THE PROVISION OF RAPID CHARGING POINTS IN LONDON

The case for government intervention

Report for Addison Lee Limited
By Dr Rebecca Driver
Report by Dr Rebecca Driver, Director, Analytically Driven Ltd

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PREFACE

Addison Lee is fully supportive of the Mayor of London's comprehensive strategy to improve air quality in London.

As an operator of some 4,200 passenger vehicles in London, we are acutely aware of the need to migrate from internal combustion engines to cleaner technology, such as electric vehicles.

However, without a comprehensive rapid charging network, this transition is not possible.

For this reason we commissioned Dr Rebecca Driver, a renowned economist, to research and write this authoritative report. I believe that this study will mark a significant turning point; where we recognise the importance of installing a comprehensive rapid charging network in London to support the uptake of electric vehicles and improve air quality.

The purpose of the report is to set out the business case for installing a network at scale, and to highlight the societal and environmental impact of failing to do so. The combined economic cost of poor air quality in London is estimated at £3.6bn per year. The upfront cost of providing a comprehensive rapid charging network is around £0.5bn, meaning the case for decisive action is clear.

To this end, the forthcoming discussions on the substance of the Government’s Automated and Electric Vehicle Bill represent a significant opportunity to ensure we, collectively, set-out the necessary action and solutions to deliver the right investment in London’s rapid charging infrastructure.

While a comprehensive charging network will not be delivered overnight, there are supportive measures that will help us to make real progress in cleaning up London’s air that can be implemented now.

We believe a greater emphasis is needed to remove the most polluting taxis and private hire vehicles from London’s roads. Whilst the Toxicity Charge is a step in the right direction for lower mileage vehicles, serious consideration should be given to additional measures to cease licensing older and more polluting vehicles ahead of the Ultra-Low Emission Zone (ULEZ) implementation deadline in 2020.

In addition, we should investigate a short-term relaxation of the Zero-Emission Capable (ZEC) requirements for operators whose fleets are composed of vehicles which meet the latest European emission standards. This will be especially important while the rapid charging infrastructure is established and vehicles more suited to the private hire industry enter the market. These measures would help to remove the oldest, most polluting, vehicles from our roads and support further uptake of much cleaner vehicles in the short-term.
I hope that this report will be viewed as a positive contribution to support the case for further intervention and investment from Government to help resolve London’s air quality issues.

Andy Boland
CEO, Addison Lee
EXECUTIVE SUMMARY

Addison Lee has commissioned Analytically Driven to investigate the costs and benefits of improving the provision of rapid recharging points in London, in order to help inform the debate on how to improve air quality in London. Addison Lee, as the operator of a large fleet of private hire vehicles, is concerned that the proposed mix of recharging points in London contains insufficient provision of rapid charging points. The proposed mix means that, despite a desire to do so, Addison Lee cannot currently justify the business case for making the switch to Ultra Low Emission Vehicles (ULEVs), because the supporting infrastructure will not address its business needs.

London currently suffers from significant air pollution, much of which is generated by road traffic emissions, particularly from diesel vehicles. In addition, the Government is committed to reducing CO\textsubscript{2} emissions to help fight climate change, which requires a move away from the use of both petrol and diesel vehicles. Addressing these problems will therefore depend on London’s ability to facilitate a switch to cleaner forms of transport such as ULEVs. These potential benefits are maximised when ULEVs are being driven using battery power.

Overall the evidence presented in the report demonstrates that there is a clear case for re-examining the mix of recharging options supported by Government, in order to place greater emphasis on providing rapid recharging infrastructure in London, as well as on key transport corridors. Doing so would not only help to address the risks associated with having insufficient range, but would also help facilitate a switch to ULEVs by drivers making longer trips. While trips of more than 25 miles only account for 7% of total trips across all road types, they account for 47% of vehicle miles travelled. As it is vehicle miles, not number of trips, that determines pollution levels, facilitating switching amongst those travelling longer distances will have a much greater impact on pollution than persuading those with average usage patterns to switch. This means that facilitating a switch to ULEVs amongst fleet operators could play a particularly important role in achieving the Government’s environmental goals.

For example, as a private hire operator on average Addison Lee’s drivers travel 144 miles each shift, which is equivalent to the distance travelled by ten average commuters in London. Estimates suggest that realistically it would take a minimum of 330 rapid (43kW or 50kW) recharging points just to satisfy Addison Lee’s recharging needs, if they were to switch their fleet to ULEVs.\textsuperscript{1} If only 25% of the 108,700 taxis and private hire vehicles operating in London were to convert to ULEVs then, assuming they face the same

\textsuperscript{1} This estimate is higher than the Energy Savings Trust estimate of 140 rapid rechargers needed for the entire private hire fleet set out in Featherstone et al (2017). There are three reasons for this. Firstly the Energy Savings Trust estimate assumes that charging will take place for 10 not 9 hours a day and if they had assumed only 9 hours of charging it would have increased their estimate to round 160 rapid rechargers. Secondly the Energy Savings Trust estimates only assume that round 2850 battery electric vehicles are operated by the sector, rather than the conversion of 4,200 vehicles in Addison Lee’s fleet. Finally, the Energy Savings Trust estimate makes no allowance for contingencies, such as gaps between vehicles using the rechargers, or rechargers being out-of-order.
constraints as Addison Lee drivers, over 2,135 rapid chargers would be required just to meet the needs of this sector. If all 108,700 converted then 8,540 would be required, without considering the needs of other types of fleet operator or private users. In contrast, the current stock of rapid recharging points available in London is 75, and the plan is only to increase this to 150 by the end of 2018 and 300 by 2020.²

The benefits of switching to ULEVs

There are clear and undisputed benefits to be had from switching to the use of ULEVs, both in terms of reduced emissions of CO₂ and the reduction in air pollution, particularly NO₂ pollution. As the Government has stated:

"The reason that further action is required is that we now know more than ever before about the extent of harm caused by poor air quality. There is clear and compelling evidence of a link between exposure to air pollution, poor health and shortened life."³

The benefits of switching to ULEVs include: helping the Government to address the impact of climate change; increasing longevity (the amount of time people are expected to live); and reducing the number of costly hospital treatments that are needed to address conditions triggered by pollution. For example, estimates suggest that the combined cost of hospital admissions for respiratory and cardiovascular conditions in London in 2010 caused by short term exposure to NO₂ and PM₂.₅ pollution was £22 million in 2014 prices. In addition, the estimated economic costs associated with reduced life expectancy from exposure to NO₂ and PM₂.₅ in 2010 amounted to up to £3,631 million in 2014 prices.⁴

Encouraging the adoption of ULEVs

While the benefits to society of switching to the use of ULEVs are clear, these benefits have a significant externality associated with them. In other words, the benefits to society as a whole are greater than the benefits to individual drivers. For example, it can be shown that drivers from wealthier areas contribute to creating roadside pollution in more deprived areas, without directly suffering from the consequences. This means that there is a clear case for Government intervention in order to facilitate a switch to ULEVs.

The evidence suggests that facilitating extensive adoption of ULEVs as the preferred mode of road transport is likely to require three types of action by government: providing financial incentives to support the purchase of ULEVs; providing incentives that make the use of ULEVs more attractive compared to other types of vehicle (for

² Targets correct as of September 12, 2017.
³ See Department for Environment, Food and Rural Affairs (2017b), paragraph 132.
example as a result of preferential access to key locations); and supporting the provision of sufficient recharging infrastructure to support the use of ULEVs. Comparing the incentive structures in London to the programmes available in other global cities shows that the programmes that London has to support the uptake of ULEVs are weaker in the areas of financial incentives and the charging infrastructure.

The current stock of rapid recharging points available in London is 75, and the plan is only to increase this to 150 by the end of 2018 and to 300 by the end of 2020. However, current policy to support the introduction of a recharging network in London is largely focused on the provision of low level 3kW and 7kW charging points. Provision of 3kW and 7kW charging points clearly has an important role to play in facilitating the switch to electric vehicles by domestic users based in London. However, 3kW and 7kW charging points are much less suited to the needs of users, such as taxi and private hire vehicle drivers, who make intensive use of the road network during their working day. This different road usage pattern means that their recharging needs will be different. In particular, taxi and private hire vehicle drivers cannot spend several hours recharging in the middle of a shift, so they need to have access to a rapid charging infrastructure. This means that the mix of recharging options, not just the number of recharging points, will be important for facilitating a shift to the use of ULEVs in London.

The costs and benefits of improving the provision of rapid recharging points

In assessing whether there is a case for Government support to boost the supply of rapid recharging options in London, it is important to understand the relative costs and benefits of different types of recharging infrastructure. Estimates suggest that, taking into account the cost of the charge point, civil works, traffic order and permits, on average the cost of installing a fixed low level (7kW) charge point is around £16,000, providing there is no need to upgrade capacity at the local electricity substation. In contrast, the average cost of providing a rapid recharging point is in the region of £40,000 to £50,000. This excludes any power upgrade costs, which vary greatly but on average are around £10,000 for installing a rapid recharging point. Therefore, on average it would be possible to install up to 3.75 low level charging points for every rapid recharging point.

However, in capacity terms, the average cost of installing 1kW of charging capacity would only be £1,200 for a 50kW charger, or £1,395 for a 43kW charger, compared to £2,285 for a 7kW charger. This means that the cost for supporting a given amount of mileage using a 7kW charger is 1.9 times that of a 50kW charger and 1.6 times higher than that of a 43kW charger. Therefore, although low level charge points in residential areas help mimic the perceived benefits that earlier adopters typically enjoy, namely

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5 Targets correct as of September 12, 2017.
6 Estimated costs of different recharging options where provided by TfL.
the ability to charge their vehicle at home, it would be more cost effective to concentrate on the provision of rapid rechargers. Furthermore, there are several additional important benefits associated with rapid rechargers. In particular:

- Rapid rechargers are more likely to be used by drivers that make more intensive use of the road network. For example, Addison Lee drivers travel on average 144 miles in a shift, while average commuting distances in London are 7 miles. Therefore a single charge by an Addison Lee driver at a rapid recharging point will deliver the equivalent vehicle miles of 10 ordinary commuters travelling to and from work. In pollution terms, therefore, the rapid recharger would deliver a much larger potential reduction in pollution than spending the equivalent amount of money on low level charge points, because it is better suited to supporting drivers with high mileage.

- Rapid rechargers can support far more vehicles than a low level charge points. The theoretical charging time for a 24kW battery using low level charge point is 8 hours using a 3kW charger, or 3 hours and 25 minutes using a 7kW charger. This compares to around 30 minutes using a rapid recharger (43kW or 50kW) and 12 minutes using a 120kW super charger. In other words, assuming that the vehicles concerned needed to be fully recharged, a 3kW charge point would support a maximum of 4 vehicles a day, while the 120kW rapid recharger would support a maximum of 120 vehicles a day.

- Rapid rechargers are likely to become more important as battery sizes increase. It would take over 25 hours to fully recharge the 90kWh battery associated with the 2018 Jaguar iPace using a 3.5kW domestic recharger and almost 13 hours to fully recharge the vehicle using a 7kW charger. Increasing the capacity of domestic rechargers to overcome these prolonged charging periods is not feasible. A typical household with a 60 amp main fuse would not be able to run a 22kW charger (which requires 96 amps) and could only use an 11kW charger (which requires 48 amps) if it switched off all other high demand electrical items such as kettles, ovens and immersion heaters for the 8 hours it would take to fully recharge a 90kWh battery.

