-up modelling approach was used, applying a series of assumptions to the CAV market forecasts to estimate gross economic impacts. The approach for the economic analysis has been reviewed by the Bank of England and the Office for National Statistics.

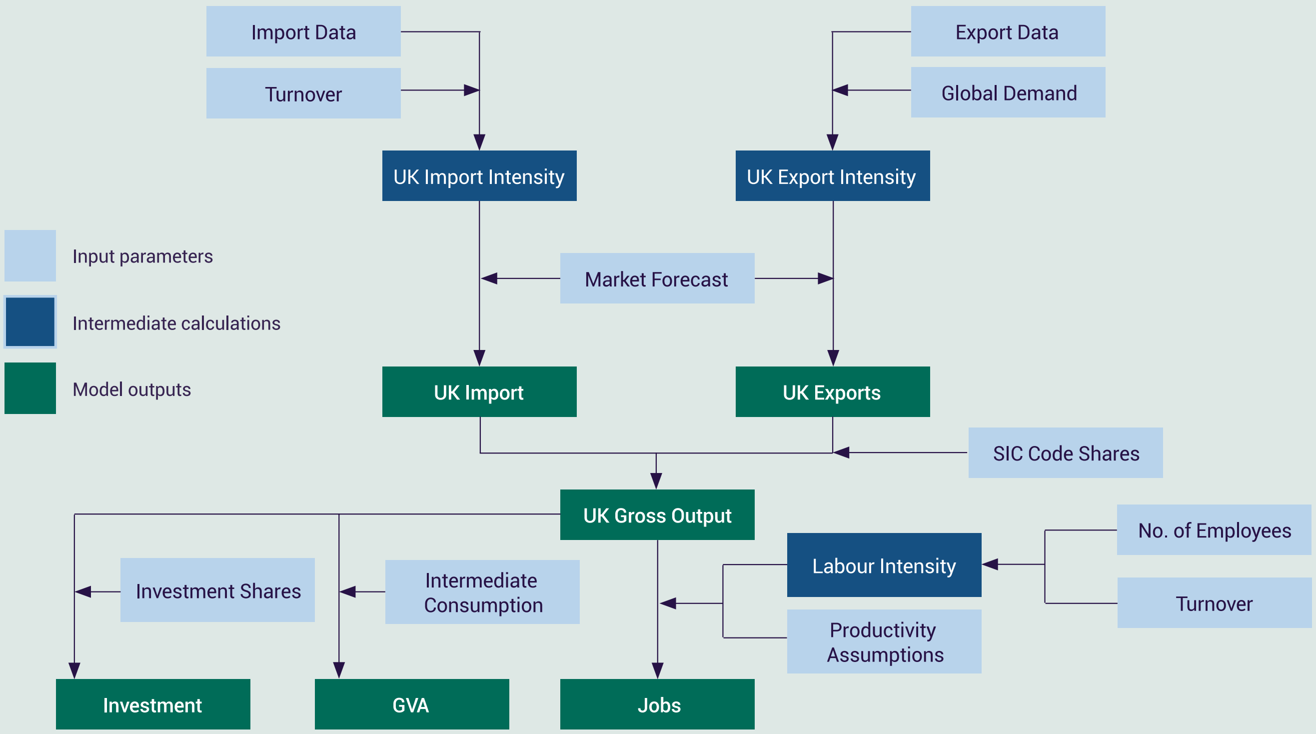
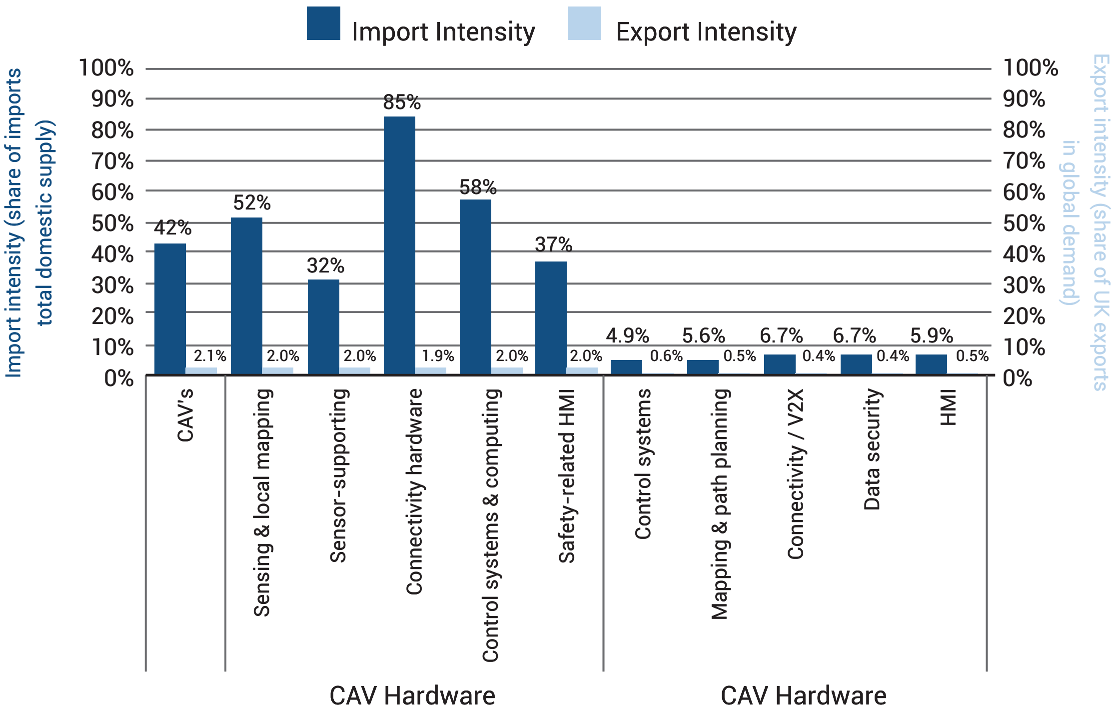


Figure 4.3 *Overview of the economic framework*

Impacts on trade

Historic trade intensities for similar products were mapped to the CAV technologies, resulting in the import and export intensities shown in the diagram below, which shows the likely scale of production of CAVs and CAV technologies in the UK. Whilst import intensities were estimated for each individual technology, due to data limitations, export intensities (the ratio of UK exports to global demand) were calculated at the more aggregated UK SIC 2007 2-digit class[29] and so the same export intensity is assumed across all CAV-related hardware technologies (2.0%). For CAV-related software technologies, key technologies where the UK is particularly competitive were recognised through stakeholder engagement and so assumed the export intensity was 20% higher (0.5-0.6%) versus standard assumption for software (0.4%).

[29] The export intensity for CAVs is based on that for the '29: Motor vehicles, trailers and semi-trailers'. The export intensity for CAV hardware technologies is based on that for '26: Computer, electronic and optical products' and the export intensity for CAV software technologies is based on that for '62: Computer programming, consultancy and related services'.



Key assumptions

Import and export intensity assumptions for CAVs and CAV technologies are based on historical trade shares for similar existing products.

Figure 4.4 Import and export intensities for CAV and CAV technologies

4.1 Imports

Focusing firstly on imports, the assumed UK capabilities for the manufacture of CAVs (i.e. the vehicle assembly) are reflective of current trends in the automotive sector[30], with 42% of domestic demand met by imports. The CAV hardware technologies are also represented by relatively high import intensities (between 32% and 85%), as historical trade data for similar technologies suggest that other countries face lower manufacturing costs (i.e. are more competitive) than in the UK.

By contrast, the data suggests that the UK is likely to have higher relative capabilities in the development of CAV-related software, reflecting strong international competitiveness in the high value-added services and knowledge-based sectors. For software, lower import intensities of between 5% and 7% are assumed. As software development and production is a high value added activity, the fact that the UK is likely to have relative strengths in this area would create larger GDP gains for the UK (for each unit produced, there are relatively high margins and high labour costs, with little value flowing out of the economy in the form of raw material imports).The diagram below shows the projected impacts of CAV market growth scenarios on UK imports of the connected and autonomous vehicles themselves (in the chart on the left) and technologies that enable automation (in the chart on the right). In the central scenario, imports of CAVs are estimated to grow year-on-year in line with growth in the UK market for CAVs, with an estimated £22bn worth of CAVs imported in 2035. This compares to £52bn[31] of imports of motor vehicles to the UK in 2018. In the central scenario, imports of CAV technologies are expected to reach £3.1bn by 2035.

[30] Eurostat Comext database, ONS International Trade in Services statistics and the OECD STAN database.
[31] ONS (2016) "UK Trade in goods by classification of product by activity times series dataset" Available here

In the central UK lead scenario, more rapid growth in domestic demand for CAVs leads to stronger growth in imports of CAVs and CAV technologies. In this scenario imports of CAVs reach £32bn in 2035, and imports of CAV technologies reach £2.6bn in the same year.

Over the 2030-2035 period, there is a slowdown in the rate of growth in imports of CAV-related technologies in both the central and central UK lead scenarios, due to two key factors. Firstly, by 2030, there is a larger eduction in CAV-related technology costs compared to current levels. Secondly, there is a difference in the types of technologies that are imported, as the market transitions from L3 to L4/L5 CAVs. By 2030, the market for CAV hardware technology has matured enough to meet the requirements of L3 autonomous vehicles. OnceL3 has been achieved the focus switches to producing L4/L5 vehicles, which are assumed to have a relatively higher software value, compared to L3 vehicles (as discussed in Section 3.4.2). This results in a reduction to the sensing and mapping hardware market, and an increase in software market value. With sensing and local mapping hardware contributing to 78% of total imports, and strong domestic capabilities in CAV software, this is a key factor in explaining the slowdown in growth of imports of CAV technologies between 2030 and 2035.

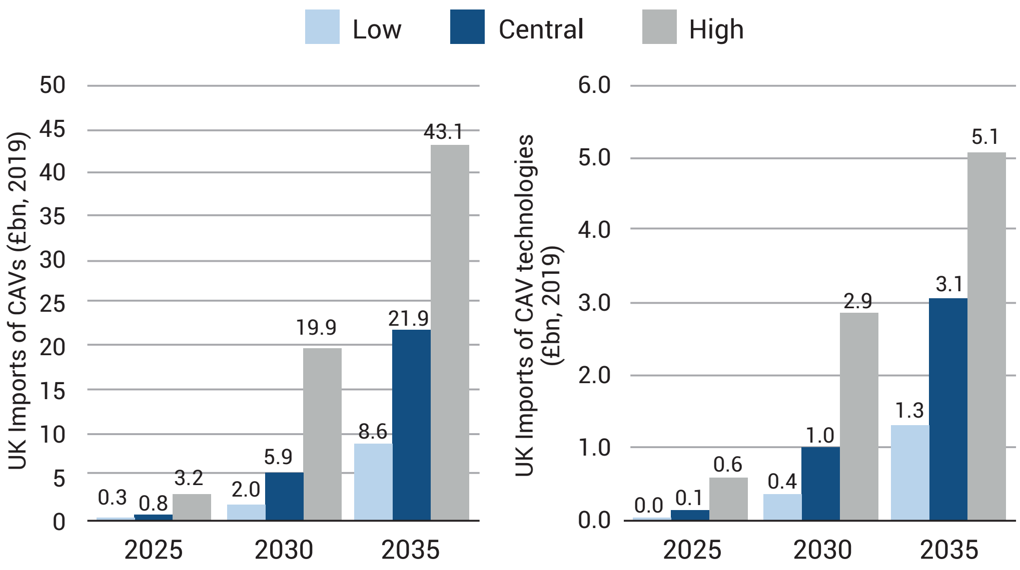


***Figure 4.5** UK imports of CAV and CAV technologies, by scenario*

Key assumptions

Imports are calculated as a share of estimated UK sales of CAVs and CAV technologies.

We assume 42% of CAVS will be imported, 32-85% of CAV hardware technologies will be imported and less than 10% of CAV software technologies will be imported (based on historical import shares for similar technologies).

As shown in Figure 4.6, across all years, UK imports of CAV technologies are dominated by 'Sensing & local mapping hardware'. The value of the market for this technology is relatively high (accounting for around 78% of the market for all CAV technologies) and it is assumed that the UK has relatively weak capabilities in this type of manufacturing, which explains its heavy dependence on imports.

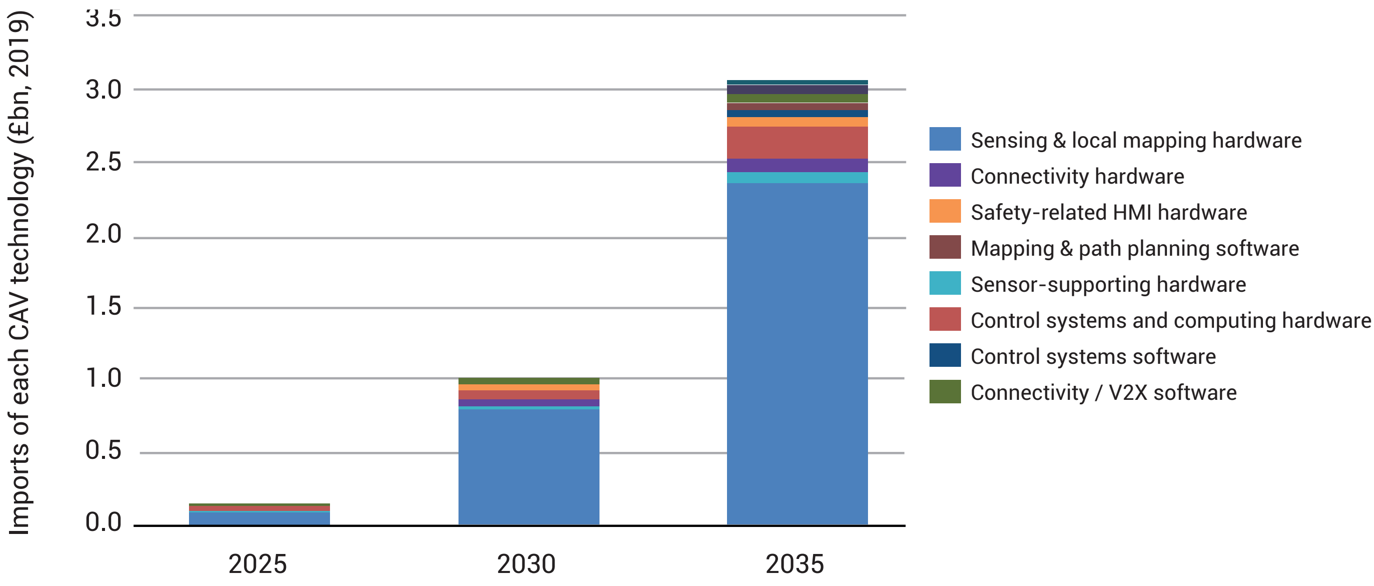
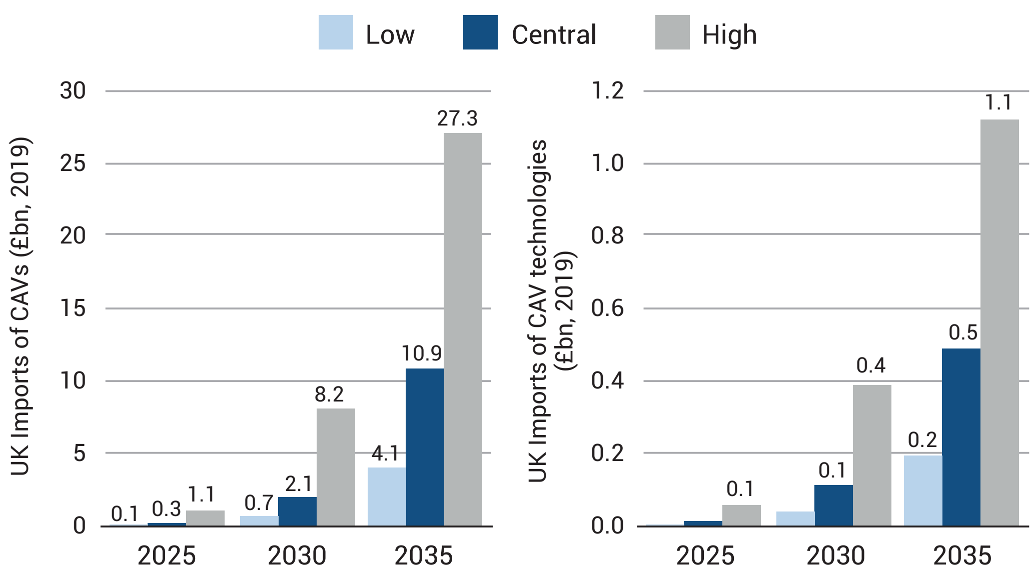


