AUTOMATED VEHICLES: AUTOMATICALLY LOW CARBON?

Institution of MECHANICAL ENGINEERS

LowCVP
Low Carbon Vehicle Partnership

UNIVERSITY OF LEEDS
Institute for Transport Studies

The UK context for automated and connected cars

Google, Apple, Tesla; all household names which are becoming inextricably linked to the vision of the so-called driverless, autonomous or automated vehicles, holding out the prospect of a revolution in the ways we'll move around in future. But what are the potential benefits and pitfalls from this revolution in mobility technology? The LowCVP and the Institution of Mechanical Engineers (IMechE) commissioned the Institute for Transport Studies, Leeds to investigate the potential impacts of these exciting new technologies and to provide some pointers as to how policy makers may need to respond to make sure they can deliver the greatest benefits in terms of carbon emissions and air quality.

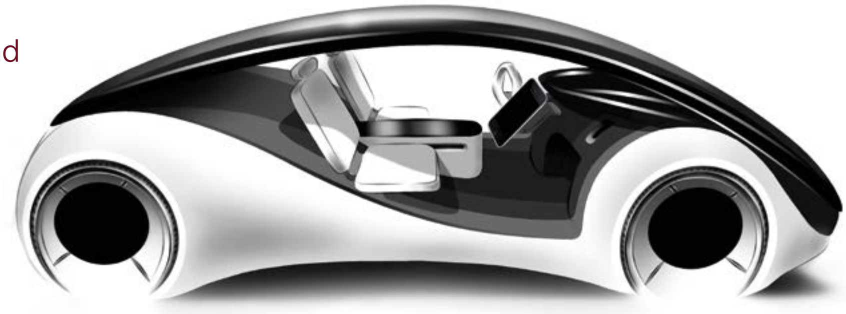
The UK government is keen to maintain its edge in automotive research and technology and, driven by the perceived benefits of connected and automated vehicles (CAVs), aims to be a leader in this area. The Department for Transport (DfT) has identified four key benefits from the adoption of CAVs: (i) creating more free time, (ii) improving safety, (iii) reducing emissions and easing congestion, and (iv) increasing access to vehicles for everyone.[i] KPMG estimates the benefits of a high level of automation to be: 25,000 new manufacturing jobs and 320,000 additional new jobs, a reduction of 25,000 accidents saving 2,500 lives and an additional £51bn of economic and social benefit per year by 2030.[ii] DfT has clarified that UK legislation already allows the testing of automated vehicles on UK roads and has developed a code of practice for such on-road testing in 2015.

A separate division spanning the DfT and the Department for Business, Innovation and Skills (BIS) – the Centre for Connected and Automated Vehicles (CCAV) - has been created to oversee development in this area. The government has announced a £200m fund to develop CAV technology.

Currently, pilot tests are ongoing in Bristol, Coventry, Greenwich and Milton Keynes through this fund. Independently, the University of Oxford has developed and demonstrated its own highly automated car.

Summary and policy implications

Automation and smart connectivity in road vehicles is happening apace. How might these elements be combined and integrated into the mobility system to have the most positive impact on energy efficiency and carbon reduction?



The only certainty is that the impacts of automation on energy demand and carbon emissions are highly uncertain:

- The combination of connectivity, automation plus shared ownership and use has the potential to lead to a substantial reduction in energy use and help accelerate the introduction of low carbon vehicles. However, these **energy and carbon benefits are by no means guaranteed. The net impact will ultimately depend on how their introduction spurs further innovation** in vehicle and transport system design combined with mobility service provision.

- **The majority of system-wide energy efficiency benefits are likely to result from high levels of connectivity and coordination between vehicles and infrastructure, not through automation per se.** The greatest benefits will come from streamlining traffic flow, eco-routing, optimising network capacity and reducing congestion. **These can materialise even at the low levels of automation we are already witnessing today.**

- Lower levels of automation are unlikely to encourage significant changes in mode choice or car use. At full automation (e.g. 'driverless'), **behavioural responses are extremely uncertain** as they are highly dependent on the degree to which the current paradigm of individual private car ownership transitions to new models of shared access and use:

  - On the one hand, **if the current private ownership model continues, improved comfort, functionality and 'driveability' could substantially increase the attraction and use of cars for private travel,** including for some population segments unable or unwilling to drive. This will mean more car trips but also longer ones due to the ability to use car travel time more productively.