- The usage patterns for rapid rechargers are more likely to encourage multiple users per day. For example, a commuter returning from work in the evening to charge on a public low level charger in his or her residential area is unlikely to want to move their vehicle late at night once it is charged and, even if they did, it is unlikely that anyone else would get up to check if a station had become free at that time. This means that low level charging points will effectively be blocked for significant periods of time, even when they are not in use – in this example until the commuter returns in the morning. In contrast, even if users of rapid rechargers do not immediately move their vehicle after recharging has finished (for example because they have gone to the shops), it is less likely that they

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7 Earlier adopters of ULEVs typically have access to off-street parking, meaning that they can charge their vehicle at home. This is not true for most Londoners. TfL estimate that around two thirds of Londoners are dependent on on-street parking.

8 See the discussion in National Grid (2017).
The availability of rapid rechargers may have an important role in encouraging the use of ULEVs because of their role in managing risk. In particular, not only do readily available rapid recharging options help address the issue of ULEV vehicles having insufficient range to undertake long journeys, they can also help address range anxiety, which is a key barrier to the adoption of ULEVs. In addition, by influencing the likelihood and consequences of batteries having insufficient charge to complete journeys, rapid rechargers may have a role in addressing some of the behavioural biases that impact people’s willingness to take risk and cognitive biases in how people assess risk. Without a strategy to address them, these behavioural and cognitive biases might otherwise impede the adoption of ULEVs.

The rapid recharging infrastructure will play a particularly important role in facilitating a switch to ULEVs by fleet operators such as Addison Lee. Encouraging ULEV use amongst fleet operators has three potentially important benefits: its impact on the type of cars entering the second-hand car market, as fleet operators account for over 50% of the new car registrations in the UK; the benefits of the signalling that ULEV use by the taxi and private hire sector would provide, by demonstrating that ULEVs can meet the needs of those travelling long and unpredictable distances for work; and the higher environmental benefits that can be achieved by converting heavy road users to ULEVs.

Taken together these benefits mean that there is a clear case for re-examining the mix of recharging options supported by Government, in order to place greater emphasis on providing rapid recharging infrastructure in London, as well as on key transport corridors. Estimates suggest that realistically it would take a minimum of 330 rapid (43kW or 50kW) recharging points just to satisfy Addison Lee’s recharging needs, if they were to switch their fleet to ULEVs with typical 24kWh batteries. If only 25% of the 108,700 taxis and private hire vehicles operating in London were to convert to ULEVs then, assuming they face the same constraints as Addison Lee drivers, over 2,135 rapid chargers would be required.

There are also potential benefits from boosting the supply of rapid recharging points over and above the level dictated by demand, as this could help encourage the adoption of ULEVs through its impact on perceptions of risk. However, it is important to recognise that systematically boosting the supply of rapid rechargers is likely to necessitate some form of government support. This is because the reason for the provision is not solely about meeting the demand for recharging (which could therefore be priced into the use of the recharger), but also about influencing perceptions of risk. Government support would be justified because of the impact on the externalities associated with vehicle emissions.
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1.0 **INTRODUCTION**

London currently suffers from significant air pollution, much of which is generated by road traffic emissions, particularly from diesel vehicles. In addition, the Government is committed to reducing CO\textsubscript{2} emissions to help fight climate change. Addressing these problems will therefore depend on London’s ability to facilitate a switch to cleaner forms of transport such as Ultra Low Emission Vehicles (ULEVs).\(^9\) For this to happen it will be important that the infrastructure needed to support this switch is provided and in particularly that there is sufficient recharging infrastructure to support extensive use of electric vehicles. Providing this infrastructure is likely to require support from government to overcome the chicken and egg nature of this investment: if electric vehicles are not in use there is no demand for recharging points, but until recharging points are provided it is not practical for many people to switch to an electric vehicle.

Current policy to support the introduction of a recharging network in London is largely focused on the provision of low level 3kW and 7kW charging points. Provision of 3kW and 7kW charging points clearly has an important role to play in facilitating the switch to electric vehicles by domestic users based in London. However, 3kW and 7kW charging points are much less suited to the needs of users, such as taxi and private hire vehicle drivers, who make intensive use of the road network during their working day. This different road usage pattern means that their recharging needs will be different. In particular, taxi and private hire vehicle drivers cannot spend several hours recharging in the middle of a shift, so they need to have access to a rapid charging infrastructure (such as 43kW and 50kW charging points). This means that the mix of recharging options, not just the number of recharging points, will be important for facilitating a shift to the use of electric vehicles in London.

Addison Lee, as the operator of a large fleet of private hire vehicles,\(^10\) is concerned that the proposed mix of recharging points in London contains insufficient provision of rapid charging points. The proposed mix means that, despite a desire to do so, Addison Lee cannot currently justify the business case for making the switch to electric vehicles, because the supporting infrastructure will not address its business needs.

Addison Lee has therefore commissioned Analytically Driven Ltd to assess the evidence on the costs and benefits of providing a rapid recharging infrastructure and the role

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\(^9\) This report concentrates on electric vehicles, which in the short-term at least are likely to be the more viable options for encouraging the use of ULEVs. This is because a comparison of the upfront costs associated with purchasing ULEVs shows that the costs of Fuel Cell Electric Vehicles (FCEVs) are significantly higher than the costs of Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicles (PHEVs) or Extended-Range Electric Vehicles (E-REVs). In addition, the running costs are also currently higher. Electric vehicles play a particularly important role because not only are their emissions of roadside pollutants lower, they also potentially involve lower CO\textsubscript{2} emissions depending on the energy used to generate the electricity. While petrol vehicles generate less air pollution than diesel vehicles, they also generate higher CO\textsubscript{2} emissions, which is harmful for climate change.

\(^10\) Addison Lee are licenced to operate private hire vehicles under the Private Hire Vehicle (London) Act 1998. The key difference between private hire vehicles and taxis is that private hire vehicles must be pre-booked and (unlike taxis) cannot ply for hire on the streets and at ranks.
that it might play in facilitating a switch to electric vehicles. The aim is that the research will help inform the debate on how to improve air quality in London.\footnote{This includes the consultation on tackling nitrogen dioxide launched by the UK Government on the 5\textsuperscript{th} of May 2017, see Department for Environment, Food and Rural Affairs (2017a).}

In order to address the question posed, the analysis is divided into five parts: Section 2 reviews the benefits of achieving a switch to Ultra Low Emission Vehicles (ULEVs), and serves as a reminder of what is at stake; Section 3 reviews the evidence on what factors are likely to encourage a switch to ULEVs, including the role of the recharging infrastructure; Section 4 reviews the evidence on range and range anxiety and discusses the role of the rapid recharging infrastructure in helping to support a switch to ULEVs; Section 5 focuses specifically on the role of rapid recharging options in facilitating a switch to ULEVs for fleet operators; and Section 6 reviews the costs and benefits of different charging options, as well as some of the practical issues associated with providing the charging infrastructure and how these might be affected by the mix of recharging options. Finally, Section 7 concludes.
2.0 THE BENEFITS OF SWITCHING TO ULTRA LOW EMISSION VEHICLES IN LONDON – AND THE COSTS OF FAILING TO DO SO

The UK Government’s stated aim is that nearly all new cars and vans will be zero emission by 2040. To achieve this, there will therefore need to be a complete shift away from vehicles using internal combustion engines (ICEs) powered by petrol or diesel. To put this in context, only 3.3% of the 2.7 million new cars sold in the UK in 2016 were Alternatively-Fuelled Vehicles (AFVs), including low emission options such as electric vehicles, with 49.0% of cars sold being petrol cars and 47.7% of cars being diesel. Even in Norway, which has the highest share of electric vehicle sales in any market, sales of electric vehicles still only account for around 22% of vehicle sales.

Box 1 What are ultra low emission vehicles?

An ultra low emission vehicle (ULEV) is defined as a vehicle that uses low carbon technologies, emits less than 75g of CO₂/km from the tailpipe, and is capable of operating in zero tailpipe emission mode for a range of at least 10 miles. ULEVs include:

- Battery Electric Vehicles (BEVs), which are vehicles powered solely by a battery charged from the electricity grid. Typical pure electric cars currently have a range of around 100 miles.
- Plug-in Hybrid Electric Vehicles (PHEVs) are vehicles with both a plug-in battery and an internal combustion engine (ICE). Once the range of the plug-in battery has been used, the vehicle reverts to hybrid mode (utilising both battery power and ICE), without range compromise. Typical PHEVs have a pure-electric range of around 30 miles.
- Extended-Range Electric Vehicles (EREVs) are vehicles powered by a battery charged from the electricity grid, but with an ICE powered generator on board to extend the range if needed. The pure electric range of an E-REV is typically between 40 and 100 miles.
- Fuel Cell Electric Vehicles (FCEVs) are vehicles that use hydrogen gas as a fuel. Power is generated by a fuel cell stack, which is used to drive the FCEV’s electric motor. Additional power is supplied when needed from a secondary battery, which is also used to store additional short-term energy recovered from

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13 SMMT (2017).
14 Hall, Moulitak and Lutsey (2017). Sales of electric vehicles in Norway’s capital Oslo are 26.6%, around 1.2 times the national average.
15 For more details on the type of ultra low emission vehicles available see SMMT (2016).
regenerative braking. FCEVs typically have ranges of 300 miles or more.

2.1 Switching to ULEVs and the environment

The motivation for switching to ULEVs, such as electric vehicles, is environmental. In particular, as set out in Box 2, the UK Government has committed both to reduce carbon dioxide (CO₂) emissions and to ensure that air pollution caused by factors such as nitrogen dioxide (NO₂) and particulate matter (PM₂.₅) and (PM₁₀) remain below prescribed limits.¹⁶

Box 2: Key Relevant UK Environmental Commitments

Under the Climate Change Act 2008, the UK is committed to ensuring that by 2050 emissions of carbon dioxide (CO₂) will be at least 80% lower than their 1990 level.

On air pollution, under the Air Quality Standards Regulations 2010, which bring into law the EU’s Ambient Air Quality Directive (2008/50/EU), the UK is committed to ensuring that:

- Nitrogen dioxide (NO₂) levels in individual locations will average less than 40 µg/m³ a calendar year.
- NO₂ levels in individual locations will average less than 200 µg/m³ an hour, with this limit being exceeded no more than 18 times a calendar year.
- PM₂.₅ (Particulate matter which passes through the inlet of a size selective sampler with a 50% efficiency cut-off at 2.5 µm aerodynamic diameter) levels in individual locations will average less than 25 µg/m³ a calendar year.
- PM₁₀ (Particulate matter which passes through the inlet of a size selective sampler with a 50% efficiency cut-off at 10 µm aerodynamic diameter) levels in individual locations will average less than 40 µg/m³ a calendar year.
- PM₁₀ levels in individual locations will average less than 50 µg/m³ a day, with this limit being exceeded no more than 35 times a calendar year.

In the case of CO₂ emissions, comparing vehicles using an internal combustion engine shows that diesel vehicles generate lower emissions than petrol vehicles, see Table 1. This explains why historically governments sought to encourage a switch from petrol to diesel vehicles. However, even compared to diesel vehicles there are big gains to be had in terms of reducing CO₂ emissions by switching to electric vehicles, particularly

¹⁶ Air Quality Standards also set levels for factors such as sulphur dioxide and lead. The reason for focusing on NO₂ emissions is that this is the area where the UK struggles to meet the targets set by the EU. In the case of particulate matter (PM₂.₅) and (PM₁₀), although the UK has proved more effective at keeping these within the prescribed limits, exposure can still have adverse effects on health even when the levels for these emissions are below the prescribed limits, see Greater London Authority (2012).
purely battery operated electric vehicles (BEVs) which generate zero emission directly from the tailpipe (in other words the emissions produced by the vehicle itself).