Figure 4.6 UK imports by technology, central scenario

4.2 Exports

Export shares (the ratio of UK exports to global demand) for CAVs and CAV technologies were estimated at between 0% and 3% based on historical export shares for similar technologies, using SIC07 code mapping. Out of the four world regions, Europe accounts for the largest share of UK exports, as the UK's closest neighbouring region. The outcome of negotiations on the future trade relationship with the EU will largely determine the extent to which the UK could expect to continue exporting such high shares of these technologies to the rest of Europe. At the time of publication, with limited information on the form of the future trade relationship between then UK and the EU and other global regions, we assume that the UK continues to capture the same share of the EU and global export markets for these types of technology.

The central scenario, by 2035, we estimate that exports of CAVs will reach £10.9bn and there will be a further £0.5bn of exports of CAV-related technologies from the UK.



Key assumptions

Exports are calculated as a share of global demand for CAVs and CAV technologies.

We assume that the UK captures a 2.1% share of global demand for CAVs, a 2.0% share of global demand for CAV hardware technologies and a 0.5% share of global demand for CAV software technologies.

Figure 4.7 UK exports of CAVs and CAV technologies, by scenario

Figure below shows that the growth of UK exports of CAV related technologies is supported by the growth in both hardware and software exports.

A high UK capabilities sensitivity was introduced to test how the economic results would be affected if it was assumed that the UK was more competitive in CAV-related industries than that implied by historical trade shares for similar technologies. The results of this sensitivity analysis are presented and discussed in Section 4.9.

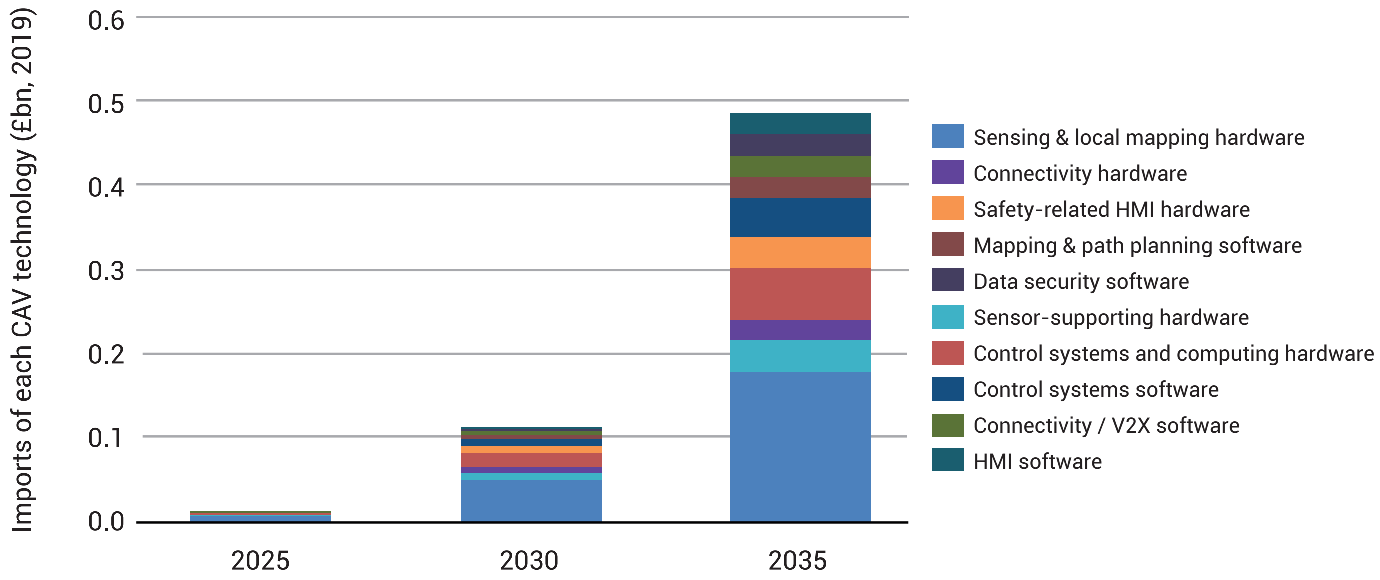


Figure 4.8 UK exports by technology, central scenario

Impact on gross output and investment

4.3 Gross output

UK gross output for CAVs in 2035 is estimated to reach £24.3bn in the central scenario, with the value of producing CAV-related technologies in the UK contributing a further £4.4bn to gross output.

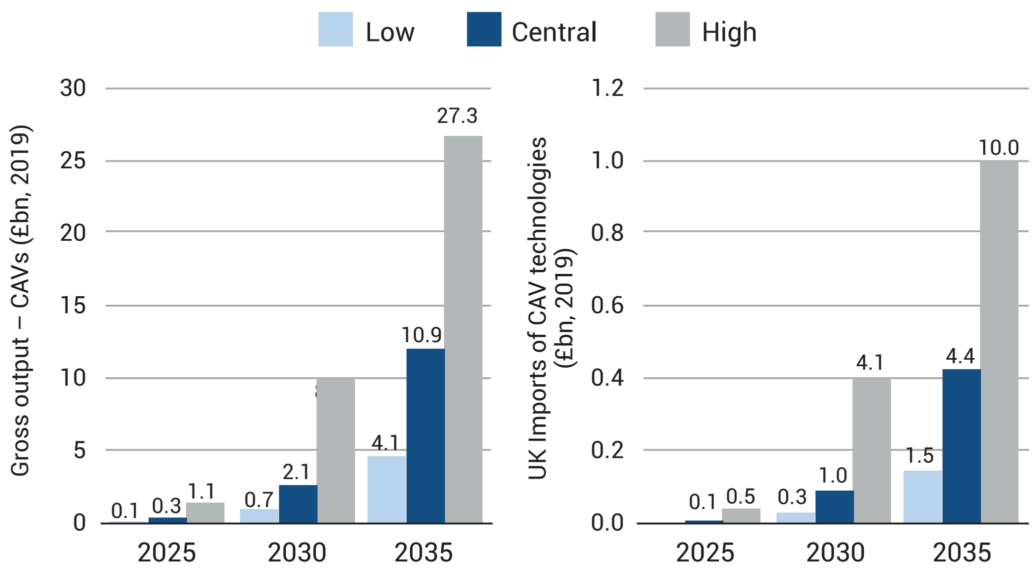


Figure 4.9 UK gross output in CAV and CAV technologies, by scenario

Key assumptions

Gross output is estimated based on the CAV market forecasts, after making an adjustment to take account of net trade effects.

Central case: Global market for CAVs reaches £550bn by 2035, of which £35bn is UK-based demand.

Figure below shows that, in the central scenario, UK gross output for CAV-related software technologies is over three times as large as gross output for hardware technologies, reflecting the UK's relative strengths in developing software and low dependence on software imports. The largest contributor to UK gross output in CAV technologies in 2035 is from Connectivity / V2X software, with a 23% share.

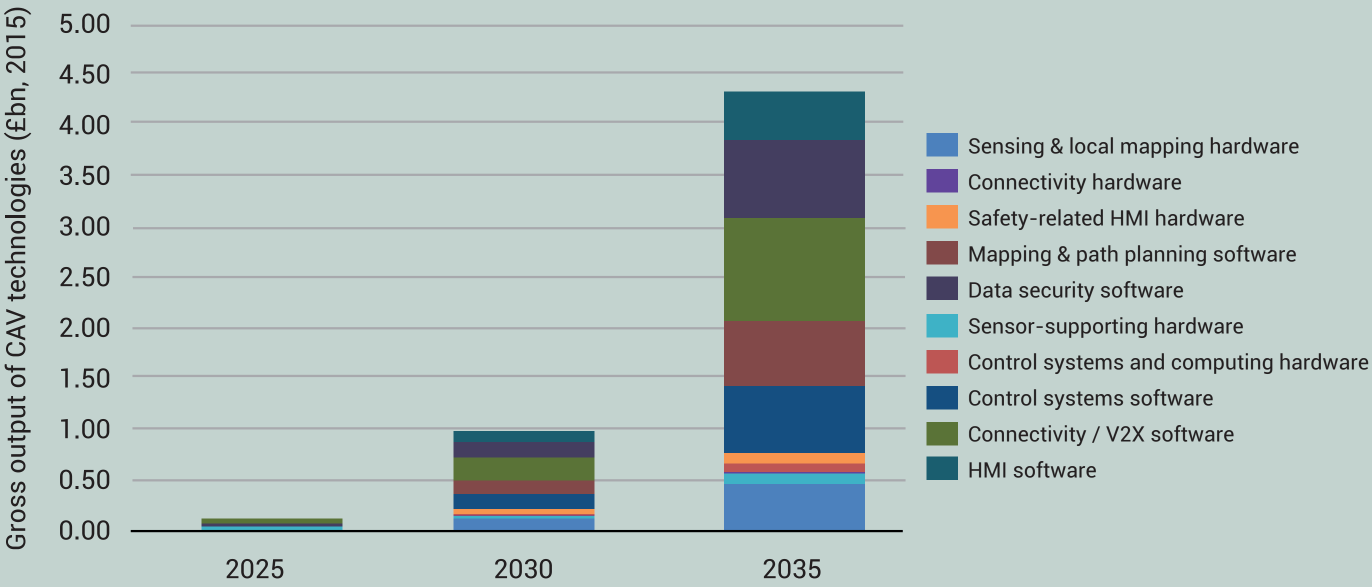


Figure 4.10 UK gross output by technology, central scenario

4.4 Investment

Facing less stringent regulations than in key competitor countries, and with high expected growth in domestic CAV markets, the UK is in a strong position to attract inward investment in CAV industries. The UK has not ratified the Vienna Convention on Road Traffic and has allowed the piloting of fully autonomous vehicles on public roads without need for primary legislation, something that the rest of the EU is still constrained by. The less strict UK regulations will likely speed up the development of complete automated driving systems through advanced road-testing facilities and could attract large inward investments. Firms will be able to benefit from the use of well-equipped testing facilities, such as MIRA, Europe's largest transport sector R&D cluster worth around $450million (MIRA, 2016).

Annual investment by firms to support the manufacture of CAVs in the UK is estimated to increase to £1.7bn by 2035. Investment to support the production of CAV technologies in the same scenario is expected to reach £0.4bn, annually, by 2035.

Of all CAV-enabling technologies, investment for the development of connectivity / V2X software is forecast to be largest, reflecting that this technology is estimated to be the largest contributor to UK gross output.

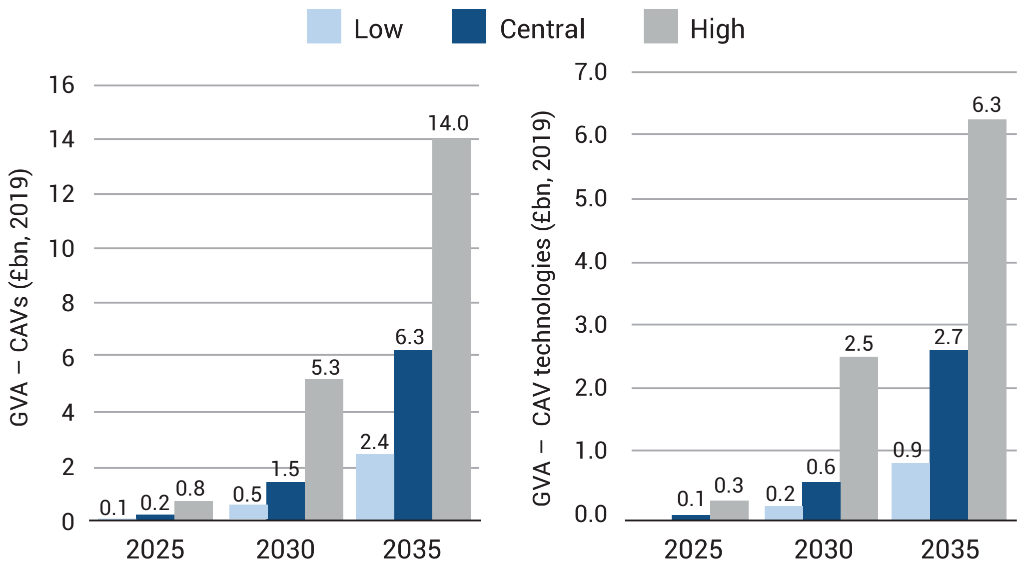
Our estimates of investment are based on the ratio of spending on fixed capital assets to gross output in well-established industry sectors. In the emerging CAV-related industries, it is highly likely that there will be an early investment stimulus, as companies work to develop products in anticipation of strong growth in the future CAV market.

Impacts on GVA

4.5 Direct effects

The GVA results reflect the same broad trends as shown in the gross output estimates. The UK manufacturing sector is assumed to maintain its current position in terms of relative global capabilities in the automotive sector and in component manufacturing. In the central scenario, annual GVA related to the production of CAVs is estimated to reach £6.3bn by 2035 and GVA in firms that are producing CAV technologies is expected to reach £2.7bn.

Of the CAV technology groups, the UK has relatively strong capabilities in software development and design, and this is reflected in both the gross output and GVA estimates: UK gross output in software accounts for around 82% of total gross output and around 87% of total GVA in CAV-enabling technologies. Software and information services are high value-added sectors and, therefore, the estimated increases in GVA are relatively high, reflecting GVA to gross output ratios of 60%-95%.



