Deliverable D3.4 – Social impact of en-route charging technical report

Project acronym & number:	UNPLUGGED
Project Number	314 126
Project title:	Wireless charging for Electric Vehicles
Status:	Final
Authors:	Chris Torkington, Denis Naberezhnykh (TRL) and Sylvia Heyvaert, Omar Hegazy, Thierry Coosemans (VUB)
Contributors:	Mehmet Emre, Jean Hopkin, Sviti Pabari, Dr Marcus Jones (TRL)
Due date of deliverable:	30/06/2014
Document identifier:	UNPLUGGED_D3.4_V1.0
Revision:	Version 1.0
Date:	26/09/2014

UNPLUGGED: Wireless charging for Electric Vehicles

UNPLUGGED project aims to investigate how the use of inductive charging of Electric Vehicles (EV) in urban environments improves the convenience and sustainability of car-based mobility. In particular, it will investigate how smart inductive charging infrastructure can facilitate full EV integration in the urban road systems while improving customer acceptance and perceived practicality. UNPLUGGED will achieve these goals by examining in detail the technical feasibility, practical issues, interoperability, user perception and socio-economic impacts of inductive charging. As one special variant, inductive en-route charging will be investigated thoroughly.

As part of the project, two smart inductive charging systems will be built, taking into consideration requirements from OEMs, energy utilities and end users. The systems will be innovative and will go beyond the current state of the art in terms of high power transfer, allowing for smart communication between the vehicle and the grid, as well as being in line with the latest inductive charging standards and considering interoperability. These innovative inductive charging systems designed and built as part of the project will then be tested and assessed in order to understand their potential impacts on urban mobility and the acceptance of e-mobility. Application in an en-route charging scenario in particular will be examined for different vehicle types, ranging from cars to buses.

It is anticipated that UNPLUGGED will provide clear evidence on and demonstrate whether the use of smart inductive charging infrastructure can overcome some of the perceived barriers for e-mobility, such as range and size of on-board energy storage, and practical difficulties associated with installing traditional charging post infrastructure.

Project Consortium

- fka Forschungsgesellschaft Kraftfahrwesen mbH Aachen , Germany
- ENIDE SOLUTIONS .S.L , Spain
- CENTRO RICERCHE FIAT SCPA, Italy
- UNIVERSITA DEGLI STUDI DI FIRENZE, Italy
- VOLVO TECHNOLOGY AB, Sweden
- Continental Automotive GmbH, Germany
- Hella KGaA Hueck & Co., Germany
- VRIJE UNIVERSITEIT BRUSSEL, Belgium
- IDIADA AUTOMOTIVE TECHNOLOGY SA, Spain
- TRL LIMITED, United Kingdom
- COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES, France
- ENDESA SA, Spain
- ENEL DISTRIBUZIONE S.P.A., Italy
- FUNDACION CIRCE CENTRO DE INVESTIGACION DE RECURSOS Y CONSUMOS ENERGETICOS, Spain
- POLITECNICO DI TORINO, Italy
- TRANSPORT FOR LONDON, United Kingdom
- BAE Systems (Operations) Ltd, United Kingdom

More Information

Coordinator: Sebastian Mathar (coordinator)

Mail: mathar@fka.de Tel +49 241 80 25631 - Mobil +49 177 7886140 - Fax +49 241 80 22147

Forschungsgesellschaft Kraftfahrwesen mbH Aachen

Steinbachstr. 7 - 52074 Aachen - Germany

info@unplugged-project.eu - www.unplugged-project.eu

Dissemination Level

PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Change History

Version	Notes	Date
V0.1	VUB study chapter completed	24/01/2014
V0.2	Socio-economic model section completed	31/05/2014
V0.3	Preliminary survey results chapter added	30/06/2014
V0.4	Completed chapter on survey result analysis	04/07/2014
V0.5	TRL internal review comments	11/07/2014
V0.6	TRL review of draft deliverable	11/08/2014
V0.7	Version ready for review by UNPLUGGED reviewers	29/08/2014
V1.0	Final version	26/09/2014

Abbreviations

CO_2	Carbon Dioxide
DfT	Department for Transport
CNG	Compressed Natural Gas
EM	Electromagnetic
EV	Electric Vehicle
ICE	Internal Combustion Engine
IPT	Inductive Power Transfer
NEDC	New European Driving Cycle
NO_x	Nitrogen gas pollutants
PHEV	Plug-in Hybrid Electric Vehicle
PM	Particulate Matter
RE-EV	Range Extended Electric Vehicle
TfL	Transport for London
VFM	Value for money
WPT	Wireless Power Transfer

Table of Contents

1 Executive Summary

This report combines two individual pieces of work for the UNPLUGGED project into a socio-economic impact assessment. The first is an analysis of results from an online survey designed to investigate the social acceptance of wireless charging for EVs, undertaken by VUB and TRL in Belgium and the UK respectively. The second is an environmental impact assessment for the introduction of wireless charging technology in cities.

Social acceptance was assessed via two approaches:

- a survey carried out by VUB based on the Living Labs project to seek high level opinions from EV trial participants in Belgium on their interest in wireless charging for EVs
- a TRL survey of EV trial participants and key UK stakeholders via an online survey to enable users and stakeholders to offer opinions and information on wireless power transfers (WPT) for electric vehicles (EVs).

Most of the respondents to the TRL questionnaire were from the UK. Although some responses received were from other European countries and the USA, the numbers were too low to be able to include them in the analysis. Therefore, the TRL survey analysis represents an assessment of social acceptance of WPT for EVs in the UK and VUB analysis represents an assessment of social acceptance of WPT for EVs in Belgium.

Key outcomes from the TRL study:

Overall, the majority of respondents seem to think that wirelessly charged vehicles are a good idea. Stakeholders may be slightly less optimistic about WPT vehicles and infrastructure than private users. This may be due stakeholders having more awareness of WPT and its possible drawbacks, for example possible high costs of infrastructure, versus potential benefits. Reduced running costs were highlighted as one of the main potential benefits for private users. Stakeholders saw reduction in CO_2 and improved air quality as their key benefits.

Concerns highlighted in the comments section of the survey included possible unknown health and safety issues due to EM radiation, additional expenditure on vehicles, infrastructure and electricity, and scepticism over environmental benefits when compared to current vehicles.

Key outcomes from the VUB study:

Respondents who were able to integrate an electric car in their daily life showed some interest in the technology of inductive wireless charging. As a result, inductive charging systems could be an option to improve the consumer acceptance for EVs since it is easier to use and safer than any other charging or refuelling methods. More importantly, this technology gives the EV a competitive advantage compared to conventional cars because no stops are needed in order to recharge, if used en-route. When following the wireless trend of other electronic devices, wireless charging of EVs could increase the level of flexibility for consumers of electro-mobility, which is currently perceived as being too low.

On the other hand, this relatively new technology does not convince people to buy an EV. The majority would not consider the installation of wireless charging and would not be willing to pay more for such a charging session in public places.

Key outcomes from socio-economic impacts study:

This task built on the assessment framework developed by TRL for Task 3.2.6 which modelled introduction of wireless charging into the London bus fleet in order to provide a high level assessment of socio-economic and environmental impacts of inductive charging for buses in London. The work described in this report, carried out as part of WP 3.4, extends to additional vehicle types (taxis, vans and cars) and two other European cities (Barcelona and Florence). Other large vehicles with the exception of buses have not been modelled in this piece of work.

The results presented in this document are not intended to be treated as definitive calculations for possible or expected socio-economic and environmental impacts of EVs using WPT charging. TRL took care to ensure that the results presented are as representative as possible and are based on the most up-to-date information, however, due to the nature of such high level analysis, the need to make a large number of assumptions and uncertainties surrounding key technology specification and performance parameters, these results should only be considered indicative.

The models in general show that switching to an EV fleet and an Unplugged EV fleet, even by as little as 5%, can offer cost savings when capital, operating and societal costs are all taken into consideration, provided certain assumptions are taken into account as described in further detail in the report.

The impacts of WPT are difficult to isolate because the role of WPT is largely to facilitate more practical use of EVs and increase the proportion of electric-only distance driven. Therefore, a like–for–like comparison would require increasing the electric-only mileage per year for all vehicles considered, which then results in increased costs for fuel and maintenance, as well as higher emissions. It is thus not possible to fully quantify the possible socio-economic impacts of the introduction of WPT charging in this analysis. The analysis does however highlight that the introduction of WPT charging would facilitate achieving the benefits for EVs for higher proportion of fleets being converted; this is because without WPT charging, it would not be practical to replace some standard vehicles with EVs due to range constraints and long charging times.

2 Introduction to Task 3.4

This report is made up of two main parts. The first part is further subdivided into the two separate studies on social acceptance of wireless charging technology, presented in Section 3 and Section 4.

Section 3 is based upon responses to a questionnaire compiled by TRL. It was made available online via the website smartsurvey.co.uk, an online survey portal, which is designed to make it easy to gain responses to questionnaires and filter results quickly and efficiently. The questionnaire included an information sheet at the beginning, to introduce respondents to the concepts relating to charging of electric vehicles. This information sheet can be found in Appendix A.

In order to elicit responses from stakeholders, and to some extent private users, contact was made with various transport organisations and companies. It was stated to each organisation's point of contact that the questionnaire related to EV use and wireless power transfer technology and was part of a European wide project titled Unplugged. Those organisations that agreed to send out the questionnaire link to their contacts are listed below.

Association of Local Bus Company Managers (ALBUM)
Passenger Transport Executives (PTEs) – Bus Operations and Sustainability Groups
Abellio
National Taxi Association
The National Private Hire Association (NPHA)
TfL Taxi and Private Hire office (formerly Public Carriage Office)
British Vehicle Rental and Leasing Association (BVRLA)
Society of Motor Manufacturer & Traders (SMMT) – Technology and E-Mobility group

Other similar organisations stated they would forward the questionnaire, but no confirmation of this was received.

The response rate to the questionnaire by stakeholders is not known as only two organisations confirmed how many people they would forward the questionnaire to. The questionnaire was also forwarded on to members of Intelligent Transport Systems (UK) (ITS) (UK) Electric Vehicle Infrastructure working group and the Institute of Engineering and Technology (IET). To obtain private users' thoughts and opinions, the questionnaire was forwarded to members of the TRL EV trial database. This corresponds to approximately three hundred members of the public who have previously taken part in EV trials at TRL.

Section 4 is based on responses to a survey carried out by VUB in Belgium. A test panel of consumers took part in a trial to test an electric vehicle. The analysis focuses on inductive charging and is based on post-trial responses to the survey.

The second part of the report (Section 5) summarises the results of a socio-economic assessment in which modelling was used to assess the potential impact of replacing part of the vehicle fleet in cities with EVs and wirelessly charged EVs. This task is based on the model used by TRL in Task 3.2.6 and the factors used to create the original model. This has been adapted for additional vehicles types in London and additional European cities.

3 TRL Questionnaire Results

3.1 The respondents

The questionnaire results were obtained using an online survey website. Only completed surveys were included within the data being analysed. Respondents included members of the public that had undertaken an electric vehicle trial at TRL. They also included stakeholders from various organisations representing, engineers, health and safety management, policy makers and heads of transport operations. There were 113 respondents in total to the survey. Of these 101 were responses from the UK. Only responses from the UK were included in the results.

In total 87 of the questionnaires were completed by 'private users' and the remaining 14 were completed by 'stakeholders' representing views of their organisations rather than their personal views.

Depending on the answer to the first question, respondents were classified as 'private users' if they were responding as either a user of a mobility service or as a driver of a car or van. For the purposes of analysis the two responses from users of a mobility service were discounted so that only respondents identifying themselves as “drivers” were considered in the analysis. Bus drivers’ and taxi drivers’ responses were excluded as they were classified as professional drivers, hence not a private user. Some van drivers would also be expected to have been professional drivers and some of their questionnaire responses indicate that this was the case. However, the questionnaire did not allow for car and van driver responses to be differentiated consistently, therefore, ‘private users’ responses to the questionnaire include both car and van drivers.

This left 84 car or van drivers’ questionnaires to be analysed in order to generate the results. Figure 1 shows the responses used in the analysis split by private users and stakeholder types.

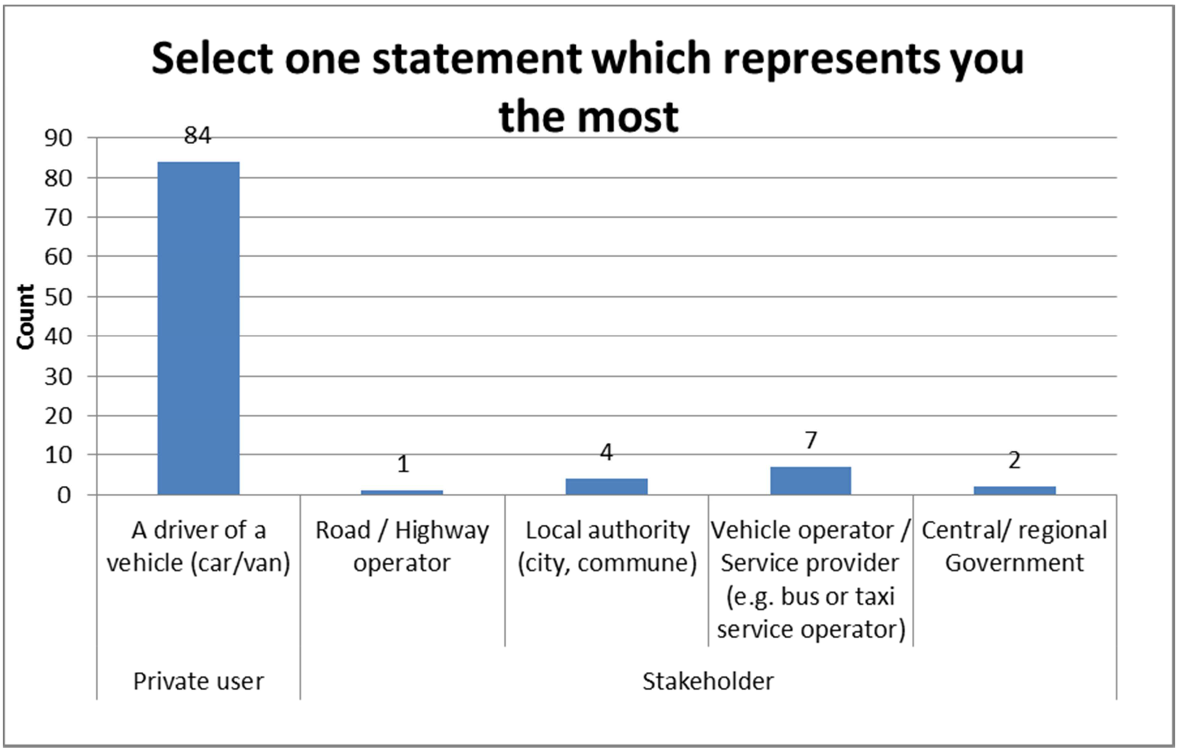


Figure 1 – Types of respondent

One of the final questions asked the respondents whether they had been aware of wireless power transfer before they started the questionnaire. Figure 2 shows the responses for stakeholders and private users.

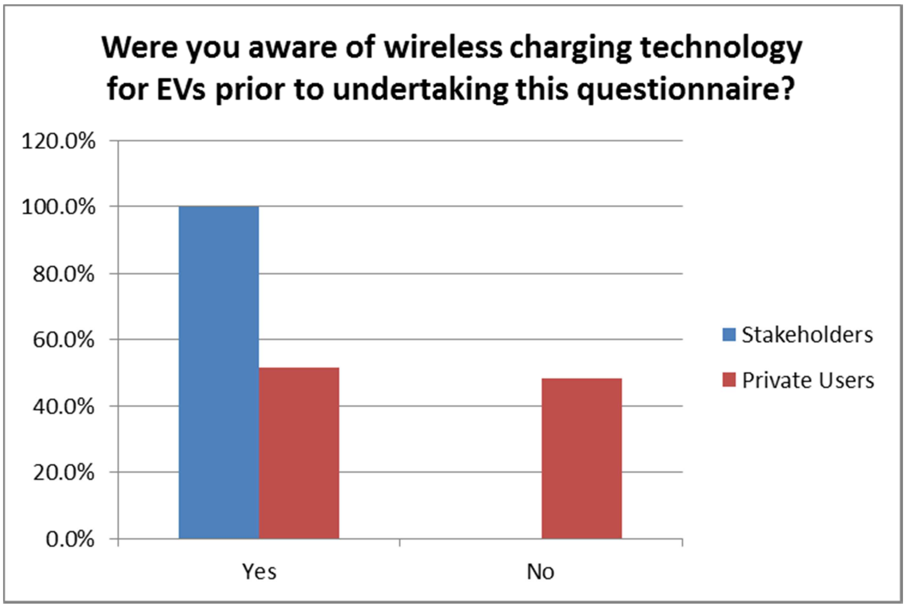


Figure 2 – Awareness of wireless charging technology for EVs prior to undertaking the survey

All of the stakeholders said they were previously aware of wireless charging technology. Out of the private user respondents, 52% stated they were aware of wireless charging technology, but the other 48%

stated that they had not been aware of it. It is worth noting that as the sample group were people who have previously taken part in EV trials, they are likely to be more interested in this technology than then general public. Therefore, it is possible that these results overrepresented the proportion of private users who are already aware of wireless charging for EVs.

3.2 Stakeholder responses to the questionnaire

Figure 3 shows that half of the stakeholder respondents saw themselves as vehicle operators or service providers and the rest were road operators or public authorities. It should be noted that in the UK, there is only one Highway Operator – the Highways Agency.

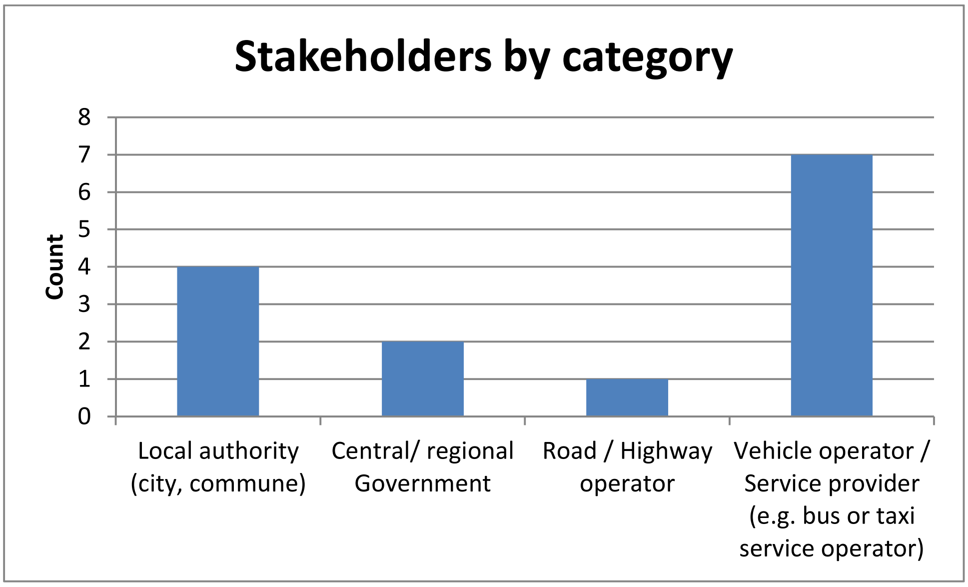


Figure 3 - Roles of stakeholder respondents

3.2.1 Stakeholder opinions on where wireless charging should take place

For this section of the questionnaire ten statements were presented and respondents were asked to rate their general opinion on a five point scale between 'total agreement' and 'total disagreement'.

The statements covered the following scenarios:

- Wireless charging for cars and vans should be undertaken directly on the road: charging while driving.
- Wireless charging for taxis should be undertaken directly on the road: charging while driving.
- Wireless charging for buses should be undertaken directly on the road: charging while driving.
- Wireless charging for cars should be undertaken at home, e.g. in the garage or on the parking place in front of my house.
- Wireless charging for buses should be undertaken at the bus depot at the end of the day.
- Wireless charging for taxis should be undertaken at taxi depot or at home at the end of the day.
- Wireless charging of cars should be undertaken in public car parks, e.g. shopping centres, town centres, other leisure activity car parks.
- Wireless charging of taxis should be undertaken in taxi ranks.
- Wireless charging of buses should be undertaken at bus stops and bus stations.
- Wireless charging of ALL electric vehicles should be undertaken while stationary at traffic lights, junctions, rail crossings and other types of mandatory stops en route.

Figure 4 shows the responses to the question on the location of wireless charging in each of the parts of this question. It shows that stakeholders were very much in agreement that wireless charging should be undertaken in public car parks, taxi ranks and at bus stops and at bus stations. Stakeholders also favoured wireless charging for cars at home.

There was less consensus among stakeholders about wireless charging whilst driving on the road. There is no clear agreement or disagreement with those statements. The responses given to the parts of the question which refer to on-road charging while driving show no overall majority and several neutral responses.

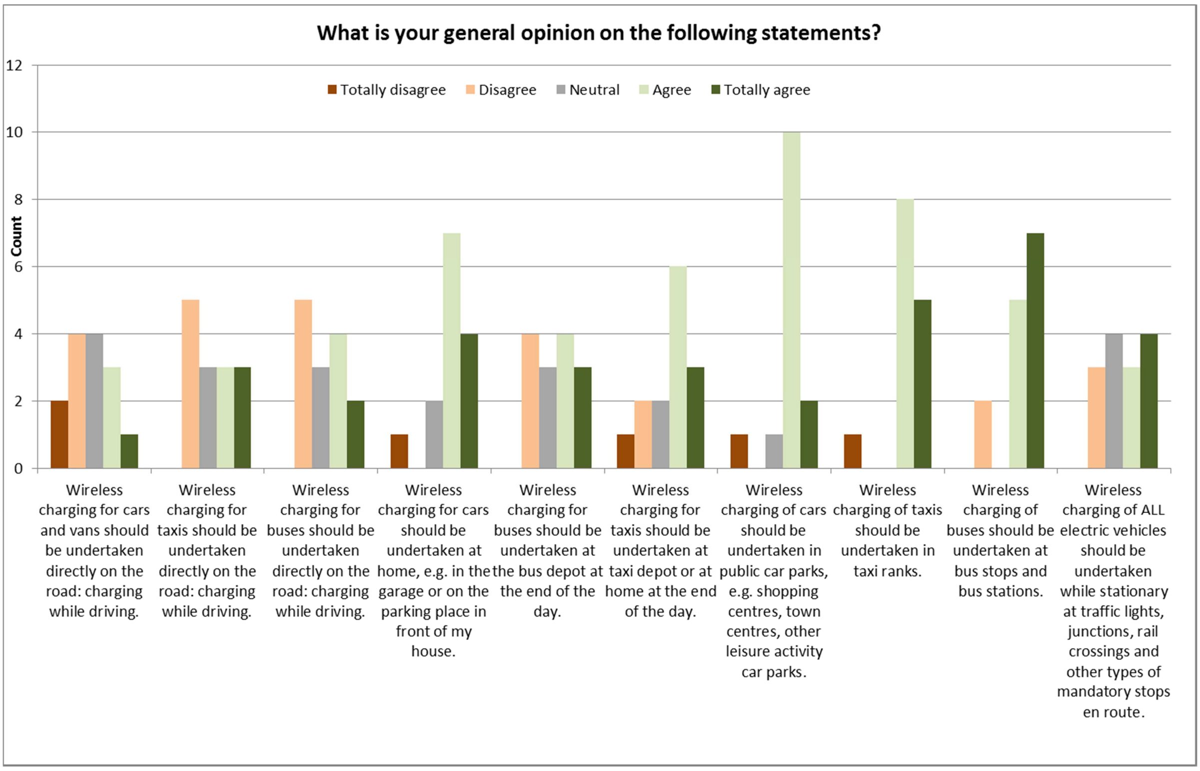


Figure 4 - Stakeholder views on the location of wireless charging

3.2.2 Stakeholder opinions on who should be responsible for each of the scenarios

Using the same scenarios described above, stakeholders were asked who they thought should be responsible for providing wireless charging infrastructure in each of the scenarios. The options they were presented with were as follows:

- A user of an electric mobility service (e.g. passenger in a bus or a taxi)
- Driver/ vehicle owner
- "Service Provider / Vehicle Operator"
- Local Authority (city, commune)
- Central Government
- Road / Highway operator

Figure 5 shows that for charging whilst driving, stakeholders tended to agree that road or highway operators should be responsible. Most also stated that they believed that charging for cars, vans and taxis should take place at home or the depot. Half said buses should be charged at the depot by the service provider or operator and most of the rest said this was the responsibility of the driver or operator. For charging of cars in public places there was a split in opinions. Half said the local authority should be responsible, with the remainder suggesting driver or owner responsibility or the service provider or operator.

Opinions were divided on charging of taxis at taxi ranks, buses at bus stops and vehicles at stops on their route, though a slight majority thought the road or highway operator would be responsible for on-road charging at stationary points such as traffic lights.