Table 1  Illustrative tank-to-wheel CO\(_2\) emissions by vehicle type

<table>
<thead>
<tr>
<th></th>
<th>Petrol C Class</th>
<th>Diesel C Class</th>
<th>PHEV</th>
<th>E-REV</th>
<th>BEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO(_2)g/km</td>
<td>136</td>
<td>109</td>
<td>49</td>
<td>13</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: SMMT (2016).

While the analysis in Table 1 is based on tank-to-wheel emissions data, even if the CO\(_2\) emissions linked to energy production are included (using well-to-wheel calculations that include the emissions linked to generating the energy used), there are still significant gains to be had from switching to electric vehicles, see Figure 1. Furthermore, these gains will become more significant as the use of renewable energy sources increase. Making this switch is therefore important if climate change policy is to be successful in achieving its goals. Indeed, the evidence suggests that even with a complete switch in passenger vehicles to BEVs and a significant increase in the use of solar power, the UK will still struggle to meet its climate change goals.\(^{17}\)

Figure 1  A comparison of CO\(_2\) emissions from electric and internal combustion engine vehicles

Note: The calculations assume that the country’s average generation portfolio is used to charge electric vehicles. The figures for the fuel cycle are those for the generation of the energy used. In the case of the petrol and diesel used in internal combustion engines this includes emissions from production, refining and distribution activities. Based on analysis of 14 metropolitan regions: Beijing, Shanghai and Shenzhen in China; Copenhagen in Denmark; Paris in France; Amsterdam and Utrecht in the Netherlands; Oslo in Norway; Stockholm in Sweden; Zurich in Switzerland; London in the UK; and San Jose, San Francisco and Los Angeles in California in the US.

Source: Hall, Moultak and Lutsey (2017).

\(^{17}\) See the discussion in Sussams and Leaton (2017).
One of the problems with addressing the environmental impacts of vehicle emissions is that, at least comparing ICEs, the solution that works best for one type of emission can be worse for other emission types. While diesel engines do better in terms of tailpipe emissions of CO\textsubscript{2}, they perform worse in terms of emissions of NO\textsubscript{X}. For example, petrol cars produced using the current Euro 6 standards cars have target NO\textsubscript{X} emissions of a maximum of 0.06g/km compared to a target of 0.08g/km for diesel cars. Furthermore, estimates suggest that for cars produced using the current Euro 6 standards, petrol cars have real world emissions of 0.06g/km compared to real world emissions of 0.6g/km for diesel cars, making the differences even starker.\textsuperscript{18} As Figure 2 shows, sometimes, even between different types of vehicle using the same fuel, differences in how the engines are structured can switch the relative performances of different types of emission. Real world comparisons of the performance of trucks and cars built using the most recent European standards shows that trucks do better on NO\textsubscript{X} emissions but worse on CO\textsubscript{2} emissions.

**Figure 2** Average real world NO\textsubscript{X} and CO\textsubscript{2} emissions of Euro V/VI/6 heavy-duty and light-duty diesel vehicles

Note: On average NO\textsubscript{X} emissions per kilometre from diesel cars are more than double those of diesel trucks, even though CO\textsubscript{2} emissions from trucks are five times those of diesel cars.

Source: Muncrief (2016).

In terms of the impact of vehicle emissions, the situation in London is particularly acute. As demonstrated in Figure 3, London, particularly the area of central London

\textsuperscript{18} See Department for Environment, Food and Rural Affairs (2017b).
together with the major road network serving Greater London, suffers from significant air pollution. Government forecasts suggest that while roads in all other local authorities will meet statutory annual mean limits for NO₂ by 2030, in the case of the Greater London Authority there will still be 41 roads with pollution levels above the statutory limit in 2030, albeit down from 103 roads in 2017.¹⁹

**Figure 3**  Annual mean NO₂ concentration in 2013 in Greater London

![Annual mean NO₂ concentration in 2013 in Greater London](image)

**Note:** Under EU law the maximum annual mean NO₂ allowable is 40 µg/m³.

**Source:** Aether (2017).

This means that it will be particularly important to find ways to bring down air pollution levels in London, while at the same time also working to meet CO₂ targets. As roadside emissions from vehicles account for by far the largest share of roadside NOₓ concentrations in London, it is clearly the case that shifting to ULEVs will be an important part of any solution. The motivation for making this shift is clear. As the Government has stated:

“The reason that further action is required is that we now know more than ever before about the extent of harm caused by poor air quality. There is clear and compelling evidence of a link between exposure to air pollution, poor health and shortened life.”²⁰

¹⁹ See Department for Environment, Food and Rural Affairs (2017b).

²⁰ See Department for Environment, Food and Rural Affairs (2017b), paragraph 132.
2.2 Impact of air pollution on longevity and health

As can be seen from Table 2, the pollution levels experienced in London have serious implications for life expectancies. In the case of males, for example, the impact of exposure to the NO\textsubscript{2} pollution experienced in London in 2010 is estimated to have caused on average a 17 month reduction in life expectancy and the PM\textsubscript{2.5} exposure a 9.5 month reduction in life expectancy.\textsuperscript{21} Taken together the result of the combined impact of NO\textsubscript{2} and PM\textsubscript{2.5} pollution is estimated to have led to up to 140,743 life years being lost in 2010. However, it is noticeable that even an extremely modest reduction in pollution levels in London (of just 1µg/m\textsuperscript{3}) could result in a significant number of life years gained, if it could be sustained for the period 2010-2114.

Table 2  Impact on mortality and life expectancy of exposure to 2010 concentrations of PM\textsubscript{2.5} and NO\textsubscript{2} in London

<table>
<thead>
<tr>
<th></th>
<th>Anthropogenic PM\textsubscript{2.5}</th>
<th>NO\textsubscript{2} (less 30% overlap with PM\textsubscript{2.5} exposure)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life years lost as a result of equivalent deaths in 2010</td>
<td>52,630</td>
<td>88,113</td>
<td>Up to 140,743</td>
</tr>
<tr>
<td>Equivalent deaths at typical ages in 2010</td>
<td>3,537</td>
<td>5,879</td>
<td>Up to 9,416</td>
</tr>
<tr>
<td>Male average loss of life expectancy if exposed to 2010 concentrations for a lifetime</td>
<td>9.5 months</td>
<td>17 months</td>
<td>n/a</td>
</tr>
<tr>
<td>Female average loss of life expectancy if exposed to 2010 concentrations for a lifetime</td>
<td>9 months</td>
<td>15.5 months</td>
<td>n/a</td>
</tr>
<tr>
<td>Life years gained over the period 2010-2114 from a sustained 1µg/m\textsuperscript{3} reduction in pollutant relative to 2010 levels.</td>
<td>573,145</td>
<td>376,334</td>
<td>Up to 949,479</td>
</tr>
</tbody>
</table>

Note: The estimates presented represent the central estimates. However, there are significant uncertainties associated with these estimates, including how to calculate the impact of exposure to both types of pollutant. A life year is one year lived for one person. Equivalent deaths at typical ages are the deaths that would account for the loss of life years due to the pollutant being considered.


The estimates in Table 2 suggest the impacts of air pollution on life expectancy and mortality are most severe in the case of exposure to NO\textsubscript{2}. This is important, because in the case of NO\textsubscript{2} pollution around two thirds of the pollution experienced in London comes from within London itself, see Figure 4. In contrast, in the case of PM\textsubscript{2.5} pollution over 70% of the pollution experienced in London is generated from sources outside London. Therefore management of NO\textsubscript{2} pollution levels, for example through

\textsuperscript{21} In practice the impacts of exposure to air pollution will not be evenly spread throughout the population. Vulnerable groups like the old and the young will see the most severe impacts on their health.
the introduction of ULEVs, is something that is more manageable through London-based policy initiatives.

**Figure 4** Source of the mortality burden associated with exposure to 2010 levels of PM$_{2.5}$ and NO$_2$ in London

![Figure 4 Source of the mortality burden](image)

**Note:** The mortality burden is life years lost and equivalent deaths. Assumes a 30% overlap between the impact of the PM$_{2.5}$ and NO$_2$ exposure. *It is not possible to differentiate between roadside and non-roadside London sources of NO$_2$.*

**Source:** Watson et al (2015)

Furthermore, it is important to recognise that while emissions of NO$_X$ by diesel vehicles are responsible for a significant number of premature deaths each year, as set out in Figure 5, the majority of those deaths are not in fact linked to excess emissions. This means that a policy of encouraging electric car use will be more effective than simply ensuring that diesel vehicles comply with emission standards.

**Figure 5** Annual premature deaths attributable to on-road diesel vehicle NO$_X$ emissions, 2015

![Figure 5 Annual premature deaths](image)

**Note:** *Counts only those premature deaths resulting from NO$_X$ emissions produced in the other regions shown here.*

**Source:** ICCT (2017).
While the impact of air pollution on longevity is clearly extremely serious, as shown in Figure 6, in practice the impact on longevity represents the tip of the iceberg in terms of the costs associated with air pollution. These costs are particularly felt by the young and the elderly.

**Figure 6  Impact of air pollution on health**

Note: Based on WHO analysis.
Source: Greater London Authority (2012).

For example, looking beyond simply the impact on life expectancy, there were an estimated 1,992 hospital admissions due to respiratory problems and 740 due to cardiovascular problems as a result of short term exposure to PM$_{2.5}$ in London in 2010. Similarly, there were an estimated 419 hospital admissions due to respiratory problems associated with short term exposure to NO$_2$.\footnote{22 See Watson et al (2015).} For just these two conditions, in 2014 prices the combined cost of hospital admissions amounted to £22 million in 2010, see Table 3. However, beyond that the costs associated with pollution will be significantly higher, including doctors’ appointments and days lost from work.

**Table 3  Estimated annual monetised costs of air pollution in London at 2014 prices**

<table>
<thead>
<tr>
<th></th>
<th>Exposure to 2010 levels of PM$_{2.5}$</th>
<th>Exposure to 2010 levels of NO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality costs</td>
<td>£1,358 million</td>
<td>£2,273 million</td>
</tr>
<tr>
<td>Cost of respiratory hospital admissions</td>
<td>£14 million</td>
<td>£3 million</td>
</tr>
<tr>
<td>Cost of cardiovascular hospital admissions</td>
<td>£5 million</td>
<td></td>
</tr>
</tbody>
</table>

Note: The estimates presented represent the central estimates. However, there are significant uncertainties associated with these estimates, including how to calculate the impact of exposure to both types of pollutant. This has been accounted for by reducing the costs of exposure to NO$_2$ by 30%.

Over and above costs such as the cost of the hospital admissions themselves, there are also economic costs associated with the reduced life expectancy. In 2010 these costs amounted to up to £3,631 million in 2014 prices.

2.3 The justice implications of pollution

Another problem associated with pollution occurs when the source of pollution is not where the effects are felt most strongly, as this can create perceptions of injustice. This is particularly true where those in more deprived areas are suffering from pollution. In general the evidence typically suggests that residents in more deprived areas face higher levels of pollution.

In the case of vehicle NO\textsubscript{X} emissions, what is evident from the data is that wealthier households in England generally face lower levels of exposure, but their own personal driving behaviours are liable to create higher levels of emissions, see Figure 7. This raises questions about environmental justice. The situation in London is slightly more complicated, because the wealthy areas of central London face high levels of air pollution. However, what is clear is that there are significant levels of NO\textsubscript{2} pollution around the main arterial routes into central London and these routes are often in more deprived areas, see Figure 8.