Key assumptions

GVA is calculated as gross output net of intermediate consumption, based on the UK Supply and Use tables.

Central case: Gross output in CAV sector reaches £24bn by 2035 and gross output in CAV technologies reaches £4.4bn in the same year.

Figure 4.11 GVA in CAV and CAV technologies

4.6 Indirect effects

The indirect GVA effects show the total contribution to GVA in the supply chain for the CAV technologies. For example, manufacturing CAV hardware technologies will require raw material inputs, such as plastics and metals, produced by other firms in its supply chain. An increase in gross output in CAV technologies will therefore lead to an increase in demand, gross output and GVA in the industry sectors that are manufacturing the raw materials required to produce the CAV technologies. The impact of growth in market demand for CAV technologies on these supply chain industries are known as 'indirect effects'.

The indirect effects of producing CAV technologies were estimated using GVA multipliers from the ONS (2016)[32]. The results show that an additional £1.2bn GVA each year is estimated to be created in the supply chain for CAV technologies, by 2035, in the central scenario.

[32] Indirect supply chain effects for manufacturing CAVs are not presented to avoid double-counting (as the firms manufacturing CAV-enabling technologies form part of the supply chain for the CAV manufacturing sector)

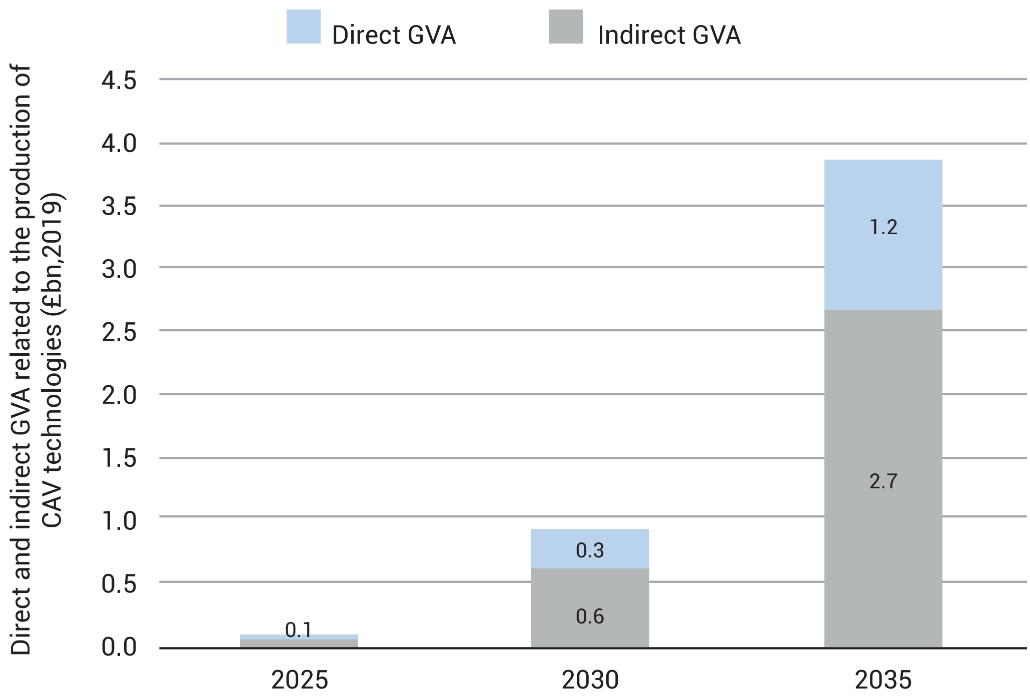


Figure 4.12 Direct and indirect GVA related to the production of CAV technologies, central scenario

Impacts on jobs

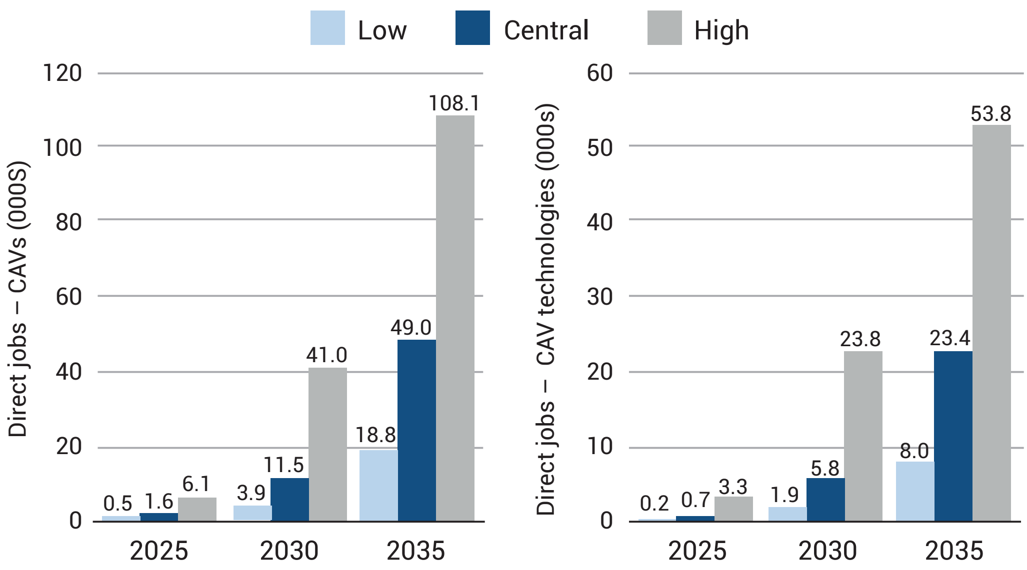
The jobs results reflect the trends in gross output and GVA. As firms increase production of CAVs and CAV technologies, their labour requirements will increase and new (direct) jobs will be created. In addition, an increase in output and demand for labour in the supply chains for these technologies will lead to an increase in indirect jobs.

4.7 Direct effects

As shown in Figure 4.13, in the central scenario, by 2035, an estimated 49,000 CAV manufacturing jobs are created. However, many of the jobs relating to the manufacture and assembly of CAVs will, in practice, replace jobs in the traditional automotive manufacturing sector.

The results show that total direct jobs related to the manufacture of CAV technologies reach 23,400 in the central scenario by 2035. These jobs relating to the manufacture of CAV-enabling technologies can be considered as 'net additional jobs' (i.e. they do not displace existing jobs).

The jobs related to CAV technologies are mostly concentrated in the software industries (i.e. 80% in 2035), as shown in Figure 4.14, where UK capabilities are strong, gross output is high and the labour intensity of production is high (around 6-8 jobs per £1 million of production). The remaining jobs (20% in 2035) would be in the production of CAV hardware, such as sensors. Over 90% of the jobs created in developing CAV software and over 80% of the jobs relating to the manufacture of CAV hardware are expected to be in professional, technical and skilled trade occupations.



Key assumptions

Direct jobs Direct jobs are calculated as a function of gross output. We assume that the labour intensity of CAV production is around 2 jobs per £1million output, the labour intensity of producing CAV hardware and software is around 5-7 jobs per £1million output.

Figure 4.13 *Direct jobs in CAV and CAV technology, by scenario*

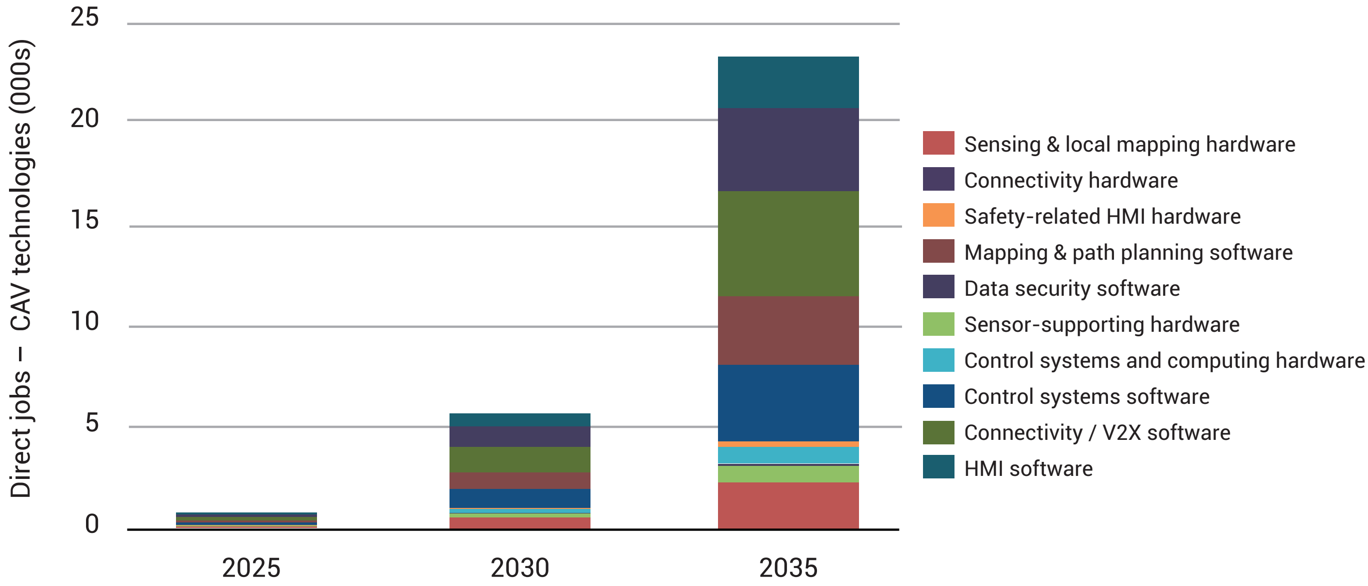


Figure 4.14 *Direct jobs by technology, central scenario*

4.8 Indirect effects

As with GVA, the number of indirect jobs in the supply chain for CAV technologies is estimated. The results show that, in the central scenario, in addition to the 23,400 direct CAV technology jobs created by 2035, an additional 14,600 jobs are created in the supply chains for these technologies.

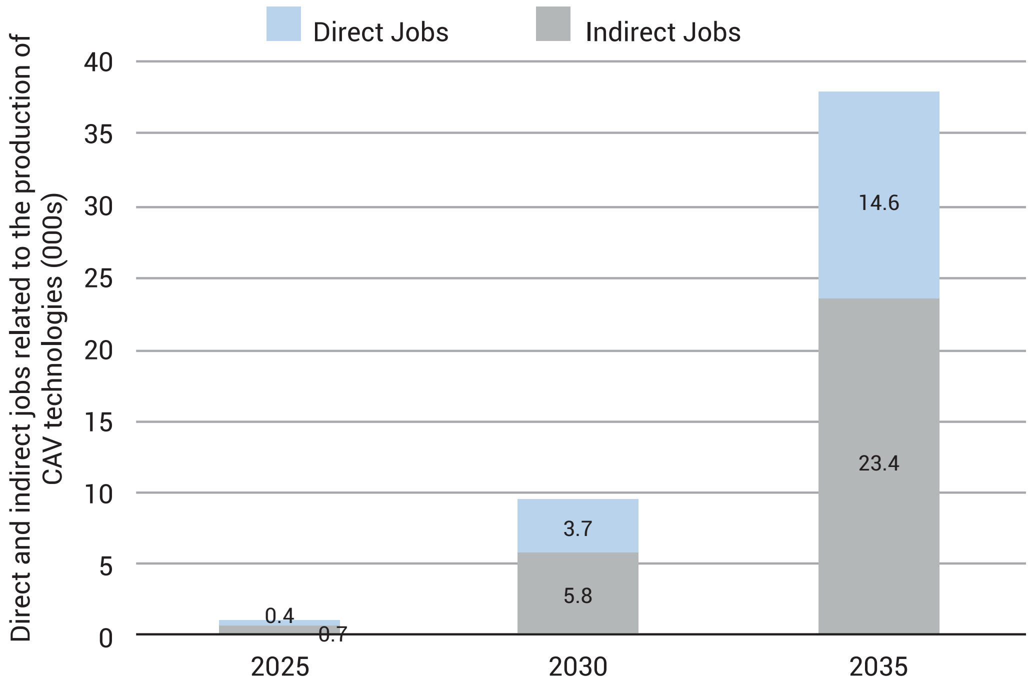


Figure 4.15 *Direct and indirect jobs related to the production of CAV technologies*

Sensitivity to key assumptions

Sensitivity analysis was carried out to test the robustness of the results to changes in key assumptions on:
– UK capabilities and competitiveness in CAV technologies
– the value shares of software relative to hardware that is required by CAVs
– global sales shares
– discounts on the vehicle sales price for large fleet operators

As shown in the summary tables below, if the UK is more competitive in producing CAVs and CAV technologies than it historically has been for similar technologies (i.e. under the high capabilities sensitivity), GVA and jobs estimates could be larger, as the UK would be able to increase output from the manufacturing of CAVs and CAV technologies through lower dependency on imports and capturing a higher share of CAV export market. If the software requirements for CAV technologies are lower (relative to hardware) than assumed in the central scenario (and the other scenarios presented so far), however, the benefits to the UK would be lower (due to relatively greater dependency on hardware imports, and lower demand for exported software).