  - On the other hand, **if automation is combined with connectivity as well as shared ownership and use, large reductions in energy use could result.** Innovations in mobility services (such as 'mobility on demand', shared taxis, car clubs) might facilitate lower car ownership, more shared use, greater utilisation and turnover of vehicles and right-sizing by matching vehicle size to utilisation patterns.

What needs to happen next?

- Achieving the desired combination of outcomes related to CO2, energy, air quality, safety and accessibility **will need careful, synergistic and timely policy design with coordination between the automotive industry, telecommunication industry, transport system operators and mobility service providers.**
- There is a risk that automation could outpace the implementation of the smart connectivity features required for system optimisation. Therefore, **establishing data safeguarding and sharing protocols and provisions for smart connectivity at an early stage of deployment is very important for realising the benefits.**

- **Demand management will need to be a key component of policy making to mitigate against unsustainable net increases in the use of cars.** Policies could include road user charging, low emission zoning and regulating empty running.

- Regulations or innovative policies (e.g. 'off-cycle' credits for carbon intensity improvements achieved over the standard test cycle) may be required to **encourage manufacturers to provide efficiency optimising features** like automated eco-driving, eco-routing, platooning or energy saving algorithms in the vehicles.

- Given the uncertainties, it may be prudent to **regulate or incentivise the sales and use of highly and fully automated cars**, at least until demand response becomes clearer. Sales could be limited to vulnerable users, mobility or public transport service providers and allowing high and full automation for electric or low-carbon propulsion only.

- Low-carbon, **alternative fuel pumps and charging stations need to be planned and designed for automated, unattended dispensing or charging** in order to alleviate the inconveniences of refuelling these vehicles and encourage their uptake.

- The introduction of automated vehicles in a context of shared car ownership and use will be key to realising energy and carbon benefits. **Policy can provide a supportive environment for new mobility services** to develop by delivering open data protocols, supporting technology incubation and providing local authorities with resources to enhance skills and offer incentives to local mobility service companies.

- Technological innovations can fail due to overselling and a failure to address consumer concerns early enough. It cannot be taken for granted that higher levels of automation will automatically win wide public acceptance. Therefore, automated vehicle technology, as well as increased connectivity and data sharing, **can only happen after significant public engagement to foster acceptance and positive adoption behaviours.**

Automated, autonomous or connected?

Vehicle *automation* can take place alongside *connectivity* between: (i) vehicle-to-vehicle (V2V) (ii) vehicles and infrastructure (V2I, I2V) (iii) or both (V2X) in order to coordinate traffic. But the more a car is connected or coordinated, the *less* autonomous it is.

Therefore, the terms *autonomous* and *automated* vehicles should not be used interchangeably; rather the key characteristics are automation and connectivity (Fig. 1).
While there are synergies between these technologies and they are expected to evolve simultaneously, it is possible for a vehicle to have the characteristics of one without the other (e.g. current vehicles can be 'connected' to the traffic stream through GPS and mobile phones, without any automation).

Also, not all automated vehicles are driverless; there are different levels of automation and only Level 5 or full automation is the truly driverless one (Table 1), while Level 4 or High automation also allows driverless mode in certain conditions (e.g. motorway travel).