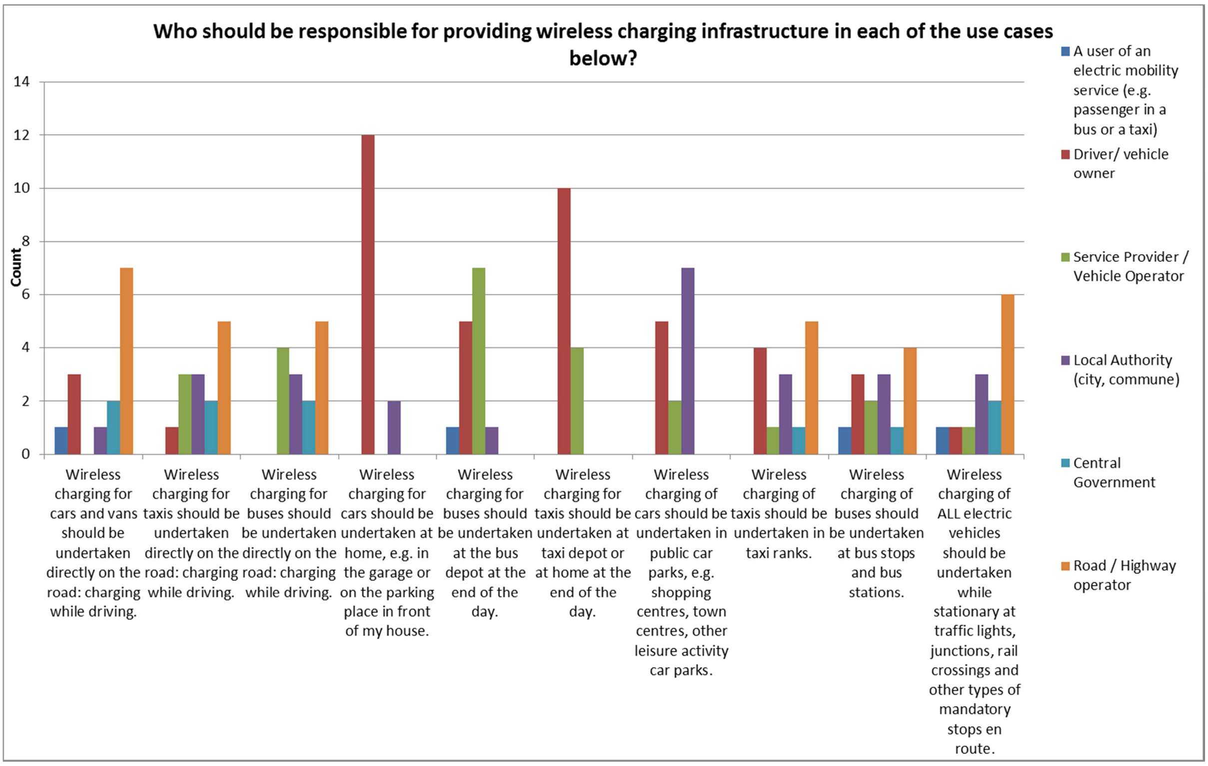


Figure 5 - Stakeholder views on responsibility for wireless charging infrastructure

3.2.3 Investing in wireless charging infrastructure

3.2.3.1 Key investment factors for stakeholders

Stakeholders were asked about the importance of various factors when deciding whether to invest in wireless charging vehicles and infrastructure. Those factors were:

- CO_2 reduction
- Air quality improvement
- Reduced running costs
- Improved practicality / simplicity of charging
- Automation and user friendliness
- Luxury / Premium function
- Technological innovation / leadership

Figure 6 indicates that ‘simplicity and practicality’ of use are considered to be the most important aspects when investing in new vehicles and infrastructure; this factor attracted the largest number of ‘extremely important’ answers.

‘Air quality improvement’, ‘CO_2 reduction’ and ‘Reduced running costs’ were considered to be the next most important factors.

‘Luxury / Premium function’ and ‘Technological innovation / leadership’ were the only factors which some stakeholders thought were ‘not at all important’.

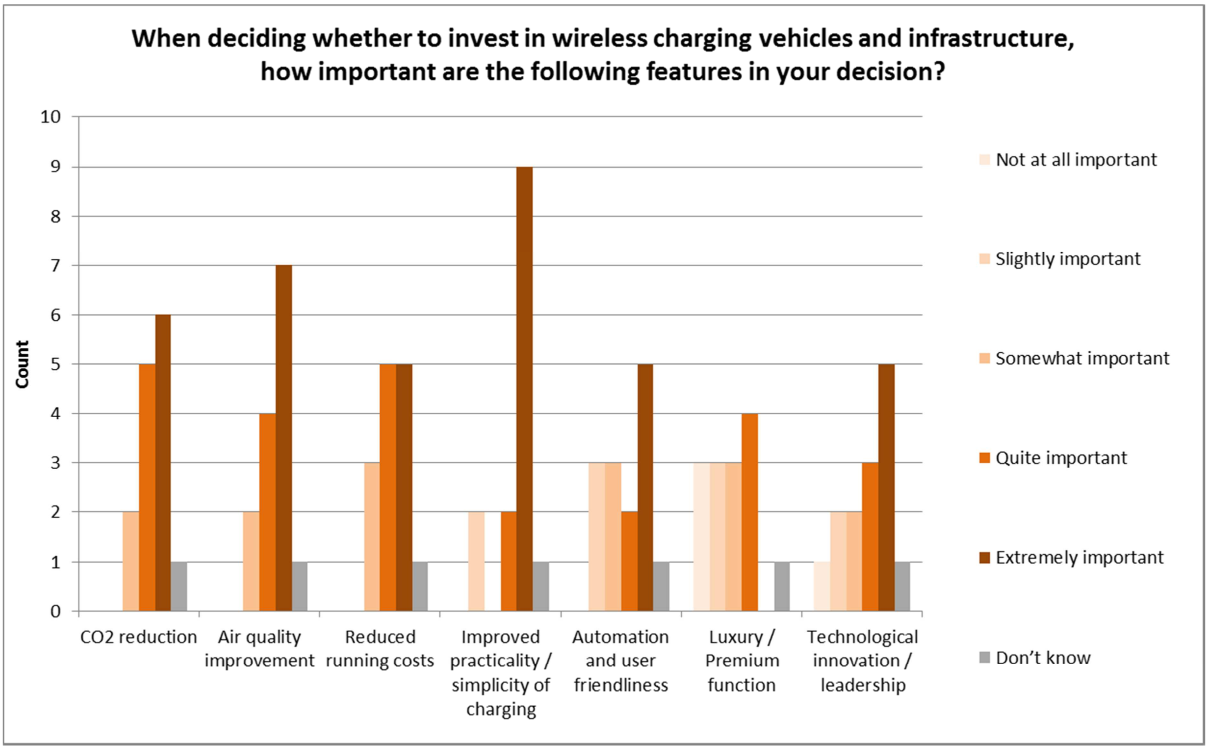


Figure 6 - Stakeholder views on the importance of factors when deciding to invest in EV vehicles and infrastructure

3.2.3.2 **Willingness to invest in wirelessly charged vehicles**

Stakeholders were asked how much extra cost they would be willing to invest, provided that the benefits they considered important were addressed by wireless power transfer.

For a car or van, Figure 7 shows that seven out of twelve stakeholders said they would be willing to pay extra for an EV with wireless charging capability, though the remaining five who responded would not be willing to pay anything extra.

Several respondents would be willing to pay between 16% and 20% extra for wireless charging compared with a normal EV.

In the case of buses and taxis, one respondent said they were willing to pay less to purchase an EV with wireless power transfer capabilities than to purchase a normal EV.

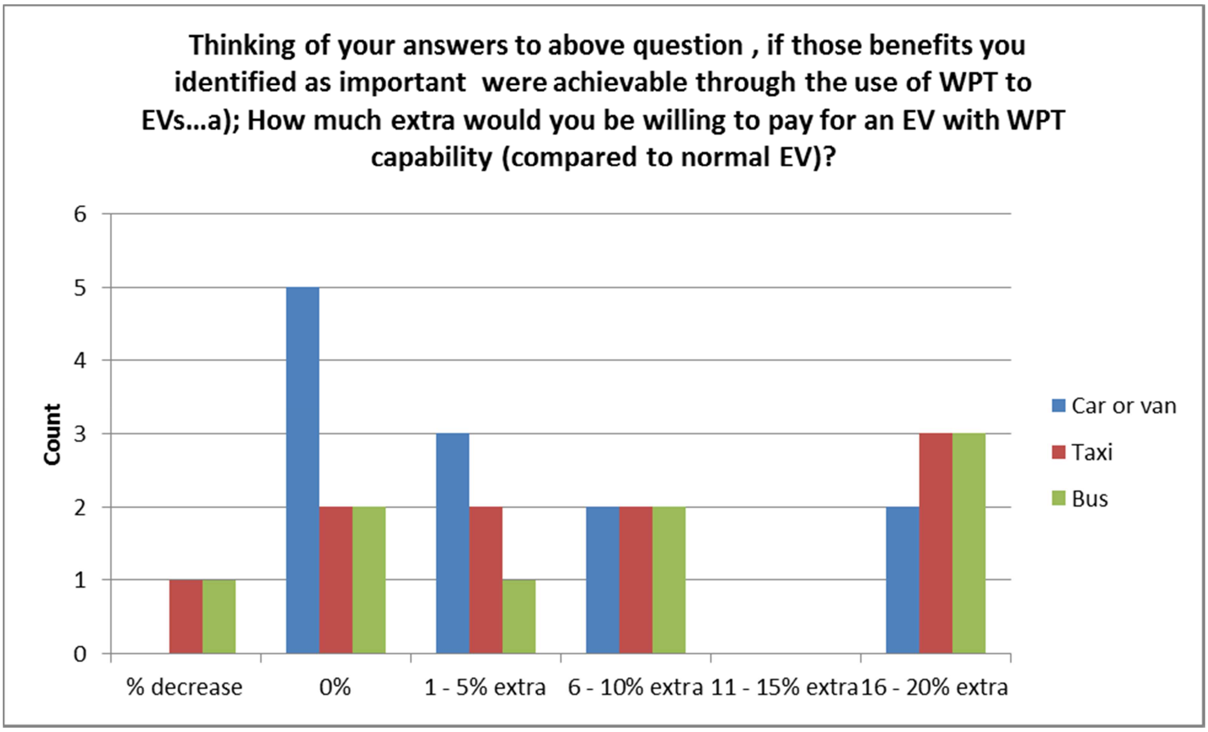


Figure 7 – Stakeholder willingness to pay extra for an EV with wireless power transfer capability

3.2.3.3 Stakeholder opinions on investment in wireless charging

Stakeholders were asked their opinions on three statements about investment in wireless charging infrastructure and one about establishing low emissions:

- Wireless charging can help to establish low emission zones in cities
- I would only invest in a wireless charging vehicle if someone else paid for infrastructure
- I would only invest in a wireless charging infrastructure if there was already infrastructure in other locations
- I would consider buying an EV more if it had a wireless charging capability

Figure 8 shows that stakeholders were mostly in strong agreement that 'Wireless charging can help to establish low emission zones in cities' and '…would only invest in a wireless charging vehicle if someone else paid for infrastructure'.

There was less consensus regarding the other two statements, indicating that there were mixed views on being the first area to invest in wireless charging and on whether vehicles with wireless charging would be more likely to attract buyers.

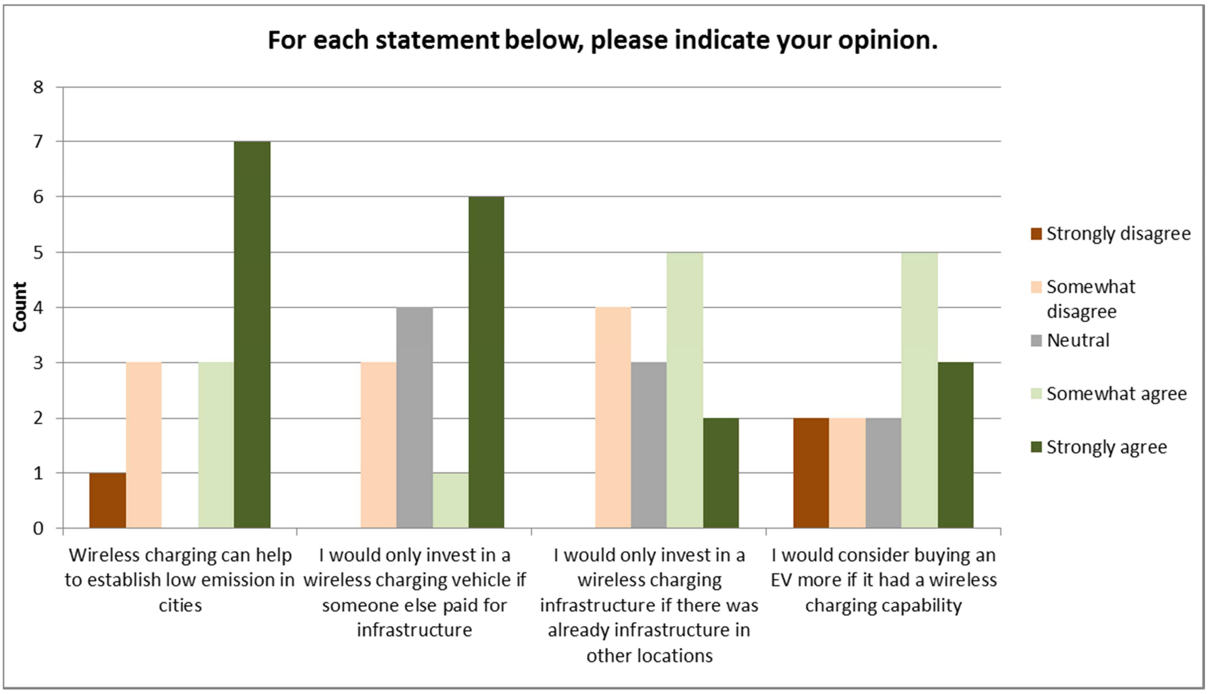


Figure 8 - Stakeholder views on investment in wireless charging

3.2.4 Preferable mode of transport

This question asked whether the respondents would prefer to use wirelessly charged electric buses or taxis instead of petrol or diesel internal combustion engine (ICE) equivalents, using the information sheet (see Appendix A) to refer back to.

Figure 9 shows that respondents tended to think that in the case of buses and taxis, they would prefer or possibly prefer to use EVs over ICE equivalents.

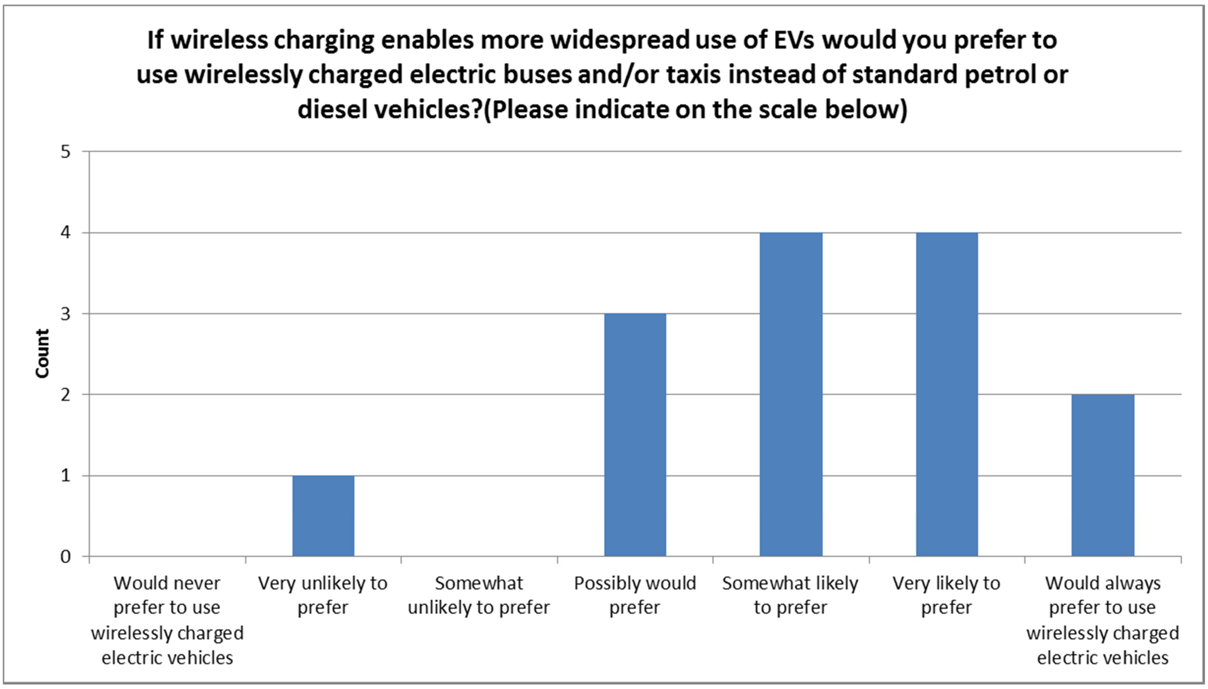


Figure 9 - Stakeholder preferences for wirelessly charged public transport over petrol or diesel

3.2.5 Expectations of cost

3.2.5.1 Expectations of service cost

Figure 10 shows stakeholders' opinions on whether wirelessly charged taxi and bus services would cost more or less than the same services using standard ICE vehicles. It shows that the majority thought that the services would cost the same as a standard service for both buses and taxis. Only one respondent for each category thought that the services would cost more if vehicles were charged wirelessly.

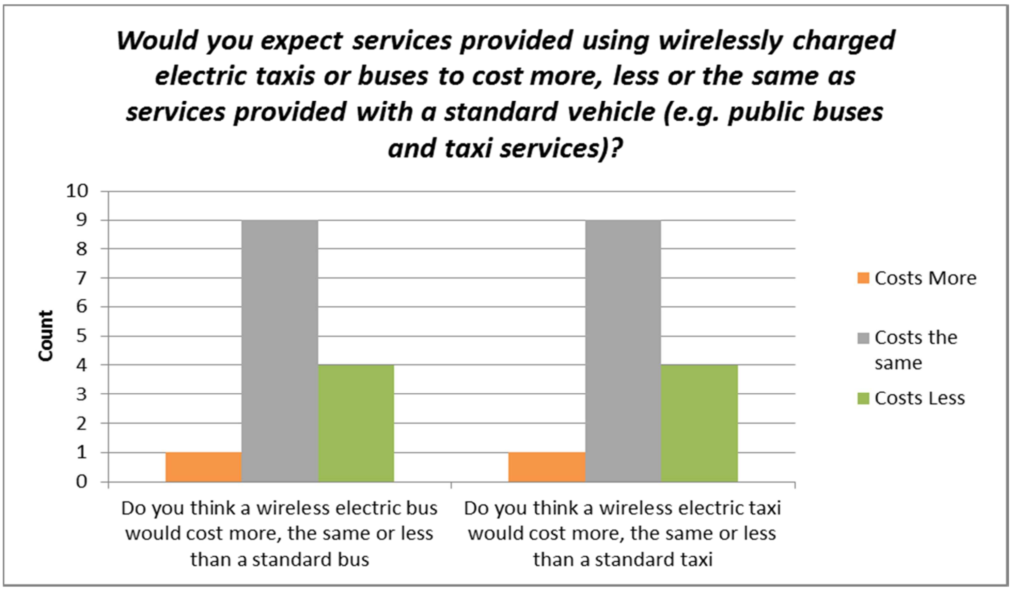


Figure 10 - Stakeholder expectations about service costs

3.2.5.2 Service cost comparison

The respondents were then specifically asked to state what they believed the percentage difference between wirelessly charged electric vehicle services and standard vehicles would be.

Figure 11 shows that the majority of respondents thought that the service cost of EV equivalent buses and taxis should be approximately the same as standard vehicles. Some respondents expected a difference of up to 20% less and a few expected a higher cost.

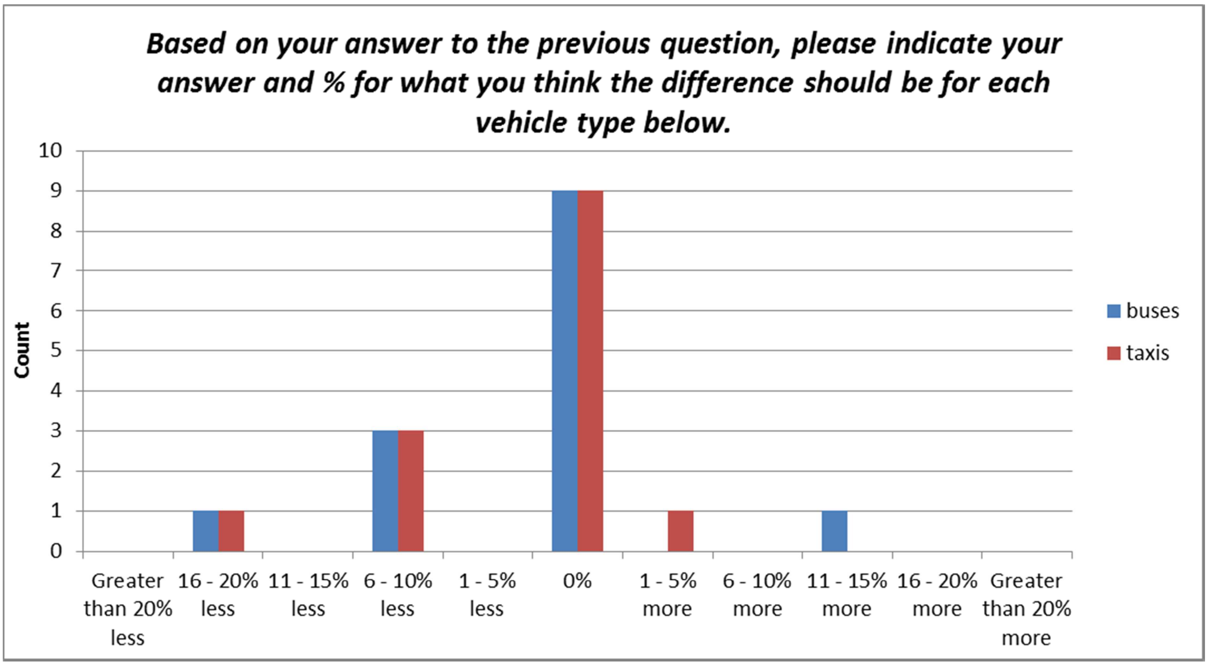


Figure 11 - Stakeholder expectations on the percentage difference in service costs between standard and wirelessly charged electric vehicles

3.2.5.3 Vehicle cost comparisons

Stakeholders were asked for opinions on the cost of EVs and standard vehicles versus wirelessly charged EVs. Figure 12 shows that respondents mainly thought wirelessly charged EVs would cost the same as standard EVs. Stakeholders were equally divided on whether wirelessly charged vehicles would cost the same as or more than standard vehicles. None indicated that they thought that vehicles with wireless charging would cost less than standard EVs.

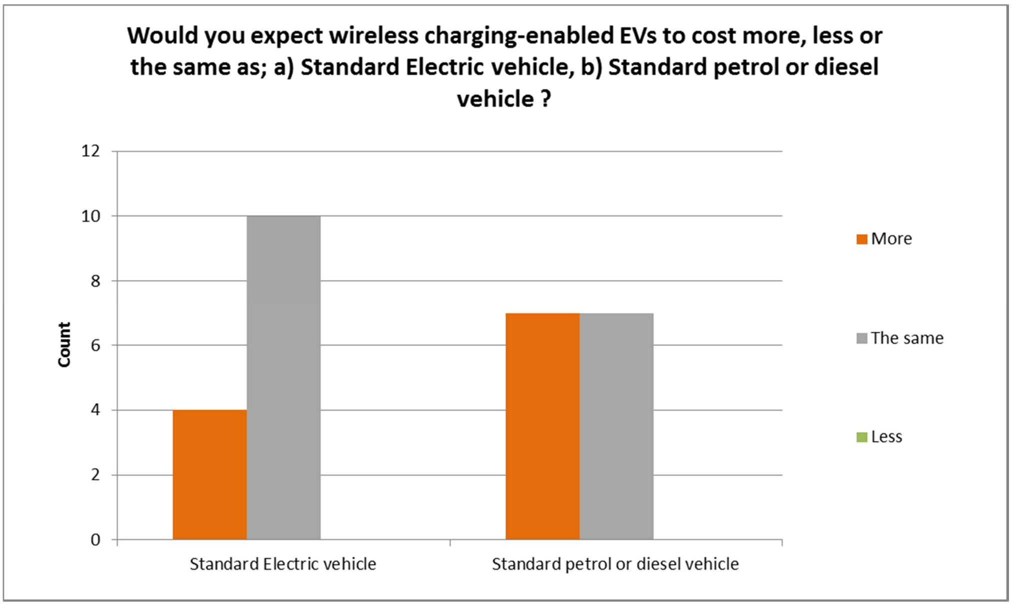


Figure 12 - Stakeholder expectations about the difference in vehicle costs between wirelessly charged EVs and standard EVs and petrol or diesel vehicles

3.2.6 Stakeholder opinions on wireless power transfer

At the end of the questionnaire, stakeholders were asked their overall opinion of wireless power transfer technology. Figure 13 shows that overall, the majority of the stakeholders thought that wireless power transfer technology is a good idea, by the time they had reached the end of the survey. By this point in the survey, the stakehodlers would have thought about the relative strengths and weaknesses of this technology by answering earlier questions.

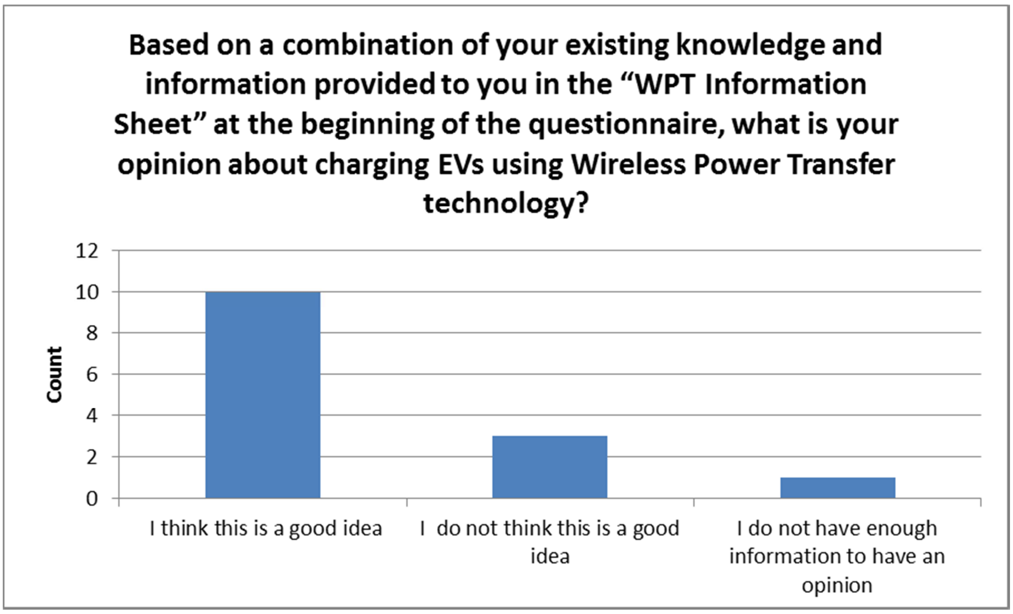


Figure 13 - Stakeholder opinions about charging EVs using Wireless Power Transfer technology

3.2.7 Stakeholder responses to other questions

This section gives additional information on stakeholders' responses question so far not included in the results.

3.2.7.1 Likelihood of purchasing an electric vehicle

Stakeholders were asked whether they would consider the purchase of an EV. There were more stakeholders who considered that they would be likely to purchase an EV than who thought they were unlikely to purchase an EV. The responses were:

- Absolutely not – 1
- Very unlikely - 0
- Somewhat unlikely - 2
- Possibly – 3
- Somewhat likely - 2
- Very likely - 1
- Certainly - 5

They were also asked whether they would consider the purchase of a wirelessly charged EV. Similarly, there were more stakeholders who considered they would be likely to purchase a wireless power transfer EV than who thought they would be unlikely to purchase one. The responses were:

- Absolutely not – 1
- Very unlikely - 1
- Somewhat unlikely - 1
- Possibly – 1
- Somewhat likely - 4
- Very likely - 2
- Certainly - 4

3.2.7.2 Willingness to pay extra for EV purchase

Stakeholders were asked if the benefits they considered important were achievable through wireless power transfer, how much extra would they be willing to pay, in comparison with a normal EV.