CAV		2025	2030	2035
Central scenario	Direct GVA (£bn)	0.2	1.5	6.3
	Direct Jobs	1,600	11,500	49,000
Central – High UK capabilities	Direct GVA (£bn)	0.3	2.5	10.6
	Direct Jobs	2,700	19,600	82,000
Central – Low software share	Direct GVA (£bn)	0.2	1.5	6.3
	Jobs	1,600	11,500	49,000
Central – Aligned (similar rates of CAV uptake in North American and European market)	Direct GVA (£bn)	0.2	1.6	6.5
	Jobs	1,600	12,100	50,500
Central – Reverted (lower uptake of CAVs in Europe, higher uptake of CAVs in North America)	Direct GVA (£bn)	0.1	0.8	4.9
	Jobs	700	6,500	37,900
Central – Accelerated North America uptake	Direct GVA (£bn)	0.2	0.9	3.3
	Jobs	1,600	6,700	25,400

Table 4.3 Economic results relating to the manufacture of CAVs in the central scenario and key sensitivities tested

CAV technologies		2025	2030	2035
Central scenario	Direct GVA (£bn)	0.1	0.6	2.7
	Direct Jobs	700	5,800	23,400
Central – High UK capabilities	Direct GVA (£bn)	0.1	0.9	3.6
	Direct Jobs	1,100	9,100	34,300
Central – Low software share	Direct GVA (£bn)	0.1	0.5	1.9
	Direct Jobs	600	5,200	18,700
Central – Aligned (similar rates of CAV uptake in North American and European market)	Direct GVA (£bn)	0.1	0.6	2.8
	Jobs	700	6,100	24,300
Central – Reverted (lower uptake of CAVs in Europe, higher uptake of CAVs in North America)	Direct GVA (£bn)	0.0	0.4	2.1
	Jobs	300	3,800	18,600
Central – Accelerated North America uptake	Direct GVA (£bn)	0.1	0.3	1.3
	Jobs	700	3,200	11,400

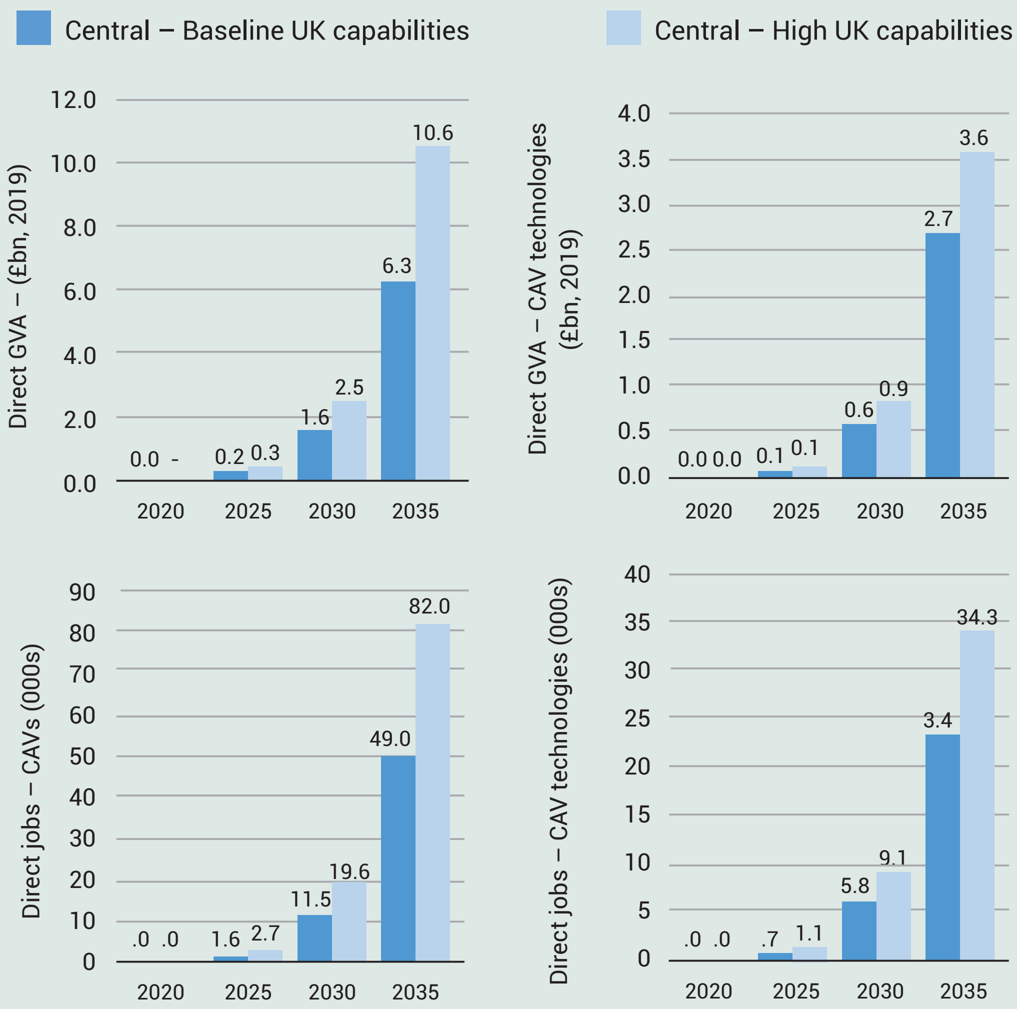
Table 4.4 Economic results relating to the development and manufacture of CAV technologies in the central scenario and key sensitivities tested

4.9 High UK capabilities sensitivity

The high UK capabilities sensitivity tests the impact on the economic results if the UK were more competitive in the production of CAV technologies than the data for similar technologies suggests. In the high UK capabilities sensitivities, UK import shares were halved and UK exports shares were increased by 50% (relative to that assumed in the main scenarios). With a lower share of imports and the UK capturing a higher share of export markets, there is an improvement to the balance of trade and an increase in gross output, GVA and jobs.

Figure below shows the difference in GVA and jobs related to the manufacture of CAVs and CAV technologies in the central scenario, under the assumption of high UK capabilities compared to under the baseline assumptions. In 2035, GVA in the central scenario with high UK capabilities is £10.6bn (around £4bn greater than GVA in the same scenario under the baseline assumptions). Under this sensitivity, the number of direct jobs related to the manufacture of CAVs reaches 82,000 by 2035 (compared to 49,000 under the baseline assumptions).

A similar trend is seen for GVA in CAV technologies. In 2035, GVA related to the production of CAV technologies in the central scenario with high UK capabilities reaches £3.6bn (around £0.6bn greater than in the central scenario under the baseline assumptions). By 2035 the number of direct jobs in CAV technologies reaches around 34,000 under the central scenario with high UK capabilities, compared to around 23,000 jobs under the central scenario with baseline assumptions for UK capabilities.



Key assumptions

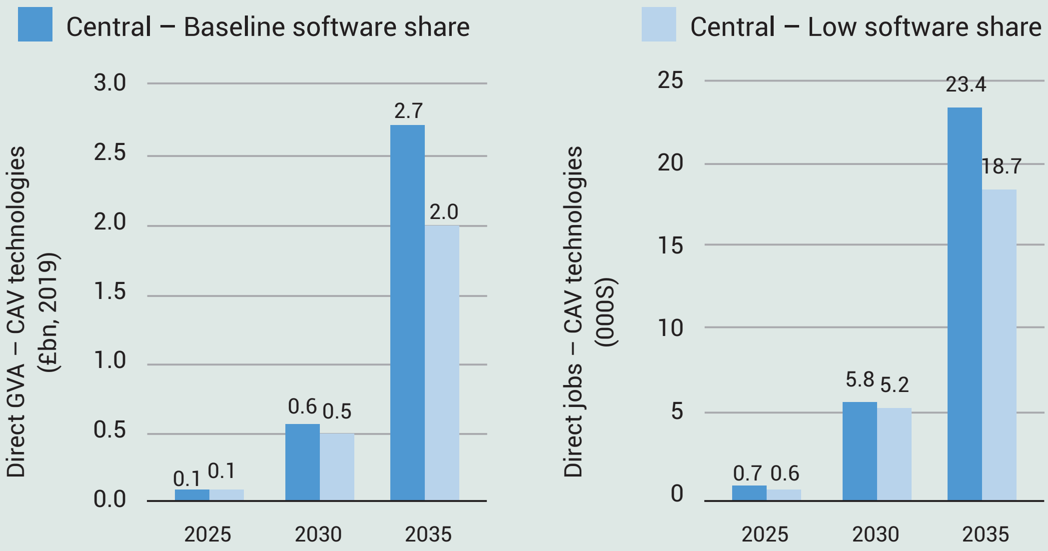
Central Case: Import and export shares for CAVs and CAV technologies based on mapping to existing industries.

Central – low software share: UK import shares halved and UK export shares increased by 50% comapred to in the central case with baseline assumptions.

Figure 4.16 Direct GVA and jobs related to the production of CAVs and CAV technologies in the central scenario and the central scenario with a high UK capabilities assumption

4.10 Low software share sensitivity

The sensitivity of the economic results to changes in the assumptions on the share of software vs hardware in CAV technologies was also assessed. A 'low software share' variant of the central scenario was tested, where the share of software was assumed to remain fixed from 2025 onwards making up a 35% share of the total value of CAV technologies (compared to a increasing to 57% share by 2035 in the baseline assumptions). The gross contribution of CAV technologies to gross output, GVA and jobs in the 'low software share' variant is around 20% to 25% lower than in the Central scenario by 2035, reflecting the UK's strong capabilities in developing software relative to the manufacturing of hardware. In the 'low software share' variant, the lower gross output estimates are compensated for by an increase in imports of hardware to meet demand in the domestic market. The low software share sensitivity was only applied to CAV technologies and there is no impact on the results in the CAV manufacturing sector. The results are shown in the figure below.



Key assumptions

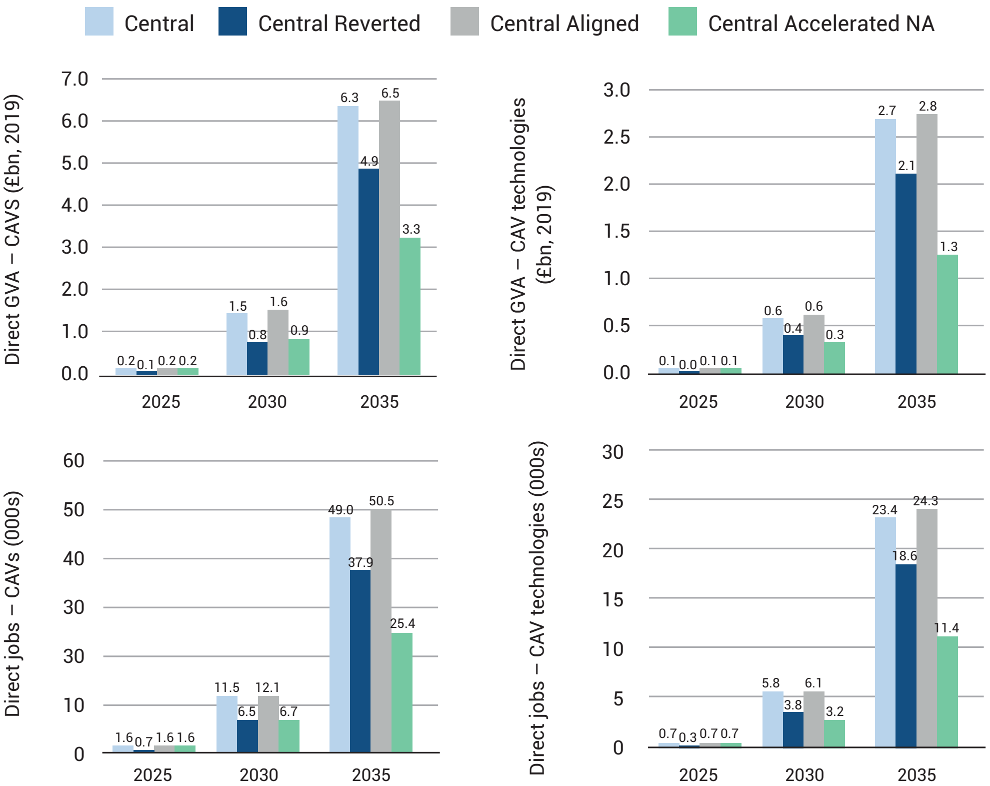
Central Case: The share of software relative to hardware for each CAV technology increase over time is 35-60%

Central – low software share: The share of software relative to hardware held constant at 2025 value 35%

Figure 4.17 Direct GVA and jobs related to the production of CAV technologies in the central scenario and the central scenario with a low software share assumption

4.11 European and North American CAV sales share sensitivities

To test the sensitivity of the results to different rates of growth across global markets, we tested scenarios with variations in the relative growth of the UK and Europe versus the North American market for CAVs. Comparing the central scenario to the 'central aligned' (where the UK and European market size remain unchanged and the North American market grows faster than in the central case), we find that changes in the North American market has a relatively small impact on output and employment in the UK automotive sector, due to the fact that vehicles manufactured in the UK only account a small share of vehicles sold in North America. Thus, despite the US market value increasing by 50% by 2035 (compared to in the central scenario), GVA and Jobs in the UK only increase by around 3-4% by 2035 (compared to in the central scenario). By contrast, in the 'Central Accelerated NA' sensitivity, there is much slower growth in the UK and Europe post-2025 (such that the UK and Europe market size is almost 60% lower than the central case by 2035). This sensitivity leads to a reduction in GVA and jobs in the UK of around 50% (compared to the central case) as the faster growth in the North American market (and UK exports to this region) only slightly offsets the impact of the smaller domestic market. In both of these sensitivities, it is not assumed that trade and competitiveness are linked to the rate of growth in the domestic market for CAVs, although it could be argued that faster growth in domestic demand would attract inward investment, leading to an increase in production and net exports of CAVs.



Key assumptions

Central Reverted: CAV sales in the UK and Europe follow the slower growth of North American market in the central scenario. By contrast, the North American market grows faster, at the same rate as the UK and Europe did in central scenario

Central Aligned: North American market grows faster than in the central case, in line with UK and Europe in the central scenario.

Central Accelerated NA: Growth in North American market accelerates after 2025, while growth in UK and European markets falls behind the US.

Figure 4.18 Direct GVA and jobs related to the production of CAVs and CAV technologies in the central scenario under different assumptions on growth in UK, European and North American markets

4.12 The impact of discounts to fleet operators

Finally, we ran a series of sensitivities to test the economic impact of a change in the market size due to discounts offered to fleet operators. Such discounts for fleet operators (of up to 20% of the vehicle sales price), were assumed lead to a reduction of 4-5% of the overall market value for CAVs relative to the central case, after taking account of the probable share of CAV sales to fleet operators. Our analysis shows that this discount would not have an impact on the employment figures: the same vehicles are being manufactured and so the same material and labour inputs will be required to manufacture them. However, the sales discount for fleet operators would reduce the level of output and GVA related to the manufacture of CAVs. The results show that, if fleet operators were offered a 20% discount on the CAV sales price, gross output, investment and trade in CAVs would all be around 5% lower compared to the central case (consistent with the reduction in the size of the CAV market) and GVA would be around 20% lower than in the central case, reflecting the fact that the discount would erode profit margins in the sector.

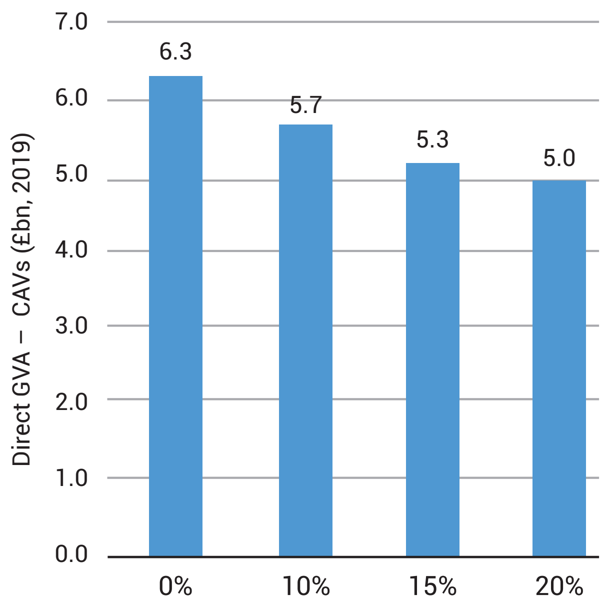


Figure 4.19 *Direct GVA related to the production of CAV technologies in the central scenario under different fleet operator discounts in 2035*

... the sales discount for fleet operators would reduce the level of output and GVA related to the manufacture of CAVs

5. Conclusions

CAV market value

- Projections of CAV uptake assume that total car, van and HGV sales increase over time, whilst the bus sales remain stagnant (both for the UK market and the global market), and that L3-L5 CAV sales account for an increasing share of this total. The main results for the market sizing reflect a Central scenario for global L3-L5 CAV adoption, which is informed by estimated technology costs and consumer willingness to pay (based on previous studies).
- The central scenario indicates that in the UK, L3-L5 CAVs account for 36% of total annual sales by 2035, equating to vehicle sales of 1.36 million CAVs (including cars, vans, HGVs and buses). The CAV uptake is different across vehicle types, with cars leading in terms of CAV technology integration. CAVs represent 40% of total annual cars sales in 2035 in the UK and over 94% of all CAVs sold in the UK in that year.
- Global uptake in the central scenario indicates that the global annual sales of L3-L5 CAVs could account for 15% of total sales by 2035. CAV uptake in Europe and the UK is assumed to be ahead of uptake in other regions, due to several factors including a supportive regulatory framework for CAVs.
- UK sales result in a projected total domestic CAV market size of £41.7bn in 2035 for the central scenario (as shown in Figure 3.2), of which £6.4bn represented by CAV technologies.
- In the central scenario, in 2035 the global market size is estimated at £650bn from CAV sales, of which £100bn in total for CAV technologies. The higher and lower bounds for the global CAV sales market are £1,763bn and £234bn respectively, with the large range mainly reflecting the high level of uncertainty in the rate of uptake.