**Figure 7** Percentage of households in poverty against annual mean NO\textsubscript{2} concentrations (left) and total private vehicle NO\textsubscript{X} emissions from vehicles owned by residents (right)

![Graph showing percentage of households in poverty against NO\textsubscript{2} concentrations and total private vehicle NO\textsubscript{X} emissions.](image)

**Note:** LSOA stands for Lower-layer Super Output Areas. There are 34,753 LSOA in the 2011 Census in England and Wales. Background pollution data come from Defra. MOT data on mileage, vehicle type, fuel type and engine size are used to calculate total and average NO\textsubscript{X} emissions for all private vehicles registered in each LSOA. Error bars indicate 95% confidence intervals.

**Source:** Barnes and Chatterton (2016)
Figure 8  Locations of the 30% most deprived LSOA in Greater London compared to areas where NO$_2$ levels exceed annual limits

Note: LSOA stands for Lower-layer Super Output Areas. There are 34,753 LSOA in the 2011 Census in England and Wales.

Source: Aether (2017).
3.0 SWITCHING TO ULTRA LOW EMISSION VEHICLES

As set out above, reducing vehicle emissions will bring significant benefits. These benefits are not just in the form of helping to tackle climate change or increased life expectancy. They are also directly linked to the potential to cut the costs of health care linked to emissions. The lower emissions are, the greater the potential benefits will be.

National and local governments are therefore working to find ways to promote more widespread use of ultra low emission vehicles (ULEVs). To do this successfully, they will need to ensure that cars such as electric vehicles are attractive to different market segments. At the moment private ownership of ULEVs is heavily concentrated amongst middle-aged, well-educated, affluent males who live in urban households containing two or more cars and who have the ability to charge at home. Therefore unless ULEVs start to appeal to a wider audience, it will not be possible to realise the potential gains from falling emissions.

So what does the evidence suggest could change the mix of vehicles sold in the UK and, in particular, what factors are likely to influence demand for electric vehicles?

3.1 The role of price in sales of ULEVs

One factor that will clearly be important in take-up is price. Although the prices of ULEVs have been falling, as shown in Table 4 the retail price of ULEVs is significantly higher than typical petrol and diesel cars. While the Government’s Plug-in Car Grant (PiCG) and differences in Vehicle Excise Duty mean that the discrepancies in the upfront costs are slightly lower than for retail prices, they still remain significant.

In the case of the upfront costs associated with purchasing ULEVs, it is clear that the costs of Fuel Cell Electric Vehicles (FCEVs) are significantly higher than the costs of Battery Electric Vehicles (BEVs), Plug-in Hybrid Electric Vehicles (PHEVs) or Extended-Range Electric Vehicles (E-REVs). In addition, the running costs are also currently higher. For this reason, this report concentrates on electric vehicles, which in the short-term at least are likely to be the more viable options for encouraging the use of ULEVs.

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23 See Box 1 for the definition of ULEVs.
24 See the discussion in Brook Lyndhurst (2015).
Table 4  Illustrative running costs for ULEVs compared to petrol and diesel vehicles over three years

<table>
<thead>
<tr>
<th></th>
<th>Petrol C class</th>
<th>Diesel C Class</th>
<th>PHEV</th>
<th>E-REV</th>
<th>BEV</th>
<th>FCEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail price</td>
<td>£15,890</td>
<td>£17,115</td>
<td>£32,465</td>
<td>£33,100</td>
<td>£25,935</td>
<td>£53,105</td>
</tr>
<tr>
<td>Total upfront cost</td>
<td>£16,070</td>
<td>£17,190</td>
<td>£30,020</td>
<td>£30,655</td>
<td>£21,490</td>
<td>£53,160</td>
</tr>
<tr>
<td>Fuel costs</td>
<td>£4,716</td>
<td>£3,525</td>
<td>£2,118</td>
<td>£1,446</td>
<td>£1,449</td>
<td>£5,711</td>
</tr>
<tr>
<td>Total three year running costs</td>
<td>£6,088</td>
<td>£5,145</td>
<td>£3,551</td>
<td>£2,646</td>
<td>£2,753</td>
<td>£6,161</td>
</tr>
<tr>
<td>Residual value after three years</td>
<td>£6,375</td>
<td>£6,454</td>
<td>£10,145</td>
<td>£12,531</td>
<td>£8,340</td>
<td>TBC</td>
</tr>
<tr>
<td>Total cost of ownership</td>
<td>£15,783</td>
<td>£15,881</td>
<td>£23,426</td>
<td>£20,770</td>
<td>£15,903</td>
<td>TBC</td>
</tr>
</tbody>
</table>

**Note:** Based on data from Go Ultra Low. The difference between the retail price and the total upfront costs are the grants received under the PICG, the Vehicle Excise Duty and the Registration Fee. Running costs are estimated assuming distances of 36,000 miles over three years. In the case of fuel costs for hydrogen vehicles, it is assumed that these will be £10/kg. The difference between the fuel costs and total running costs is the cost of insurance and servicing. The residual value is the estimated price on the second-hand car market. Estimates suggest that ULEV residual values are competitive with similar sized ICE vehicles. The total cost of ownership after three years consists of the total upfront costs plus the total running costs minus the amount an owner would get back by selling the car on the second-hand car market. ICE stands for internal combustion engine, BEV is battery electric vehicle, PHEV is Plug-in hybrid electric vehicle, E-REV is Extended-range electric vehicle and FCEV is Fuel Cell Electric Vehicle.

**Source:** SMMT (2016).

Even after the availability of grants and other government incentives, the difference in the upfront costs between petrol and diesel ICES and electric vehicles are much higher than the differences in the total costs of ownership, particularly in the case of BEVs. This is in part because fuel costs for electric vehicles are expected to be much lower than for other options. However, the evidence suggests that consumers tend to heavily discount savings in running costs such as the cost of fuel. This means that consumers may not fully factor in these benefits when considering their options. In addition, although the evidence to date suggests that that the values retained in ULEVs are similar to the values retained in petrol and diesel cars on the second-hand market, the size of ULEV market is currently a small fraction of the total second-hand market and there is little consensus on how residual values for electric cars will evolve. This creates additional uncertainty about the benefits of owning ULEVs.

Recent forecasts from the Carbon Tracker Initiative and the Grantham Institute make clear how important price differentials will be in the development of the electric car market. Compared to the cost estimates from 2014, where the relative costs of producing electric vehicles were only expected to fall below those for internal

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25 See the discussion in Brook Lyndhurst (2015).
26 See the discussion in SMMT (2016).
combustion engines in 2050, recent developments and cost reductions in the electric vehicle market mean that costs are now forecast to fall below those for internal combustion engines by 2020 at the latest. Based on the new cost forecasts, the estimates suggest that by 2050 BEVs will account for 69% of the global road transport market (essentially the entire passenger vehicle fleet), regardless of whether climate policies are strengthened further or not. However, if instead costs mirror the path anticipated in 2014, then the forecasts show that BEVs will not be part of the road transport market in 2050. Furthermore, under this high cost scenario, only under a strengthened climate policy will there be a role for PHEVs in the vehicle market, but even then their market share will only be 8%.27

3.2 Encouraging the adoption of ULEVs

The UK Government is keen to facilitate extensive adoption of ULEVs such as electric vehicles as the preferred mode of road transport. The evidence suggests that achieving this aim is likely to require three types of action by government: providing financial incentives to support the purchase of ULEVs; providing incentives that make the use of ULEVs more attractive; and supporting the provision of sufficient recharging infrastructure to support the use of ULEVs. In the case of London, comparing its incentive structures to the programmes available in other global cities, the programmes London has to support the uptake of electric vehicles are weaker in the areas of financial incentives and the charging infrastructure, see Figure 9.

**Figure 9** Qualitative evaluation of electric vehicle support actions in main electric vehicle markets

<table>
<thead>
<tr>
<th>Country</th>
<th>City</th>
<th>Financial incentives</th>
<th>Nonfinancial incentives</th>
<th>Charging infrastructure</th>
<th>Research and campaigns</th>
<th>Transit and fleets</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Shanghai</td>
<td>++</td>
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<td>+</td>
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<td>Shenzhen</td>
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<td>+</td>
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<td>Beijing</td>
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<td>Paris</td>
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<td>Amsterdam</td>
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<td>London</td>
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<td>United States</td>
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<td>San Francisco</td>
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<td>+</td>
</tr>
<tr>
<td></td>
<td>Los Angeles</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

**Note:** A blank indicates no known policy action, + some action, and ++ extensive action.

**Source:** Hall, Moultak and Lutsey (2017).

27 See the discussion in Sussams, and Leaton (2017).
3.2.1 The role of financial incentives to support the purchase of electric vehicles

The discrepancy in retail prices, combined with the uncertainties associated with the total cost of ownership calculations, mean that there is currently a clear role for government intervention in order to encourage sales of ULEVs. Such intervention will help a relatively new technology compete in an established market and in doing so will help overcome the externalities associated with vehicle emissions.

All 14 of the largest global metropolitan markets for electric vehicles had some form of financial incentive in place. Collectively these 14 metropolitan markets accounted for 32% of global electric vehicle sales in 2015, despite having just 1.5% of the global population. In the case of the three largest markets in California, for example, the financial incentives included a Federal tax credit of up to $7,500 and a state rebate of up to $2,500.\(^{28}\)

In the case of the UK, the Plug-in Car Grant helps address the gap in upfront costs, although smaller incentives, such as differences in Vehicle Excise Duty rates, also help. The current levels of Plug-in Car Grants are shown in Table 5.

**Table 5**  UK Government Plug-in Car Grant, as at 5 June 2017

<table>
<thead>
<tr>
<th>Category</th>
<th>CO(_2) emissions</th>
<th>Zero emissions range</th>
<th>Grant</th>
<th>Maximum Grant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Under 50g/km</td>
<td>At least 70 miles</td>
<td>35% of cost</td>
<td>£4,500</td>
</tr>
<tr>
<td>2</td>
<td>Under 50g/km</td>
<td>10 to 69 miles</td>
<td>35% of cost</td>
<td>£2,500*</td>
</tr>
<tr>
<td>3</td>
<td>50 to 75g/km</td>
<td>At least 20 miles</td>
<td>35% of cost</td>
<td>£2,500*</td>
</tr>
</tbody>
</table>

*Note:* *Only available for vehicles with a recommended retail price of less than £60,000. The Plug-in Car Grant (PiCG) only applies for new cars.*

While significant differences in prices remain, schemes such as the Plug-in Car Grant can help stimulate the market for electric vehicles. However, over time it is likely that the price differentials will shrink. In particular, rising demand for electric cars and falling costs, reflecting the benefits of research and development activities, will help electric car manufacturers achieve economies of scale. Therefore, it will be important for governments to review the incentives they offer, in order to ensure that they do not distort the market.

3.2.2 The role of incentives that make the use of electric vehicles more attractive

While financial incentives to support the purchase of electric vehicles are important, the evidence is clear that other types of incentives play an equally important role in

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\(^{28}\) Hall, Moultaik and Lutsey (2017). These 14 metropolitan regions were: Beijing, Shanghai and Shenzhen in China; Copenhagen in Denmark; Paris in France; Amsterdam and Utrecht in the Netherlands; Oslo in Norway; Stockholm in Sweden; Zurich in Switzerland; London in the UK; and San Jose, San Francisco and Los Angeles in California in the US.
THE PROVISION OF RAPID CHARGING POINTS IN LONDON

boosting sales of electric vehicles. Typical incentives include programmes such as: access to bus lanes; access to carpool lanes (sometimes referred to as high-occupancy lanes); exemption from congestion charges; free or reduced cost parking; exemptions from regulations banning vehicle access; and activities designed to improve the information available to help decision making, such as outreach and education. In addition to these types of incentives, typical incentives to boost the use of electric vehicles also encompass the recharging infrastructure. As can be seen from Figure 10, both the number of incentive programmes used and the extent of the public recharging infrastructure appear to have a positive impact on electric vehicle sales.