Almost all of the stakeholders said they would be willing to pay extra for WPT buses or taxis over standard EVs. None of the stakeholders would be willing to pay more than 20% extra than the cost of a standard EV equivalent. One of the stakeholders would want to pay less for a wirelessly charged taxi or bus than for a standard EV equivalent.

3.2.7.3 Willingness to install wireless charging infrastructure

Stakeholders were asked whether they would be willing to pay for installation of wireless charging infrastructure on their premises and if they were to invest, how much they would be willing to pay. Different vehicle types were considered separately.

Only five stakeholders responded to the question about cars and vans. Of these, only two stated they would pay toward installing wireless charging infrastructure. Only one stated how much they would be willing to pay: €250.

Only three stakeholders responded to the question about taxis and all stated they would not be willing to pay for installation at their premises.

Six stakeholders responded to the question about buses. Two stated they would be willing to pay for wireless charging infrastructure at their premises. The amounts which these two stakeholders would be willing to pay towards installing the wireless charging infrastructure were €40,000 and €100,000.

3.2.7.4 Stage of investment

Stakeholders were asked what percentage of the vehicle fleet would have to be wireless EVs before they would consider investing in public wireless charging infrastructure. They were also asked to indicate if they would not consider investing in wireless charging infrastructure at all. The question was once again divided into vehicle categories.

Six stakeholders said they would invest in charging infrastructure for cars and vans, depending upon the percentage of wirelessly charged EVs on the road. One stakeholder would not require any WPT cars or vans in order to invest. Another would invest at 5% penetration, two required 10% and one stakeholder responded they would require 50% penetration. Three stakeholders would not invest at all in infrastructure.

For wireless charging infrastructure for buses, six stakeholders said they would invest, depending upon level of penetration. The percentage penetration rate ranged from 10% to 40%. Three stakeholders would not be willing to invest in public wireless charging infrastructure. These were the same stakeholders as those who said they would not invest in infrastructure for cars and vans.

Considering wirelessly charged electric taxis, seven stakeholders said they would invest, at between 10% and 30% penetration. The same three stakeholders as before said they would not invest at all in public wireless charging infrastructure for buses.

3.2.8 Additional stakeholder comments

Upon completion of the questionnaire, respondents were given the opportunity to air any views or thoughts that they might want to provide in an open response comments section. Key points from those statements have been included below. Of the fourteen stakeholders to respond, there were additional comments from eight. The full text information is available in the appendix.

3.2.8.1 Doubts about readiness of technology

Some stakeholders were feeling sceptical about current technology capability. One stakeholder felt it was led by other agendas such as government rather than the industry or suppliers of EV.

> "*My views are somewhat negative about the VFM for wireless charging at the moment and I do not believe there should be significant investments made using public money particularly as it is far from clear at this stage what users habits will be as technology improves. It may be that if battery tech gets much better that the range of vehicles becomes so good that little additional charging is required outside of the home or depot in which case large infrastructural investments would be wasted. It could also be that in 15 years' time*. *Wireless charging is standard in most EVs and there would be justification in public investment but at present it feels that vested interests are pushing the agenda."*

3.2.8.2 Lack of public information available on wireless charging and trials

The need for more public information was mentioned by two of stakeholders. These stakeholders felt that there was not enough information, creating uncertainty and a trial would provide 'real' information in terms of functionality as well as costs. One stakeholder commented:

> "*In order to fully understand the potential of this technology it would be useful to have results from 'real-world' trials of a variety of vehicles, demonstrating the technology in static and en-route charging environments. At this stage it is unclear how this technology will affect infrastructure and vehicle costs."*

3.2.8.3 More information about how this impacts cost of EVs

Some of stakeholders wanted to understand how the costs would impact the overall cost of EV, in particular how much, who and how to pay for the wireless technology. One stakeholder was doubtful about pricing:

> "*I could not see how the customer paid for the charging which may have clouded some answers.*"

More Stakeholders expressed concerns about how the technology would be paid for by Private Users.

3.2.8.4 Scepticism about environmental benefits compared to conventional vehicles

One stakeholder was sceptical about the environmental benefits of EVs:

> *"At this point in EV development and battery technology although at the point of use they are perceived to be cleaner the total cradle to grave measure of 'clean' or 'not clean'; vs say a standard gas/diesel bus is not as clear cut. Couple that to indeterminate battery life, limited range capabilities, increased costs of purchase and operation and you have a political desire for cleaner cities being met by inappropriate technology. If electric is the solution we have to look at the source of the electricity the pollution that generates and the pollution that the mining manufacture and disposal of rare earth batteries to fully encompass their green credentials."*

3.3 Private users' responses to the questionnaire

The results in this section are from respondents who were identified as private users. Private users' responses were considered to have come from passengers in a bus or taxi or drivers of either a car or a van.

Private users who answered the survey were almost all drivers, rather than users of a mobility service. This may be due to the surveys being forwarded to people who took part in EV trials at TRL. The results in this section should be considered as indicative of car and van drivers. However, it should also be noted that most drivers are also likely periodically, to be a passenger on a bus or in a taxi.

3.3.1 Private user opinion on where wireless charging should take place

As in the case of stakeholders, private users were presented with ten statements and asked to rate their general opinion on a 5 point scale between 'total agreement' and 'total disagreement'. The statements covered the same scenarios as were presented to stakeholders:

- Wireless charging for cars and vans should be undertaken directly on the road: charging while driving.
- Wireless charging for taxis should be undertaken directly on the road: charging while driving.
- Wireless charging for buses should be undertaken directly on the road: charging while driving.
- Wireless charging for cars should be undertaken at home, e.g. in the garage or on the parking place in front of my house.
- Wireless charging for buses should be undertaken at the bus depot at the end of the day.
- Wireless charging for taxis should be undertaken at taxi depot or at home at the end of the day.
- Wireless charging of cars should be undertaken in public car parks, e.g. shopping centres, town centres, other leisure activity car parks.
- Wireless charging of taxis should be undertaken in taxi ranks.
- Wireless charging of buses should be undertaken at bus stops and bus stations.
- Wireless charging of ALL electric vehicles should be undertaken while stationary at traffic lights, junctions, rail crossings and other types of mandatory stops en route.

Figure 14 shows that private users were very much in agreement that wireless charging should be undertaken in public car parks and shopping centres, taxi ranks and at bus stops and at bus stations. Most of the responses indicate that they were in favour of wireless charging in many locations.

There was a less clear majority in favour of wireless charging for cars and vans whilst driving on the road. Opinions on these statements were more divided than for other statements. The greatest level of disagreement was for wireless charging on the road (for all vehicle types) and wireless charging at mandatory stops.

Overall, most private users seemed to be supportive of wireless charging for EVs.

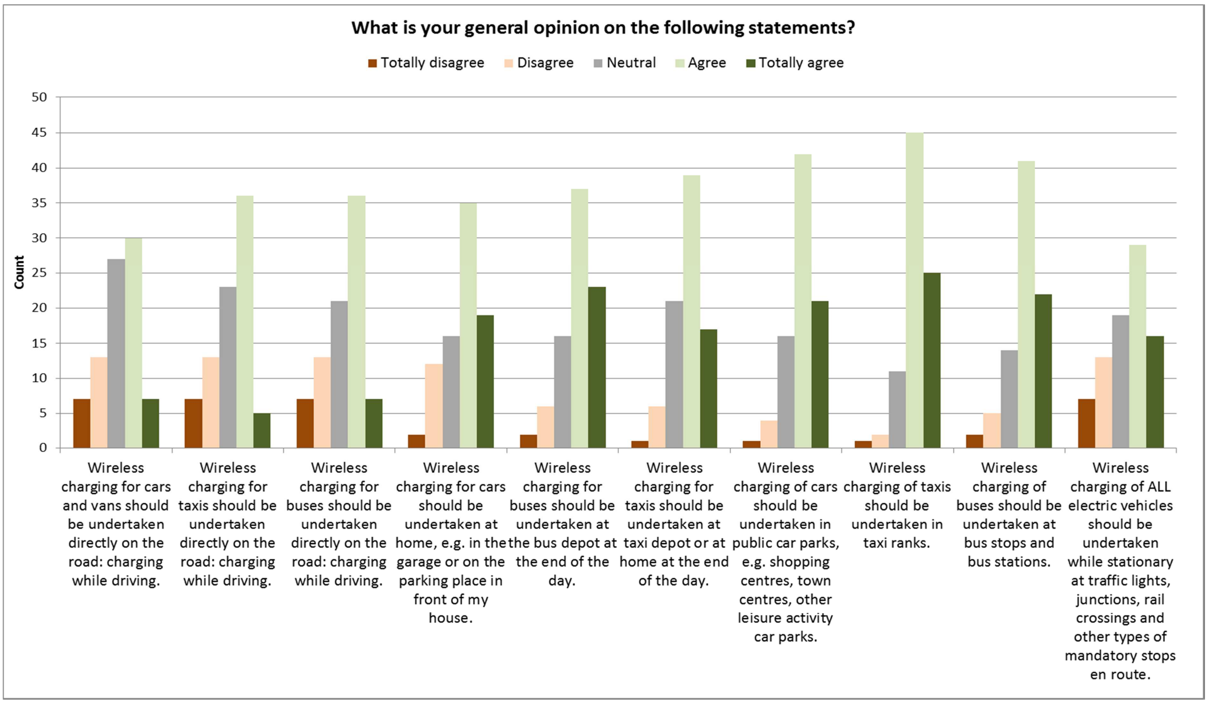


Figure 14 – Private users' views on the location of wireless charging

3.3.2 Private user opinions on who should be responsible for each of the scenarios

Using the same scenarios described above, private users were asked who they thought should be responsible for providing wireless charging infrastructure. The options they were presented with were as follows:

- A user of an electric mobility service (e.g. passenger in a bus or a taxi)
- Driver/ vehicle owner
- "Service Provider / Vehicle Operator"
- Local Authority (city, commune)
- Central Government
- Road / Highway operator

Figure 15 shows that for wireless charging whilst driving, there was no clear majority on who private users thought should be responsible for providing such infrastructure. Other questions show either a clear single answer majority or a combination of two answers.

Most private users thought that infrastructure for wireless charging at home for cars or vans should be the responsibility of the 'driver or vehicle owner'. These responses are also in line with the current situation for plug-in charging, where most EV drivers accept that it is their responsibility to provide the charging infrastructure for their vehicles at home.

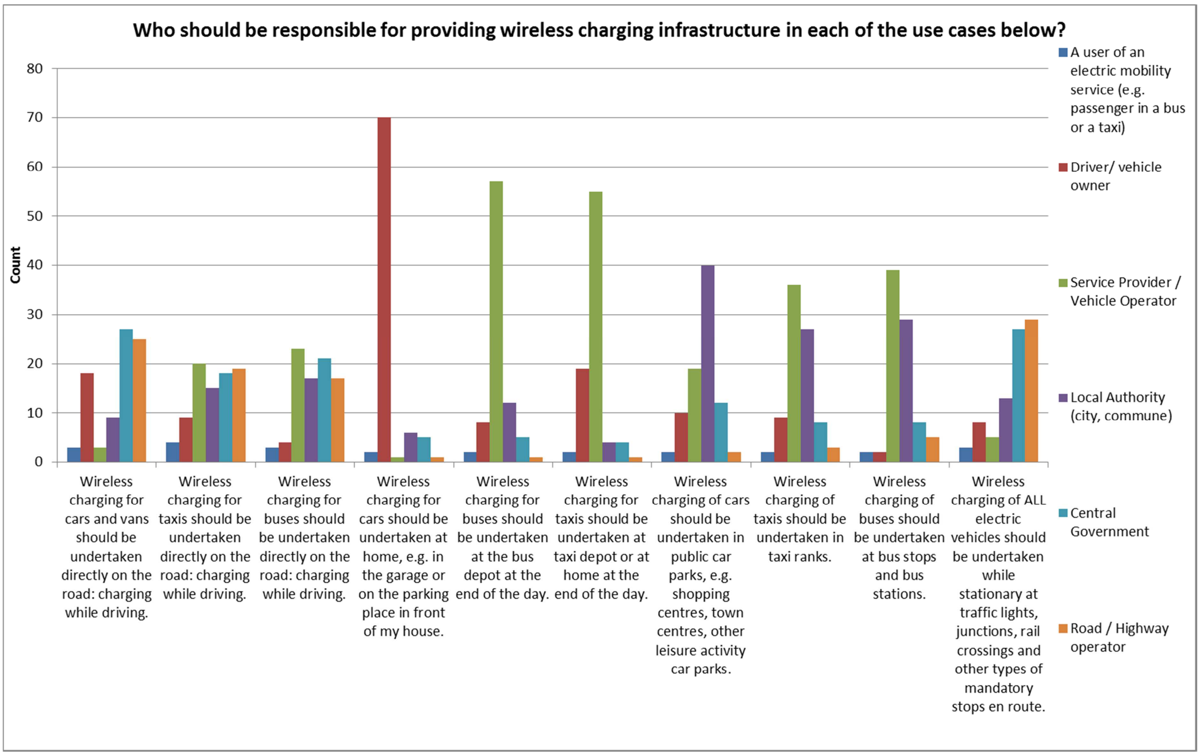


Figure 15 – Private user views on responsibility for providing wireless charging infrastructure

3.3.3 Investing in wirelessly charged vehicles

3.3.3.1 Private users who would consider purchasing electric vehicles

Figure 16 shows the likelihood that private users would consider purchasing an EV versus a wirelessly charged EV. It shows that people would be more likely to consider purchasing a wireless power transfer enabled EV than a normal plug-in EV.

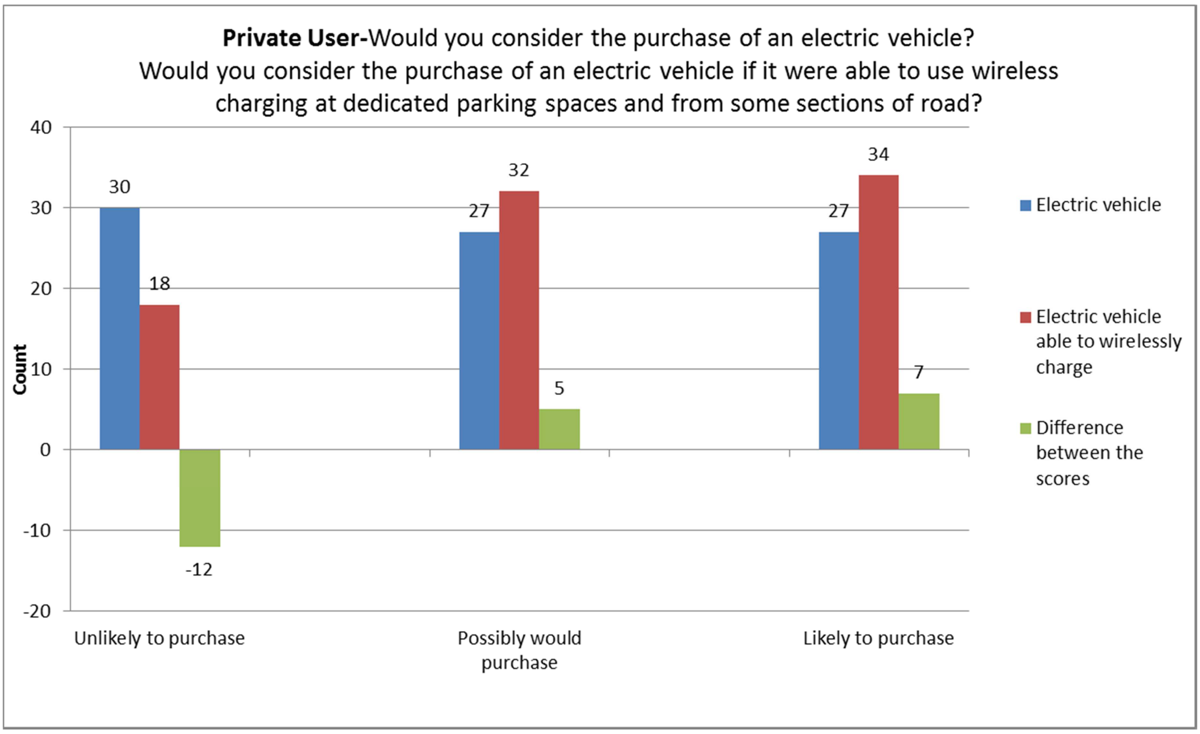


Figure 16 – Private user views on purchasing an EV

Statistical testing of the results indicates that there was a statistically significant decrease in the proportion of private users who said they were 'unlikely to purchase' an EV with wireless charging compared with the proportion who were 'unlikely to purchase' a standard EV[1]. However the difference in the percentage who said they were 'likely to purchase' a wirelessly charged EV compared with a standard EV was not statistically significant at the same level.

3.3.3.2 Key investment factors for private users

Private users were asked about the importance of various factors when deciding whether to invest in wireless charging vehicles and infrastructure. Those factors were:

- CO_2 reduction
- Air quality improvement
- Reduced running costs
- Improved practicality / simplicity of charging
- Automation and user friendliness
- Luxury / Premium function
- Technological innovation / leadership

For private users, Figure 17 indicates that 'reduced running costs' and 'simplicity and practicality' are of highest importance when investing in new vehicles and infrastructure.

As for stakeholders, 'Luxury / Premium function' and 'Technological innovation / leadership' were the factors most likely to be scored as 'not at all important' in investment decisions.

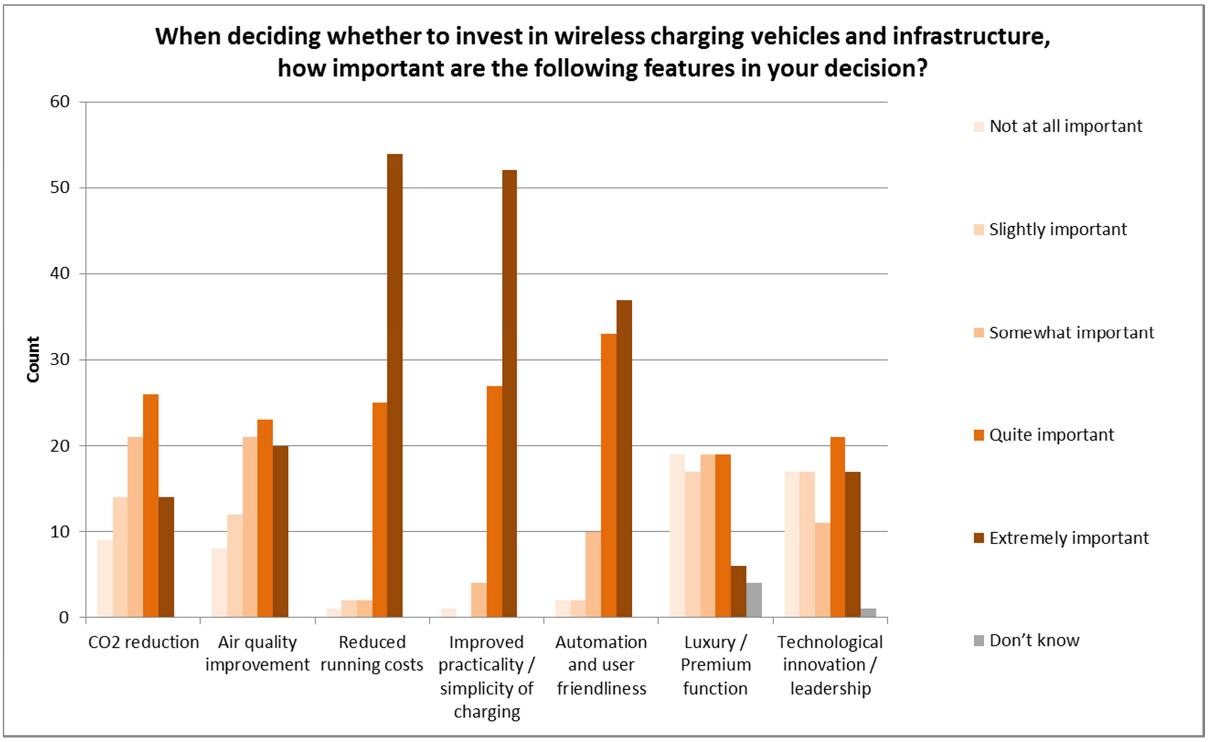


Figure 17 – Private users' views on the importance of factors when deciding to invest in EV infrastructure

3.3.3.3 Willingness to invest in wirelessly charged vehicles

Private users were asked how much extra they would be willing to invest provided the benefits they considered important were addressed by wireless power transfer.

Figure 18 shows that the most common response was 0%, meaning they would not be willing to pay extra. There are a large number who would pay extra, with several percent of the respondents stating they would be willing to pay more than 30% extra. There are no responses for a percentage decrease, meaning no respondents would only be willing to pay less for a WPT vehicle than for a standard EV. The variation in responses between different vehicle types should also be noted. Although for taxis and buses and

[1] $P<0.05$

the most common response was around 0% for cars, the most common response was around 6-10% extra.

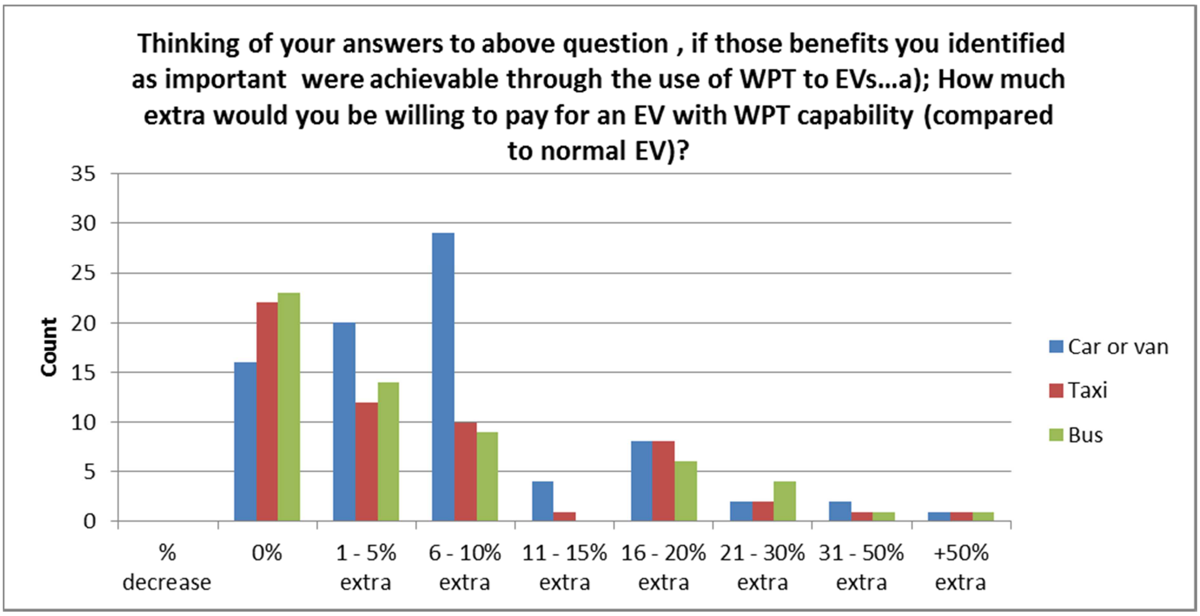


Figure 18 - *How much extra would you be willing to pay for an EV with wireless power transfer capability?*

3.3.3.4 **Private user opinions on investment in wireless charging**

Figure 19 shows that most private users agreed that 'wireless charging can help to establish more green / zero-emission zones in cities' and many agreed that they would consider buying an EV if it had wireless charging.

The greatest source of disagreement came from the statement saying 'I would only invest in a wireless charging capable vehicle if someone else paid for the wireless charging infrastructure'. This seems to show that some private users would be willing to pay towards wireless charging infrastructure. When considering these answers along with answers in Figure 15, it appears that users are willing to pay for home wireless charging and do not see this as a barrier to adoption of this technology in EVs.

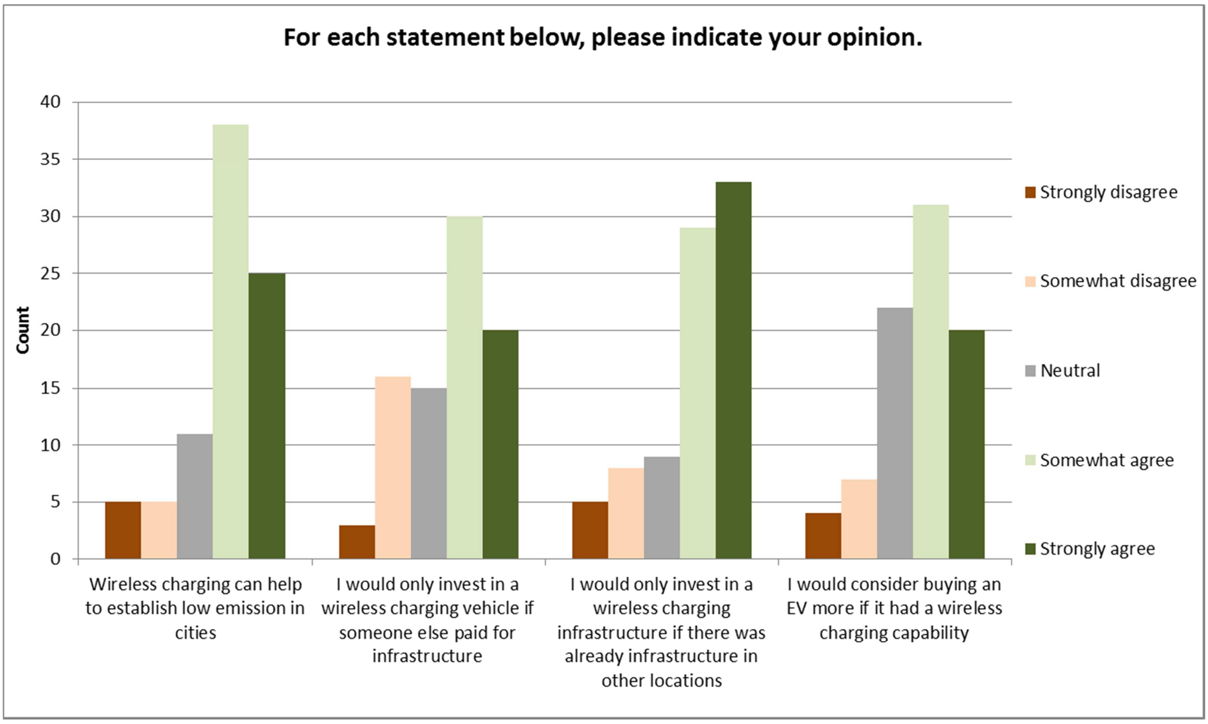


Figure 19 - Private users' views on investment in wireless charging

3.3.4 Preferable mode of transport

Private users were asked about their preferences for wirelessly charged electric buses and taxis over diesel and petrol equivalents. Figure 20 indicates that most private vehicle users would prefer to use wirelessly charged electric buses and taxis over standard ICE vehicles if wireless charging enabled more widespread use of EVs.