UK economic impacts

- In the central scenario, it is estimated that the gross direct contribution of CAV and CAV technologies to UK GVA would reach £6.3bn and £2.7bn, respectively, by 2035. In this scenario, it was estimated that jobs in the manufacture and assembly of CAVs would reach 1,600 people in 2025 and 49,000 by 2035. This compares to around 168,000 people who are currently employed in the UK automotive sector (Office for National Statistics, 2019). There would be 23,400 net additional direct jobs in the production of CAV technologies in the UK by 2035, with a further 14,600 indirect jobs created in the supply chain for these technologies.
- The UK's strengths and competitiveness in software design and development puts UK firms in a strong position to capture a large share of the domestic (and global) market for high value-added CAV-related software. However, it is likely that much of the CAV-related hardware (in particular, sensing and mapping hardware) would be imported from abroad.

Recommendations for further research

Based on the findings of the report, there is a high potential for significant economic benefits to the UK, as a direct result of the development of the CAV market. Most of these potential benefits would result from CAV sales and production in the UK. However, the sale and production of CAV technologies would also contribute to various economic benefits, and therefore a more detailed understanding of certain aspects of these markets would be beneficial in fully understanding the potential, and to determine the best approach for government and industry to foster future economic benefits.

Outside of CAV production, software development and integration is likely to provide the most economic benefits to the UK. However, this area is relatively poorly understood in terms of the value chain within the automotive sector, and in terms of the associated economic impacts, partly due to a lack of specific data on these areas of economic activity. This lends a significant degree of uncertainty to the economic benefits cited in this report. As an example of this, the sensitivity test which shifted the software share of CAV component value from 57% by 2035 (L3-L4/5) down to 35% to resulted in a 25% reduction in GVA and jobs dependent on CAV technologies (no effect on economic benefits resulting from CAV sales and production).

Future research into the following areas could help to create a clearer picture of the likely economic benefits of CAVs:

- Approach to software valuation in UK car companies and in CAV-related SMEs, including development costs, as well as pricing models for OEMs (i.e. one-off or regular updates) and consumers (per-vehicle or per-month), and understanding the possible cost reductions for software over time (accounting for possible updates required).
- Understanding the value chain for software (e.g. how is software developed in the UK made available to other markets, and what are the implications for the economic benefits resulting from these value transfers?)

This report only considered the markets associated with CAVs and their components. However, the UK has leading capabilities in both on-road testing, and virtual environment testing, which could be beneficial in terms of testing CAVs and CAV software respectively. Extensive testing will be essential for CAVs to gain the low failure rates needed for commercial deployment, and as such both these capabilities could have the potential to attract significant economic benefits as the CAV market grows, in addition to those already discussed in this report.

To inform public policy, further research into the wider economic impacts associated with the transition to CAVs would be constructive. To fully understand the net economic benefits of the transition to CAVs would involve taking account of the impact of new CAV business models, behavioral changes and productivity or welfare improvements from more efficient use of travelling time.

6. Appendices

A – EXTRACT FROM SAE INTERNATIONAL STANDARD J3016

Level	Name	Narrative definition	DDT		DDT fallback	ODD
			Sustained lateral and longitudinal vehicle motion control	OEDR		
Driver performs part or all of the DDT						
0	**No Driving Automation**	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*	Driver	Driver	Driver	n/a
1	**Driver Assistance**	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the *DDT* (but not both simultaneously) with the expectation that the *driver* performs the remainder of the DDT	Driver and System	Driver	Driver	Limited
2	**Partial Driving Automation**	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*	**System**	Driver	Driver	Limited
ADS ("system") performs the entire DDT (while engaged)						
3	**Conditional Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* with the expectation that the *DDT fallback-ready user is receptive* to ADS-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately	System	**System**	Fallback ready user (becomes the driver during f allback)	Limited
4	**High Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will *respond to a request to intervene*	System	System	**System**	Limited
5	**Full Driving Automation**	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*	System	System	System	**Unlimited**

Table 6.1 SAE Summary of levels of driving automation. DDT = dynamic driving task; OEDR = object and event detection and response; ODD = operational domain design; ADS – automated driving system[33]

[33] SAE International, 2016. J3016TM. Surface vehicle recommended practice – Taxonomy and definitions for terms relating to driving automation systems for on-road motor vehicles.

B – ASSUMPTIONS ON VEHICLE SALES AND CAV UPTAKE

This edition of the Market Forecast included an updated vehicle sales projection for most vehicle types. For the first time a disaggregation of the Low Duty Vehicle (LDV) category into cars and vans was provided, alongside the inclusion of the policies on encouraging the uptake of Ultra Low Vehicles (ULEVs). The general approach used in estimating the cars and vans sales is highlighted in the diagram below:

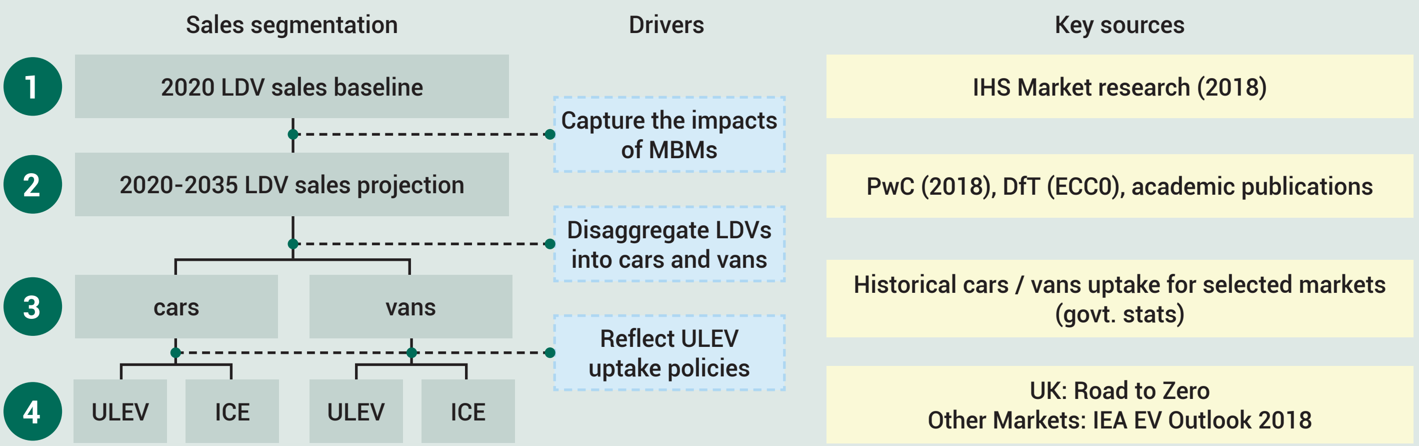


***Figure 6.1** Approach for estimating the scale of LDV sales over the 2020 – 2035 period*

Desk-based research was also employed to understand the projected sales of HGVs and buses. In the case of HGVs market size, there was no new compelling evidence that the 2017 Market Forecast project required updating. In the case of buses, data from LMC Automotive Limited (2019) points out that the bus market is cyclic, in line with the renewal of bus fleets aross the world, with sales over the 2020 – 2023 expected to fluctuate on a yearly basis by less than ±2%. It was decided to keep bus sales constant to current levels over the 2020-2035 period on this basis.

As mentioned in the report, the CAV uptake scenarios for the UK were generated by the CCAV team using internal modelling and are based on market observations. The uptake rate of CAV technologies is based on market penetration forecasting approach for new technologies. This assumes an s-curve of sales volumes over time, as early adopters invest in new technologies despite their relatively high price, which creates initial sales volume that allows cost reductions to ensue, which enables mass-market adoption and rapid growth, followed by gradual convergence on market saturation.

Different cases (Central, High, and Low) were provided for the UK uptake for all vehicle types. These reflect a lag in CAV uptake in heavier vehicle types relative to passenger cars due to technology integration challenges. A 3-year lag for Buses, 5-year lag for Vans and an 8-year lag for Trucks is assumed. A special case was provided for North American “vans” which include a large share of pick-up trucks and SUVs. The UK scenarios are used to estimate the uptake of CAVs across different markets using assumptions regarding geographic differences based on Goldman Sachs (2015). Based on observed market trends and literature, this approach assumes that the UK and Europe will be leading in terms of CAV uptake compared to other markets. The diagram below compares the uptake in the UK relative to the other markets.

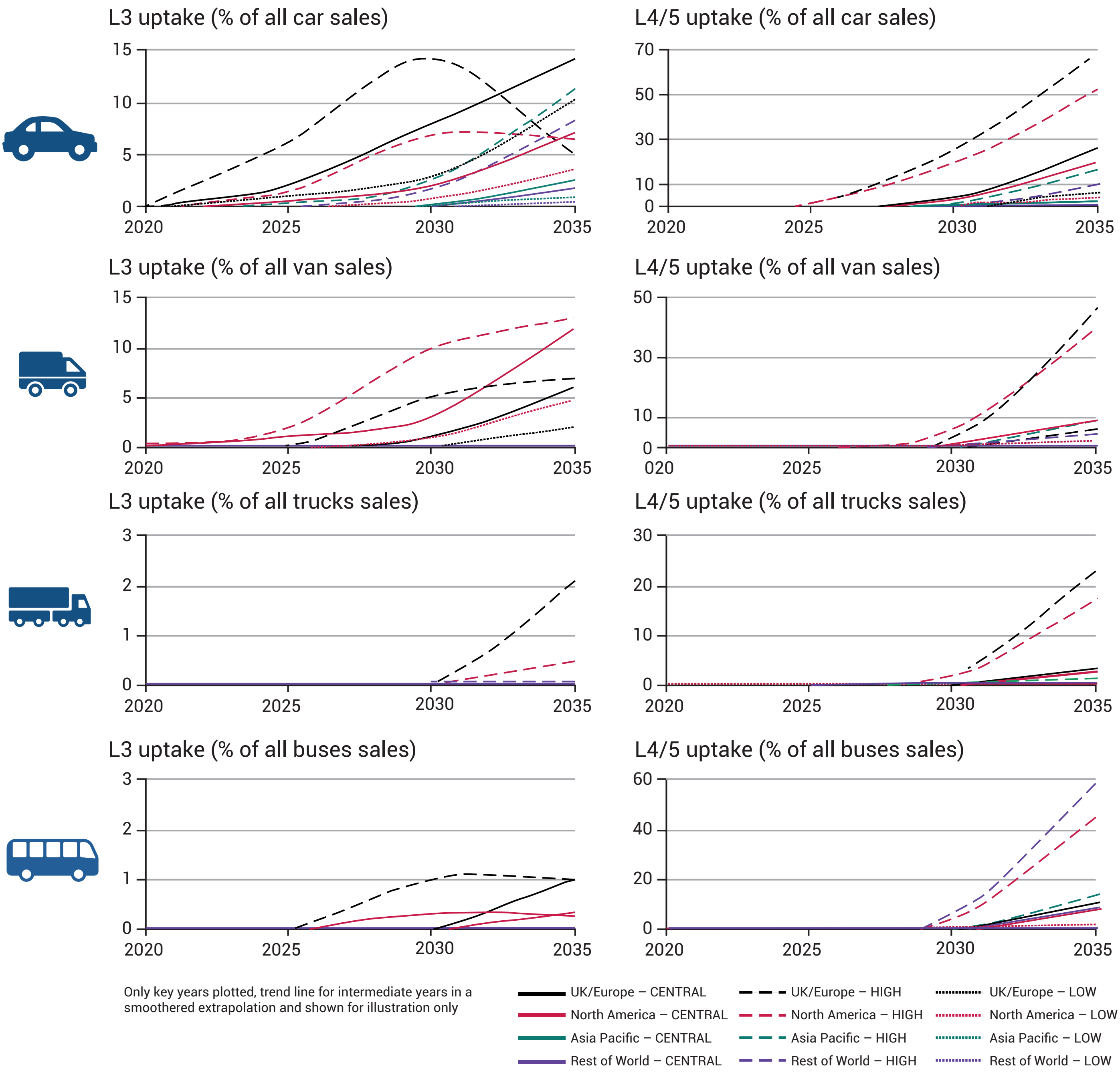


Figure 6.2 *CAV uptake across different scenarios and markets*

Sensitivities on CAV uptake across different markets
UK's CAV uptake relative to the Rest of the World, in particular the North America, was challenged through three sensitivities as described below.

- **Reverted:** in this sensitivity the North American market follows the trajectory that the UK and Europe follows in the Central case. Conversely, the uptake of CAVs in the UK and Europe is modelled lower than in the Central scenarios, and follows the trajectory assumed for North America under the Central case.
- **Aligned:** assumes similarities between the North American and the European markets, with the CAVs uptake rates in these markets following an identical trajectory in time. This means that the uptake in North America is higher in this case compared to the Central scenario.
- **Accelerated North America uptake:** in this sensitivity, it is assumed that the CAV uptake across the European and North American markets commences at the same rate up until 2025, after which the North American uptake accelerates whilst the UK/Europe continues to growth a lower rate and fall behinds North America.

The diagram below shows a comparison between the uptake rates across different autonomy levels and cross different markets in key year. A comparison between the Central case (continuous lines) and each given sensitivity (dashed lines) is shown. For example, it can be observed that in the case of the Reverted case, the North American market (dashed red line) follows the trajectory of the UK/Europe (continuous black line) in the Central case. Conversely, the reverted update in the UK/Europe (dashed black line) overlaps with the North American uptake (continuous red line) as in the Central case.