Figure 10 Electric vehicle promotion activities, charging infrastructure and electric vehicle share of new vehicles in the 25 most populous US metropolitan areas

Note: The analysis allows for 29 different types of incentive, encompassing incentives at federal, state, city, infrastructure and utility levels. Of the 29 possible support activities: 5 were financial incentives to purchase electric vehicles; 8 were incentives that make the use of electric vehicles more attractive; 5 were programmes designed to improve the information available; and 11 were linked to providing the appropriate charging infrastructure. Registration data was provided by IHS Automotive.


In the case of London, beyond the role of the PiCG, the main incentives provided are linked to exemptions from the congestion charge for entering central London, but some London Boroughs also offer free or reduced cost parking. Currently cars entering the Congestion Zone in central London are exempt from the £11.50 daily charge, if they are either a BEV or a PHEV that meets the Euro 5 standard. From October 2017 a new Toxicity Charge (T-Charge) will also apply for the most polluting vehicles (defined as cars that fail to meet the Euro 4 standards) entering the

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29 See, for example, the discussion in Brook Lyndhurst (2015) and Hall, Moultak and Lutsey (2017).
30 See Hall, Moultak and Lutsey (2017).
31 Congestion charges apply for vehicles entering the congestion zone between 7am and 6pm on Monday to Friday.
congestion zone during peak hours, which again would not apply to BEV cars or PHEVs that meet the relevant standard. From September 2020 the Congestion Zone will become an Ultra Low Emission Zone (ULEZ), where charges for entry will apply 24 hours a day for any vehicle failing to meet Euro 4 standards for petrol cars and Euro 6 standards for diesel cars.32

3.2.3 The importance of the recharging infrastructure

Over and above the financial and non-monetary incentives that are provided, the evidence is also clear that the availability of an adequate recharging infrastructure plays an important role in encouraging sales of electric vehicles.33 The reason is that access to charging infrastructure gives drivers more confidence to use the full range of their vehicles and therefore extends the functional daily range of vehicles. In the case of California, for example, there are roughly 281 public charging points per million residents, allowing the state to support a market share for electric vehicles of 3.7%. In contrast, in the rest of the US there are on average 87 charging points per million people and the share of electric vehicles is just 0.5%, see Figure 11.34

**Figure 11** Electric vehicle market share and public charging infrastructure per capita for California and other US metropolitan areas

Note: The size of each circle represents the number of new electric vehicle registrations by metropolitan area. The 13 labelled metropolitan areas are those with the highest electric vehicle sales in California, and together account for 97% of the state’s electric vehicle market. Public charge points consist of both Level 2 (which supply 6.6kW) and direct current fast charge points (which supply 48kW).


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32 Transport for London has been consulting on whether to bring forward the introduction of the ULEZ to April 2019.
33 See, for example, the discussion in Brook Lyndhurst (2015), Lutsey (2017), Sussams and Leaton (2017) Lutsey et al (2015) and Hall, Moultak and Lutsey (2017).
34 Lutsey (2017).
Different types of recharging infrastructure also fulfil different roles. The current market for electric vehicles is highly concentrated amongst richer, urban users with access to off-street parking, meaning they tend to charge their vehicles overnight at home. It is likely that this overnight charging pattern will continue to be the prevalent model for domestic users, albeit supplemented by the use of relatively slow on-street 3kW and 7kW charging stations in residential areas for those without access to off-street parking. However, greater reliance on public charging infrastructure, together with the need to persuade those taking longer journeys to switch to electric vehicles, also means that there will be a growing role for rapid recharging options. As can be seen from Figure 12, the provision of rapid charging points is also highly correlated with the share of electric vehicle sales.

**Figure 12  Electric vehicle market share and fast charging infrastructure per capita for 11 global metropolitan areas**

![Electric vehicle market share and fast charging infrastructure per capita for 11 global metropolitan areas](image)

**Note:** Data from Hall, Moulak and Lutsey (2017) for the provision of direct current fast charge points (which supply 48kW) in 11 metropolitan regions: Copenhagen in Denmark; Paris in France; Amsterdam and Utrecht in the Netherlands; Oslo in Norway; Stockholm in Sweden; Zurich in Switzerland; London in the UK; and San Jose, San Francisco and Los Angeles in California in the US. The red dot represents London’s position. Oslo has by far the highest share of electric vehicle sales as well as the highest provision of fast charging options.

**Source:** Analytically Driven Ltd
4.0 **HOW THE CHARGING INFRASTRUCTURE INFLUENCES A THRIVING ULEV MARKET**

Many of the key challenges associated with shifting the passenger car market in London to one where ULEVs are the car of choice are linked to the range of the vehicles on offer. Range can influence sales of ULEVs directly, if when fully charged the ULEV models on offer do not have sufficient range for people's needs. However, range can also influence people’s choices indirectly, depending on their perception of the risks associated with having insufficient range to complete their journeys. This makes it important to provide sufficient recharging options to support the change to ULEVs, including options that help people with the risk management aspects of undertaking journeys in ULEVs. Rapid recharging options therefore provide potentially important benefits as a way of meeting these challenges.

4.1 Range and recharging

In order to encourage a shift to ULEVs, it will be important that they can deliver sufficient range to meet people’s needs. As set out in Box 1, SMMT analysis suggests that the pure electric range associated with ULEVs is currently: around 100 miles in the case of Battery Electric Vehicles (BEVs); around 30 miles in the case of Plug-in Hybrid Electric Vehicles (PHEVs); and between 40 and 100 miles in the case of Extended-Range Electric Vehicles (E-REVs).

The environmental benefits of switching to ULEVs are maximised when they are operating on battery power, rather than the backup options associated with PHEVs and E-REVs. Therefore, for journeys to be undertaken using purely battery power (given the current models available), road use patterns will need to be based entirely around trips that are less than a maximum of 50 miles, to allow consumers to get both there and back on a single charge. Alternatively, effective top-up recharging options need to be provided.

In the case of travel patterns in England, as Figure 13 shows, journeys of more than 50 miles account for only 3% of trips across all types of road, 12% of trips on motorways that are part of the strategic road network (SRN) and 2.2% of trips on ‘A’ roads that are parts of the SRN. Therefore, in theory consumers would be able to undertake most trips using battery power given the current range of ULEVs available.

However, from the point of view of pollution, what is important is not the number of trips that are undertaken, but the number of vehicle miles that are driven on a stretch of road. From that perspective, what Figure 13 shows is that, while the number of trips made by those travelling long distances is low, the impact of those trips on road usage is much more significant. In particular, 28% of vehicle miles travelled on all types of

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35 SMMT (2016).
36 See the discussion in Section 2.
road involve journeys of more than 50 miles, with this type of trip accounting for 42% of vehicle miles on motorways that are part of the SRN and 18% of vehicle miles on ‘A’ roads that are parts of the SRN.

**Figure 13 Trip distances by road type**

Furthermore, given the potential battery operated range of PHEVs and some E-REVs is shorter than for BEVs, it is also important to consider road usage at shorter distances, if battery-only travel is to be maximised. In total 47% of vehicle miles travelled on all roads involve journeys of 25 miles or more, 68% of trips on motorways and 41% of trips on ‘A’ roads.

Given this road usage pattern, it will be important that any strategy to reduce air pollution in London also tackles how to facilitate a switch to ULEVs by those travelling longer distances. Without this, it will not be possible to tackle pollution levels effectively on many of the most polluted roads in London, which are the key ‘A’ roads and motorways serving the city. This is particularly true as London is a key destination both for work and leisure within the UK and many of the journeys made by those travelling to London will involve a car. For example, the 2011 Census shows that over a quarter of workers with jobs in London travel to work by car.
One issue that is likely to influence the use of ULEVs will be how convenient it is to recharge vehicles quickly when on long journeys. For example, in California there is recognition of the need to ensure that there are sufficient rapid recharging options both in urban locations and also on key transport corridors, in order to encourage the use of ULEVs.\textsuperscript{37}

While not all vehicles are able to use all types of recharging point, there are clear differences in relative charge times when comparing rapid recharging options to typical domestic options, see Figure 14. Outside workplace and domestic situations where vehicles can more easily be left to charge over longer periods, drivers are particularly likely to value the speed of recharging options, and by extension how long it will take them to obtain the range they need, when evaluating the benefits of ULEVs.

**Figure 14** Theoretical charging times by type of charger

![Figure 14: Theoretical charging times by type of charger](image)

**Note:** Theoretical time needed to fully charge a 24kW battery by charger type. Note not all electric vehicles are able to use all types of recharger. Batteries may take longer to charge in practice if there are inefficiencies involved in their ability to take the charge.

**Source:** Analytically Driven Ltd

### 4.2 Role of recharging options in risk assessment – range anxiety

One of the barriers that is often mentioned in connection with the adoption of electric vehicles is range anxiety – the worry that an electric vehicle will not reach its destination without running out of charge.\textsuperscript{38} This type of problem could occur for several distinct reasons: the distance proposed for a single trip is beyond the range of the vehicle; a necessary diversion might increase the distance travelled beyond the range of the vehicle; there is insufficient time to recharge properly between trips; an

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\textsuperscript{37} See, for example, the discussion in California Energy Commission (2014) and AESC (2015).

\textsuperscript{38} See, for example, the discussion in Brook Lyndhurst (2015).
emergency means that the vehicle is needed when it has not been fully recharged; or a charging point is not available when the vehicle would normally be charged. In each case clearly available rapid recharging options could help address these types of concerns, by providing consumers with a viable strategy to overcome the perceived problem.

How consumers weigh up the risks associated with range anxiety will depend not only on the probability of the risk occurring, but also any behavioural or cognitive biases that influence how they evaluate these risks. (See Box 3 for a discussion of the types of biases that might influence people’s assessment of risk.) To the extent that these biases are likely to make people more risk averse, it may therefore be advantageous to boost the supply of rapid recharging options over and above the level needed to meet estimated demand. This is because over provision of rapid recharging options could help signal that the perceived risks associated with range anxiety are likely to be unfounded.

In addition, strategies of this type may well be particularly important in persuading people beyond the current early adopters to switch to ULEVs, as early adopters tend to have a different risk profile. Not only are they typically wealthier, making it easier for them to afford options like hiring cars for long trips, but early adopters also typically have access to a second car to fall back on. This means that the risks they face are lower than would be the case for most households. For example, in London only 17.9% of households have access to more than one car or van.

There are therefore potential benefits from boosting the supply of rapid recharging points over and above the level dictated by demand, as this could help encourage the adoption of ULEVs. However, it is important to recognise that systematically boosting the supply of rapid rechargers is likely to necessitate some form of government support. This is because the reason for the provision is not solely about meeting the demand for recharging (which could therefore be priced into the use of the recharger), but also about influencing perceptions of risk. Government support would be justified because of the impact on the externalities associated with vehicle emissions.

**Box 3 Behavioural and cognitive biases influencing risk assessment**

It is well understood in financial services that there are a range of behavioural and cognitive biases that influence people’s approach to investment. In particular, how individuals evaluate and treat risk can often go against “rational” behaviour. One obvious reason for this is the difficulty or inability of individuals to measure risk. However, even when risk can be measured, it does not ensure rational behaviour.

There are two types of issue that might influence how individuals assess the costs and benefits of switching to a ULEV: the first involve behavioural biases in their willingness to take risks; and the second are cognitive biases in terms of how people assess risk.