Figure 1: Autonomous and Connected vehicles

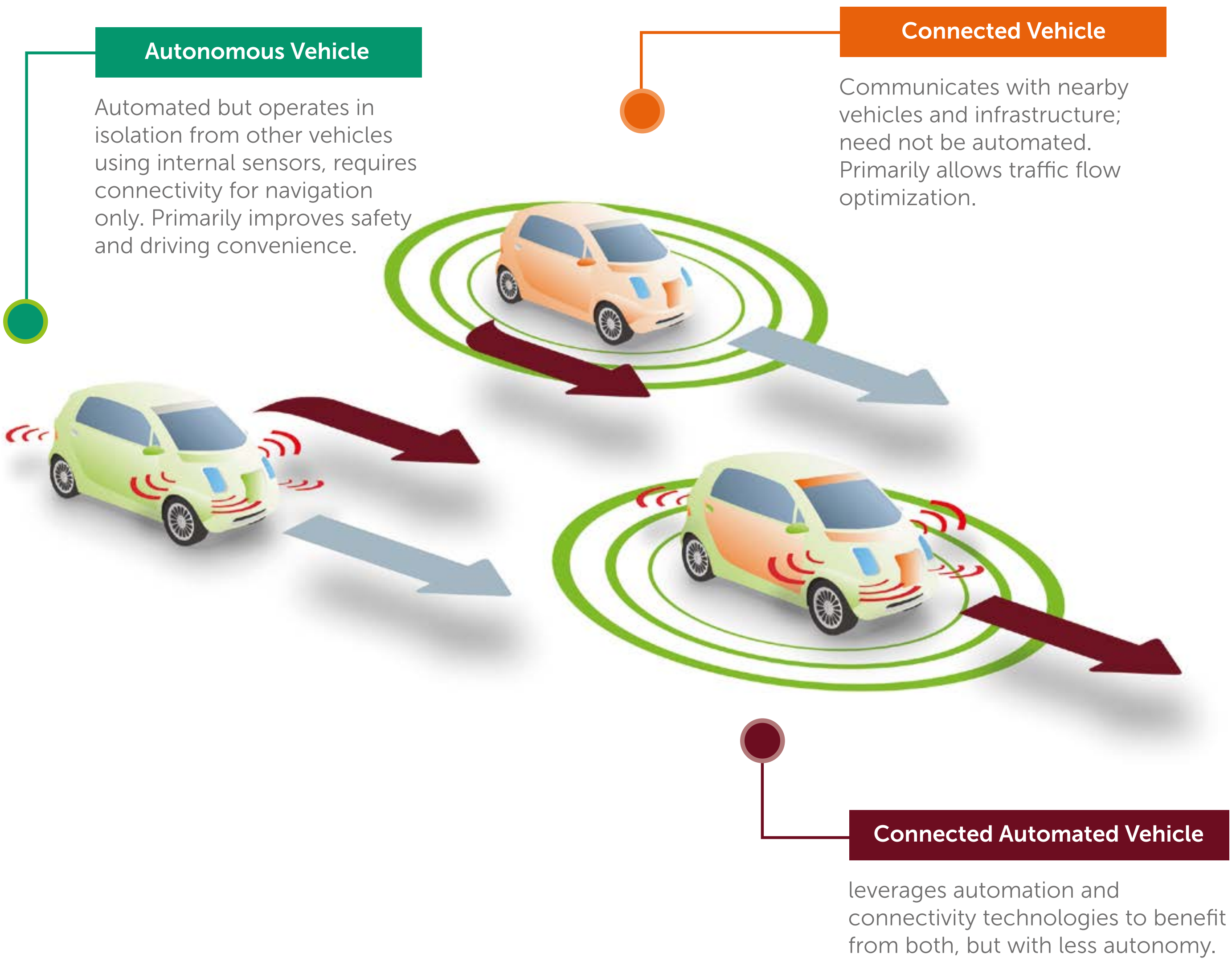
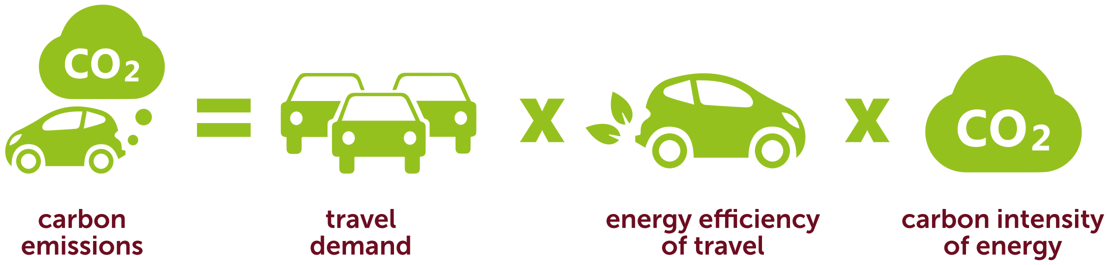


Table 1: Different levels of automation (adapted from SAE[iii] and KPMG[ii])

	SAE level	Name	Steering, acceleration, deceleration	Monitoring Driving Environment	Fallback Performance of Dynamic Driving Task	System Capability (Driving Modes)	Timeline
Human monitors environment	**0**	**No automation** The full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	🧍	🧍	🧍	n/a	Now
Human monitors environment	**1**	**Driver assistance** The *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	🚗 🧍	🧍	🧍	Some driving modes	Now
Human monitors environment	**2**	**Partial automation** The *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	🚗	🧍	🧍	Some driving modes	Now
Car monitors environment	**3**	**Conditional automation** The *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	🚗	🚗	🧍	Some driving modes	2017
Car monitors environment	**4**	**High automation** The *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	🚗	🚗	🚗	Some driving modes	2025
Car monitors environment	**5**	**Full automation** The full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	🚗	🚗	🚗	All driving modes	2025