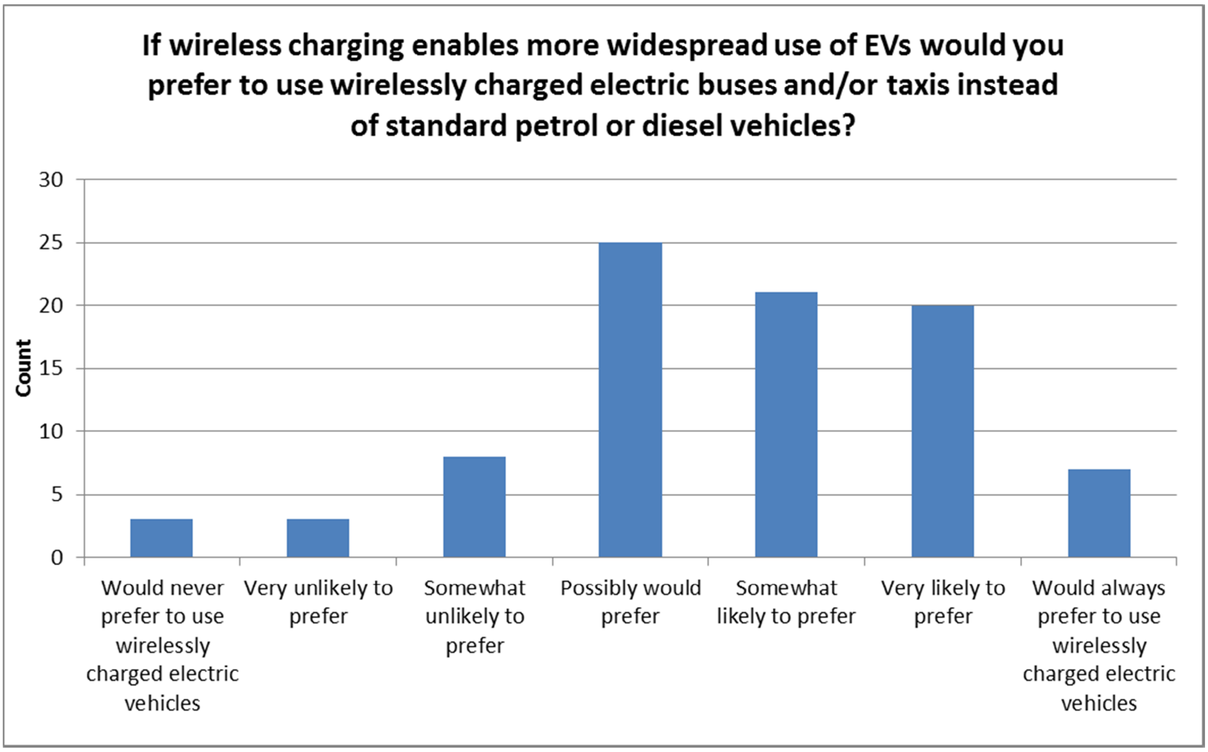


Figure 20 – Private user preferences for wireless charged public transport over standard petrol or diesel vehicles if wireless charging enables more widespread use of EVs

3.3.5 Expectations of cost

3.3.5.1 Expectations of service costs

Figure 21 shows private users' opinions on whether wirelessly charged taxi and bus services would cost more or less than the same services using standard ICE vehicles. It shows that private vehicle users mostly thought that wirelessly charged electric vehicles services would cost the same as with standard vehicles. Slightly more thought that the services would cost less than thought they would cost more.

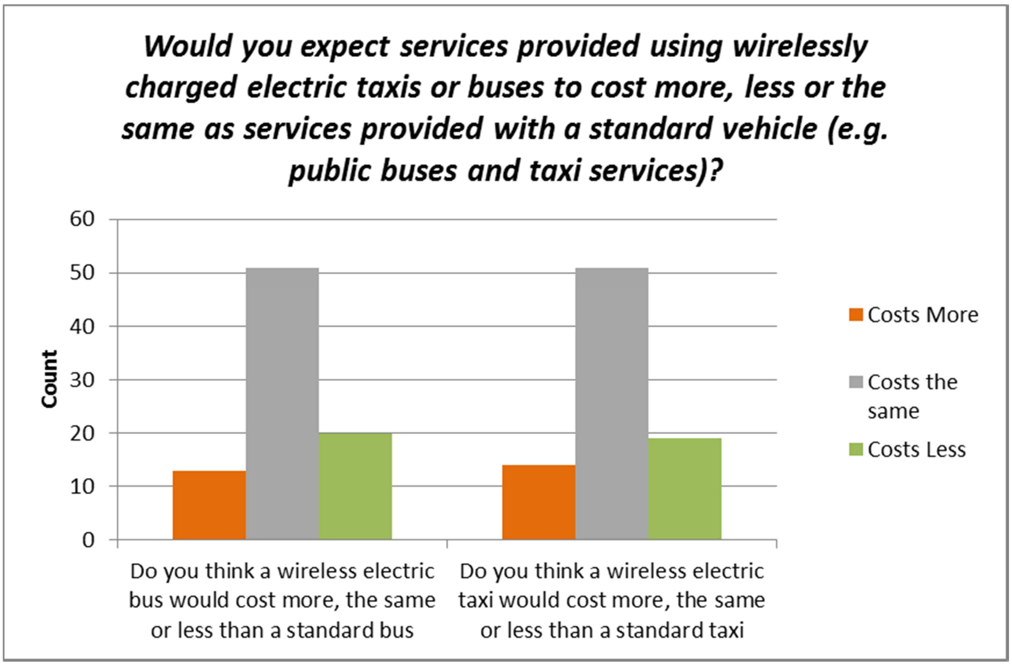


Figure 21 – Private user expectations about service costs

3.3.5.2 Service cost comparison as a percentage difference

Private users were asked about what they thought the percentage difference in cost would be between the cost of services running wirelessly charged vehicles and standard vehicles. Figure 22 shows that most respondents thought that there should be no difference. Just under 10% of respondents thought that services provided by wirelessly charged buses and taxis would be more than 20% cheaper than services by standard vehicles. Reasons for this are unknown but could be related to anticipated lower running costs.

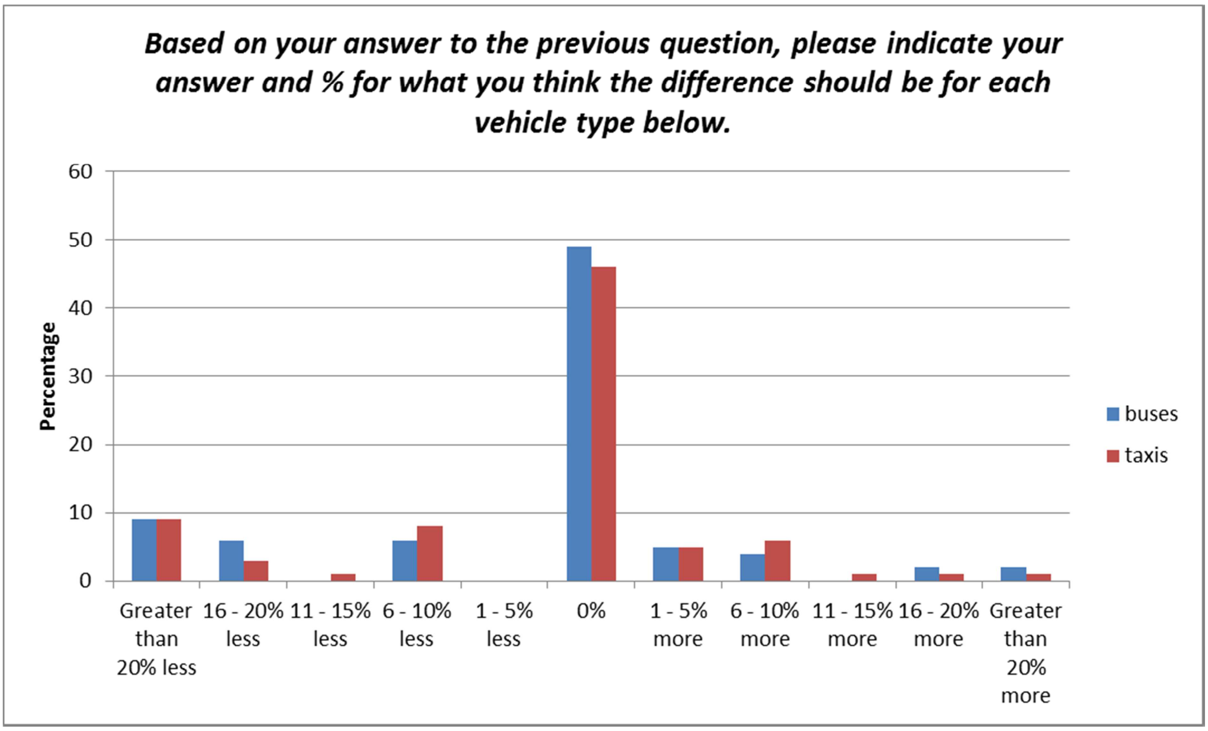


Figure 22 – Private user expectations on the percentage difference in service costs between standard and electrically charged vehicles

3.3.5.3 Vehicle cost comparisons

Private users were asked for their opinions on the cost of EVs and standard vehicles versus wirelessly charged EVs. Figure 23 shows that the majority of respondents thought that wirelessly charged EVs would cost more than standard EVs. A greater number of respondents thought that they would also cost more than standard ICE vehicles.

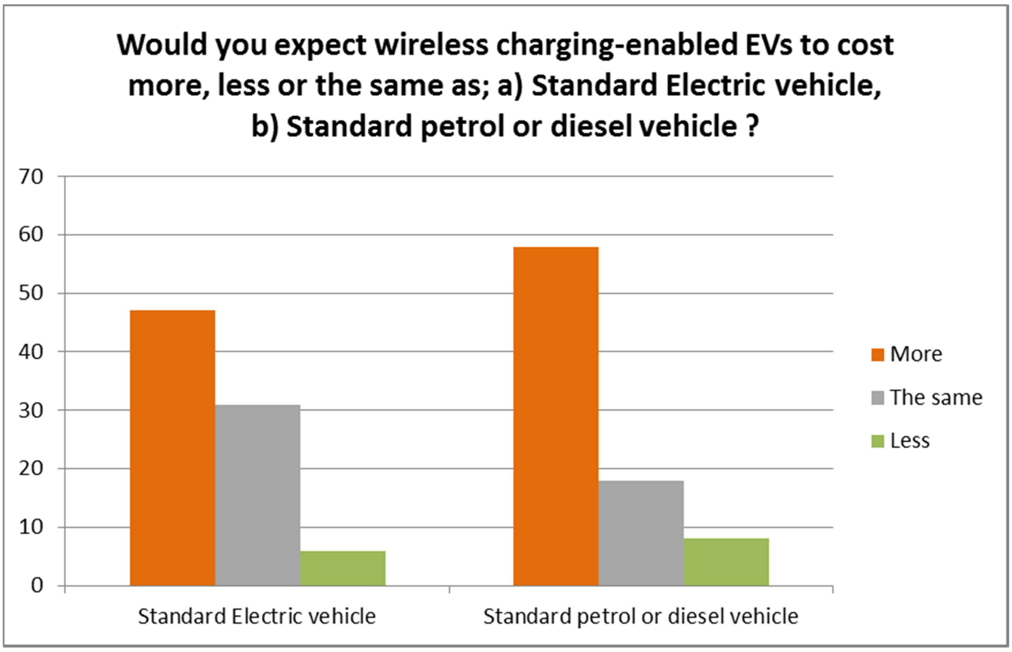


Figure 23 – Private user expectations about vehicle costs

3.3.6 Post questionnaire opinion on the topic of wireless power transfer

At the end of the questionnaire, private users were asked about their overall opinions on WPT technology. Figure 24 shows that overall, the vast majority of the questionnaire respondents thought that WPT technology is a good idea, by the time they had reached the end of the survey.

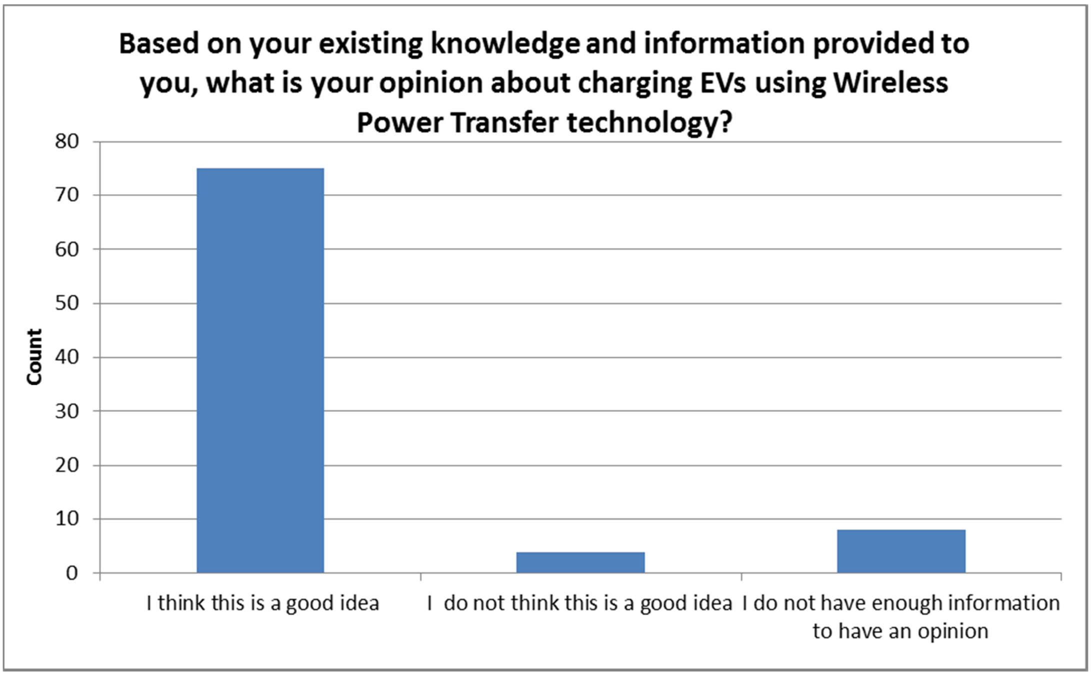


Figure 24 – Private user opinions about charging EVs using Wireless Power Transfer technology

3.3.7 Additional Private User Comments

Private users were invited to provide additional comments; out of the 87 private users, there were comments from 34.

Analysis of the comments has identified several themes that were not featured in the closed questions, and these are discussed in more detail below.

- Concerns about the impact of radiation on health and safety/other H&S concerns of installing wireless chargers
- Affordability and finance
- Concerns regarding further increased cost of EVs compared with other vehicles
- Government funding to encourage uptake of EVs
- Lack of public information available on wireless charging and trials
- Concerns about cost effectiveness compared to conventional ICE. vehicles
- Justification of infrastructure expense
- Doubts about readiness of technology
- Scepticism about environmental benefits compared to conventional vehicles.

Each one of these themes is discussed in more detail below.

3.3.7.1 Health and Safety concerns regarding wireless charging infrastructure

Some of the respondents appear to be concerned about the health and safety impact of installing wireless technology. It is interesting to note that while the stakeholders did not appear to have any concerns on this, it was something identified by some private users. One respondent stated

> "*I would be against the installation of these chargers being laid into the road all over the place including outside people's houses and remain sceptical about the safety of them*".

Another respondent was concerned that the magnetic wireless charging may impact current medical equipment such as pace makers or even birds; another that EV wireless charging could damage existing wirelessly charged telephones. On a different safety point another respondent asked about potential impacts on road surfaces of installing the equipment.

3.3.7.2 Affordability and Finance

Many responses indicate that affordability is a significant barrier to adopting new technology especially when the alternative options such as petrol and diesel cars are relatively cheaper with regards to the initial outlay. This theme appeared to dominate the comments section.

3.3.7.3 Concerns regarding further increased cost of EVs compared with other vehicles

A small number of private users mentioned that they were concerned about the further costs related to EV as these vehicles are already relatively more expensive than standard petrol and diesel ones. If the running costs would be excessive then the technology is not likely to be adopted. One said:

> "*To facilitate speedy uptake the key issue will be costs. The system needs to be affordable and therefore central government need to make the infrastructure available and if taxes can't fund it then have a levy on the electricity metered. The electricity used should be paid for via home electricity supplier contract to prevent individual firms charging excessively the facility otherwise the technology will never take off*".

3.3.7.4 Government funding to encourage uptake of EVs

A small number of private users mentioned that they think that the Government should fund the wireless charging infrastructure. One said:

> "*Central Government must also make available funds to enable charging to be economical and effective".*

3.3.7.5 Lack of public information available on wireless charging and trials

Concerns about lack of information were expressed by private users; these covered functionality, the effect on health and cost implications. There were suggestions that more research is required to provide this information. One private user claimed there is

> "*Too little information/experience to understand how quickly charging of battery will take place*".

The lack of information is also demonstrated by the fact that many of the comments were posed as questions.

3.3.7.6 Concerns about cost effectiveness compared to conventional ICE vehicles

There were several private users who were sceptical about implementing the wireless infrastructure, mainly on the grounds of practicality and cost benefit.

> *"EV's need to be cheaper to buy in the first place to allow for less well-off people to afford them. They are still too expensive for the average person to afford. Until then a Wireless Power Charging System will only be of use to the minority thus not proving all the environmental benefits possible. There is no point putting in the infrastructure if only 10% of people will own a car capable of using it."*

3.3.7.7 Justification of infrastructure expense

Several of the private users felt that at current level of usage and interest in EV, there is no justification for this huge investment. One claimed:

> "*I don't think wireless charging on the entire road network is a great idea at present. (This requires) too much of an outlay for too little payback. I do think it could be worthwhile in bus lanes though where buses/taxis are in higher concentration and you could focus the investment to where it would be most worthwhile. I'd eventually like to see wireless charging everywhere but don't imagine this would happen till the use of electric vehicles is much more common and the technology has progressed*".

3.3.7.8 Doubts about readiness of technology

Interoperability between charging systems was mentioned:

> *"I think WPT is a great idea but that the main issues surrounding the roll out are:1. How to get interoperability between manufacturers to allow multi vehicles types to use the same pads and 2. How to make a business case for it."*

3.3.7.9 Scepticism about environmental benefits compared to conventional vehicles

Several private users were sceptical about the environmental benefits of EVs of all kinds, concerns not specific to wireless charging.

> *"Modern conventional petrol and diesel vehicles are generally very economical and environmentally clean, therefore I see no real point in pursuing the use of electric vehicles for domestic use."*
>
> *"…all this extra electricity still needs to be generated....at what cost?"*
>
> *"Unless high efficiency can be achieved, this could offset the total efficiency of EVs, possibly making them less efficient (well-to-wheel) than diesel technology."*
>
> *"I would never buy an electric vehicle while the environmental impact of their production and battery production and disposal is so high."*

3.4 Questionnaire Conclusions

Overall, the majority of respondents seem to think that wirelessly charged electric vehicles are a good idea once they had read all the information provided before and during the questionnaire. The stakeholder group was slightly less positive than the private users group. All stakeholders were aware of wireless inductive charging before starting the questionnaire. This may account for the slightly less positive response. Stakeholders are more aware of any possible issues or challenges relating to the uptake of wirelessly charged vehicles.

Looking at investment and costs of electric vehicles, most respondents indicated they would be willing to pay extra for a vehicle with wireless charging capability. Only a small minority indicated they would be willing to pay less for a wirelessly charged electric vehicle.

Significantly, approximately one third of private user respondents indicated they would not be willing to pay towards public wireless charging infrastructure. Those who would be willing to invest in wireless charging infrastructure indicated, on average, that they would only invest if WPT vehicles made up twenty percent of the total vehicle fleet.

On being asked to consider the importance of various factors when considering investing in wireless charging vehicles and infrastructure, the most important factor to both groups was indicated to be ‘improved practicality/simplicity of charging’, i.e. making EVs easier to use. Reduced running costs were very important to private users, while ‘CO_2 reduction’ and ‘air quality improvement’ were very important to stakeholders.

When considering standard electric vehicles against wirelessly charged vehicles, the majority of respondents think that the costs of bus and taxi services would be the same.

The additional comments made support to some extent the above conclusions. Respondents queried the potential costs of the wireless charging systems, both installation and maintenance. Other comments related to concerns over system interoperability.

There were also a number of respondents who had concerns that there may be a possibility of health impacts from EM radiation, including on wildlife. Such concerns, even though not founded on any current evidence, may be of importance to public opinion if wireless charging becomes widespread. The comments also mentioned other potential detrimental effects of wireless charging, such as having a negative influence on mobile phone and wi-fi signals.

4 VUB Case Study

4.1 Introduction

This section presents the VUB social acceptance study which took place in Belgium, based at the Flemish Living Lab Electric Vehicles[2]. This is a programme to facilitate and accelerate the innovation and adoption of electric vehicles in the Flemish region which addresses a variety of scientific research topics. Not only pure technological topics but also socio-economic aspects are examined. These include topics such as market potential analyses, travel and purchase behaviour. They also cover expectations, opinions and attitudes.

Within this living lab, a test panel of consumers was selected to try out and test an electric vehicle. A total of 96 test families have integrated an EV into their daily lives. In return they had to complete a survey before and after testing the vehicle.

This analysis focuses on inductive charging, more specifically the attractiveness of this type of charging at Belgium. This topic was mainly covered in questions which were answered after the testing period.

4.2 Living Lab Electric Vehicles

Many studies have already proven the benefits and social relevance of electric vehicles (EVs) [1]: electric vehicles can play a crucial role in the reduction of energy dependence, the integration of renewable energy sources, recuperating the economy, improving air quality and reducing noise pollution, combating climate change and a catalyst for new mobility concepts.

However, to assess the impact of driving electric vehicles in real-life conditions it is recommended that an experimental environment: a living lab, is created [2], [3]. A key element in the living lab approach is the openly collaborative involvement of all stakeholders: academia, (end) users, public sector and companies. The living lab approach is also useful to close the so-called pre-commercial gap between the development of a technology or service and its commercialisation.

The combination of a real-life testing environment with ‘real’ test users is unique. Precisely this element gives research within the living labs an attractive and innovative character.

4.3 Results

As illustrated in Figure 25, inductive charging systems are seen by the test panel as being useful on the road, both before and after the electric car trials: three-quarters of the test users indicate that this type of charging can be useful to charge while driving the electric vehicle. It could also be useful in public car parks (shopping centres and village centres), according to the respondents. The number of users who see this type of charging as useful (62% compared to 54% before). Similarly, following trials, 25% of test users thought wireless power transfer to charge a car during the night at home could be useful, an increase of 7% compared to before the tests. An opposite trend is noticeable in the bus sector (charging a bus during a bus stop): Fewer respondents see this as useful (21% after compared to 24% before).

After the trial a negligible 2% said they were not interested in wireless charging, compared with 6% before the trial.

2 http://www.livinglab-ev.be/

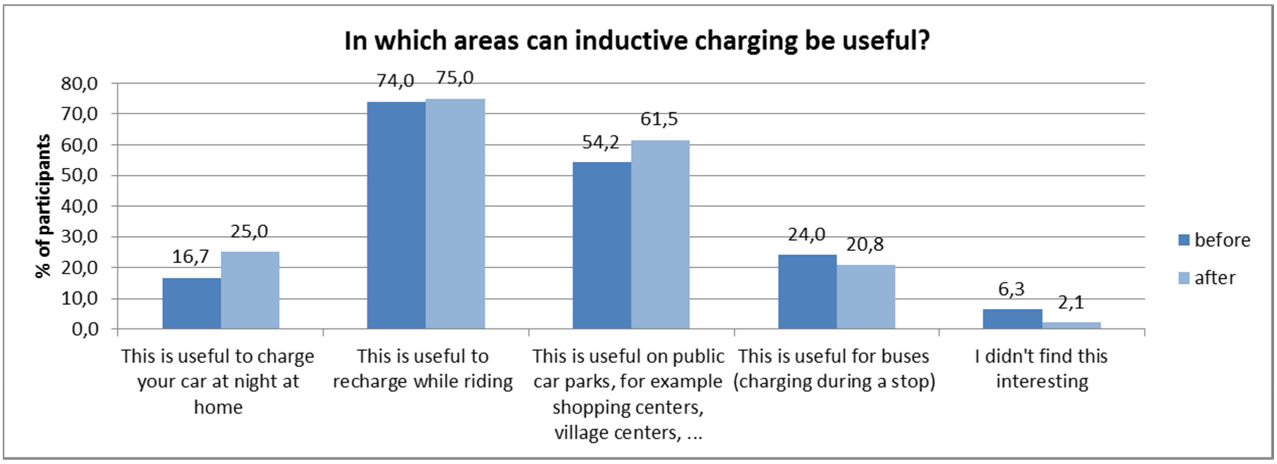


Figure 25 - Views on when inductive charging can be useful, before and after the trial

After testing an electric vehicle, respondents were asked to answer some related questions. The test panel gave their opinions based on a 5-point Likert scale (going from ‘totally disagree’ to ‘totally agree’) regarding different function areas of inductive charging. The results will be described below.

Figure 26 shows that the majority of the respondents (84%) consider inductive charging to be interesting. The greatest perceived benefit would be from charging while driving: 37% ‘totally agree’ that wireless charging should be done directly on the road, closely followed by 33% of the respondents who ‘agree’ (Figure 27). Half of the sample ‘agreed’ and 25% ‘totally agreed’ that wireless charging belongs on public car parks, like shopping centres and village centres (Figure 28). A minority 6% disagreed (‘disagreed/totally disagreed’) with this statement. Results were similar for buses: 72% believed that buses should be recharged wirelessly while stopped at the bus stop (as shown in Figure 29; 25% ‘agreed’ and 44% ‘agreed totally’).