In the case of behavioural biases linked to people’s willingness to take risks, studies
have shown that individuals are often more motivated by losses than by gains. So, for example, an individual offered £300 for a win on a coin toss, but a loss of £150 if the coin toss goes against them, is likely to decline the bet – even though the expected value of the bet is positive (£75) and “rational” behaviour dictates that they should accept the bet. Similarly, individuals generally have an aversion to extreme negative outcomes, even when the possibility of that outcome occurring is negligible. Individuals are also often more sensitive to short-term losses than they are to long-term gains. These types of behavioural biases may well deter individuals from investing in ULEVs, if they have concerns about the potential range of ULEVs and therefore the extent of any negative events, such as the need to hire an additional vehicle for long trips, or the costs of dealing with situations where the car runs out of charge. An extensive network of rapid recharging points could help to reduce these risks.

As well as biases in people’s willingness to take risk, there are also cognitive biases in how they assess risks, which may influence their assessment of the benefits of ULEVs. For example, if people find it easy to imagine an event, either because it is being talked about or because it is very vivid, they are also likely to overestimate how often it occurs (the so-called availability heuristic). Similarly, people often base their assessment of risk on how situations make them feel, with situations that give rise to negative emotions signalling unacceptable levels of risk and positive emotions the reverse (sometimes known as the affect heuristic). By influencing the likelihood and consequences of ULEVs having insufficient range, rapid recharging options could therefore help address these types of biases.

In addition, people typically use anchors to help them assess risk, which can create problems because these anchors are often not updated in line with new information. Therefore, a strategy of providing an extensive rapid recharging infrastructure could help in a rapidly evolving market like ULEVs, because it helps address people’s perceptions of risk, which are likely to be based on out-of-date information on functionality such as the range available.

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39 Expected value is the sum of the each possible outcome times the probability of that outcome occurring. In this example it is: (0.5 probability X £300) + (0.5 probability X -£150) = £75.
5.0 THE IMPORTANCE OF RAPID RECHARGING FOR FLEET OPERATORS

Switching to ULEVs can be particularly hard for fleet operators where the driving patterns associated with their business model routinely involve long journeys or can be unpredictable. Both these issues create problems for taxi and private hire operators like Addison Lee. Therefore, in order to make the business case to switch to pure electric vehicles, they need access to rapid recharging options that allow drivers to get back on the road quickly, as this provides them with a way to manage these risks. Helping this sector to make the shift to ULEVs has potential benefits, because this sector is responsible for high road usage, has a significant impact on the UK’s car market and would provide potentially important signalling effects.

5.1 The benefits of persuading fleet operators to switch to ULEVs

In order for fleet operators like Addison Lee to be able to switch to ULEVs and particularly to allow them to increase their use of battery power, they need access to a public network of rapid recharging points that will meet their needs. The need for fleet operators to be able to access a rapid recharging network may well be higher than for most private individuals. Conversely, however, the benefits associated with facilitating their switch to electric vehicles can also be higher for three reasons: their impact on the second-hand car market; the benefits of the signalling that ULEV use by this sector would provide; and the benefits that can be achieved by converting heavy road users to ULEVs.

5.1.1 Fleet operators and the UK car market

Fleet operators are an important part of the UK car market, accounting for 51.3% of the 2.7 million new car registrations in 2016.40 Furthermore, not only do fleet operators account for a significant share of the new car market, the vehicles that they use will also have an important impact on the vehicles available on the second hand car market. For example, companies like Addison Lee renew their fleet every three years on average. Therefore persuading fleet operators to switch to ULEVs, will influence the type of vehicle on the second hand car market, which is significantly bigger than the market for new cars. More than 8 million used cars were sold in 2016, meaning that 23.9% of the stock of cars on the road in 2015 changed hands in 2016.41

40 Business owners accounted for a further 3.9% of sales, with private sales accounting for 44.8% of registrations in 2016. Fleet operators are any business with at least 25 registered vehicles, while business owners have at most 24 registered vehicles. SMMT (2017).
41 SMMT (2017).
5.1.2 Fleet operators and signalling

Particularly in the case of highly visible fleets like taxi and private hire companies, the use of electric vehicles within this sector may provide an important signalling device about the benefits associated with using ULEVs. This will be particularly true where consumers are suffering from range anxiety. If firms whose business model relies on driving long and unpredictable distances feel confident using ULEVs, this will reassure potential buyers that the risks are manageable.

5.1.3 Fleet operators and road use

Finally, businesses such as taxi and private hire firms tend to make greater use of the road network. For example, drivers with Addison Lee are on average travelling 144 miles a day, which is much higher than most private users. This compares to average commuting distances in London of 7 miles, meaning switching one Addison Lee driver to using an electric vehicle has a similar impact on road usage patterns to switching around 10 average commuters.

This means that the benefits of switching fleet users to ULEVs are greater than those from switching private individuals. This is because the impact on the vehicle miles travelled using low emission options will be larger. Furthermore, the more they can use ULEVs, the lower the environmental costs of the services they provide. As with all vehicle use, the greatest environmental benefits will be achieved where they can rely solely on battery power and this is where rapid recharging options are particularly important.

The case for concentrating on enabling fleet operators to switch to ULEVs is further reinforced by the patterns of car ownership and use compared to pollution levels in London Boroughs. As can be seen from Figure 15.A, there is a strong positive relationship between the fraction of mortality attributable to long term exposure to PM$_{2.5}$ and the share of households with no access to a car. In other words the impact of pollution is highest where car ownership is lowest. Similarly, looking at the share of households with access to more than one car, the impact of pollution is lowest where there are high levels of multi-car ownership, see Figure 15.B. In terms of car use patterns, the impact of pollution is also lowest in London Boroughs with a higher share of commuters driving to work, see Figure 15.C.

However, while the relationship is not as strong, the impact of pollution is higher in London Boroughs with a higher number of workers arriving to work in a taxi, see Figure 15.D. Indeed, particularly high numbers of workers based in Westminster and the City of London take a taxi to work. Therefore, while it is clearly going to be important to address pollution from domestic car use, taken together the evidence suggests that focusing on domestic car use will have a more limited impact in those Boroughs suffering from the highest pollution levels.

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42 2011 Census data show that the averaging commuting distances in London is 11.2km, or 7 miles. This means on average the round trip made by a commuter will be 14 miles.
Figure 15  Percentage of mortality attributable to long term exposure to PM$_{2.5}$ compared to patterns of car ownership and commuting methods in London Boroughs

A. Percentage of households with no access to a car

B. Percentage of households with access to 2 or more cars

C. Percentage of commuters driving a car or van to work

D. Number of workers arriving to work in a taxi

Note: Data for car ownership and method of travel to work are from 2011 Census. Data for the fraction (%) of mortality attributable to long term exposure to PM$_{2.5}$ are from Greater London Authority (2012). Data are for all 33 London Boroughs. Data for Plots A, B and C are for the resident population. Data for Plot D are for the workplace population, which is the number of people who work in that location (regardless of where they are resident). Each plot shows a trend line depicting the slope of the relationship between the two variables, but in the case of Plot D the trend line is dotted because the $R^2$ is low (less than 0.2), indicating that the relationship is not statistically robust. Although it is not shown, there is a similar correlation between pollution and the share of residents using a taxi to get to work as the one shown in Plot D for the workday population.

Source: Analytically Driven Ltd
5.2 Why fleet operators need rapid recharging – the experience of Addison Lee

Addison Lee does not operate any ULEVs, although around 12% of Addison Lee’s fleet is made up of hybrid electric vehicles. However, recognising the environmental and social benefits associated with switching to ULEVs, particularly when they are operated using battery power, Addison Lee would like to be in a position to switch to electric vehicles. Addison Lee considers that this switch will only be viable, if it is able to access an adequate public network of rapid recharging points. It has reached this conclusion for three main reasons: the ability of its drivers to access recharging facilities at home; the location of its drivers; and the length and variability of the journeys its drivers need to make each shift.

5.2.1 The challenges for drivers from switching to ULEVs

Switching to ULEVs creates two challenges from the point of view of drivers for Addison Lee.

The first of these challenges is that many drivers do not have access to off-road parking. This makes it difficult for them to access appropriate charging infrastructure at home between shifts, particularly in areas that are not seeking to provide low level 3kW and 7kW charging infrastructure in residential areas. This means that access to rapid recharging options would make it easier for them to make the switch, as it would allow them to charge their vehicles quickly either at the start or end of their shift, as well as potentially during their shift.

The second challenge relates to where drivers live in relation to Addison Lee’s main base of operations in London. As Figure 16 demonstrates, in many cases the drivers are based a considerable distance from London. This matters, because current BEVs do not have adequate range to cover a shift without being recharged, and the existing pure electric range of PHEVs (which are the main alternatives) is only around 30 miles. Therefore, for a driver based in places like Rochester, Crawley or Luton the majority of their shift would be done using conventional ICE technology, which limits the environmental benefits of making the switch.

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43 A hybrid vehicle is powered by an internal combustion engine. It uses a battery and electric motor to capture and re-use braking energy, supplementing direct power from the ICE. The power source is selected automatically by the vehicle, depending on speed, engine load and battery charge level. This battery cannot be plugged in - it is charged by regenerative braking supplemented by ICE generated power.
5.2.2 The compatibility of ULEVs with vehicle usage

Addison Lee’s business model is based around moving people and things. Between September and November 2016 it undertook over 1 million journeys on behalf of clients, with the paid component of those trips (i.e. excluding travel between jobs, or between home and a client) involving more than 10.2 million miles.

On average drivers for Addison Lee travel 144 miles in each shift. This is currently further than the battery only range of most ULEVs, meaning in order to make the switch effective charging options need to be available to facilitate on-the-job charging.

The most common forms of rapid recharging points can fully charge what is currently a car battery of 24kWh in around half an hour. Therefore, given the size of Addison Lee’s fleet of cars operating in London, in order for 4,200 vehicles to be fully charged using rapid rechargers it would still require 88 rapid rechargers just to deal with the daily demand from Addison Lee. Furthermore, this assumes that it is possible to arrange recharging so that one driver starts recharging as soon as another has stopped for the entire 24 hour period (meaning each rapid recharging point charged 48 vehicles a day).

In practice, however, the demand patterns for private hire vehicles mean that the majority of Addison Lee drivers would only have time to access the recharging infrastructure in between the peak demand periods associated with the morning commute, lunch time, evening commute and late evening (post event) peaks. Therefore, assuming drivers were also willing to charge their vehicle immediately before or after a shift, Addison Lee drivers would only be able to use the rapid recharging network for around 9 hours a day. This means that in practice just dealing
with the daily demand from Addison Lee would require 235 rapid recharging points. Furthermore, even this is an under estimate, as:

- it is unlikely that it will be possible to schedule recharging to take place back-to-back without any delays between drivers arriving to have their vehicle recharged. Even just a five minute delay between vehicles recharging would reduce the potential capacity of the rapid recharging network to around 85% of its theoretical level and a 15 minute delay would reduce the potential to 67% of its theoretical level;
- Addison Lee drivers may need to recharge more than once a day (particularly where they do not have access to recharging facilities at home);
- some recharging points are likely to be better located than others, meaning demand will not be evenly spread across the recharging infrastructure; and
- not all charging points are likely to be working at all times – on June 29th 2017, of the 37 public rapid or super charging points with 24 hour access within the M25 only 70% had no issues reported, see Box 4.

A contingency of 40% is likely to be the minimum needed to account for these factors, which would mean that a minimum of 330 rapid recharging points would be needed just to meet the needs of the Addison Lee fleet. This compares to the current stock of rapid recharging points available in London which is 75, with the plan being only to increase this to 150 by the end of 2018 and 300 by the end of 2020.