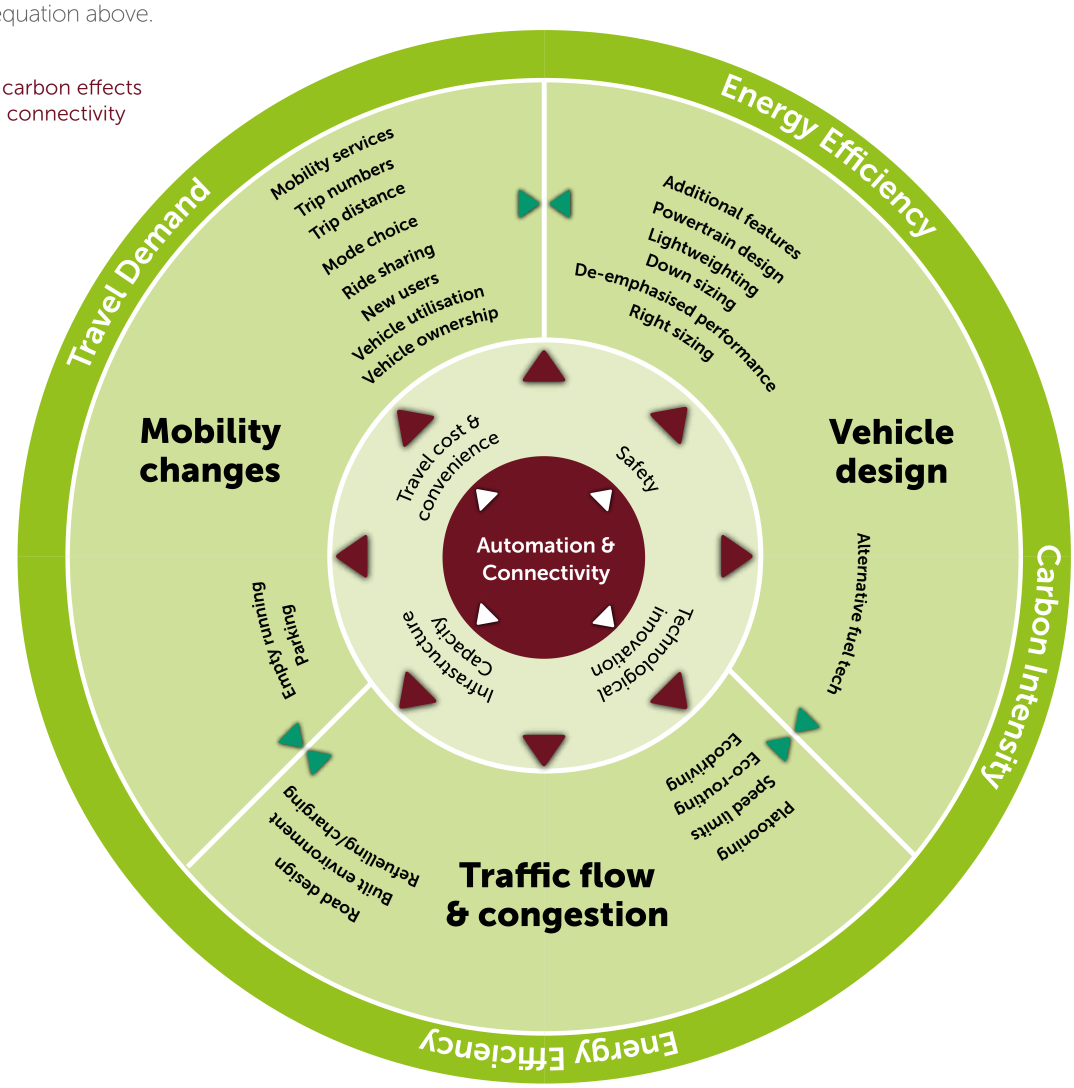
How can the carbon impacts of automation be measured?