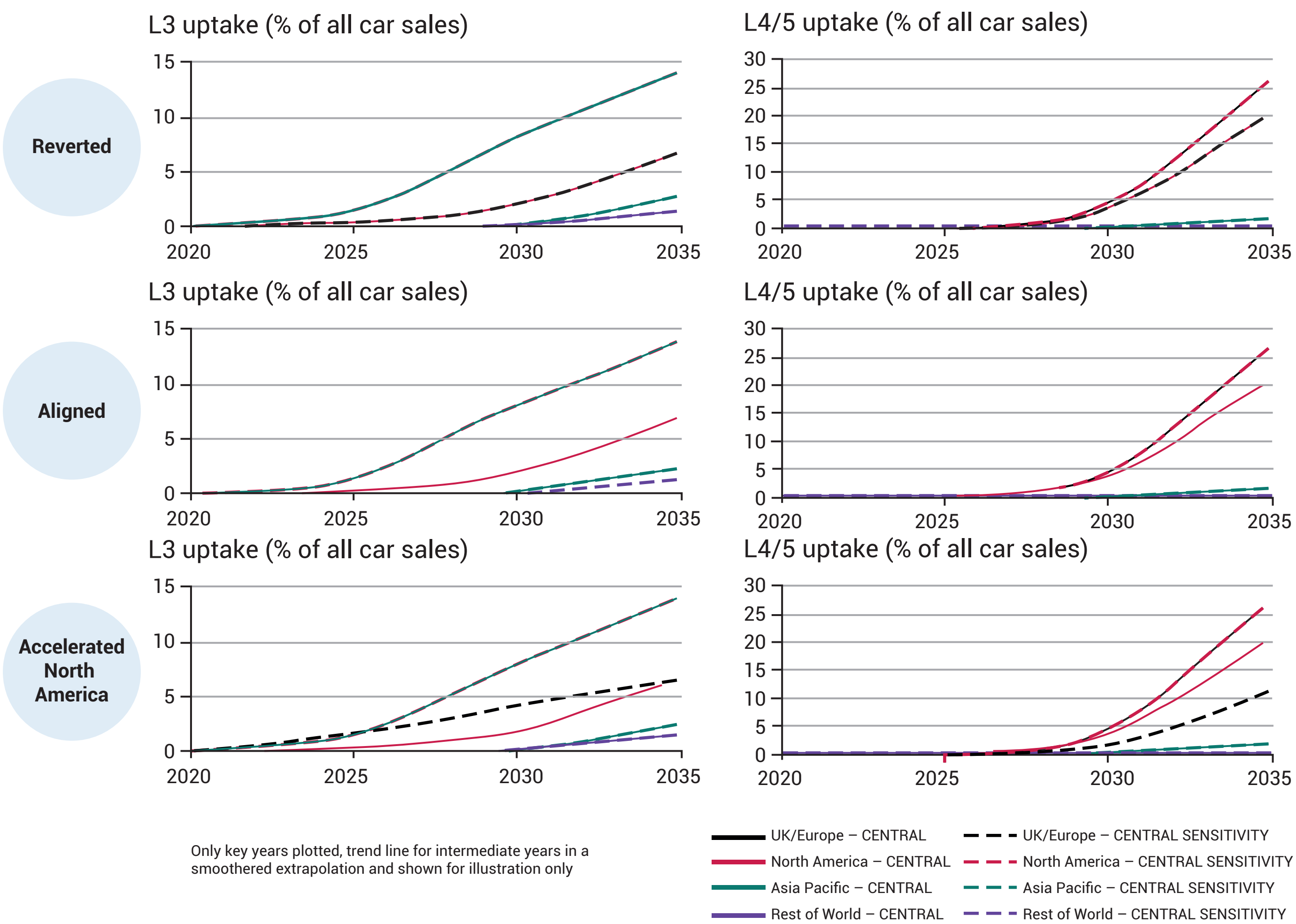


***Figure 6.3** Alternative CAV uptake curves assumed for market size sensitivities*

These sensitivities lead to the following numbers of sold CAVs. It must be noted that the total number of sold vehicle is modelled is assumed the remain constant, as highlighted in the scope of this study, however the composition of the sales in terms of autonomy levels changes in time as shown in the next diagram.

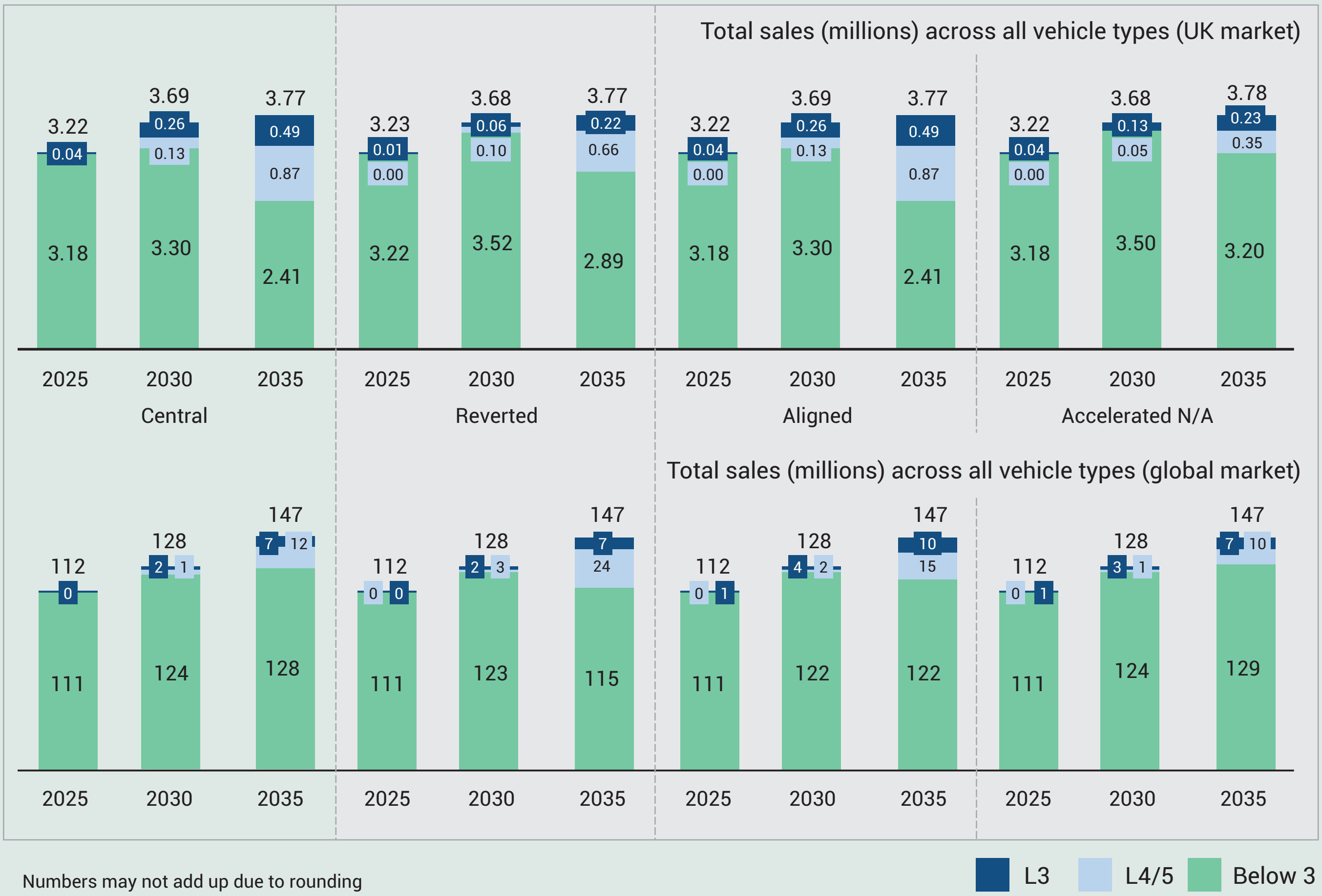


Figure 6.4 Summary of number of sold vehicle under different sensitivities size of the global market

C – ASSUMPTIONS FOR RELATIVE COMPONENT VALUES

As discussed in the report, a key area of uncertainty in this study is the relative value of hardware and software in autonomy packages for CAVs. Assumptions on the costs of autonomy packs were revised in the 2020 edition of the Market Forecast, with the assumptions from the previous study representing the starting point. Those were compared with available literature sources and were subject to industry consultation[34]. Figure 6.5 summarises the process behind the values used in this study.

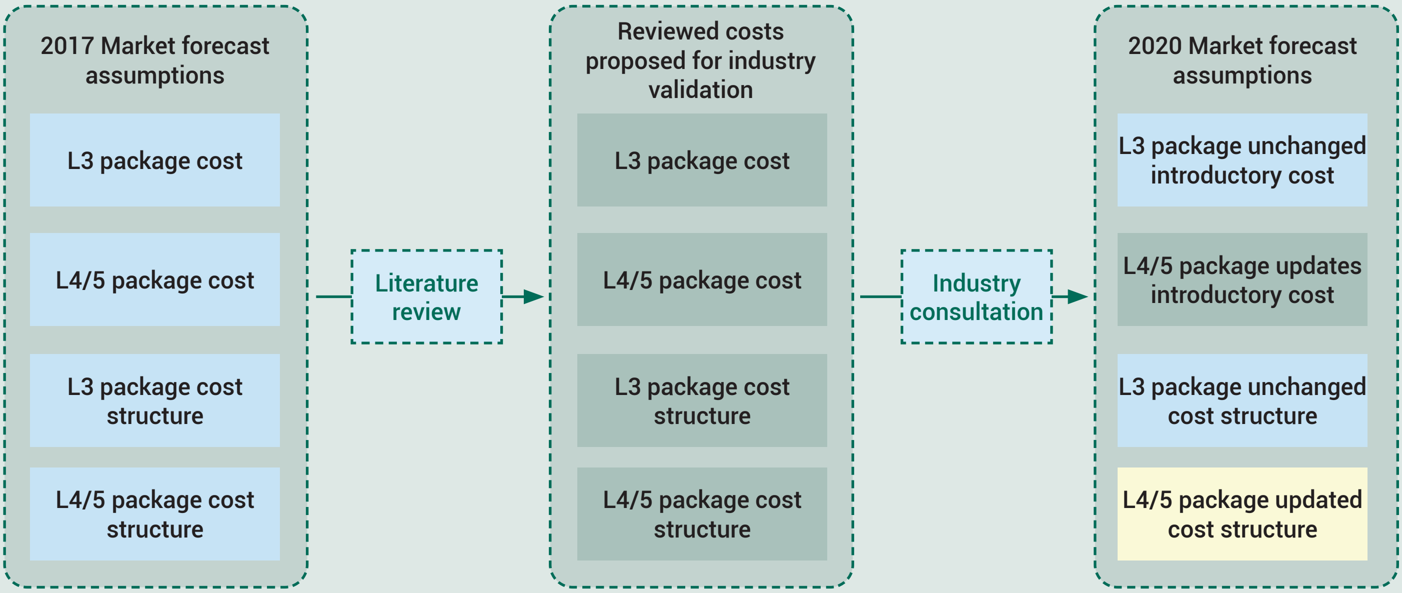


***Figure 6.5** Approach to finding values for hardware and software aspects of components*

The cost of the L3 autonomy pack was validated by industry as still actual whilst the cost of the L4/5 pack was updated as follows:

- BCG in the "Reimagined car" (The Boston Consulting Group, 2017), points that the price of an L4/5 pack would be around $7,100 in 2030 (approximative ~ £4,750 in 2019 currency). This price also contains a mark-up of 30% which was removed.
- The composition of the cost was further revised, considering that an L4/5 pack would contain 5 LIDAR sensors/vehicle (each at ~$200 in 2030). The introductory costs in 2025 was back calculated from the 2030 value and the corresponding uptake of CAV in 2025 and is estimated at £5,417 for the L4/5 pack.

Industry consultation also pointed out that the share of computer vision through cameras is expected to be greater for the L4/5 pack than initially assumed, leading to a readjustment of the Lidar/Cameras share in the total vehicle costs. The diagram below shows the different cost compositions of the L4/5 pack introductory costs used in the 2017 and 2020 editions of this Market Forecast.

[34] SAE International, 2016. J3016TM. Surface vehicle recommended practice – Taxonomy and definitions for terms relating to driving automation systems for on-road motor vehicles

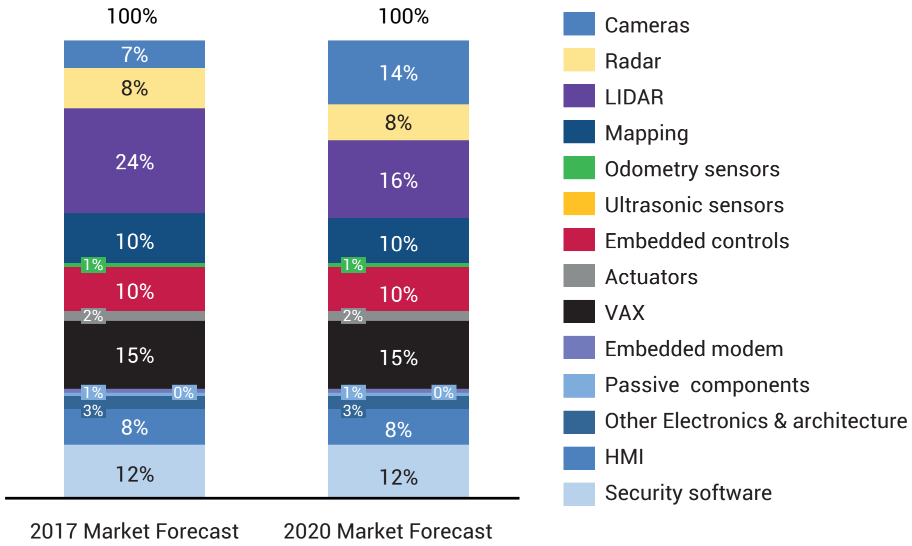


***Figure 6.6** Differences in the introductory costs of L4/5 packages across the two editions of the Market Forecast*

In terms of future cost projections, industry consultation pointed out that whilst the cost of autonomy packs is expected to drop in time thanks to technological learnings and economies of scale driven by cumulative uptake, a true learning curve would only apply to the hardware components. It is expected that the software costs would remain flat as the software itself would be licensed and would require continuous development under the form of new features, updates, validation, and fixes. This non-linear correlation between the costs of hardware and software is represented in our modelling, which considers that the costs of hardware drops in time whilst software costs remain constant – see section 3.5.

The SIC codes and descriptions of the relevant economic activities associated with each component are shown in Table 6.2 and Table 6.3, alongside the final assumed share of the total autonomy package value. Note that the value for the software technologies is assumed to be linked to activities in four different SIC codes. The distribution across these four SIC codes for each type of software has been estimated based on knowledge of the requirements for the different types of software. However, this is unlikely to have a great impact on the economic analysis, as some of the key stages in the analysis use data that is aggregated at a two-digit SIC code level (and as such, will result in similar economic impacts across all software-related SIC codes).