Using wireless charging at home was less interesting to respondents compared to the other places, although almost half of the test sample agreed or totally agreed with this statement (respectively 24% and 22%) as shown in Figure 30. Almost a third (31%) of the respondents did not agree (‘disagreed/totally disagreed’) that wireless charging should take place at home and a quarter were neutral.

The overall conclusion is that the sample of drivers agreed with the idea of wireless charging outside on the street, but found it less attractive at home.

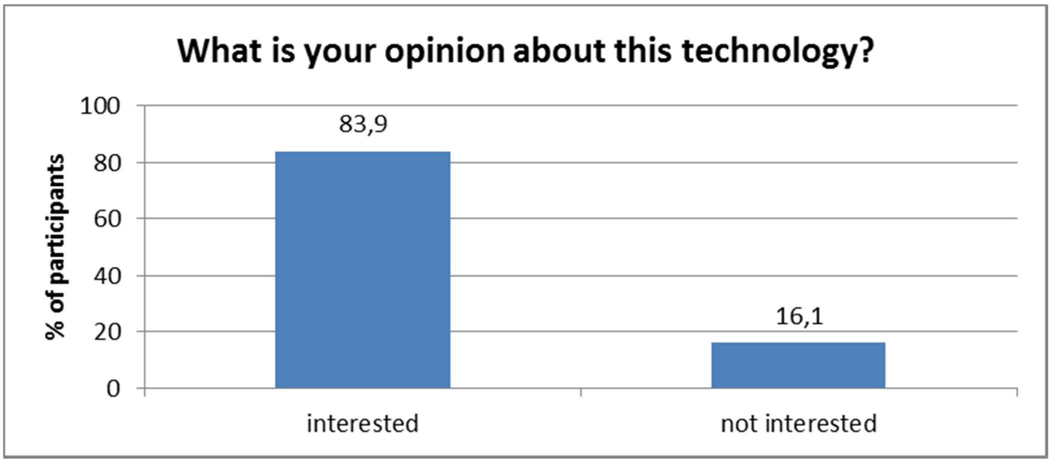


Figure 26 - Proportion who were interested in wireless charging

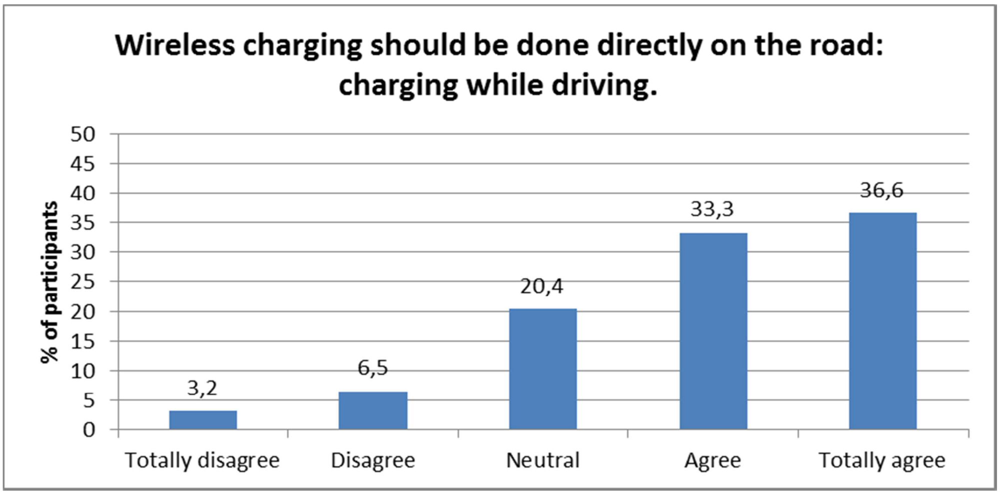


Figure 27 - Views on whether wireless charging should be done directly on the road

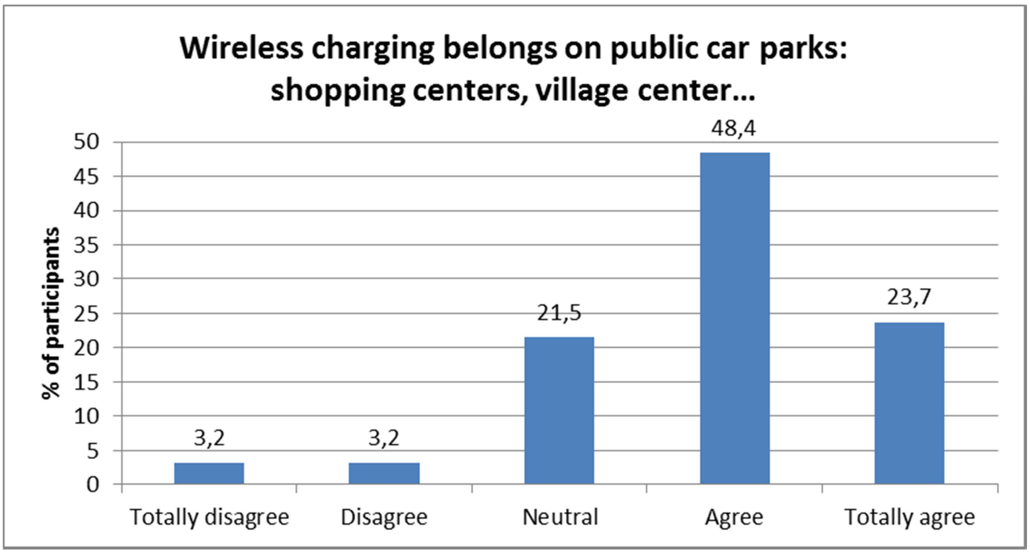


Figure 28 – Views on whether wireless charging should be done in public car parks

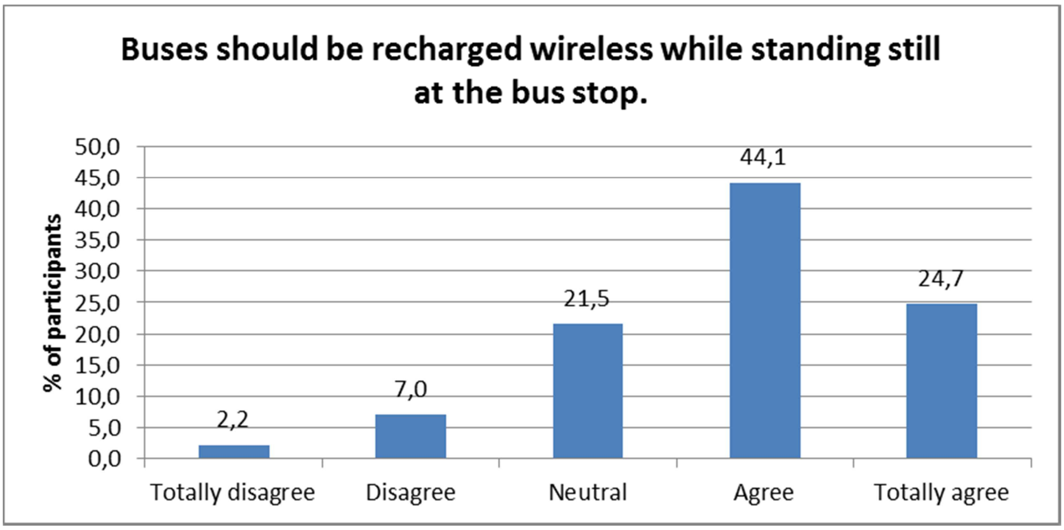


Figure 29 - Views on whether buses should be able to recharge wirelessly while standing still at the bus stop

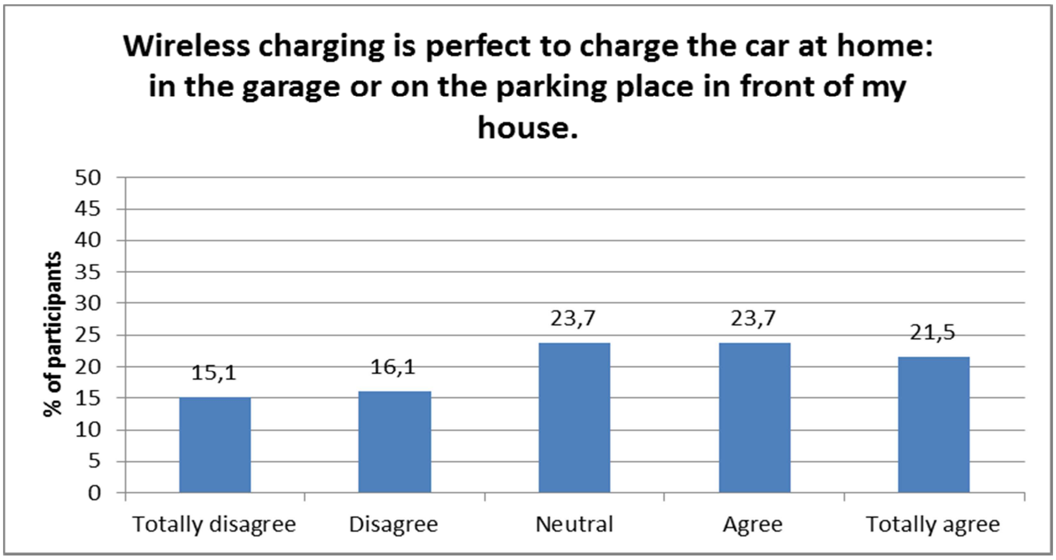


Figure 30 – Views on whether wireless charging is useful to charge the car at home

As can be seen in Figure 31, the majority of the sample said they would not consider buying an electric vehicle simply because the charging cable can be replaced by a wireless system, but 32% of the respondents said they would take this option into consideration.

On the other hand, the possibility of wireless charging is not the essential element to convince someone to buy an electric vehicle. Table 1 shows the relation between considering buying an EV in the future and considering a purchase if wireless charging would be an option. If a member of the sample does not want to buy an EV in the future, the possibility of wireless charging will not be the factor to change that decision.

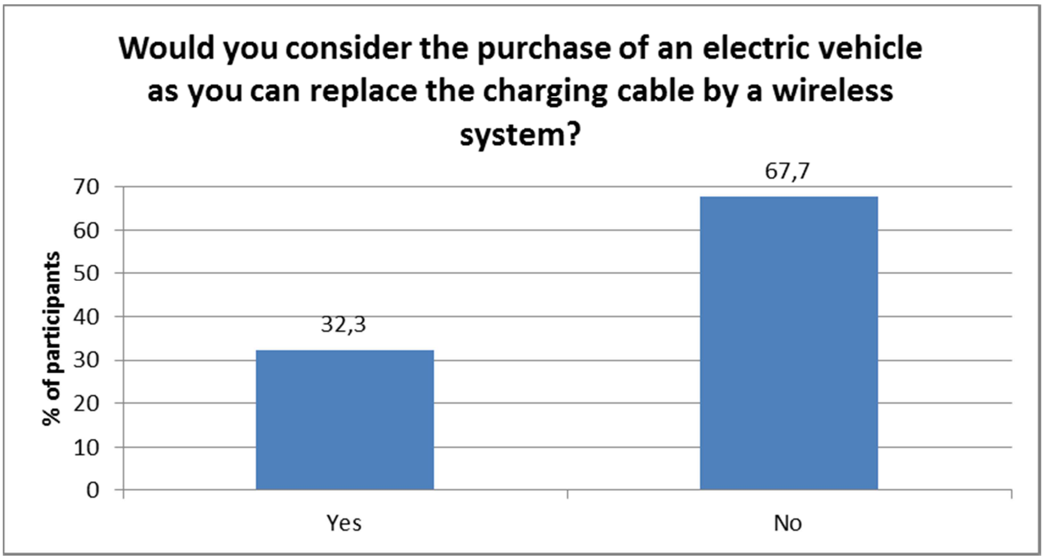


Figure 31 - Proportion who would consider buying an EV if wireless charging is an option

Table 1: The relation between considering an EV in the future and if wireless charging would be an option.

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Would you consider buying an electric vehicle in the future?</th></tr>
<tr><th>yes</th><th>no</th></tr>
<tr><th rowspan="2">Would you consider the purchase of an electric vehicle as you can replace the charging cable by a wireless system?</th><th>yes</th><td>32,2%</td><td>0%</td></tr>
<tr><th>no</th><td>57,8%</td><td>10,0%</td></tr>
</table>

Almost all members of the sample (8 out of 10) said they would use the regular charging at home instead of an inductive charging system (Figure 32). Probably the installation cost was the deciding factor: regular charging with cable would cost around 1.000€ compared to 3.000€ for inductive charging. Wireless charging is a more specific and complicated technology which requires a more specialised installation.

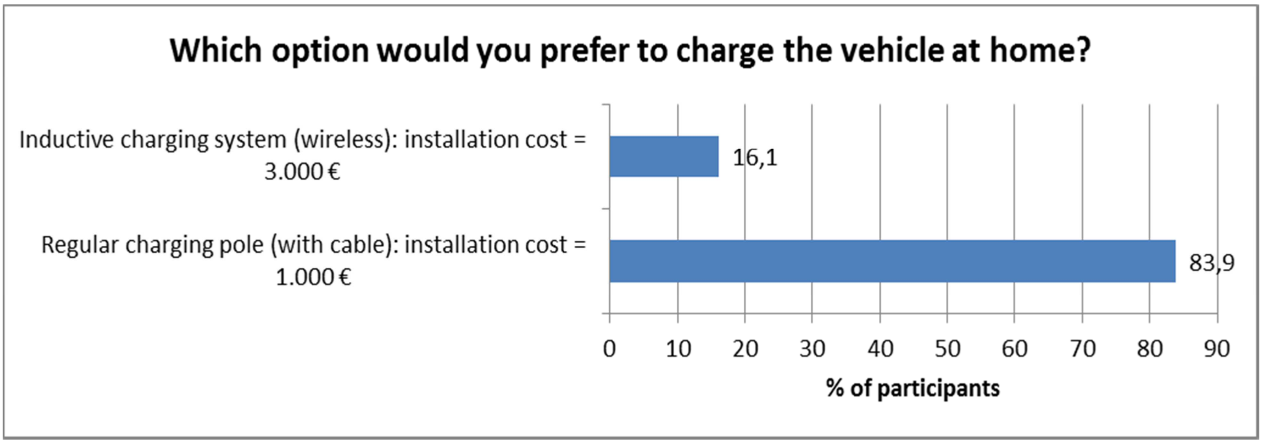


Figure 32 – Preferences for charging an EV at home: via inductive or regular charging

Inductive charging systems could also be implemented in public places, such as supermarket or public car parks. Although inductive infrastructure is more practical to use, 66% of the test panel said they were not willing to pay more for wireless charging there (Figure 33). Some respondents showed some willingness: 15% said they would pay 0,5€ more and 14% were willing to pay up to 1€ more per charging session.

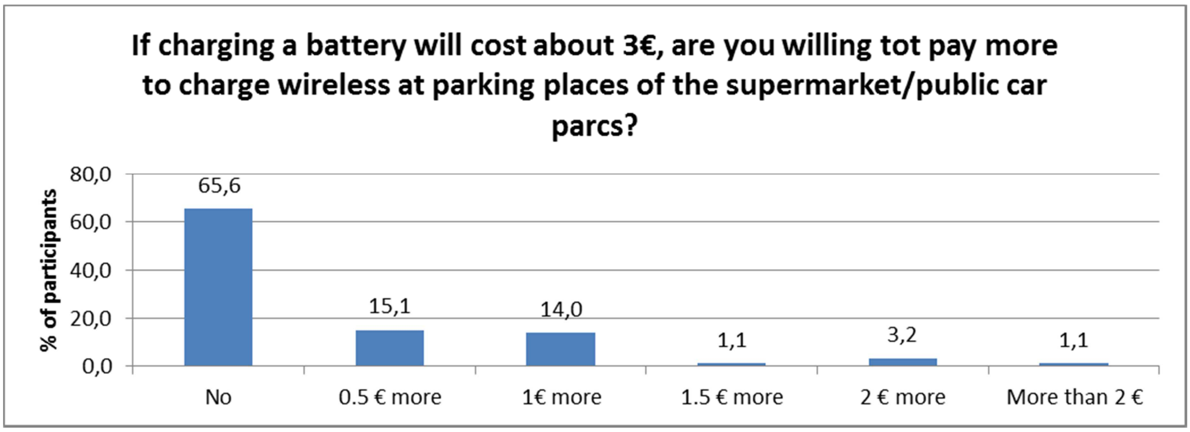


Figure 33 - Willingness to pay more for inductive charging in public places

4.4 VUB Case Study Conclusion

Respondents who were able to integrate an electric car into their daily life showed some interest in the technology of inductive wireless charging. As a result, inductive charging systems could be an option to improve the consumer acceptance for EVs since it is easier to use and safer than any other charging or refuelling methods. More importantly, this technology gives the EV a competitive advantage compared to conventional cars because no stops are needed in order to recharge. When following the wireless trend of other electronic devices, wireless charging of EVs could increase the level of flexibility for consumers of electro-mobility, which is currently perceived as too low.

On the other hand, this relatively new technology does not convince people to buy an EV. The installation price plays an important role in this decision. The majority would not consider the installation of wireless charging and say they are not willing to pay more for such a charging session in public places.

5 Socio-economic Impact Assessment

This task extends the modelling carried by TRL as part of Task 3.2.6 to cars, taxis, vans and includes information from London, Barcelona and Florence. Each section below concentrates on an individual city and the separate vehicle types. The assessment quantifies the costs (capital and operational) of replacing 5% and 20% of each type of vehicle with electric and electric wirelessly charged (Unplugged) vehicles, the expected changes in vehicle emissions and the economic impacts of those changes.

The models are based upon information supplied to TRL by external partners (University of Florence for Florence, ENIDE for Barcelona and TfL for London). Where only limited data was made available, only the analysis for which there was sufficient data was completed. The following are the key data that were requested from partners and on which the modelling was based:

- Vehicle population and annual mileage
- Fuel price
- Vehicle emissions
- National average emissions from electricity generation
- Vehicle purchase price
- Vehicle maintenance costs
- Charging infrastructure investment costs
- Maintenance costs for charging infrastructure
- Cost of emissions
- (Baseline noise figures).

5.1 London

The information for modelling London vehicles was provided by TfL. The information has been applied to the correct model for the data, which has been amended in order to apply to the specific vehicle type. Bus data is not considered separately for London as it has previously been modelled and reported upon.

Scope and key assumptions

- Energy consumption of plug-in charging and inductive charging enabled vehicles is the same
- Fleet size does not increase or change composition over the term covered by the analysis
- Depreciation is assumed to be linear and spread over 7 years for vehicles and charging infrastructure
- Annual discount rate for benefits and costs is assumed to be 3.5%, which is the rate currently used for assessing transport investment in the UK
- UNPLUGGED vehicles are assumed to have additional costs due to secondary coils, power electronics and additional control equipment compared with electric plug-in vehicles but also have batteries which are 40% smaller
- Price of fuel and value of emissions are assumed to be fixed over the term covered by the analysis and based upon cost at the location specified
- Accident data is taken into account when calculating societal costs but accident likelihood and severity is assumed to be the same across all vehicle types due to lack of any data to suggest otherwise.
- Diesel bus baseline Euro V (five) engine type
- All buses are considered to be single-decker buses except if specified
- To provide fair comparison noise data is not considered in this model as accurate information was unavailable except from London.
- Other specific exceptions are indicated within each section

5.1.1 London car modelling

This section of analysis is based on the current London car fleet. It uses the key measures to model this and been broken down to cars of the following types:-

- Petrol
- Diesel
- EV
- EV Unplugged

This is a simplified model in comparison with the previous bus fleet analysis for London buses and is based on available data. This model uses an estimated vehicle fleet of three million cars, with 40% being petrol and 60% diesel.

Current total fleet costs are estimated to be approximately €58 billion per year in year one reducing to €50 billion in year seven.

The societal cost or benefit values are based on the value of hospital related admissions due to poor air quality from traffic and from accidents, though accident data is based on total fleet numbers and hence does not vary in these models. (This is assuming that EVs are no more dangerous than ICE vehicles.)

5.1.1.1 **5% Electric cars**

If in London 5% of cars were replaced by electric cars the analysis suggests that capital costs would be greater by approximately €89 million per year in the first year dropping to €72 million greater in year seven. This is offset by the reduction in operating costs: €134 million lower in the first year and €108 million lower in year seven. Societal benefits are €6.6 million in the first year and drop to €5.4 million by year seven. These benefits are the reduction in societal costs with electric cars compared with the societal costs associated with the current fleet. The differences in cost, although quite large are small in comparison to total costs. This is discussed later. The reducing costs or benefits over time stem from the depreciation factor applied to the model.

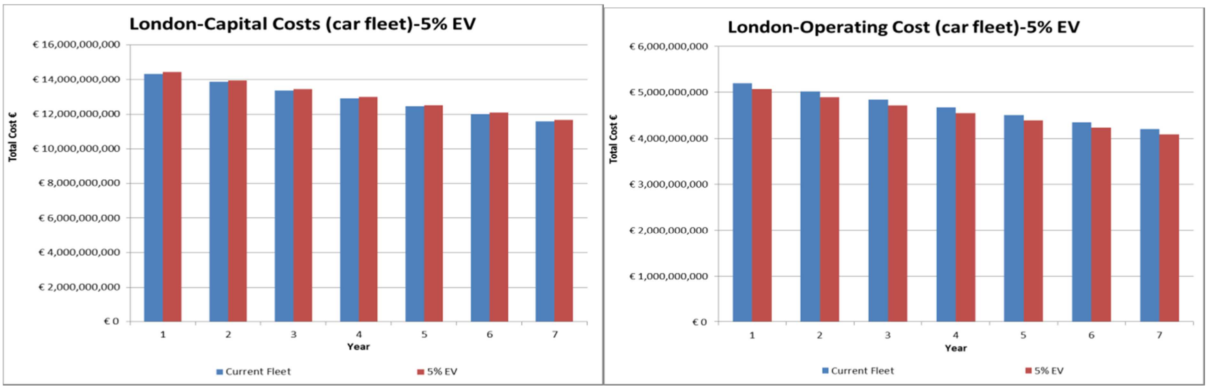


Figure 34 - *Fleet impact on capital (a) and operating costs (b): 5% electric take-up rate London cars*

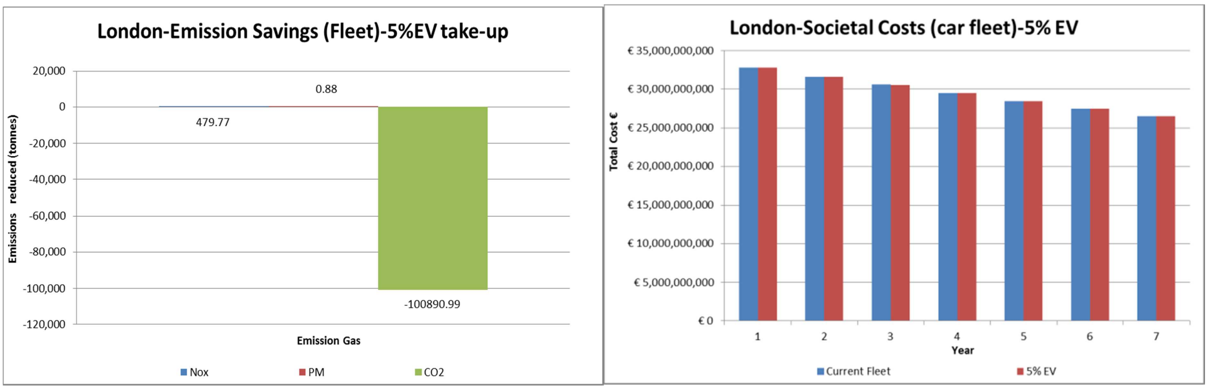


Figure 35 - *Reduced emissions in tonnes (a) and resulting societal cost reductions (b) - London cars 5% EV*

This change in fleet composition would reduce Carbon Dioxide (CO_2) emissions by just over 100,000 tonnes. Oxides of nitrogen (NO_x) would increase by nearly 480 tonnes and Particulate Matter (PM) by 0.9 tonnes.

5.1.1.2 **5% Unplugged cars**

If 5% of cars were replaced by Unplugged electric cars the analysis suggests that capital costs would be greater by approximately €43 million per year in the first year dropping to €35 million greater in year seven. This is slightly offset by the reduction in operating costs: €134 million lower in the first year and €108 million lower in year seven. Societal benefits are €6.7 million in the first year and drop to €5.4 million by year seven.

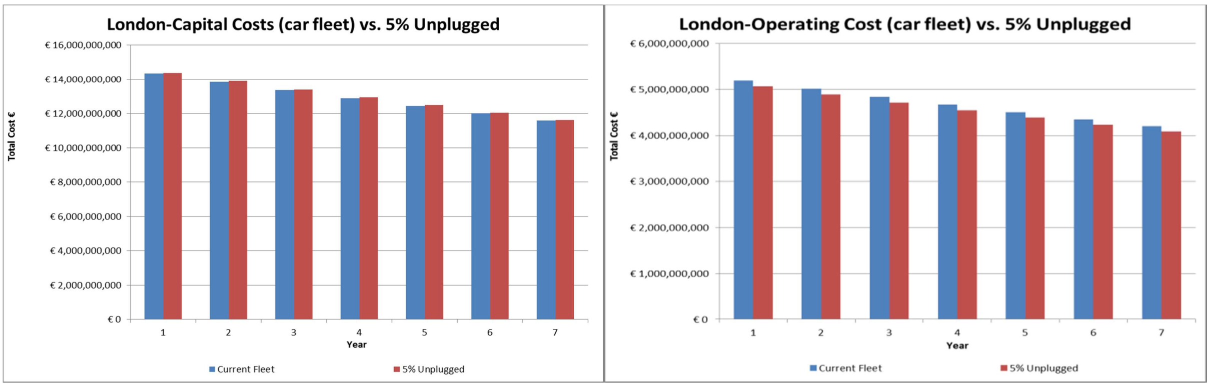


Figure 36 - *Fleet impact on capital (a) and operating costs (b): 5% Unplugged take-up rate London cars*

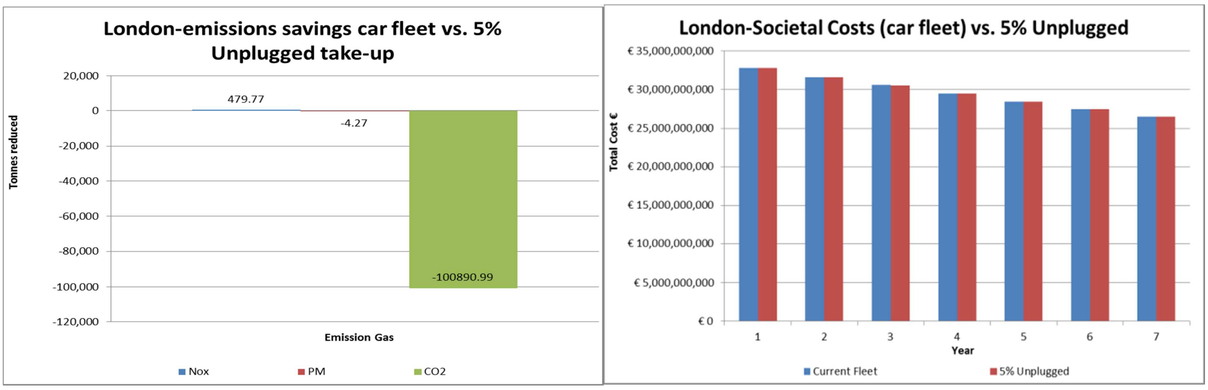


Figure 37 - *Reduced emissions in tonnes (a) and resulting societal cost reductions (b) - London cars 5% Unplugged*

This change in fleet composition would reduce Carbon Dioxide emissions by just over 100,000 tonnes.