Furthermore, these rechargers will not just be used by Addison Lee drivers. Estimates suggest that there are 21,300 taxis and 87,400 private hire vehicles operating in London. If only 25% of these 108,700 vehicles were to convert to electric then, assuming they face the same constraints as Addison Lee’s drivers, over 2,135 rapid chargers would be required. If all 108,700 converted than 8,540 would be required, without considering the needs of other types of fleet operator or private users.

While it is possible that increases in the range of electric vehicles may reduce the need for rapid recharging points over time, it is likely that significant reliance in the rapid recharging infrastructure will remain a feature of the taxi and private hire sector. This is because there can be significant variability in the length of journeys undertaken. For example, some individual journeys by Addison Lee’s drivers are more than 100 miles

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44 This estimate is higher than the Energy Savings Trust estimate of 140 rapid rechargers needed for the entire private hire fleet set out in Featherstone et al (2017). There are two reasons for this. Firstly the Energy Savings Trust estimate assumes that charging will take place for 10 not 9 hours a day and if they had assumed only 9 hours of charging it would have increased their estimate to round 160 rapid rechargers. Secondly the Energy Savings Trust estimates only assume that round 2850 battery electric vehicles are operated by the sector, rather than the conversion of 4,200 vehicles in Addison Lee’s fleet. For the same reasons that are set out in the rest of this section, the Energy Savings Trust estimate will also be an underestimate, because it makes no allowance for contingencies.

45 Data provided by Transport for London. Target correct as of September 12, 2017.

one-way. This means that even if the range of the ULEV vehicles on offer were to increase sufficiently to address the average distance travelled per shift by Addison Lee’s drivers, rapid recharging options would still be required for risk management purposes.

Furthermore, increased range is often provided by an increase in battery size, which in turn can make options for rapid recharging more important. This is partly because these changes can make domestic recharging less feasible – it would take over 25 hours, for example, to fully recharge a 90kWh battery using a domestic 3.5kW charger. However, it also reflects the fact that such changes in specification can act to shift the amount of mileage obtained for a kWh of charge in ways that increase the need for rechargers. For example, a vehicle with a battery size of 24kWh and a range of 100 miles will do 4.2 miles for each kWh of charge. However, the 2018 Jaguar iPace is expected to do 310 miles using a 90kWh battery, meaning that while the range of the vehicle will have more than trebled, it will only do 3.4 miles per kWh of charge. Therefore the 2018 Jaguar iPace will require more charging time for a given distance travelled, pushing up demand for rapid rechargers. These changes also make it more likely that other drivers will want to rely on a rapid recharging infrastructure.

The benefits in terms of reduced emissions of CO₂ and NO₂ from switching fleet vehicles such as taxis and private hire vehicles to ULEVs are higher than the benefits of switching private cars, because they have a bigger impact on vehicle miles travelled. Therefore, this suggests that there is an important role for government in supporting a more rapid expansion in the rapid recharging infrastructure in London. Furthermore, these recharging options need to be scattered throughout London, in order to maximise the risk management benefits associated with the provision of rapid recharging options.

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**Box 4 The reliability of the rapid recharging infrastructure in London**

Estimates from the Financial Times in 2015 suggested that around 23% of charge points in London were out of service. As Table 6 shows, analysis of the rapid (43kW and 50kW) and super (120kW) charge points in London on 29th June 2017 suggest similar problems persist, with only 70% of charge points having no reported issues.

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48 A battery size of 24kWh with a range of 100 miles represents the performance and specification of the typical BEV discussed in SMMT (2016).
50 See Featherstone et al (2017) for analysis of the geographic spread of recharging options and likely usage.
<table>
<thead>
<tr>
<th>Table 6</th>
<th>Reliability of the rapid recharging infrastructure in London</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>43kW</td>
</tr>
<tr>
<td>Number of sites</td>
<td>9</td>
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<td>Number of charge points</td>
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<tr>
<td>Number of charge points with no issues reported</td>
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<tr>
<td>(% of total)</td>
<td>58%</td>
</tr>
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</tr>
<tr>
<td>(% of total)</td>
<td>17%</td>
</tr>
</tbody>
</table>

Note: Data for public charging points within the M25 with 24 hour access on 29th June 2017, based on status on Zap map (https://www.zap-map.com/live/). Some charge points can charge using more than one type of connector and all 43kW rapid charging points can also charge connections that take a 50kW charge. This means the total column differs from the sum of the three types of charge identified.

Source: Analytically Driven Ltd.
6.0 THE BUSINESS CASE FOR GOVERNMENT INTERVENTION TO BOOST THE SUPPLY OF RAPID RECHARGING POINTS

There are clear and undisputed benefits to be had from switching to the use of ULEVs, both in terms of reduced emissions of CO₂ and the reduction in air pollution, particularly NO₂ pollution. These benefits include: helping the Government to address the impact of climate change; increasing longevity; and reducing the number of costly hospital treatments that are needed to address conditions triggered by pollution. These potential benefits are maximised when ULEVs are being driven using battery power.

The benefits associated with persuading drivers to switch to ULEVs have a significant externality associated with them. In other words, the benefits to society as a whole are greater than the benefits to individual drivers. For example, it can be shown that drivers from wealthier areas contribute to creating roadside pollution in more deprived areas, without directly suffering from the consequences. This means that there is a clear case for Government intervention in order to facilitate a switch to ULEVs.

The question that this report has sought to address is what role should the provision of a more extensive rapid recharging network play as part of encouraging the switch to ULEVs. In order to make this assessment it is therefore important to understand the relative costs and benefits of different types of recharging infrastructure.

6.1 The relative costs and benefits of providing rapid recharging points

Estimates suggest that, taking into account the cost of the charge point, civil works, traffic order and permits, on average the cost of installing a fixed low level (7kW) charge point is around £16,000, providing there is no need to upgrade capacity at the local electricity substation. In contrast, the average cost of providing a rapid recharging point is in the region of £40,000 to £50,000. This excludes any power upgrade costs, which vary greatly but on average are around £10,000 for installing a rapid recharging point. Therefore, on average it would be possible to install up to 3.75 low level charging points for every rapid recharging point.

However, in capacity terms, the average cost of installing 1kW of charging capacity would only be £1,200 for a 50kW charger, or £1,395 for a 43kW charger, compared to £2,285 for a 7kW charger. This means that the cost for supporting a given amount of mileage using a 7kW charger is 1.9 times that of a 50kW charger and 1.6 times higher than that of a 43kW charger. Therefore, although low level charge points in residential areas help mimic the perceived benefits that earlier adopters typically enjoy,
the ability to charge their vehicle at home,\(^{53}\) it would be more cost effective to concentrate on the provision of rapid rechargers. Furthermore, there are several additional important benefits associated with rapid rechargers. In particular:

- Rapid rechargers are more likely to be used by drivers that make more intensive use of the road network. For example, Addison Lee drivers travel on average 144 miles in a shift, while average commuting distances in London are 7 miles. Therefore a single charge by an Addison Lee driver at a rapid recharging point will deliver the equivalent vehicle miles of 10 ordinary commuters travelling to and from work. In pollution terms, therefore, the rapid recharger would deliver a much larger potential reduction in pollution than spending the equivalent amount of money on low level charge points.

- Rapid rechargers can support far more vehicles than a low level charge points. The theoretical charging time for a 24kW battery using low level charge point is 8 hours using a 3kW charger, or 3 hours and 25 minutes using a 7kW charger. This compares to around 30 minutes using a rapid recharger (43kW or 50kW) and 12 minutes using a 120kW super charger. In other words, assuming that the vehicles concerned needed to be fully recharged, a 3kW charge point would support a maximum of 4 vehicles a day, while the 120kW rapid recharger would support a maximum of 120 vehicles a day.

- Rapid rechargers are likely to become more important as battery sizes increase. It would take over 25 hours to fully recharge the 90kWh battery associated with the 2018 Jaguar iPace using a 3.5kW domestic recharger and almost 13 hours to fully recharge the vehicle using a 7kW charger. Increasing the capacity of domestic rechargers to overcome these prolonged charging periods is not feasible. A typical household with a 60 amp main fuse would not be able to run a 22kW charger (which requires 96 amps) and could only use an 11kW charger (which requires 48 amps) if it switched off all other high demand electrical items such as kettles, ovens and immersion heaters for the 8 hours it would take to fully recharge a 90kWh battery.\(^{54}\)

- The usage patterns for rapid rechargers are more likely to encourage multiple users per day. For example, a commuter returning from work in the evening to charge on a public low level charger in his or her residential area is unlikely to want to move their vehicle late at night once it is charged and, even if they did, it is unlikely that anyone else would get up to check if a station had become free at that time. This means that low level charging points will effectively be blocked for significant periods of time, even when they are not in use – in this example until the commuter returns in the morning. In contrast, even if users of rapid rechargers do not immediately move their vehicle after recharging has finished (for example because they have gone to the shops), it is less likely that they

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53 Earlier adopters of ULEVs typically have access to off-street parking, meaning that they can charge their vehicle at home. This is not true for most Londoners. TfL estimate that around two thirds of Londoners are dependent on on-street parking.

54 See the discussion in National Grid (2017).
would block the recharging station for prolonged periods and charging structures could more easily be put in place to discourage that.

- The availability of rapid rechargers may have an important role in encouraging the use of ULEVs because of their role in managing risk. In particular, not only do readily available rapid recharging options help address the issue of ULEV vehicles having insufficient range to undertake long journeys, they can also help address range anxiety, which is a key barrier to the adoption of ULEVs. In addition, by influencing the likelihood and consequences of batteries having insufficient charge to complete journeys, rapid rechargers may have a role in addressing some of the behavioural biases that impact people’s willingness to take risk and cognitive biases in how people assess risk. Without a strategy to address them, these behavioural and cognitive biases might otherwise impede the adoption of ULEVs.

- The rapid recharging infrastructure will play a particularly important role in facilitating a switch to ULEVs by fleet operators such as Addison Lee. Encouraging ULEV use amongst fleet operators has three potentially important benefits: its impact on the type of cars entering the second-hand car market, as fleet operators account for over 50% of the new car registrations in the UK; the benefits of the signalling that ULEV use by the taxi and private hire sector would provide, by demonstrating that ULEVs can meet the needs of those travelling long and unpredictable distances for work; and the higher environmental benefits that can be achieved by converting heavy road users to ULEVs.

Taken together therefore, these benefits mean there is a clear case for re-examining the mix of recharging options supported by Government, in order to place greater emphasis on providing rapid recharging infrastructure in London, as well as on key transport corridors. Estimates suggest that realistically it would take a minimum of 330 rapid (43kW or 50kW) recharging points just to satisfy Addison Lee’s recharging needs, if they were to switch their fleet to electric vehicles. If only 25% of the 108,700 taxis and private hire vehicles operating in London were to convert to electric then, assuming they face the same constraints as Addison Lee drivers, over 2,135 rapid chargers would be required. However, the current stock of rapid recharging points available in London is 75, and the plan is only to increase this to 150 by the end of 2018.

6.2 The volatility of the costs of installing rapid recharging options

While the average cost of installing a rapid recharging point is estimated to be up to around £60,000 including the cost of any power upgrades, discussions suggest there is significant variability in these costs. This is similar to the evidence from the US, where the cost of installing rapid rechargers varies from around $4,000 to around $50,000, see Figure 17.
One key factor underpinning this variability in the UK is the capacity of the local electricity grid and the extent to which upgrades are needed, for example to the local substation. This suggests that there could be important benefits in ensuring that information is readily available on where capacity exists in the network, to help inform location decisions.