Hardware Technologies	Components	SIC Code	SIC code activity description	Total share of package value at L3	Total share of package value at L4/5
Sensing & local mapping hardware	Cameras	2640	Manufacture of consumer electronics	9.3%	14.1%
	Radar	2651	Manufacture of instruments and appliances for measuring, testing and navigation	12.4%	7.9%
	LIDAR	2670	Manufacture of optical instruments and photographic equipment	24.7%	16.4%
	Mapping hardware	2651	Manufacture of instruments and appliances for measuring, testing and navigation	2.5%	1.2%
	Odometry sensors	2651	Manufacture of instruments and appliances for measuring, testing and navigation	1.7%	0.5%
	Ultrasonic sensors	2651	Manufacture of instruments and appliances for measuring, testing and navigation	0.3%	0.1%
Sensor-supporting hardware	Actuators	2612	Manufacture of loaded electronic boards	2.3%	2.3%
Control systems and computing hardware	Embedded controls hardware	2612	Manufacture of loaded electronic boards	1.9%	0.5%
	Passive components	2611	Manufacture of electronic components	0.5%	0.7%
	Other electronics & architecture	2611	Manufacture of electronic components	3.5%	3.2%
Connectivity hardware	V2X hardware	2630	Manufacture of communication equipment	3.2%	0.8%
	Embedded modem	2630	Manufacture of communication equipment	0.3%	0.3%
Safety-related HMI hardware	HMI hardware	2651	Manufacture of instruments and appliances for measuring, testing and navigation	2.5%	2.1%
TOTAL				**65%**	**50%**

Table 6.2 Associated SIC codes and share of autonomy package values for hardware technologies at introduction (L3 2020, L4/5 2025)

The difference compared to the mapping used in the 2017 study comes from altering the ratio for cameras and LIDAR.

Software Technologies	SIC Code	SIC code activity description	Total share of package value at L3	Total share of package value at L4/5
Mapping & path planning software	6201	Computer programming activities	2.3%	3.7%
	6202	Computer consultancy activities	0.6%	0.9%
	6209	Other information technology and computed service activities	0.6%	0.9%
	6311	Data processing, hosting and related activities	2.3%	3.7%
Control systems software	6201	Computer programming activities	4.7%	6.5%
	6202	Computer consultancy activities	0.7%	0.9%
	6209	Other information technology and computed service activities	0.7%	0.9%
	6311	Data processing, hosting and related activities	0.7%	0.9%
Connectivity / V2X software	6201	Computer programming activities	3.5%	4.2%
	6202	Computer consultancy activities	2.4%	2.8%
	6209	Other information technology and computed service activities	1.2%	1.4%
	6311	Data processing, hosting and related activities	4.7%	5.5%
HMI software	6201	Computer programming activities	3.5%	3.7%
	6202	Computer consultancy activities	1.2%	1.2%
	6209	Other information technology and computed service activities	0.6%	0.6%
	6311	Data processing, hosting and related activities	0.6%	0.6%
Data security software	6201	Computer programming activities	1.9%	4.6%
	6202	Computer consultancy activities	0.5%	1.2%
	6209	Other information technology and computed service activities	0.5%	1.2%
	6311	Data processing, hosting and related activities	1.9%	4.6%
TOTAL			**35%**	**50%**

Figure 6.3 *Associated SIC codes and share of autonomy package values for software technologies at introduction (L3 2020, L4/5 2025)*

D – SENSITIVITY ON DISCOUNTS GIVEN TO FLEET OPERATORS

The approach described below was used in modelling the impacts of discounts given to fleet operators:

- **Understanding the share of CAVs sold to fleet operators:** this was based onto the share of "shared CAVs" as modelled in the PwC (2018) study, which was interpreted as the share of CAV sales ending up as part of mobility operators' fleets. This share is shown in the diagram below for different markets and years.

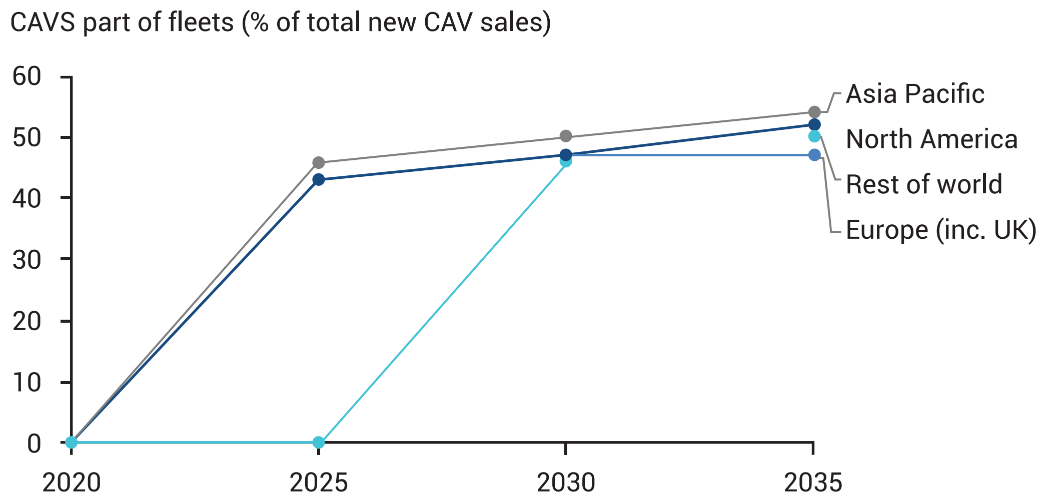
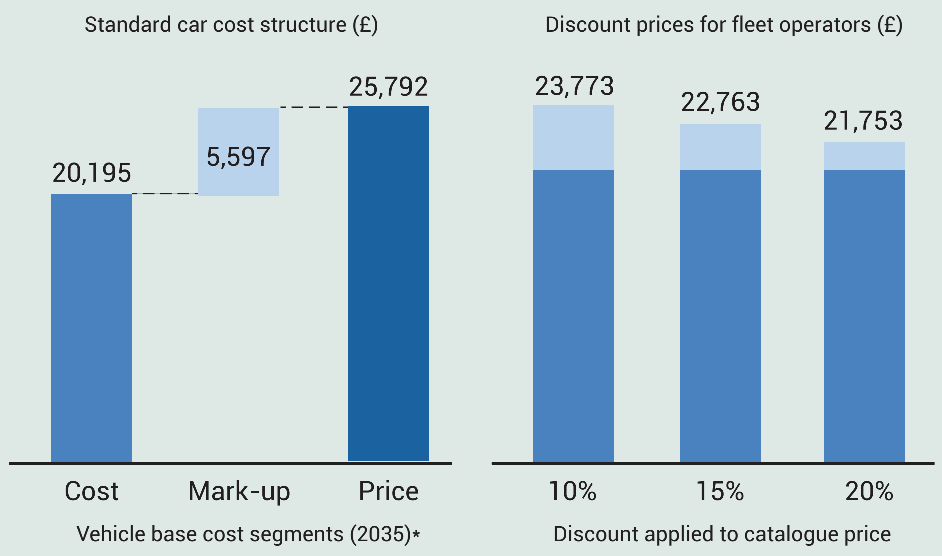


Figure 7 Share of CAV new sales part of mobility services fleets

- **It is assumed that only L4/5 cars would be suitable to be part of vehicle fleets** used in future autonomous mobility schemes, such as car sharing or taxis. L3 vehicles, which usually provide limited autonomy, could require a safety driver and would lead to increased costs for fleet operators, making this level of autonomy unattractive for such applications

- **The cost discounts were only applied to the vehicle base under the Central case.** The total costs of CAVs is composed of the vehicle base, built by the OEMs, and the autonomy package, usually out-sourced from a third party supplier. Given that discounts are negotiated with vehicle OEMs, we assume that the discounts apply to the vehicle base, onto which the OEMs has control over the price, by example by accepting a lower mark-up when winning a large order of vehicles from a fleet operator[35]. The discounts were applied to the Central case uptake only. The diagram below illustrates an example in which the OEM's mark-up (including profit) is reduced as a result of different discount rates. The discount rates were capped at 20% to avoid OEM's selling vehicles at prices below the cost of manufacturing.

[35] It must be noted that bulk sales of vehicles in not only associated with discounts provided from lowering mark-ups but also to savings for the OEMs, for example by reducing marketing efforts. However, due to the structure of the vehicle price structure, the discounts are modelled as a reduction of the mark-up only


Standard car cost structure (£)
20,195
5,597
25,792
Cost
Mark-up
Price
Vehicle base cost segments (2035)*
Discount prices for fleet operators (£)
23,773
22,763
21,753
10%
15%
20%
Discount applied to catalogue price

E – APPROACH TO THE ANALYSIS OF ECONOMIC IMPACTS

This section provides details of the methodology used to quantify each of the economic indicators in the report.

Trade

Import intensity and export intensity for CAV and CAV technologies were estimated based on historical data from the Eurostat Comext database, ONS International Trade in Services statistics and the OECD STAN database. Where possible, the most detailed data was used at the UK SIC (2007) four-digit class level. Where this data was not available, more aggregated data was used at the UK SIC (2007) two-digit class level.[36]

It was assumed that historic import and export intensities hold over the 20-year projection period. For example, if the ratio of UK exports to total global demand in CAV software is 5% in 2017, we assume that, in 2035, the ratio of UK exports to total global demand in CAV technology is still 5%. These intensities were multiplied by the CAV market forecasts to derive total UK imports and exports.

1 Historical data for the relevant SIC (2007) codes was used to estimate import intensity for CAV technologies:

$$\text{Import intensity} = \frac{\text{UK Imports}}{\text{UK Imports} + \text{Gross output} - \text{UK Exports}}$$

2 Import intensity (the ratio of imports to domestic demand) was then multiplied by the CAV market forecasts to derive UK imports (by CAV technology):

$$\text{Import intensity} = \text{Import intensity} * \text{UK Market Forecast}$$

UK export shares were calculated for four world regions: Europe, North America, Asia-Pacific and Rest of World.

1 Historical data for the relevant SIC (2007) codes was used to calculate export shares by global region, i.e. the ratio of UK exports to total domestic demand in each region:

$$\text{UK Export Share}_{\text{region}} = \frac{\text{UK Exports}_{\text{region}}}{\text{Domestic Demand}_{\text{region}}}$$

2 UK exports to each region (by technology) were then calculated by multiplying the export shares by CAV market forecasts in each global region:

$$\text{UK Exports}_{\text{region}} = \text{UK Export share}_{\text{region}} * \text{Market Forecast}_{\text{region}}$$

[36] Due to data limitations, export intensity for all CAV technologies and import intensity for CAV software technologies were calculated at the SIC07 two-digit class level. The import intensity of CAV hardware technologies was calculated using SIC07 codes at the four-digit class level

Gross output and investment

Projections for gross output in CAV and CAV technologies were based on the UK market forecasts, after making an adjustment to account for international trade effects (as quantified in Stage 1):

Gross Output = UK Market Forecast + UK exports – UK imports

Expected future demand (and expected production) are key drivers of investment in the UK and, to estimate total CAV-related investment in each scenario, it is assumed that investment in each sector is wholly dependent on current gross output of CAV-related technologies. The ratio of investment to gross output was calculated using historical data for industries that are expected to develop CAV technologies[35]. Investment shares were calculated at the SIC (2007) two-digit class level, using data for Gross Fixed Capital Formation (GFCF) and domestic output from the ONS Supply and Use Tables (2016) (see Table 6.4 for investment shares). Investment shares were multiplied by gross output for each CAV technology to give an estimate of UK CAV-related industry investments in each year.

1 Historical data for relevant SIC (2007) codes was used to estimate investment shares:

$$\text{Investment Share} = \frac{\text{Gross Fixed Capital Formation}}{\text{Total Domestic Output}}$$

2 Investment shares were then multiplied by gross output (by technology) to derive the level of investment in each scenario:

*Investment = Investment share * Gross Output*

UK SIC (2007) sector	UK SIC (2007) code	Investment share
Manufacture of computer, electronic and optical products	26	7%
Manufacture of motor vehicles, trailer and semi-trailers	29	7%
Computer programming consultancy and related activities	62	5%
Information service activities	63	11%

***Table 6.4** Investment share by UK SIC (2007) code*

GVA

GVA was calculated for CAV and CAV technologies as:

GVA = Gross output – Industry Intermediate Consumption

Industry intermediate consumption was calculated using UK input-output tables, published by the ONS. The input-output coefficients were refined to reflect our estimates of labour costs associated with manufacturing each technology[37]. Industry intermediate consumption was then calculated by multiplying gross output by the adjusted input-output coefficients.

[37] For the manufacturing of CAV hardware technologies, labour intensities (estimated at the SIC07 four-digit class level) ranged from 3 jobs per £million turnover to 8 jobs per £million turnover. As input-output tables are only available at the SIC07 two-digit class level, adjustments were applied to the coefficients in the Input-Output tables to account for higher labour intensities (and higher labour costs). We assume that higher labour intensity (and labour costs) would correspond to lower intermediate consumption, and that the same profit shares are maintained within a particular industry sector

Jobs

To estimate the impact on jobs, labour intensities for each four-digit SIC code were calculated using 2015 data. Labour intensities were calculated at a sectoral level, as the ratio of employees to million pounds of turnover (see Table 6.5 for labour intensities). The labour intensities were then adjusted to take account of expected future productivity improvements, which were estimated by assuming a continuation of historical productivity trends. Future productivity growth was based on the average growth rate in labour productivity[39] from ONS data. The productivity-adjusted labour intensity estimates were then multiplied by the gross output results to estimate the total number of jobs associated with production of CAV technologies in each scenario.

1 Historical data for the relevant SIC (2007) codes was used to estimate the labour intensity of manufacturing CAV technologies:

$$\textit{Historical labour intensity} = \frac{\textit{No. of employees}}{\textit{Million pounds turnover}}$$

2 Direct and indirect jobs associated with manufacturing each CAV technology were then estimated:

*Direct jobs = Gross output * historical labour intensity * productivity improvement*

*Indirect jobs = Direct jobs * (Employment multiplier – 1)*

Indirect jobs were calculated using direct jobs and a type one employment multiplier (ONS). The employment multiplier represents the direct and indirect impact on the supply chain from an increase in employment in a specific sector. Data was selected based on the relevant two digit SIC codes for each technology.

UK SIC (2007) sector	UK SIC (2007) code	Labour intensity (employees per £ million of turnover)
Manufacture of motor vehicles, trailers and semi-trailers	29	2.0
Manufacture of consumer electronics	2640	5.0
Manufacture of instruments and appliances for measuring, testing and navigation	2651	5.2
Manufacture of optical instruments and photographic equipment	2670	5.1
Manufacture of loaded electronic boards	2612	7.4
Manufacture of communication equipment	2630	5.4
Manufacture of electronic components	2611	6.5
Computer programming activities	6201	6.8
Computer consultancy activities	6202	8.0
Other information technology and computed service activities	6209	5.7
Data processing, hosting and related activities	6311	5.6

***Table 6.5** Labour intensities for UK SIC (2007) code*

[39] Average growth rate for CAV (29) was calculated using data from 1994-2014, for CAV software technologies (62 & 63) a period between 1990-2017 was used, and for CAV hardware technologies a period between 1994-2015 was used

Limitations of approach to economic analysis

a) Using UK SIC (2007) codes for existing industries to estimate the economic characteristics of CAV technologies

In the emergent CAV industry, there is limited data available to estimate the likely contribution of this sector to UK GVA, gross output and jobs in the future. Mapping the manufacture of CAVs and CAV technologies to UK SIC (2007) codes was an essential step to estimate the economic characteristics of the industries that are likely to produce CAV technologies in the future. The likely contribution of CAV technologies to GVA, gross output and employment in the UK (for a given market size) was estimated using labour intensities and trade ratios from existing industry data.