5.1.1.3 **5% car fleet take-up comparison**

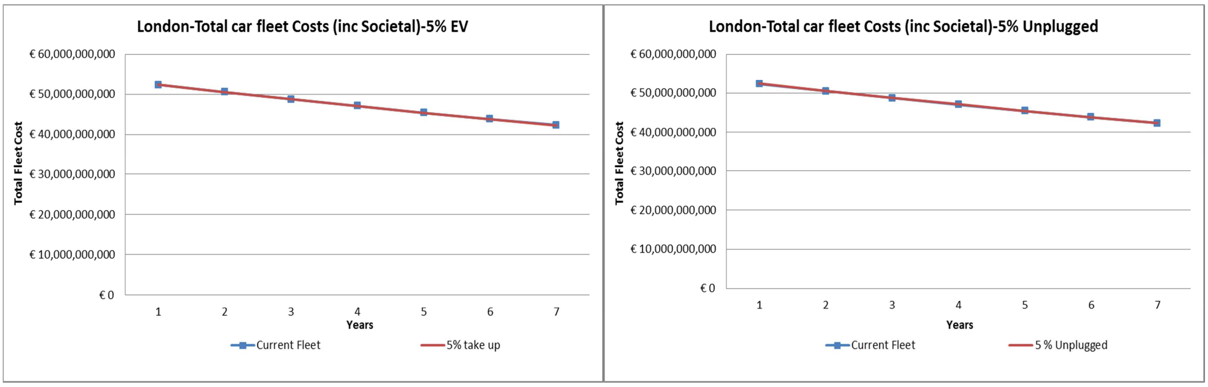


Figure 38 - *Total costs for car fleet per year for electric (a) and UNPLUGGED (b) at 5% take-up rate - London cars*

Overall benefits for the total car fleet if 5% of cars are electric are estimated to be €52 million per year in year one, reducing to €42 million per year in year seven, giving a total estimated benefit of €325 million over seven years. Against current total costs of approximately €52 billion this is calculated to be 0.1% reduction (-0.1%) in total costs. The benefit per car is thus estimated to be €108 over the seven year period.

Overall benefits for Unplugged vehicles are estimated to be €46 million in year one dropping to €38 million in year seven, which gives a total estimated benefit of €295 million. Against current total costs of approximately €52 billion this is estimated to be 0.1% higher (+0.1%) costs per year. This is approximately €98 per car over seven years.

Assuming that urban NO_x and PM is generated primarily from tailpipe emissions, and that by switching the vehicle fleet for 5% EVs the emissions for those vehicles are removed from the city, then urban NO_x is reduced by just over 8000 tonnes per year and PM is reduced by 34 tonnes per year. This stems from emissions at power stations. Any increase in emissions has less impact on public health as the power station emissions occur at a greater distance than locally produced vehicle emissions. Emissions cost data is taken from the DfT WebTAG transport analysis guidance document [5].

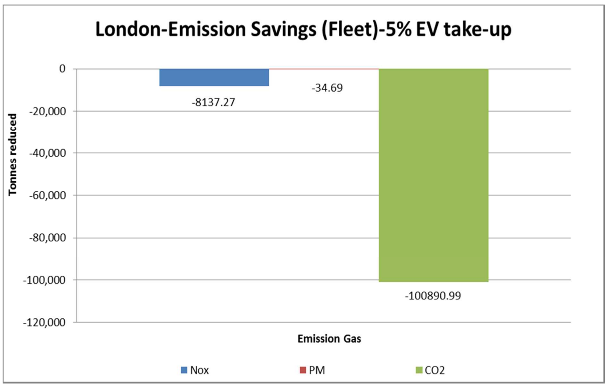


Figure 39 - *Reduced emissions if EV NO_X and PM only generated at power plant* - *London cars 5%*

5.1.1.4 **20% Electric cars**

If in London 20% of cars were replaced by electric cars the analysis suggests that capital costs would be greater by approximately €356 million per year in the first year, dropping to €287 million greater in year seven. This is offset by the reduction in operating costs: €536 million lower in the first year and €433 million lower in year seven. Societal benefits are €26.6 million in the first year and €21.5 million by year seven.

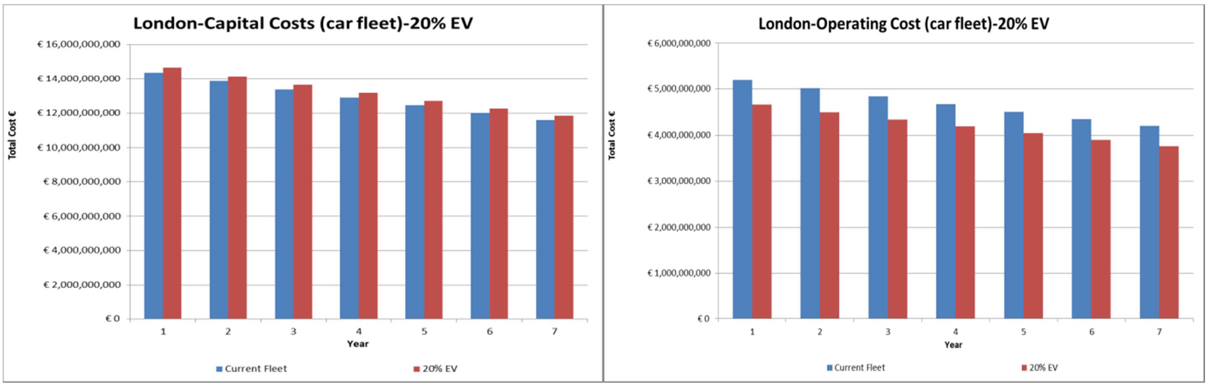


Figure 40 - *Fleet impact on capital (a) and operating costs (b): 20% electric take-up London cars*

This change in fleet composition would reduce Carbon Dioxide emissions by just over 400000 tonnes per year. Particulate matter is reduced by 1.6 tonnes per year. NO_X increases by approximately 1900 tonnes per year.

Figure 41 - *Reduced emissions (a) and resulting societal cost reductions (b) - London cars 20% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by just over 400,000 tonnes.

5.1.1.5 **20% Unplugged cars**

If 20% of cars were replaced by Unplugged electric cars the analysis suggests that capital costs would be greater by approximately €694 million per year in the first year dropping to €560 million greater in year seven. This is almost offset by the reduction in operating costs: €536 million lower in the first year and €433 million lower in year seven. Societal benefits are €26.6 million in the first year and €21.5 million by year seven.

Figure 42 - *Fleet impact on capital (a) and operating costs (b): 20% Unplugged take-up rate London cars*

Figure 43 - *Reduced emissions in tonnes (a) and resulting societal cost reductions (b) - London cars 20% Unplugged*

The change in fleet composition for Unplugged vehicles would match emissions changes for 20% electric cars

5.1.1.6 **20% car fleet take-up comparison**

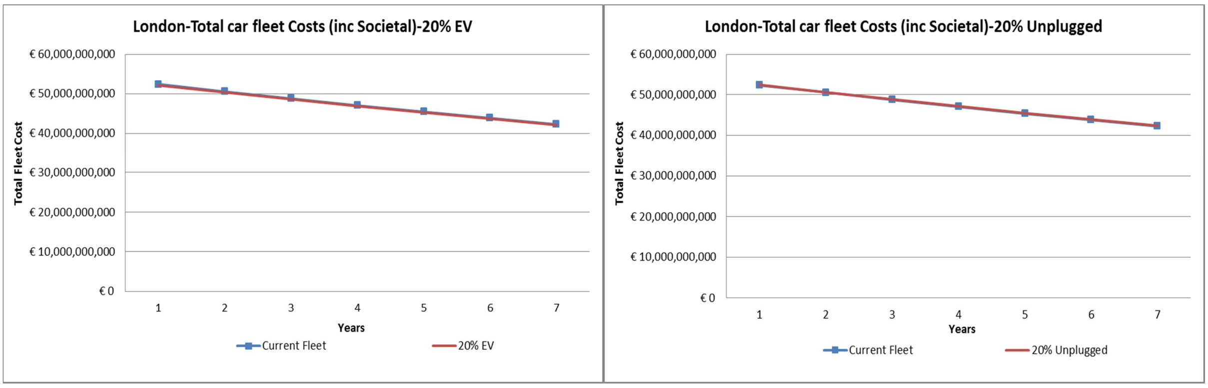


Figure 44 - *Total costs for car fleet per year for electric (a) and UNPLUGGED (b) at 20% take-up rate - London cars*

Overall benefits for the total car fleet for 20% electric cars are estimated to be €206 million per year in year one, reducing to €167 million per year in year seven, giving a total estimated benefit of €1.3 billion. Against current total costs of approximately €52 billion per year this is calculated to be 0.4% (-0.4%) reduction in total costs. The benefit per car is thus estimated to be €544 over the seven year period.

Overall Unplugged vehicles are estimated to cost €187 million extra in year one dropping to €151 million in year seven, which gives a total estimated added cost of €1.18 billion. Against current total costs of approximately €52 billion per year this is estimated to be 0.36% (+0.36%) greater costs per year.

Assuming that urban NO_x and Particulate Matter is generated primarily from tailpipe emissions, and that switching the vehicle fleet for 20% EVs will remove some of these emissions from the city, urban NO_x is reduced by slightly less than 5000 tonnes per year and PM is reduced by 16.6 tonnes per year.

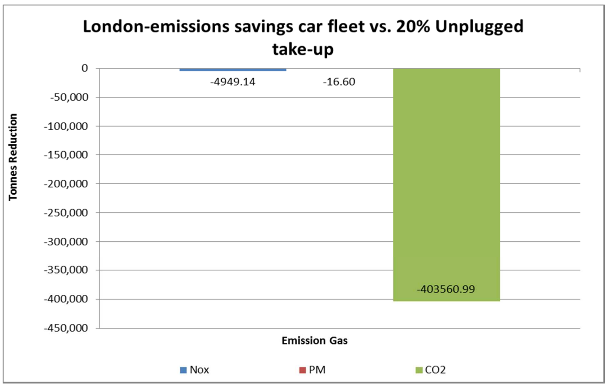


Figure 45 - *Reduced emissions if EV NO_x and PM only generated at power plant - London cars 20%*

5.1.2 London Van modelling

This model is based on a vehicle fleet of approximately 720,000 vans, with 5% being petrol and 95% diesel.

5.1.2.1 **5% Electric vans**

If in London 5% of vans were replaced by electric vans the analysis suggests that capital costs would be increased by approximately €65 million per year in the first year dropping to an extra €53 million in year seven. This is offset by the reduction in operating costs: €76 million lower in the first year and €62 million lower in year seven. Societal benefits are €36 million in the first year and drop to €29 million by year seven.

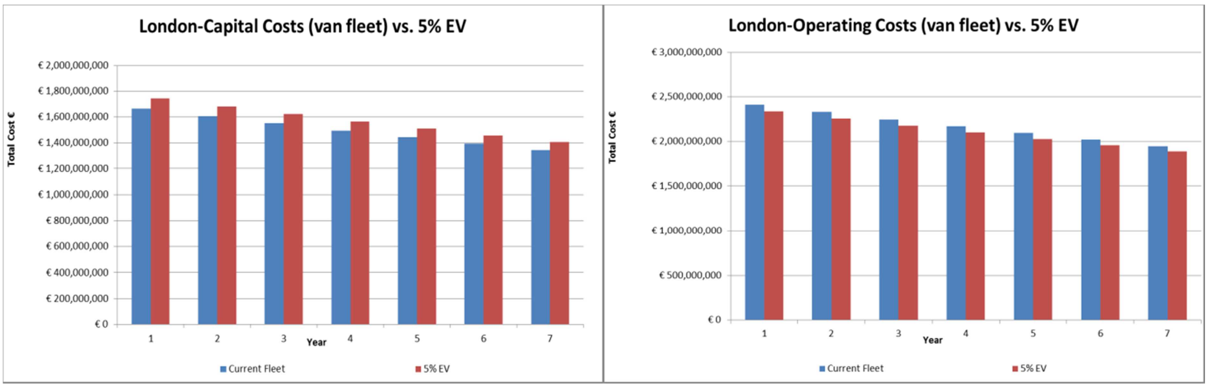


Figure 46 - *Fleet impact on capital (a) and operating costs (b): 5% electric take-up rate – London cars*

This change in fleet composition would reduce Carbon Dioxide emissions by just under 480,000 tonnes per year. Particulate Matter is reduced by 9.8 tonnes per year. NO_x decreases by approximately 450 tonnes per year.

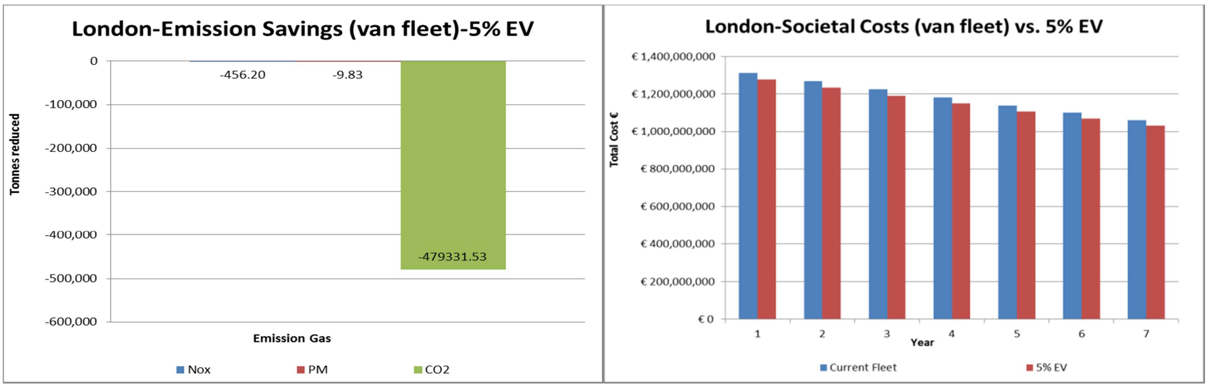


Figure 47 - *Reduced emissions in tonnes (a) and resulting societal cost reductions (b) London cars 5% EV*

5.1.2.2 **5% Unplugged vans**

If in London 5% of vans were replaced by Unplugged electric vans the analysis suggests that capital costs would be higher by approximately €75 million per year in the first year dropping to €60 million higher in year seven. This is offset by the reduction in operating costs: €76 million lower in the first year and €62 million lower in year seven. Societal benefits are €36 million in the first year and drop to €29 million by year seven.

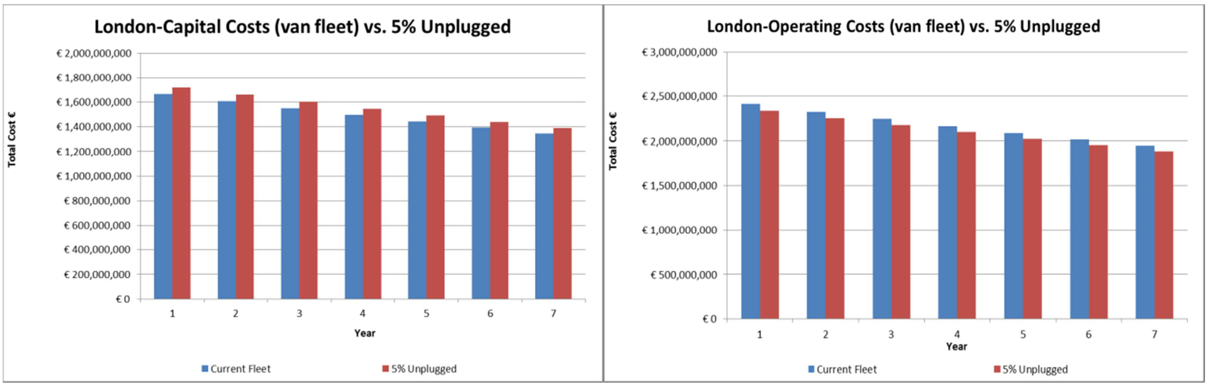


Figure 48 – *Reduced emissions in tonnes (a) and resulting societal cost reductions (b) - London vans 5% Unplugged*

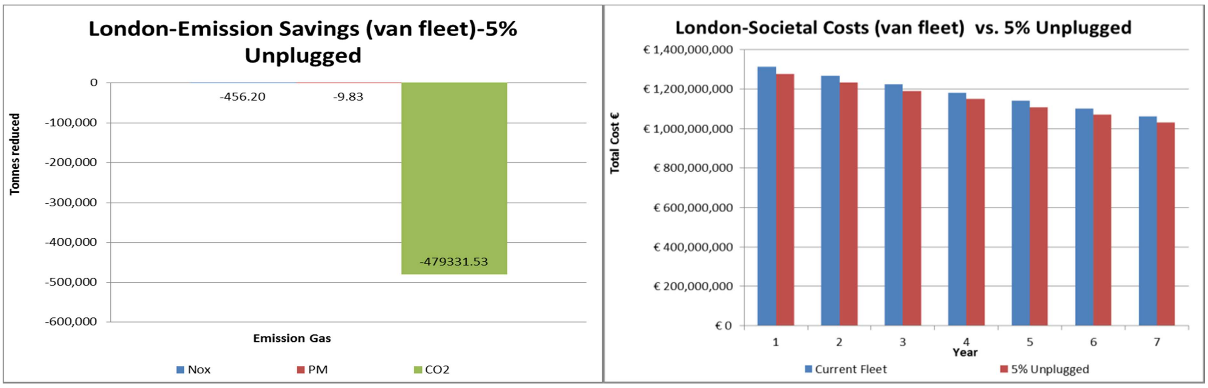


Figure 49 - *Reduced emissions in tonnes (a) and resulting societal cost reductions (b) - London vans 5% Unplugged*

Emissions are estimated to be reduced by the same quantities as for electric vans.

5.1.2.3 **5% van take-up fleet comparison**

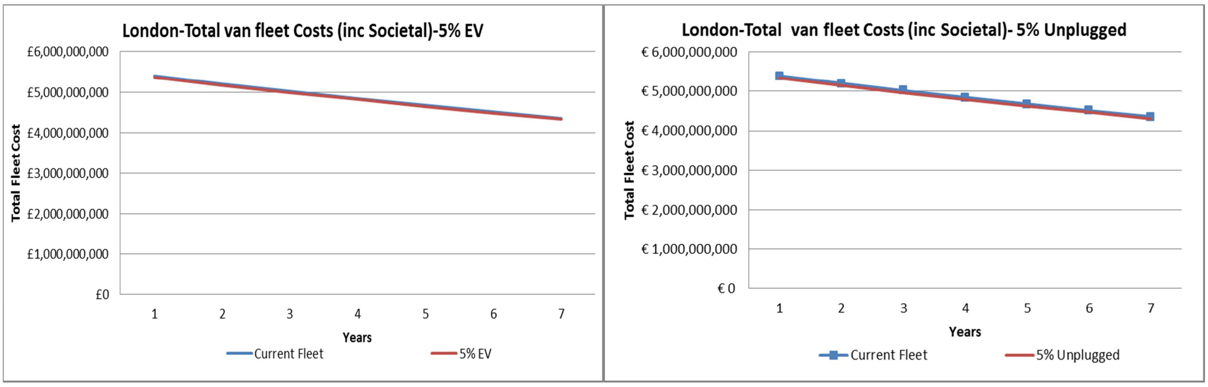


Figure 50 - *Total costs for van fleet per year for electric (a) and UNPLUGGED (b) at 5% take-up rate*

Overall decreased cost for the total van fleet for 5% electric vans are estimated to be €47.2 million per year less in year one, reducing to €38.1 million per year in year seven, giving a total estimated reduced cost of €298 million. Against current total costs this is calculated to be a 0.9% (-0.9%) decrease. The benefit per van is thus estimated to be €414 over the seven year period.

Overall 5% Unplugged vans are estimated to cost €59 million less in year one reducing to €47 million less in year seven, which gives a total estimated benefit of approximately €239 million. Against current total costs this is estimated to be 0.7% (-0.7%) lower costs per year and a reduction in cost per van of approximately €332.

Assuming that urban NO_x and Particulate Matter is generated primarily from tailpipe emissions, and that switching the vehicle fleet for 5% EVs removes some of these emissions from the city, NO_x is reduced by 18,000 tonnes per year and PM is reduced by 28 tonnes per year.

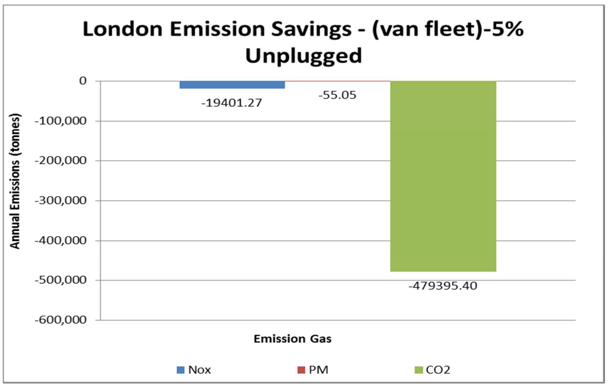


Figure 51 - *Reduced emissions if EV NO_x and PM only generated at power plant - London vans 5% Unplugged*

5.1.2.4 **20% Electric vans**

If in London 20% of vans were replaced by electric vans the analysis suggests that capital costs would be higher by approximately €307 million per year in the first year dropping to €248 million higher in year seven. This is offset by the reduction in operating costs: €305 million lower in the first year and €246 million lower in year seven. Societal benefits are €145 million in the first year and drop to €117 million lower by year seven.

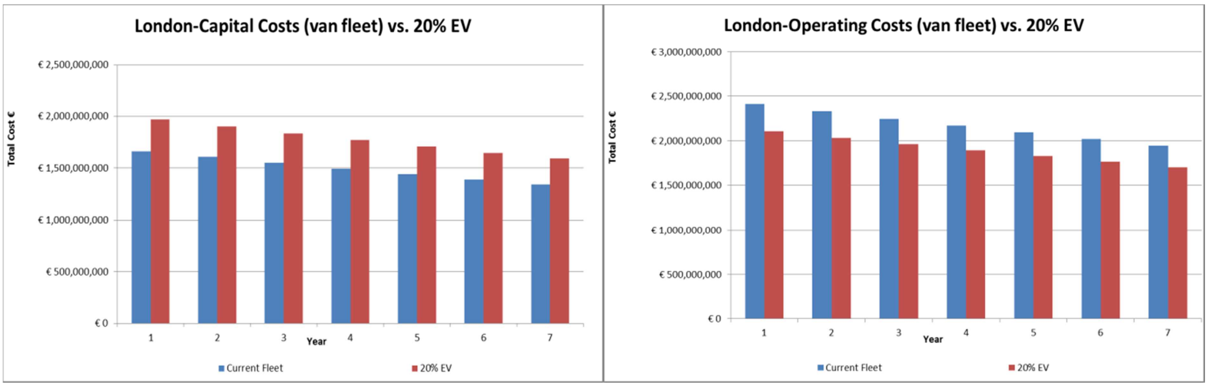


Figure 52 - *Fleet impact on capital (a) and operating costs (b): 20% electric take-up London vans*

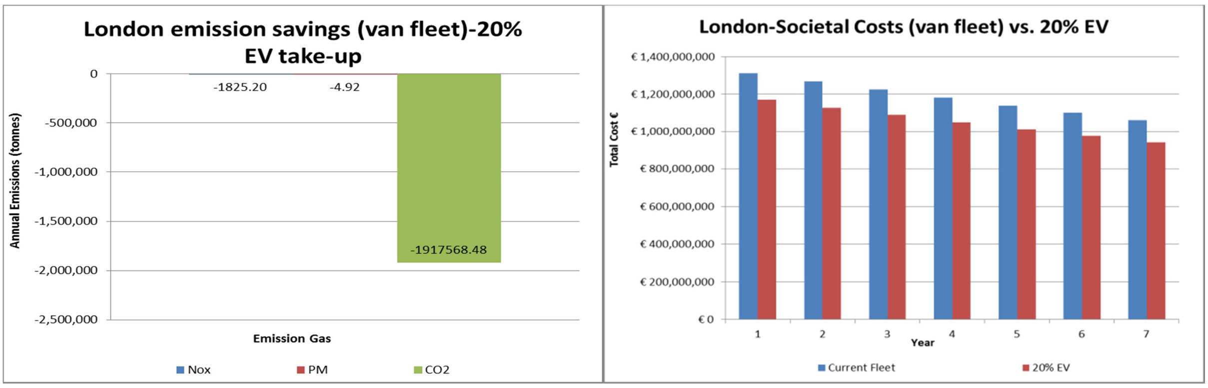


Figure 53 - *Reduced emissions (a) and resulting societal cost reductions (b) for 20% electric vans London vans*

This change in fleet composition would reduce Carbon Dioxide emissions by just over 1.9 million tonnes per year. Particulate matter is reduced by 13.5 tonnes per year. NO_x decreases by approximately 1825 tonnes per year.

5.1.2.5 20% Unplugged vans

If 20% of vans were replaced by Unplugged electric vans the analysis suggests that capital costs would be higher by approximately €399 million per year in the first year dropping to €322 million greater in year seven. This is offset by the reduction in operating costs: €305 million lower in the first year and €246 million lower in year seven. Societal benefits are €145 million in the first year and drop to €117 million by year seven.