Figure 17  The distribution of Direct Current Fast Charging Installation Costs in 2015 in the US (in thousands of dollars)

Note: Installation costs are in addition to the cost of the charging unit, which varied between $10,000 and $40,000.

6.3 The ULEV charging infrastructure and electricity demand

While switching to ULEVs brings many benefits, one of the potential challenges of switching to the use of ULEVs is its impact on electricity demand. If recharging activity is predominantly undertaken during the evening when people get home from work, which is also when domestic demand for electricity is highest, then this could create challenges for power companies in terms of their ability to meet peak demand.

In practice those challenges could be considerable. The results from the My Electric Avenue project, which was based on the observed impact on electricity usage of electric vehicle adoption by clusters of users in different communities, suggests that the peak charging times by domestic users coincide with the traditional evening peak. The estimates from the project suggest that increasing penetration of electric vehicles on low voltage distribution networks can cause both thermal and voltage problems. In particular, around 32% of UK low voltage distribution networks will require protection
against thermal or voltage problems if electric vehicle penetration exceeds 40%.

The My Electric Avenue project found that systems such as Demand Side Response management, which act to temporarily switch off electric vehicle recharging when the network is experiencing high demand, could help address some of the challenges posed by electric vehicle adoption. However, from the point of view of individual ULEV users, this may create a risk that the amount of recharging undertaken is not as much as expected. This in turn might boost the role for backup options, such as rapid recharging. It will also be worth considering the impact of different recharging options on both electricity usage patterns throughout the day and on the mix of power sources being used to generate the electricity. As Figure 18 demonstrates, estimates suggest that a switch to 7kW domestic recharging from 3.5kW will increase electricity demand during the evening peak. Interestingly, however, it also increases demand in the morning, which is more likely to be able to benefit from the availability of solar power.

The My Electric Avenue project did not model the impact of rapid recharging options on the system. However, to the extent that these may be more likely to be used during the day, when solar power is available, this may help not only to smooth demand, but also to reduce the CO₂ emissions associated with the well-to-wheel energy usage.

**Figure 18** Comparison of the impact on the pattern of electricity demand between 3.5kW and an extrapolated 7kW charging capability

- **Note:** the 3kW usage patterns are based on the observed patterns from the My Electric Avenue project. The 7kW usage patterns were extrapolated based on observed recharging times from that project.

- **Source:** EA Technology (2016).
6.3.1 Domestic capacity constraints

The National Grid has identified that the challenges associated with recharging electric vehicles at home will increase as improvements in the range of electric vehicles leads to an increase in battery sizes for electric vehicles. For example, the calculations show that using a 3.5kW recharger to recharge a battery from being 25% full to 100% full would take 6 hours for an average electric vehicle with a 28kWh battery. However, it would take over 19 hours to recharge the 90kWh battery associated with the 2018 Jaguar i Pace, which will have a range of 310 miles.\(^{58}\) It would therefore take over 25 hours using the same device to fully recharge the 2018 Jaguar i Pace’s battery. This will make it impractical for those with high vehicle usage to use typical domestic rechargers.

However, increasing the charger size in domestic settings will create problems. Average households are supplied with single phase electricity and fitted with a main fuse of 60 to 80 amps. Using a 3.5kW battery charger requires 16 amps; an 11kW charger requires 48 amps; and a 22kW charger requires 96 amps. Therefore, the maximum charger a typical household could use would be 11kW, which would fully recharge a 90kWh battery in just over 8 hours. However, if it had a 60 amp main fuse, it would not be able to use any other high demand electrical items such as kettles, ovens or immersion heaters during that period. Even if it had an 80 amp main fuse, it would still struggle to run more than one other high demand appliance while running an 11kW recharger. Furthermore, even if the household upgraded to the maximum 100 amp main fuse, it would still only be able to use a 22kW charger if all other devices were switched off for the period of over four hours that it would take to fully recharging a 90kWh battery.\(^{59}\)

For these reasons, the National Grid has identified that:

“If we want long range vehicles that can be charged in minutes, home is not going to be the place to do it.”\(^{60}\)

As the National Grid has identified, lack of off-street parking and the fact that households can have more than one vehicle will also increase the need for rapid recharging options in non-domestic settings.

\(^{58}\) National Grid (2017).
\(^{59}\) National Grid (2017).
\(^{60}\) National Grid (2017).
7.0 CONCLUSIONS

This report considers the costs and benefits of providing a more extensive rapid recharging infrastructure in London as a way of facilitating a shift towards the use of Ultra Low Emission Vehicles (ULEVs).

Analysis of the potential benefits associated with a switch to ULEVs demonstrates that it could not only help the government reduce air pollution in London, but also contribute to a reduction in CO₂ emissions. The evidence on which factors are likely to encourage a switch to ULEVs shows that the availability of public recharging options can play an important role.

One of the key barriers identified in the report to the adoption of ULEVs relates to the potential range of the vehicles, as well as the associated range anxiety (whereby potential users worry that they will have insufficient charge to meet their needs). The evidence suggests that rapid recharging options may therefore play an important role in helping to support a switch to ULEVs. Rapid recharging options not only help to address the risks associated with having insufficient range, but also facilitate a switch to ULEVs by drivers making longer trips. While trips of more than 25 miles only account for 7% of total trips across all road types, they account for 47% of vehicle miles travelled. As it is vehicle miles, not number of trips, that determines pollution levels, facilitating switching amongst those travelling longer distances will have a much greater impact on pollution than persuading those with average usage patterns to switch. This means that facilitating a switch to ULEVs amongst fleet operators could play a particularly important role in achieving the Government’s environmental goals. For example, as a private hire operator on average Addison Lee’s drivers travel 144 miles each shift, which is equivalent to the distance travelled by ten average commuters in London.

However, the practical demands of operating a business like Addison Lee means that the availability of sufficient rapid recharging options will play a particularly important role in enabling a switch to ULEVs to take place. This is a problem because the current stock of rapid recharging points available in London is 75, and the plan is only to increase this to 150 by the end of 2018 and 300 by 2020. Estimates suggest that it would take a minimum of around 330 rapid (43kW or 50kW) recharging points just to satisfy Addison Lee’s recharging needs, if they were to switch their fleet to ULEVs. If only 25% of the 108,700 taxis and private hire vehicles operating in London were to be converted to ULEVs then, assuming they face the same constraints as Addison Lee’s drivers, over 2,135 rapid recharging points would be required.

Taken together therefore, there is a clear case for re-examining the mix of recharging options supported by Government, in order to place greater emphasis on providing rapid recharging infrastructure in London, as well as on key transport corridors. The benefits of doing so could be considerable.
A1 REFERENCES


### Definitions and Abbreviations

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<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AFV</td>
<td>Alternatively-Fuelled Vehicle. Any vehicle which is not solely powered by traditional fuels (ie petrol or diesel).</td>
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<tr>
<td>BEV</td>
<td>Battery Electric Vehicle. A vehicle powered solely by a battery charged from the electricity grid.</td>
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<td>CO₂</td>
<td>Carbon dioxide.</td>
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<td>DfT</td>
<td>Department for Transport.</td>
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<tr>
<td>Equivalent deaths</td>
<td>Equivalent deaths at typical ages are the deaths that would account for the loss of life years due to the pollutant being considered.</td>
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<tr>
<td>E-REV</td>
<td>Extended-Range Electric Vehicle. A vehicle powered by a battery charged from the electricity grid, but with an ICE powered generator on board to extend the range if needed.</td>
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<tr>
<td>Fleet operators</td>
<td>Fleet operators are companies with 25 or more registered vehicles. This includes dealer demonstration models.</td>
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<tr>
<td>FCEV</td>
<td>Fuel Cell Electric Vehicle. A vehicle that uses hydrogen gas as a fuel. Power is generated by a fuel cell stack, which is used to drive the FCEV’s electric motor. Additional power is supplied when needed from a secondary battery, which is also used to store additional short-term energy recovered from regenerative braking.</td>
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<tr>
<td>HOV</td>
<td>High Occupancy Vehicle.</td>
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<tr>
<td>Hybrid</td>
<td>A hybrid vehicle is powered by an internal combustion engine. It uses a battery and electric motor to capture and re-use braking energy, supplementing direct power from the ICE. The power source is selected automatically by the vehicle, depending on speed, engine load and battery charge level. This battery cannot be plugged in - it is charged by regenerative braking supplemented by ICE generated power.</td>
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<tr>
<td>ICE</td>
<td>Internal Combustion Engine.</td>
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<tr>
<td>Life year</td>
<td>A life year is one year lived for one person.</td>
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<tr>
<td>Longevity</td>
<td>An increase in longevity is an increase in the length of time people are expected to live.</td>
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<tr>
<td>LSOA</td>
<td>LSOA stands for Lower-layer Super Output Areas. There are 34,753 LSOA in the 2011 Census in England and Wales.</td>
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<tr>
<td>µg</td>
<td>Micogramme. One millionth of a gramme.</td>
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<td>µm</td>
<td>Micrometres.</td>
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<tr>
<td>NO</td>
<td>Nitrogen oxide. A gas that can convert to NO₂ in air.</td>
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<tr>
<td>NO₂</td>
<td>Nitrogen dioxide.</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Nitrogen oxides. Both NO and NO₂ are nitrogen oxides.</td>
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<tr>
<td>OLEV</td>
<td>Office of Low Emission Vehicles.</td>
</tr>
<tr>
<td>PHEV</td>
<td>Plug-in Hybrid Electric Vehicle. A vehicle with both a plug-in battery and an internal combustion engine. Once the range of the plug-in battery has been used, the vehicle reverts to hybrid mode (utilising both battery power and ICE),</td>
</tr>
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without range compromise.

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<tr>
<th>Shorthand</th>
<th>Definition</th>
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<tbody>
<tr>
<td>PICG</td>
<td>Plug-in Car Grant.</td>
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<tr>
<td>PM$_{2.5}$</td>
<td>Particulate matter which passes through the inlet of a size selective sampler with a 50% efficiency cut-off at 2.5 µm aerodynamic diameter.</td>
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<tr>
<td>PM$_{10}$</td>
<td>As for PM$_{2.5}$, but with an aerodynamic diameter of 10 micrometres.</td>
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<tr>
<td>Private hire</td>
<td>Unlike taxis, private hire vehicles must be pre-booked in order to pick up passengers and cannot ply for hire on the streets or at taxi ranks.</td>
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<tr>
<td>Range anxiety</td>
<td>The worry that an electric vehicle will not reach its destination without running out of charge.</td>
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<td>SMMT</td>
<td>Society of Motor Manufacturers and Traders.</td>
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<td>SRN</td>
<td>Strategic Road Network.</td>
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<td>TfL</td>
<td>Transport for London.</td>
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<tr>
<td>Tank-to-wheel</td>
<td>A tank-to-wheel emissions test measures the tailpipe emissions that are produced directly by the car itself.</td>
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<tr>
<td>ULEV</td>
<td>Ultra low emission vehicle. A vehicle that uses low carbon technologies and emits less than 75g of CO$_2$/km from the tailpipe and is capable of operating in zero tailpipe emission mode for a range of at least 10 miles.</td>
</tr>
<tr>
<td>ULEZ</td>
<td>Ultra Low Emission Zone. Will cover central London from September 2020. Non-compliant vehicles will only be able to enter by paying an extra charge.</td>
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<tr>
<td>Well-to-wheel</td>
<td>A well-to-wheel emissions test captures not only the emissions from the tailpipe, but also the emissions resulting from the production of the fuel used by the car, such as the generation of electricity, or the production, refining and distribution of petrol or diesel.</td>
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<tr>
<td>WHO</td>
<td>World Health Organisation.</td>
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