Automation and connectivity can profoundly affect how we travel, how efficiently our vehicle runs and what fuel our vehicle uses for propulsion. These will all affect the net carbon emissions from road transport through the following equation:



These mechanisms are captured in Figure 2 , with first order impacts on the cost and convenience of travel, safety, infrastructure capacity and technological change 'rippling out' to impact a whole array of mobility system elements related to the three components in the equation above.

Figure 2: Ripple energy and carbon effects of automation and connectivity



Will automation change the way we travel?

Different levels of automation are likely to reduce driving stress, further enhance convenience and safety, allow more productive use of travel time and, potentially, reduce the marginal costs of vehicle use by various degrees.

Low levels of automation will still require driver attention and intervention in driving related tasks and are unlikely to substantially affect travel demand. However, at high or full automation (Levels 4-5) substantially reduced driving stress and demands on the driver are likely to make travel by car substantially more attractive. This, in turn, could encourage a reorganization of residential, employment and leisure location choices, lead to a ***modal shift*** from public transit, and increase the ***number of trips*** taken by automated cars. Fully automated (Level 5) cars can drop off a passenger in parking constrained city centres and self-park at a distant location resulting in ***empty running***. Full automation could also encourage completely ***new users*** to own cars, e.g. the disabled and the elderly, and possibly even those too young to drive now. All of these could substantially increase ***distance*** travelled by car (by up to 50-60%) and associated energy consumption.[iv]

On the other hand, full automation can completely eliminate the driver costs of providing ***Mobility-on-Demand*** (MoD) services (e.g. on-demand-taxis, ridesharing) making them an attractive, low-cost and accessible travel option compared to today's taxis. Increased uptake of MoD (and other ***Mobility-as-a-Service*** - MaaS - options such as car clubs) will potentially reduce private ***car ownership*** substantially and encourage ***right-sizing*** of vehicles to match the utilisation pattern, thus substantially improving energy efficiency (by up to 20-40%).[iv] However, net travel demand, energy and carbon impacts are still uncertain given the likely increased accessibility and affordability of car travel and some ***empty running*** of the fully automated cars between passenger drop-offs and pick-ups. Buses can also benefit from full automation, making them more affordable. Combining automated bus transit with automated MoD services to provide the last-mile solution is another possibility toward an integrated transport solution. All of these could reduce travel demand and energy consumption.

Table 2: Potential mechanisms for changes in **travel demand** due to automation and connectivity and their **energy effects** (adapted from Wadud et al.) [iv]

Mechanisms	Energy effect direction & size	Automation level required	Connectivity level required	Remarks
Distances travelled (location choice)	☹☹	2-5	I2V	Step changes at levels 4-5
Modal shift	☹☹☹	3-5	I2V	Step changes at levels 4-5
Trip Numbers	☹	3-5	I2V	Step changes at levels 4-5
New user groups	☹	4-5	I2V, V2I	Primarily at Level 5
Mobility on Demand	☺☺☺/☹	5	I2V, V2I	Right-sizing needed for large reduction
Empty running of vehicles	☹	5	I2V, V2I	Only at Level 5

☺ Reduction in energy use.
☹ Increase in energy use.

Will cars drive more efficiently?

Automation can enable several energy efficiency measures to be built-in to individual cars. Smart connectivity, on the other hand, helps streamline the external operating environment through *optimised traffic flow, eco-routing, reductions in traffic accidents* and reduced *congestion* and thus improve network capacity to deliver system-wide efficiency benefits.

While there is obvious synergy between automation and smart connectivity in delivering these system-wide benefits (e.g. accident reduction), smart connectivity and coordination is more important than automation. Likely energy savings are small, however.

Built-in ***automated eco-driving*** could improve a car's energy efficiency by around 5%-20%, despite some adverse network capacity effects.[iv] Automation combined with V2V connectivity allows vehicle ***platooning***, whereby a group of vehicles drive close to each other to benefit from reduced aerodynamic drag and improved energy efficiency at high speeds on motorways.

High levels of automation may facilitate changes in ***vehicle design***. The pleasure of quick acceleration during driving will likely diminish if a car drives itself, thereby reducing the need for high-performing engines (through ***de-emphasised performance*** and ***downsizing***). Much-improved safety could allow the removal of some of the crash avoidance features in vehicles leading to ***light-weighting***. However, this would require a very high uptake of automation and connectivity so that, in reality, relaxing current safety regulations may only be permitted for ***geofenced***, low-speed city driving. Large improvements in energy efficiency are also possible through ***right-sizing*** of vehicles, i.e. by dynamically matching the vehicle size to trip and occupancy type, but this is possible only if there is a move away from traditional car ownership to new mobility services. At the extreme, new single or dual-occupancy geofenced cars/pods might be possible in cities for low occupancy trips.