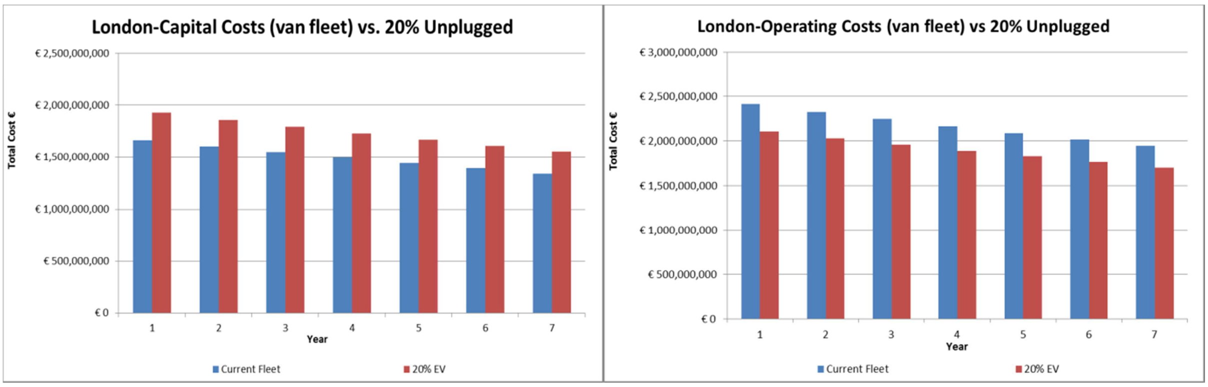


Figure 54 - *Fleet impact on capital (a) and operating costs (b): 20% Unplugged take-up rate*

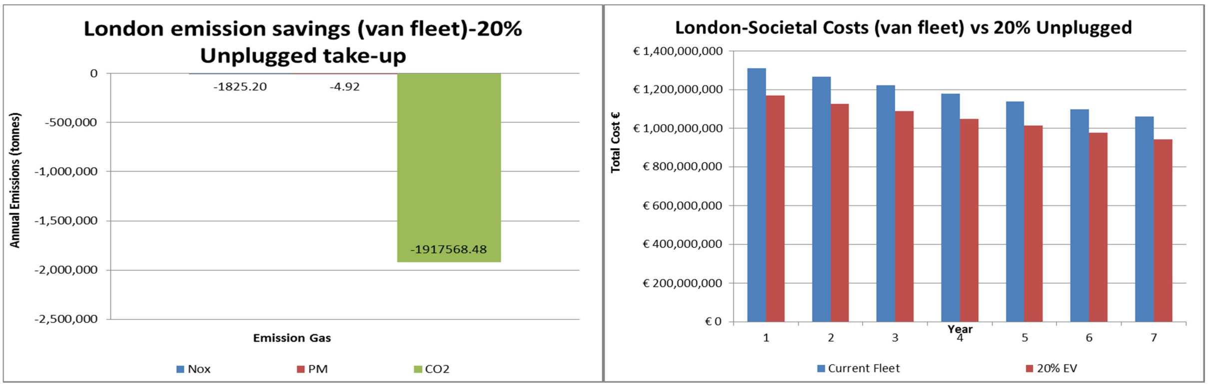


Figure 55 - *Reduced emissions in tonnes (a) and resulting societal cost reductions (b) for 20% Unplugged vans*

Emissions are estimated to be reduced by the same quantities as for electric vans.

5.1.2.6 **20% van fleet take-up comparison**

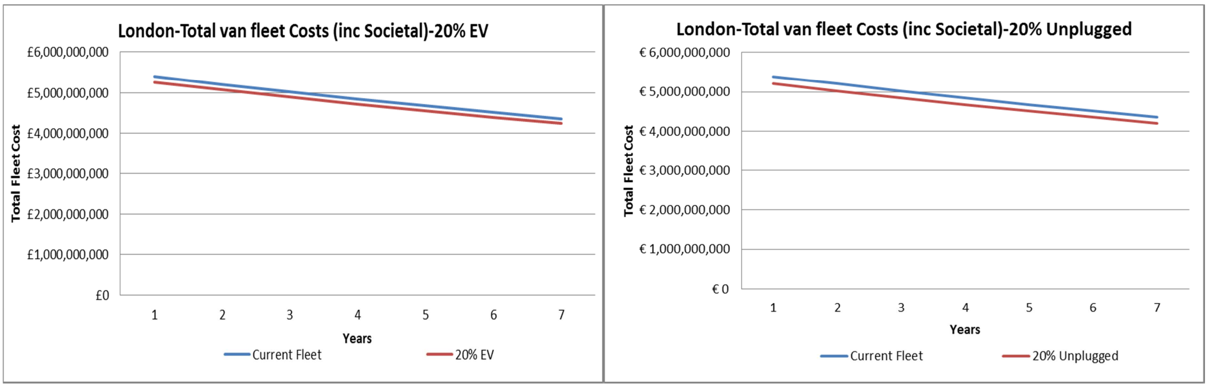


Figure 56 - *Total costs for van fleet per year for electric (a) and UNPLUGGED (b) at both at 20% take-up rate - London vans*

Overall, 20% electric vans are estimated to be €143 million less in year one, reducing to €116 million per year in year seven, giving a total estimated cost reduction of €903 million. Against current total costs this is calculated to be a 2.7% (-2.7%) decrease. The reduction in cost per van is thus estimated to be €1257 over the seven year period.

Unplugged vehicles making up 20% of vans are estimated to cost €51 million less in year one dropping to €41 million in year seven, which gives a total estimated benefit of €322 million. Against current total costs this is estimated to be 0.95% (-0.95%) lower costs per year and a reduced cost per van of approximately €447.

5.1.3 London taxi modelling

The model is based on a vehicle fleet of 22,000 which are all diesel cars.

5.1.3.1 **5% Electric taxis**

If in London 5% of taxis were replaced by electric taxis the analysis suggests that capital costs would be higher by approximately €1.3 million per year in the first year dropping to €1.1 million higher in year seven. This is more than offset by the reduction in operating costs: €7.4 million lower in the first year and €6.0 million lower in year seven. Societal benefits are €886,000 in the first year and drop to €716,000 by year seven.

Figure 57 - *Fleet impact on capital (a) and operating costs (b): 5% electric take-up rate – London taxis*

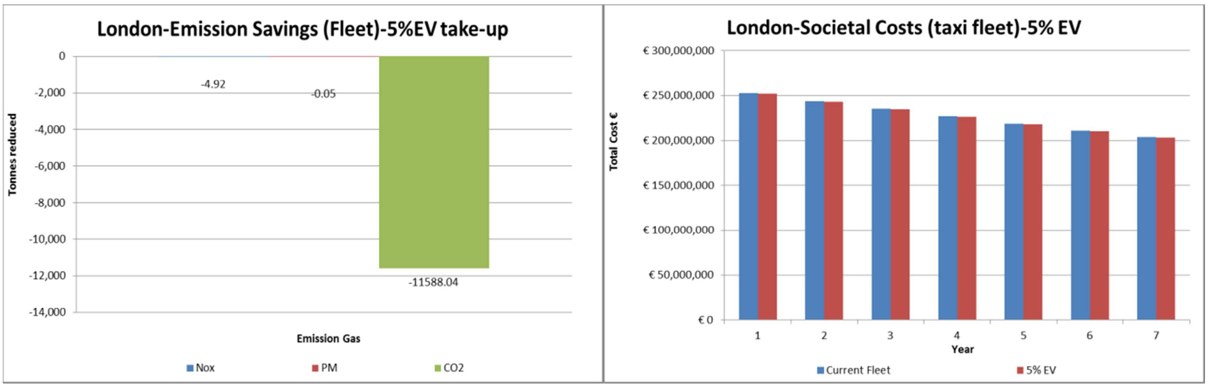


Figure 58 - *Reduced emissions in tonnes (a) and resulting societal cost reductions (b) - London taxis 5% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by almost 11,600 tonnes per year. Particulate matter is reduced by 0.05 tonnes per year. NO_x decreases by approximately 5 tonnes per year.

5.1.3.2 **5% Unplugged taxis**

If in London 5% of taxis were replaced by Unplugged electric taxis the analysis suggests that capital costs would be higher by approximately €3.8 million per year in the first year dropping to €3.0 million higher in year seven. This is more than offset by the reduction in operating costs: €7.4 million lower in the first year and €6.0 million lower in year seven. Societal benefits are €886,000 in the first year and drop to €716,000 by year seven.

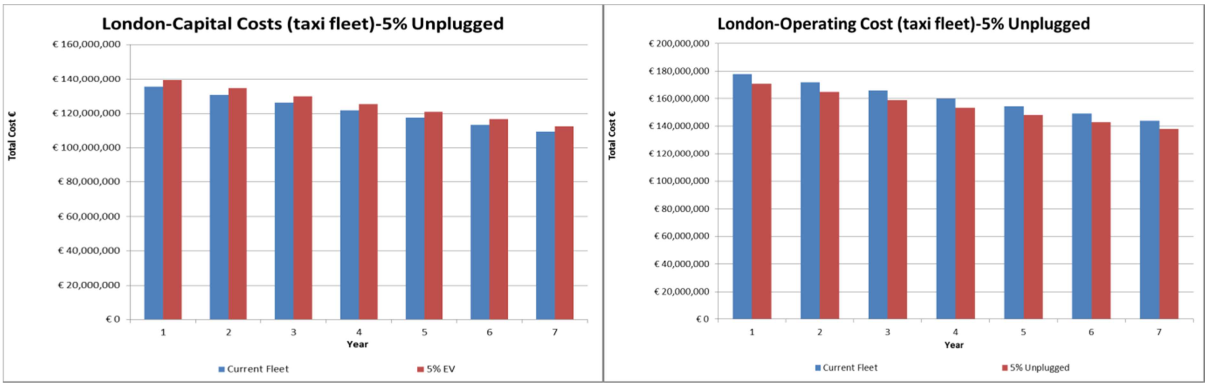


Figure 59 - *Fleet impact on capital (a) and operating costs (b): 5% Unplugged take-up rate - London taxis*

Figure 60 - *Reduced emissions in tonnes (a) and resulting societal cost reductions (b) - London taxis 5% Unplugged*

Emissions are estimated to be reduced by the same quantities as for electric taxis.

5.1.3.3 **5% taxi fleet take-up comparison**

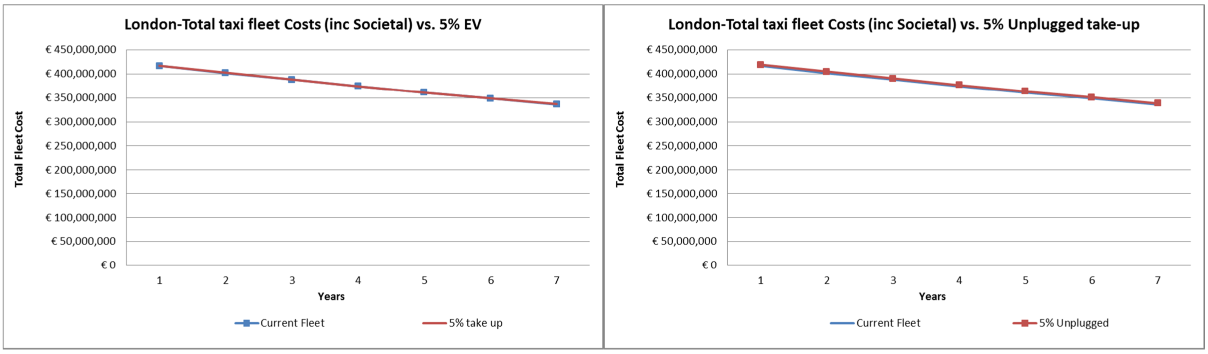


Figure 61 - *Total costs for taxi fleet per year for electric (a) and UNPLUGGED (b) at 5% take-up rate - London taxis*

Overall values for the total taxi fleet for 5% electric taxis are estimated to be €6.95 million per year in year one, reducing to €5.6 million per year in year seven, giving a total estimated reduction in cost of €43.8 million. Against current total costs this is calculated to be a 1.2% (-1.2%) decrease which is a reduced cost per taxi of €2096 over seven years.

Overall Unplugged vehicles are estimated to cost €4.5 million less in year one dropping to €3.65 million less in year seven, which gives a total estimated reduced cost of €28.5 million. Against current total costs this is estimated to be 0.8% (-0.8%) lower costs per year and a reduced cost per taxi of approximately €1352.

Assuming that urban NO_x and Particulate Matter is generated primarily from tailpipe emissions, and that by switching the vehicle fleet for 5% EVs some of these emissions are removed from the city, NO_x is reduced by 500 tonnes per year and PM is reduced by 1.1 tonnes per year.

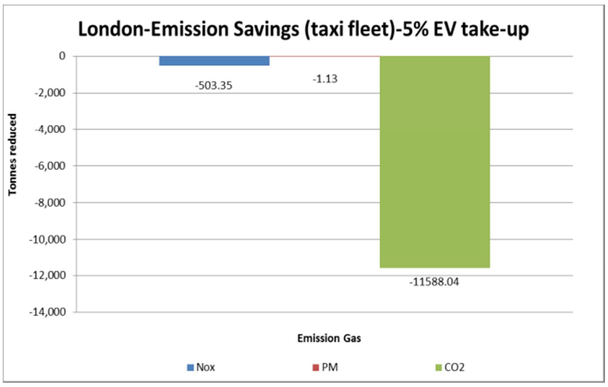


Figure 62 - *Reduced emissions if NO_x and PM only generated at power plant - London taxis 5% EV*

5.1.3.4 **20% Electric taxis**

If in London 20% of taxis were replaced by electric taxis the analysis suggests that capital costs would be greater by approximately €5.4 million per year in the first year dropping to €4.3 million greater in year seven. This is offset by the reduction in operating costs: €29.6 million lower in the first year and €23.9 million lower in year seven. Societal benefits are €3.5 million in the first year and drop to €2.8 million by year seven.

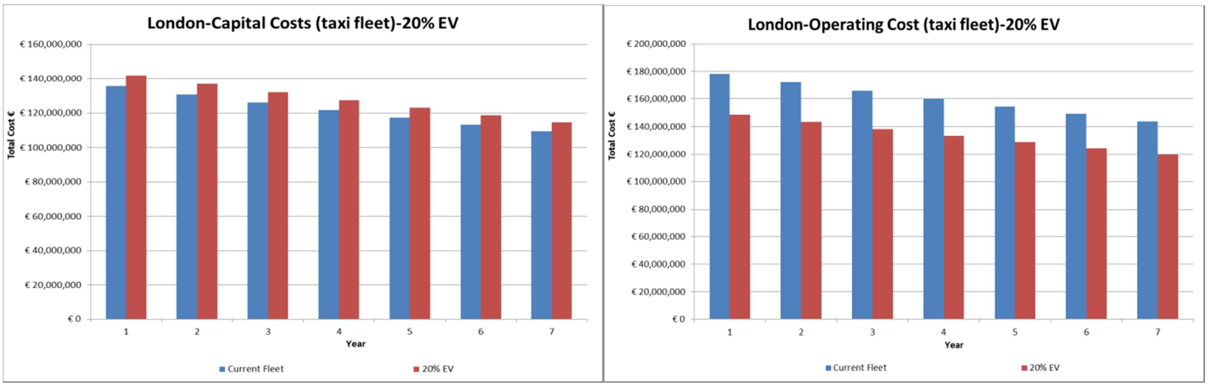


Figure 63 - *Fleet impact on capital (a) and operating costs (b): 20% EV take-up rate - London taxis*

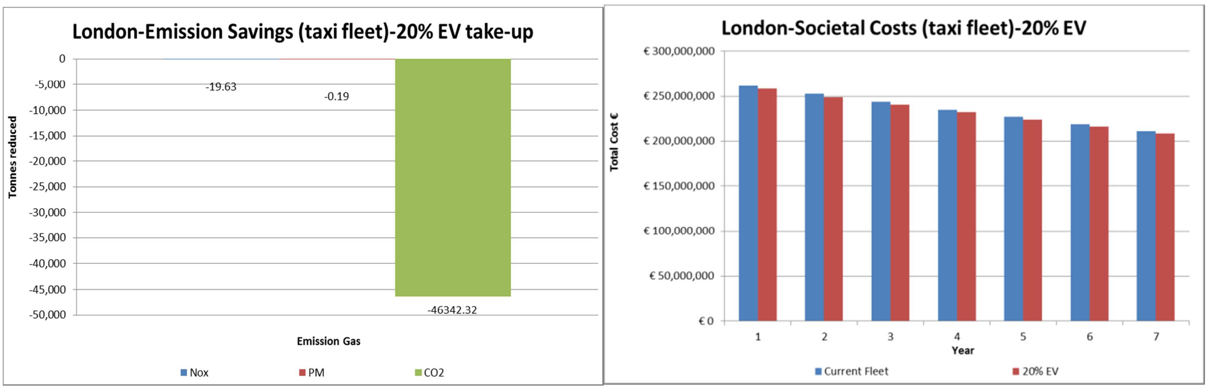


Figure 64 - *Reduced emissions in tonnes (a) and resulting societal cost reductions (b) London taxis 20% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by approximately 46,000 tonnes per year. Particulate matter is reduced by 0.2 tonnes per year. NO_x decreases by approximately 19.5 tonnes per year.

5.1.3.5 **20% Unplugged taxis**

If 20% of taxis were replaced by Unplugged electric taxis, the analysis suggests that capital costs would be greater by approximately €15.6 million per year in the first year dropping to €12.6 million greater in year seven. This is offset by the reduction in operating costs: €29.6 million lower in the first year and €23.9 million lower in year seven. Societal benefits are €3.5 million in the first year and drop to €2.8 million by year seven.

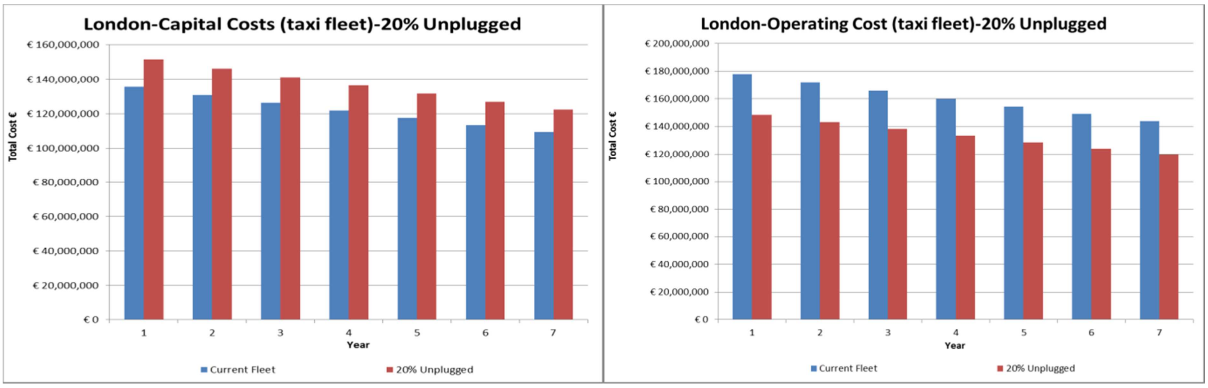


Figure 65 - *Fleet impact on capital (a) and operating costs (b): 20% Unplugged take-up rate - London taxis*

Figure 66 - *Reduced emissions in tonnes (a) and resulting societal cost reductions (b) - London taxis 20% Unplugged*

Emissions for Unplugged taxis are estimated to be reduced by the same quantities as for electric taxis.

5.1.3.6 **20% taxi fleet take-up comparison**

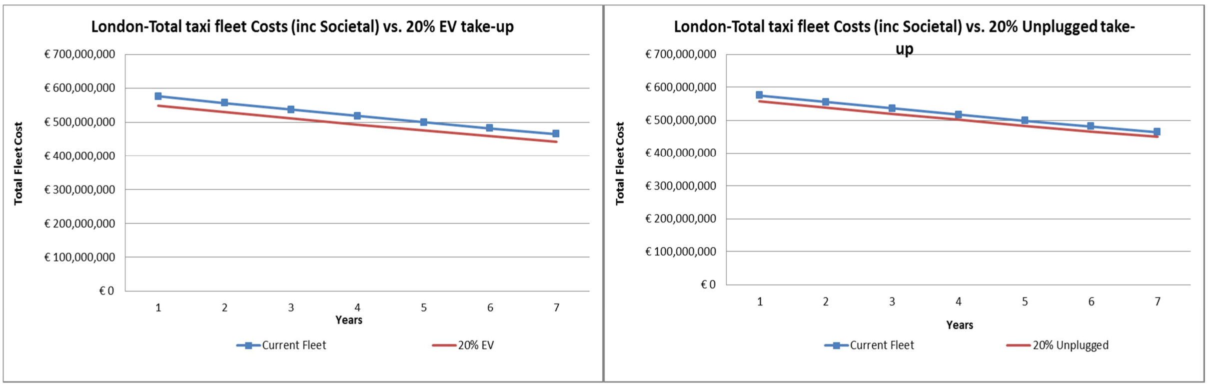


Figure 67 - *Total costs for taxi fleet per year for electric (a) and UNPLUGGED (b) at 20% take-up rate - London taxis*

The total taxi fleet benefits for 20% electric taxis are estimated to be €27.7 million per year in year one, reducing to €22.4 million per year in year seven, giving a total estimated cost reduction of €175 million. Against current total costs this is calculated to be a 5.1% (-5.1%) decrease in overall total costs and a reduced cost per taxi of approximately €7947 over seven years.

Overall 20% Unplugged taxis are estimated to cost €17.5 million less in year one dropping to €14.4 million less in year seven, which gives a total estimated benefit of €110 million. Against current total costs this is estimated to be 3.1% (-3.1%) lower costs per year and a reduced cost per taxi of approximately €5003 over seven years.

Assuming that urban NO_x and Particulate Matter is generated primarily from tailpipe emissions, and that switching the vehicle fleet for 20% EVs removes some of these emissions from the city, urban NO_x is reduced by 440 tonnes per year and PM is reduced by 1.1 tonnes per year.

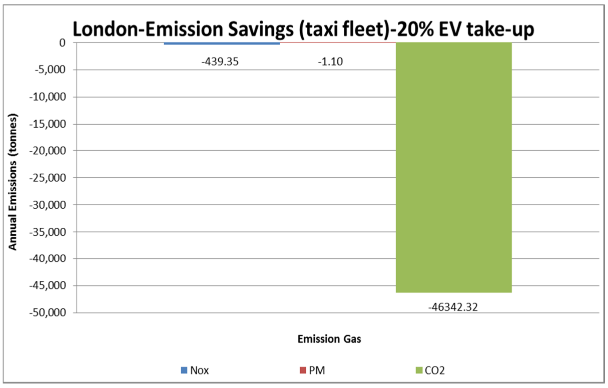


Figure 68 - *Reduced emissions if EV NOx and PM only generated at power plant - London taxis 20% EV*

5.2 Barcelona

The socio-economic model for Barcelona is based upon the following information provided by ENIDE. Only the bus fleet has been considered for Barcelona as this was the only fleet data to be completely supplied and therefore modelled accurately. No information was supplied for car or taxi fleets. Van information was incomplete and therefore not used

5.2.1 Barcelona Bus modelling

The model is based on fleet numbers in Barcelona of the following.

- 534 diesel buses
- 398 CNG (Natural gas) buses [treated as petrol for the purposes of the model]
- 132 Hybrid electric vehicles.

5.2.1.1 **5% Electric buses**

If 5% of buses in Barcelona were replaced by electric buses, the analysis suggests that capital costs would be greater by approximately €1.7 million per year in the first year dropping to €1.4 million greater in year seven. This is partly offset by the reduction in operating costs: €1.1 million lower in the first year and €906,000 lower in year seven. Societal benefits are €391,000 in the first year and drop to €315,000 by year seven.

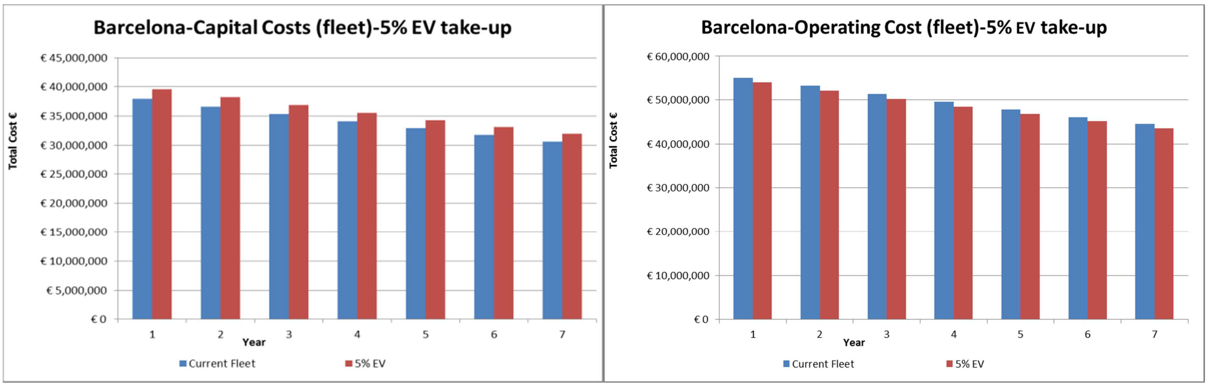


Figure 69 - *Fleet impact on capital (a) and operating costs (b): 5% electric – Barcelona buses*

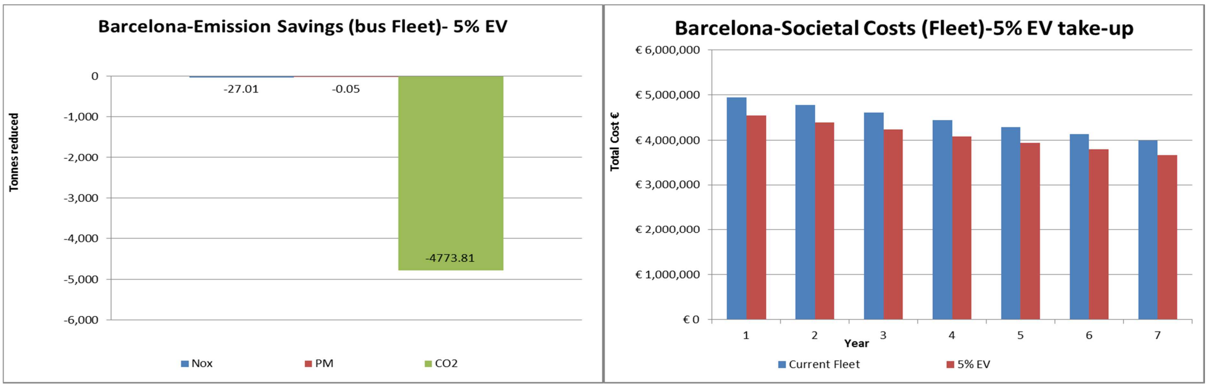


Figure 70 - *Reduced emissions (a) and resulting societal cost reductions (b) Barcelona buses 5% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by approximately 4770 tonnes per year. Particulate matter is not reduced by any significant amount. NO_x decreases by approximately 21 tonnes per year.