Whilst this approach proved to be the best method for isolating the gross economic contribution of CAV and CAV technologies, it does have some limitations. The drawbacks of this method meant that some CAV technologies may be under-represented in data. For example, the SIC07 code *'2612: Manufacture of loaded electronic boards'* is used as a proxy for *'CAV-related manufacture of sensor-supporting hardware'* but it could be the case that a large share of economic activities captured by this SIC07 code represent companies that are not currently involved in manufacturing CAV technologies (and do not plan to be in the future). Using sectoral economic data to estimate trade ratios and labour intensity is still likely to provide the best available estimates as, in many cases, the CAV technologies do map relatively well to existing products. In some cases, however, data at the SIC07 four-digit class level was not available and more aggregated data at the SIC07 two-digit class level had to be used instead. In these cases, it is likely that are results are less robust, as they would reflect average industry characteristics at a much broader level.

Data sourced for the UK capability assumptions was subject to a sense check from a review of the literature, which is described in detail in Appendix F. Tables showing the mapping of CAV-related activities to the UK SIC (2007) codes are available in Appendix E.

b) Using historical data to estimate the economic characteristics of industry sectors

Another criticism of the data-driven approach is that historical data used to assess the economic characteristics of industries is unlikely to be accurately reflect the economic characteristics of these industries in 10 or 20 years' time.

The estimates presented in this report do not account for changes in trade intensity over time, as it is difficult to predict precisely how the UK's competitive position is likely to change in the future, particularly as the focus of the analysis is on new, emerging technologies. As the trade intensities are a key uncertainty in our economic analysis, we test the impact of varying this assumption using sensitivity analysis (see Section 4.6 for more information).

The estimates of labour intensity are also based on the latest year of available data, but they are adjusted to account for expected future labour productivity improvements[40].

F – MAPPING OF CAV TECHNOLOGIES TO UK SIC (2007) CODES

For the economic analysis, we used economic data classified by UK Standard Industry Classification (SIC) code (2007)[41], to estimate the labour intensity and import and export shares of CAV technologies. The manufacture of each CAV technology was assigned to one or more SIC07 codes. The assignment was based on: keywords of CAV technologies found in the literature and information on primary activity of industries at the four-digit class level(Office for National Statistics, 2017). Where two or more SIC07 codes were relevant for one technology, a weighted average across the SIC07 codes was used to reflect the relevance of each industry for the manufacture of a specific CAV technology. Shares were applied to each of the SIC07 codes to reflect the proportion of different types of components included within a technology.

Table 6.6 shows the mapping of the production of each CAV technology to the relevant SIC code(s).

[40] Estimated labour productivity improvements over the period to 2035 are based on an extrapolation of current trends in labour productivity
[41] Henceforth referred to as SIC07

Technology	UK SIC07 4 digit class definition	SIC07 Class Heading	Specific components included in each SIC07 code
Hardware			
Sensing & local mapping hardware	2640	Manufacture of consumer electronics	Cameras (video cameras)
	2651	Manufacture of instruments and appliances for measuring, testing and navigation	Radar, Odometry sensors, Ultrasonic sensors, Sensing & local mapping hardware (i.e. GPS receivers)
	2670	Manufacture of optical instruments and photographic equipment	LIDAR
Sensor-supporting hardware	2612	Manufacture of loaded electronic boards	Actuators
Connectivity hardware	2630	Manufacture of communication equipment	Embedded modem
Control systems and computing hardware	2611	Manufacture of electronic components	Passive components, other electronics & architecture
	2612	Manufacture of loaded electronic boards	ECU hardware
Safety-related HMI hardware	2651	Manufacture of instruments and appliances for measuring, testing and navigation	External and internal sensors
Software			
Control systems software	6201	Computer programming activities	Control systems software
	6202	Computer consultancy activities	
	6209	Other information technology and computed service activities	
	6311	Data processing, hosting and related activities	
Mapping & path planning software	6201	Computer programming activities	Mapping & path planning software
	6202	Computer consultancy activities	
	6209	Other information technology and computed service activities	
	6311	Data processing, hosting and related activities	
Connectivity / V2X software	6201	Computer programming activities	Connectivity / V2X software
	6202	Computer consultancy activities	
	6209	Other information technology and computed service activities	
	6311	Data processing, hosting and related activities	
Data security software	6201	Computer programming activities	Data security software
	6202	Computer consultancy activities	
	6209	Other information technology and computed service activities	
	6311	Data processing, hosting and related activities	
HMI software	6201	Computer programming activities	HMI software
	6202	Computer consultancy activities	
	6209	Other information technology and computed service activities	
	6311	Data processing, hosting and related activities	

***Table 6.6** Mapping of CAV technologies to UK SIC (2007) codes*

G – COMPARISON OF DATA AND LITERATURE ON UK CAV CAPABILITIES

Two studies published by TSC were used to validate the assumptions on likely trade shares for CAV technologies:

- TSC (2015), 'Traveller needs and UK capability study'[42]
- TSC (2016) 'Technology Strategy for intelligent mobility'(Transport Systems Catapult, 2016b)

Both studies ranked technologies on a scale of 1-5, where a score of 1 indicates that the UK has weak capabilities and suggests the need to import a large share of that technology from abroad, and a score of 5 indicates that the UK has strong capabilities and would have a high propensity to supply to export markets. There was an issue of technology comparison between the TSC studies and the list of technologies in this project, as the categories defined were not the same. Notably, the list for this study made a clear distinction between hardware and software, enabling use of SIC code date, whereas the TSC studies combined these into complete technologies.

To compare between the data that was used to inform our modelling assumptions and the studies we compared our assumptions on UK capabilities (gross output as a proportion of UK supply) to the scores that each technology was assigned in the two studies. Our CAV technologies were mapped to the technologies from the TSC studies. If two technologies from our list mapped to one technology in another study, weighted averages based on the hardware/software split (mentioned above) were taken; see Table 6.7 which shows the mapping behind the assumptions of this study.

Traveller needs UK capability study	Technology strategy for intelligent mobility	Technology classification used in this study
-	Autonomous vehicle	CAV (29)
Connectivity networks	-	Connectivity hardware Connectivity / Vehicle to Anything (V2X) software
HMI & interaction design	-	Safety-related HMI hardware HMI software
Localisation & mapping	-	Mapping & path planning software Sensing and local mapping hardware
Data privacy and & security	Security, resilience, safety and cyber security	Data security software
Real time control	Data management and analysis	Control systems and computing hardware Control systems software
Data visualisation	-	HMI software
Sensing capabilities	-	Sensing & local mapping hardware

***Table 6.7** Technology mapping between studies*

[42] (Transport Systems Catapult, 2015)

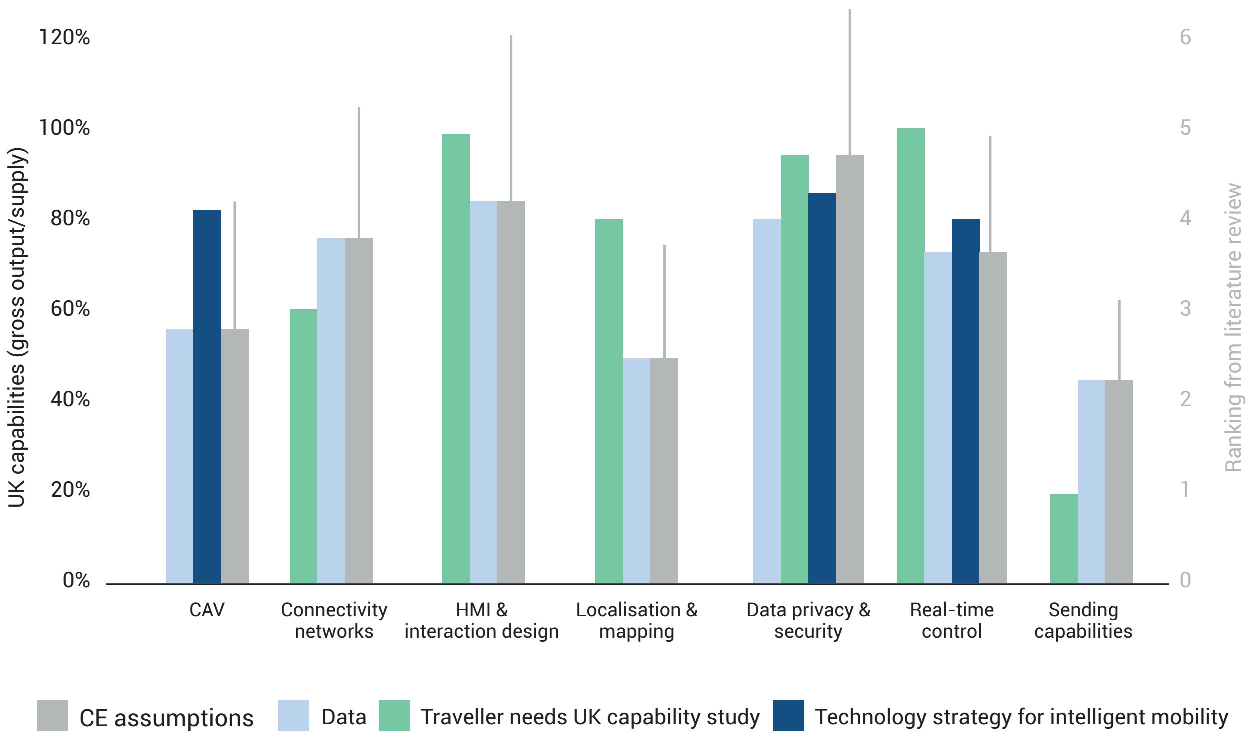
There were two main issues when mapping technologies between studies. The first issue was broad definitions, in 'Technology Strategy for Intelligent Mobility', *Data management and analysis* has been assigned to Real time control, but it could also underpin the other technologies, as some sort of data management and analysis could be assumed paramount. The other issue was overlapping technologies, *Sensing and local mapping hardware* has been used twice, once in *Localisation and mapping* and again in *Sensing capabilities.* A few technologies have been excluded from the comparison due to a combination of the issues above.

There is a disparity between the literature and data for *Sensing capabilities.* The data indicates that the UK capabilities of building sensing hardware is strong, whereas the literature suggests it is limited. The literature acknowledges that the UK's strength lies in being academically strong, particularly in vision-based sensors, but lacks the scalability of mass production required for the automotive and transport sectors. The extra funding from the Intelligent Mobility Fund, £2.2 million invested to help the advancement of sensing capabilities, may give justifications for the assumptions used in this study.

A wider gap in UK capabilities exists for *HMI interaction and design.* The literature suggests that the UK has a mature design industry that is keeping up with world leaders in app design and high technology solutions. The static and non-static information displays during the London 2012 Olympics are frequently cited by experts and success in app design such as Citymapper, Hailo and Kabbee further support UK capabilities in this area.

The gap highlights two issues with the assumptions made in this study. The first, a higher weight is attributed to hardware technologies than software technologies, therefore the manufacturing of consumer electronics (the SIC code that proxy's *Safety-related HMI hardware*) is represented more than the software that underpins the 'high tech solutions' that the UK is capable of. The second is that the SIC codes used do not cover the value added from the design industry. This could be revised by altering the share to software, or increasing the UK capabilities to reflect the review of experts.

Figure 6.2 shows, for each technology, a comparison of the UK capabilities score from the literature review and the implied UK capabilities, based on data for similar technologies. The comparison shows that, for most technologies, findings from the literature broadly support the results from the data review (which is used as the basis for our trade assumptions). The error bars show the range of assumptions applied under the high UK capabilities sensitivity.



7. Bibliography

Archambault, P., Delaney, M., Yuzawa, K., Burgstaller, S., Tamberrino, D., & Duval, A. (2015). Monetizing the rise of Autonomous Vehicles. *Goldman Sachs – Cars 2025, 3,* 81.

Charette, R. (2009). *This Car Runs on Code – IEEE Spectrum.* IEEE Spectrum.

Climate Works Foundation. (2016). *Global View Function.*

DfT. (2015). *DfT Table TRA0204 - Road traffic (vehicle kilometres) by vehicle type and road class in Great Britain, annual 2015.*

ERTRAC. (2015). Automated Driving Roadmap. *Http://Www.Ertrac.Org*, 46. https://doi.org/10.3141/2416-08

IEA. (2018). *Global EV Outlook 2018 – Towards cross-modal electrification.* https://doi.org/10.1787/9789264302365-en

Innovate UK. (2016). *Innovate UK (2016), 'CAV competition leverages over £25 million for eight R&D projects to help build infrastructure for connected and autonomous vehicles.'*

KPMG. (2015). Connected and Autonomous Vehicles – The UK Economic Opportunity. *KPMG International, March,* 1–24. https://doi.org/10.1007/978-3-642-40894-6_11

McKinsey, & Stanford University. (2016). Automotive revolution – perspective towards 2030. *Stanford University, PEEC Sustainable Transportation Seminar, January 1st,* 1–20. https://doi.org/10.1365/s40112-016-1117-8

MIRA. (2016). *Creating the CAV R&D Environment.*

Mosquet, X., Agrawal, R., Dauner, T., Lang, N., Russmann, M., Mei-Pochtler, A., & Schmieg, F. (2015). *Revolution in the Driver's Seat: The Road to Autonomous Vehicles.* Bcg.Perspectives .

Office for National Statistics. (2019). *JO OBS032: Employee Jobs by Industry* Office for National Statistics. (2017). *UK Standard Industrial Classification of Economic Activities – Office for National Statistics.*

PwC. (2018). Five trends transforming the Automotive Industry. In *PwC* (Vol. 1, Issue 1).

SAE International. (2014). Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems. In *SAE International* (Vol. J3016). https://doi.org/10.4271/J3016_201609

SMMT. (2019). *SMMT MOTOR INDUSTRY FACTS 2019.*

SMMT. (2017). *Connected and Autonomous Vehicles – Position Paper.*

The Boston Consulting Group. (2017). The reimagined car. *The Boston Consulting Group,* 1-41.

Transport Systems Catapult. (2015). *IM – Traveller needs and UK Capability Study.*

Transport Systems Catapult. (2016a). *Literature Review of the UK Value Chain for Connected and Autonomous Vehicles. July.*

Transport Systems Catapult. (2016b). *Technology Strategy for Intelligent Mobility.*

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