On the other hand, demand for ***additional in-car features*** to facilitate comfort, convenience and productive use of travel time could increase as passengers engage in 'other' activities at high and full automation (levels 4-5). In addition, increased safety would make travelling at high speeds safe, and if ***speed limits*** are relaxed, could result in an increase in energy use.

Table 3: Potential mechanisms for changes in **energy efficiency** due to automation and connectivity and their **energy effects** (adapted from Wadud et al.) [iv]

Mechanisms	Energy effect direction & size	Automation level required	Connectivity level required	Remarks
Traffic flow improvement & congestion mitigation	☺	1-5	V2X-2way	Step change at higher levels of automation & connectivity
Dynamic eco-routing	☺☺	1-5	V2X-2 way	
Automated eco-driving	☺	2-5	V2X, 2way	
Higher motorway speed limits	☹	2-5	V2X-2way	Only with regulatory changes
Vehicle platooning in motorways	☺	3-5	V2V	
Additional comfort & convenience features	☹	3-5	I2V	
De-emphasized performance	☺☺	4-5	I2V	
Light-weighting in city cars	☺☺	4-5	V2X-2way	Only with very high uptake & regulatory changes
Right-sizing	☺☺☺	5	V2I-2way	Only for MOD services

Are there synergies between automation and low carbon fuels?

An automated electric vehicle (EV) or fuel cell vehicle (FCV) would still likely cost more than an automated petrol or diesel vehicle and, as such, automation itself does not guarantee a transition to low carbon vehicles. Full automation, however, can help this transition by removing uptake barriers in several ways.

Firstly, fully automated cars could automatically travel to alternative fuel/charging stations and automatically refuel/recharge. This ***unattended refuelling/recharging*** would relieve availability constraints at work and home as well as the annoyance of more frequent recharging (EVs) or distant refuelling (FCVs) associated with the early stages of deployment. At the same time, the economics of charging stations would likely improve provided they are designed for automated, unattended dispensing or charging.

Secondly, the 'high-upfront, but low-per-mile' cost structure of alternatively fuelled vehicles make them particularly suitable for the intensive use of vehicles within MaaS or MoD operations as higher capital costs will incur shorter payback periods. ***High utilisation*** will also likely accelerate fleet turnover and the consequent introduction of new technologies.

Finally, light-weighted fully automated cars could accommodate additional battery-packs without a weight penalty (compared to EVs) in order to extend the range, therefore mitigating the ***range anxiety*** barrier associated with EVs.

Smart vehicle-to-vehicle and infrastructure connectivity is not critical to the adoption of low carbon fuels, but intelligent, live information provision about the availability and booking of refuelling/charging facilities will remain beneficial. Another ***geofencing*** innovation whereby hybrid vehicles automatically switch to electric operation within a low-emission zone can work without automation as well.

What are the non-energy impacts of automation for society?

One of the major early drivers of automation was vehicle ***safety***. 94% of accidents in the UK can be attributed to human error and automation and connectedness will reduce these accidents substantially,[i] although complete elimination is unlikely. Large safety benefits can be had through increased connectedness at early automation levels. A number of the previous energy effects, e.g. vehicle light-weighting, are also directly dependent on improved safety.

Full automation can radically improve the mobility of vulnerable groups such as the elderly and the disabled, who cannot currently drive or drive much less than their desired level. Reduction in the costs of MoD services could afford low-income groups access to cars, improving ***social inclusion and welfare***. For a connected environment, ***privacy*** remains a large concern, although autonomous operation may not have this downside.

The potential benefits of ***congestion reduction*** in a connected and automated driving environment is immense (around £15b).[v] A substantial reduction in congestion are possible through ubiquitous connectivity and coordination, at a rather low level of automation. An average UK driver spends 235 hours behind the wheel, and full automation can allow more ***productive use of time*** inside the car as the driver is freed from driving duties, with large economic benefits. However, any increases in the number of cars on the road may negate the congestion benefits to some extent.

Traffic flow improvements and automated driving will reduce emissions of air pollutants and, at higher levels of adoption, the safer and healthier road environment could encourage more walking and cycling. Once again, however, increased attractiveness of car travel without careful planning could mean that walking and cycling levels could fall overall, thus counteracting these ***public heath benefits***. Increased use cars, even if largely through shared and 'on-demand services', will have profound implications for ***urban planning***. In towns, different parking and drop-off spaces will be needed and potentially increased car distances might lead to satellite towns and villages. [vi]

Freight vehicles are likely to be one of the earliest adopters of automation. New freight transport and logistic business models will likely develop to take advantage of automation and the associated cost reductions, with knock-on effects on prices and consumer welfare. Among other industries, telecommunications will benefit directly from providing the connectivity features to the automated vehicles, while the insurance industry could see substantial changes.

Automated vehicles: automatically low carbon? Not yet ...

Automation and smart connectivity offers considerable potential to improve individual and system-wide vehicle efficiency and reduce net energy demand from road vehicles in the UK. These technologies could therefore accelerate a low-carbon transition in road transport. However, this reduction will not be a direct result of automation, but rather due to automation-facilitated changes in vehicle design, vehicle operations, the provision of mobility services and transport system optimisation.

Most importantly, the majority of the system-wide energy efficiency benefits are likely to result from high levels of connectivity and coordination between vehicles and infrastructure, not through automation per se. If the development of automated vehicles is allowed to outpace the implementation of a connected mobility ecosystem, the dangers of undesirable impacts are significantly increased. It is therefore vital that automated and connected vehicles are introduced in a properly planned environment, with clearly defined responsibilities for different stakeholders, to reap full energy and carbon benefits for society.

Some key policy recommendations to address these early considerations are presented in this briefing. Arguably the most contentious is the suggestion that automated vehicle sales may have to be deliberately restricted to specific applications and powertrains, and that wider adoption will need to go hand-in-hand with demand management policies to counter rebound travel behaviours. Taking all of this in to account, perhaps the most overarching uncertainty, yet often overlooked, is that of consumer acceptance. Public concerns over safety and data sharing, as well as social norms surrounding private car ownership, may prove to be as vital to address as some of the technical challenges. This all points to the need for considerable breadth and alignment in research, development and demonstration of automated and connected vehicle technology. It also points to a need for coordinated policy design across multiple public policy domains.

References

[i] **Department for Transport (DfT) 2015. The Pathway to Driverless Cars: Summary report and action plan,** https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/401562/pathway-driverless-cars-summary.pdf

[ii] **KPMG 2015. Connected and autonomous vehicles; The UK economics opportunity.** *A word of caution: the job figures do not include the potential job losses from commercial drivers for Level 5 automation!*

[iii] **SAE (Society for Automotive Engineers) 2014. Automated Driving:** http://www.sae.org/misc/pdfs/automated_driving.pdf

[iv] **Wadud, Z., MacKenzie, D.W., Leiby, P.N., 2016. Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles',** Transportation Research Part A: Policy and Practice, Vol. 86, pp. 1-18

[v] **CEBR 2014. The future economic and environmental costs of gridlock in 2030**, Centre for Economics and Business Research, London.

[vi] **Correia, G.H.A., Milakis, D., van Arem, B., Hoogendoorn, R. 2016. Vehicle automation and transport system performance,** in Bliemer, M.C.J., Mulley, C., Moutou, C.J., **(Eds) Handbook of Transport and Urban Planning in the Developed World,** Edward Elgar, Cheltenham

Authors

Zia Wadud
Institute for Transport Studies &
Centre for Integrated Energy Research
University of Leeds
Z.Wadud@leeds.ac.uk

Jillian Anable
Institute for Transport Studies
University of Leeds
J.L.Anable@leeds.ac.uk

Institution of Mechanical Engineers

1 Birdcage Walk
Westminster
London SW1H 9JJ

T +44 (0)20 7304 6862
F +44 (0)20 7222 8553

media@imeche.org
imeche.org

Low Carbon Vehicle Partnership

3 Birdcage Walk
London SW1H 9JJ

T +44 (0)20 7304 6880

secretariat@lowcvp.org.uk
lowcvp.org.uk

@theLowCVP'

Institute for Transport Studies

34-40 University Road
University of Leeds
Leeds LS2 9JT

Tel: +44 (0)113 3435325

info@its.leeds.ac.uk
its.leeds.ac.uk

@ITSLeeds