5.2.1.2 **5% Unplugged buses**

If 5% of buses in Barcelona were replaced by Unplugged electric buses, the analysis suggests that capital costs would be greater by approximately €2.1 million per year in the first year dropping to €1.7 million greater in year seven. This is partly offset by the reduction in operating costs: €1.1 million lower in the first year and €906,000 lower in year seven. Societal benefits are €391,000 in the first year and drop to €315,000 by year seven.

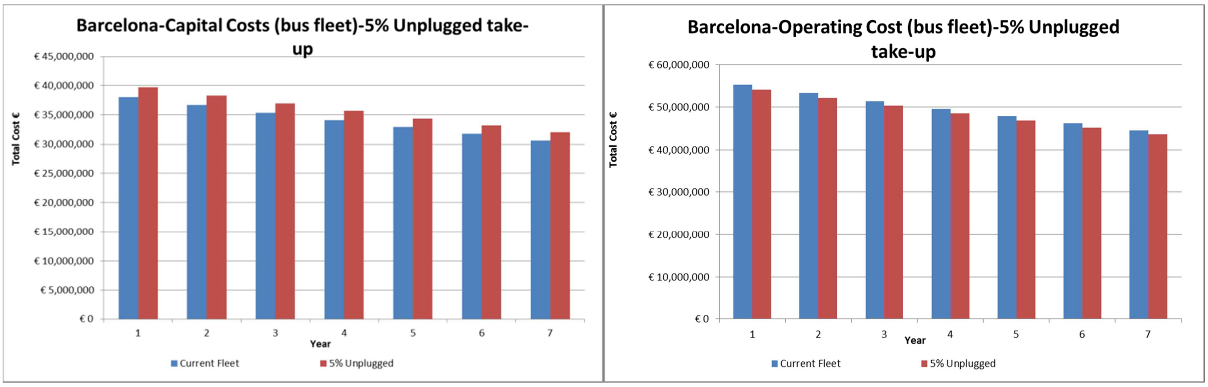


Figure 71 - *Fleet impact on capital (a) and operating costs (b): 5% Unplugged - Barcelona buses*

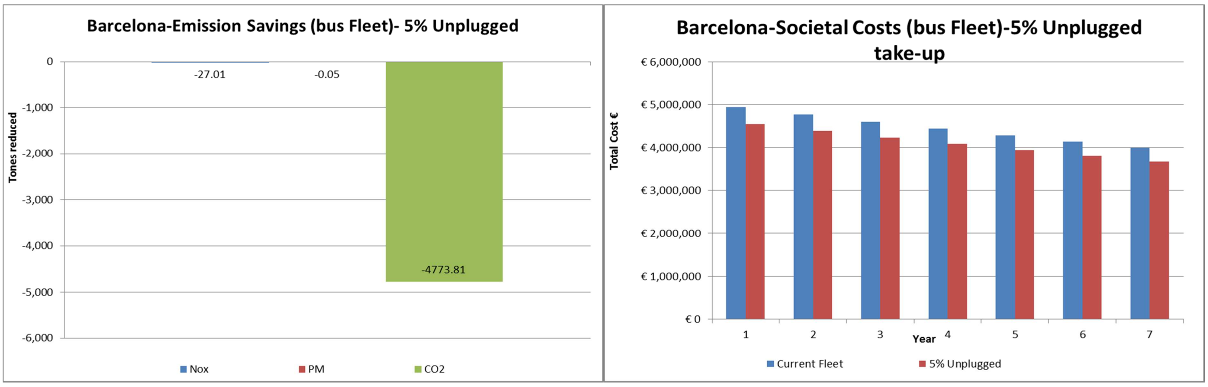


Figure 72 - *Reduced emissions (a) and resulting societal cost reductions (b) - Barcelona buses 5% Unplugged*

Emissions savings are considered to be the same as for 5% electric buses.

5.2.1.3 **5% bus fleet take-up comparison**

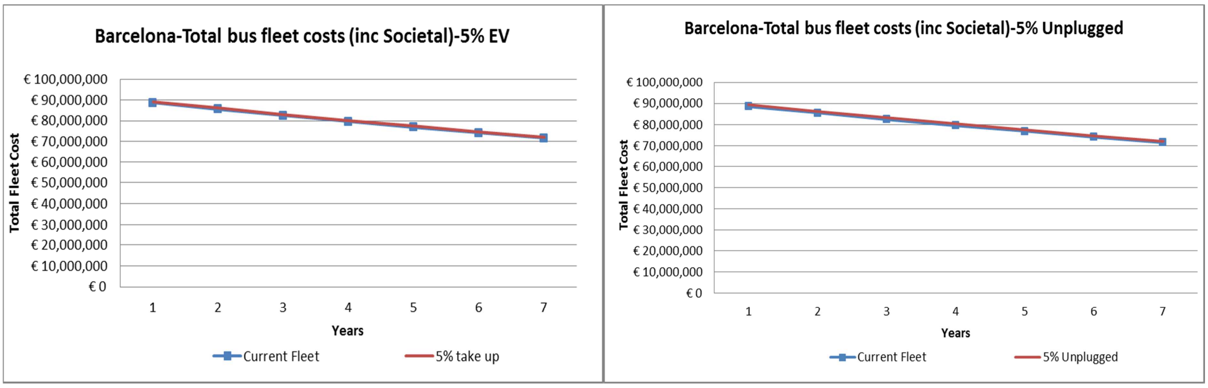


Figure 73 - *Total costs per year for electric (a) and UNPLUGGED (b) - Barcelona buses 5%*

The total bus fleet added costs for 5% electric buses are estimated to be €221,000 per year in year one, reducing to an extra €179,000 per year in year seven, giving a total estimated increased cost of €1.4 million. Against current total costs this is calculated to be a 0.22% (+0.22%) increase in overall total costs and an increased cost per bus of approximately €1307 over seven years.

Overall Unplugged buses are estimated to increase costs by €589,000 in year one dropping to an increase of €476,000 in year seven, which gives a total estimated added cost of €3.7 million. Against current total costs this is estimated to be 0.6% (+0.6%) higher costs per year and an increased cost per bus of approximately €3480 across the seven year period.

Assuming that urban NO_x and Particulate Matter is generated primarily from tailpipe emissions, and that switching the vehicle fleet for 5% EVs removes some of these emissions from the city, NO_x is reduced by 262 tonnes per year and PM is reduced by 0.05 tonnes per year.

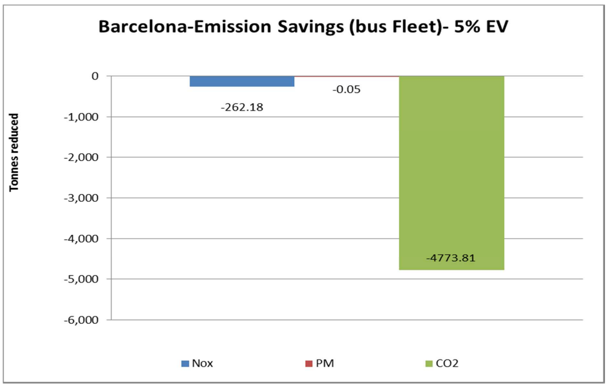


Figure 74 - *Reduced emissions if EV NO_x and PM only generated at power plant – 5% EV*

5.2.1.4 **20% Electric buses**

If 20% of buses in Barcelona were replaced by electric buses, the analysis suggests that capital costs would be greater by approximately €7.1 million per year higher in the first year dropping to €5.7 million higher in year seven. This is partly offset by the reduction in operating costs: €4.6 million lower in the first year and €3.7 million lower in year seven. Societal benefits are €1.6 million in the first year and drop to €1.3 million by year seven.

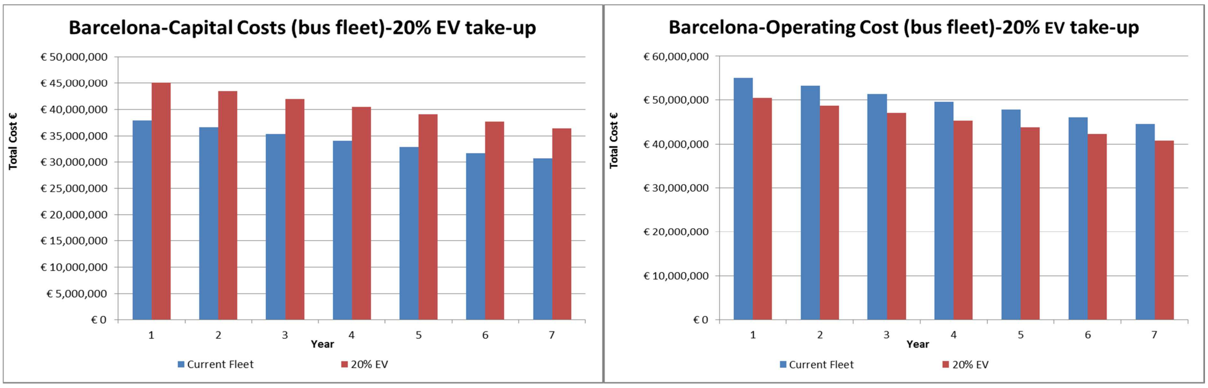


Figure 75 - *Fleet impact on capital (a) and operating costs (b): 20% EV - Barcelona buses*

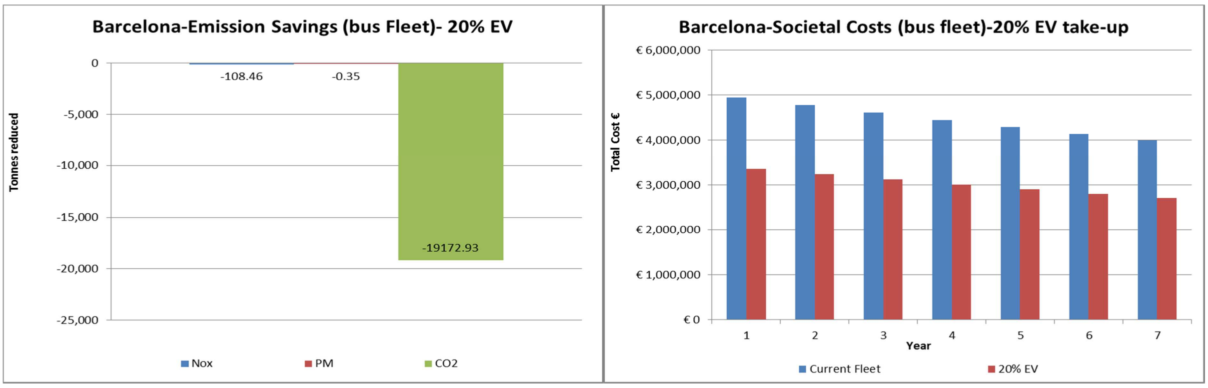


Figure 76 - *Reduced emissions (a) and resulting societal cost reductions (b) Barcelona buses 20% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by approximately 19,000 tonnes per year. Particulate matter is not reduced by any significant value. NO_x decreases by approximately 108 tonnes per year.

5.2.1.5 **20% Unplugged buses**

If 20% of buses in Barcelona were replaced by Unplugged electric buses, the analysis suggests that capital costs would be greater by approximately €8.6 million per year in the first year dropping to €6.9 million greater in year seven. This is offset by the reduction in operating costs: €4.6 million lower in the first year and €3.7 million lower in year seven. Societal benefits are €1.6 million in the first year and drop to €1.3 million by year seven.

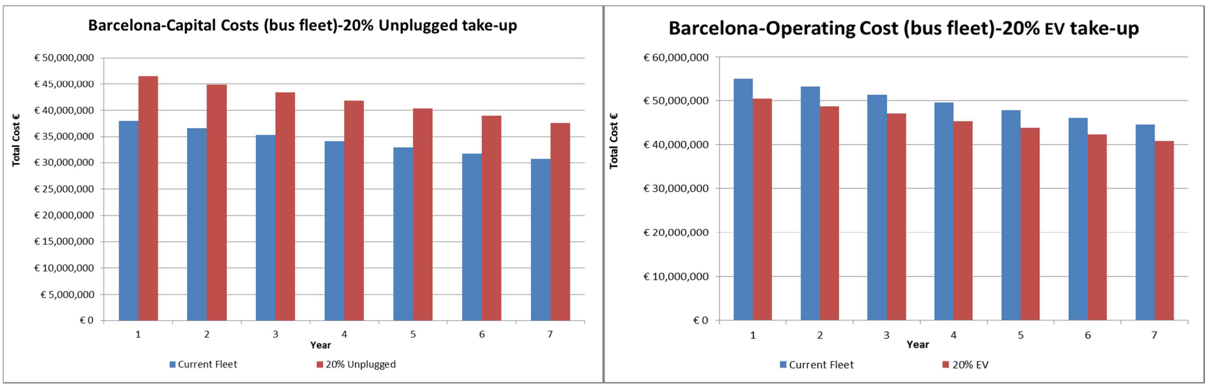


Figure 77 - *Fleet impact on capital (a) and operating costs (b): 20% Unplugged - Barcelona buses*

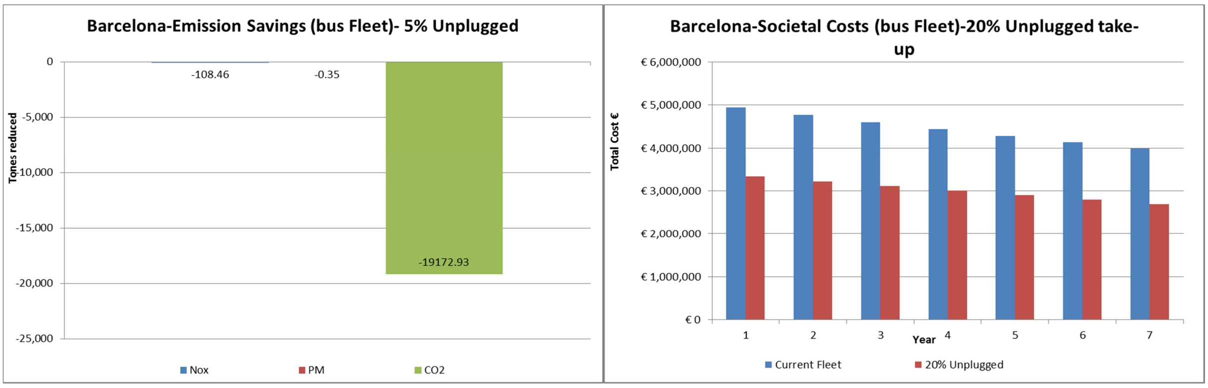


Figure 78 - Reduced emissions (a) and resulting societal cost reductions (b) - *Barcelona buses 20% Unplugged*

Emissions savings are considered to be the same as for 20% electric buses.

5.2.1.6 **20% bus fleet take-up comparison**

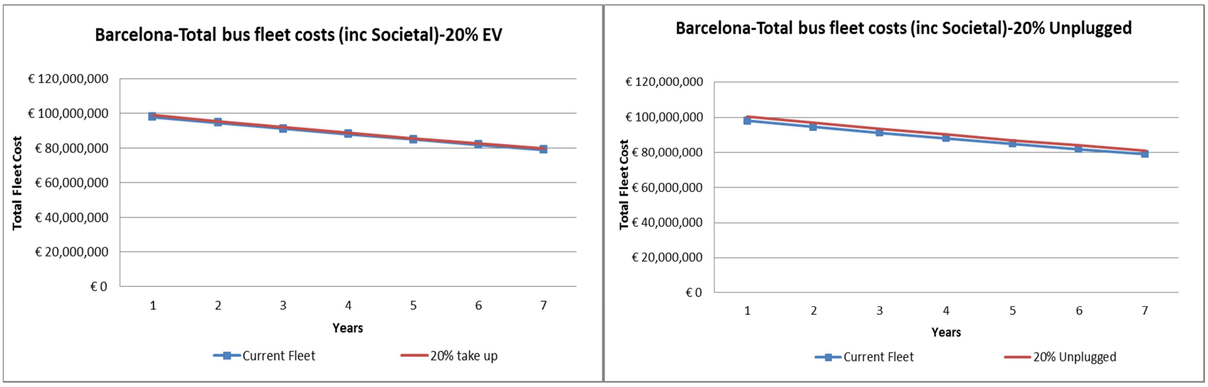


Figure 79 - *Total costs per year for electric (a) and UNPLUGGED (b) - Barcelona buses 20%*

Current fleet costs are €98.1 million in year one reducing to €79.2 million in year seven.

Overall, electric buses are estimated to cost €99.0 million in year one reducing to €80.0 million in year seven. The total increase in bus fleet cost for 20% electric buses is estimated to be €924,000 per year in year one, reducing to €746,000 per year in year seven, giving a total estimated increase in cost of €5.8 million. Against current total costs this is calculated to be a 0.9% (+0.9%) increase in overall total costs and an increased cost per bus of approximately €5,462 over seven years.

Overall, Unplugged buses are estimated to cost €100.5 million in year one dropping to €81.2 million in year seven. The total increase in bus fleet cost for 20% Unplugged electric buses is estimated to be €2.4 million per year in year one, reducing to €1.96 million per year in year seven, which gives a total estimated increase in cost of €15.3 million over 7 years. Against current total costs this is estimated to be 2.4% (+2.4%) higher costs per year and an increased cost per bus of approximately €14,322 over seven years.

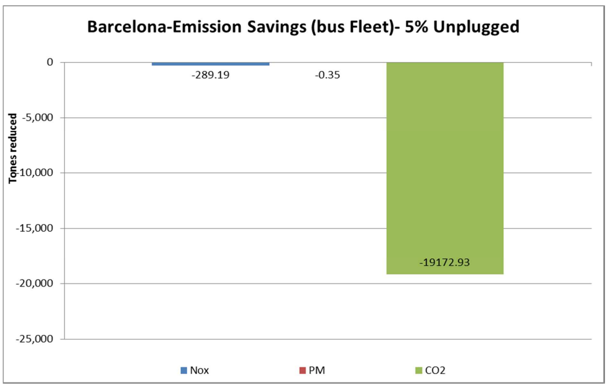


Figure 80 - *Reduced emissions if EV NO_x and PM only generated at power plant - Barcelona buses 20%*

Assuming that urban NO_x and Particulate Matter is generated primarily from tailpipe emissions and that switching the vehicle fleet for 20% EVs removes some of these emissions from the city, NO_x is reduced by 289 tonnes per year and PM is reduced by 0.35 tonnes per year.

5.3 Florence

The Florence model information has primarily been supplied by UNIFI (University of Florence)

This model uses an estimated vehicle fleet of 276,000 cars, with 65% being petrol and 35% diesel. The model uses some London emissions data to compensate for incomplete information. The data uses NEDC average emissions data for CO_2 and average emissions factors from AEA-Ricardo Life Cycle analysis work quoted by TfL.

5.3.1 Florence car modelling

5.3.1.1 5% Electric cars

The current fleet has capital costs of approximately €1.32 billion in year one reducing to €1.1 billion per year in year seven.

If in Florence 5% of cars were replaced by electric cars the analysis suggests that capital costs would be greater by approximately €6.7 million per year in the first year dropping to €5.4 million greater in year seven. This is offset by the reduction in operating costs: €7.1 million lower in the first year and €5.7 million lower in year seven. Societal benefits are €655,000 in the first year and drop to €529,000 by year seven.

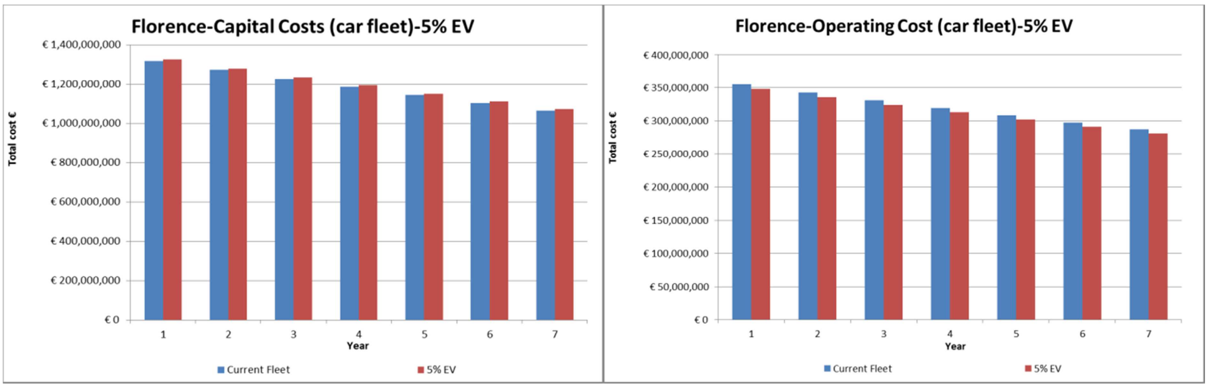


Figure 81 - *Fleet impact on capital (a) and operating costs (b): 5% electric – Florence cars*

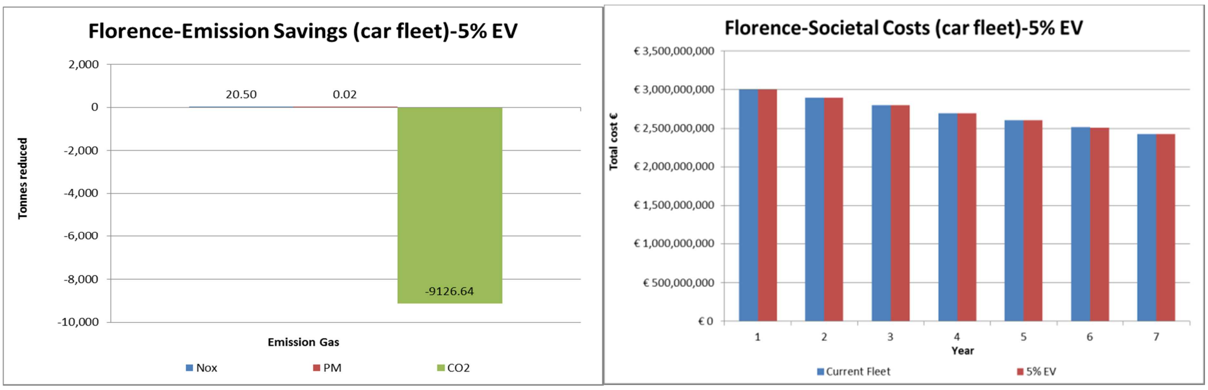


Figure 82 - *Reduced emissions (a) and resulting societal cost reductions (b) - Florence cars 5% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by 9100 tonnes per year. Particulate matter increases by 0.02 tonnes per year. NO_x increases by approximately 20 tonnes per year.

5.3.1.2 **5% Unplugged cars**

If in Florence 5% of cars were replaced by Unplugged electric cars the analysis suggests that capital costs would be greater by approximately €15.5 million per year in the first year dropping to €12.5 million greater in year seven. This is partly offset by the reduction in operating costs: €7.1 million lower in the first year and €5.7 million lower in year seven. Societal benefits are €655,000 in the first year and drop to €529,000 by year seven.

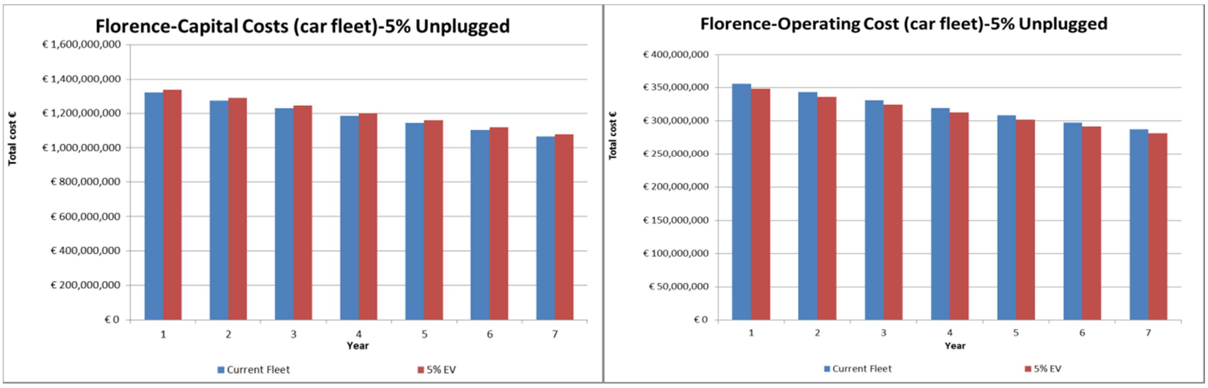


Figure 83 - *Fleet impact on capital (a) and operating costs (b): 5% Unplugged - Florence cars*

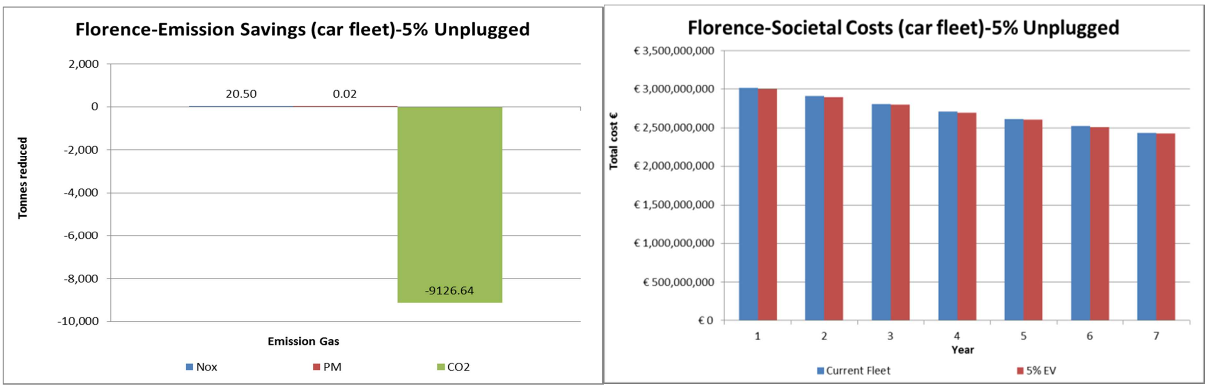


Figure 84 - *Reduced emissions (a) and resulting societal cost reductions (b) - Florence cars 5% Unplugged*

Emissions savings are considered to be the same as for 5% electric cars.

5.3.1.3 **5% car fleet take-up comparison**

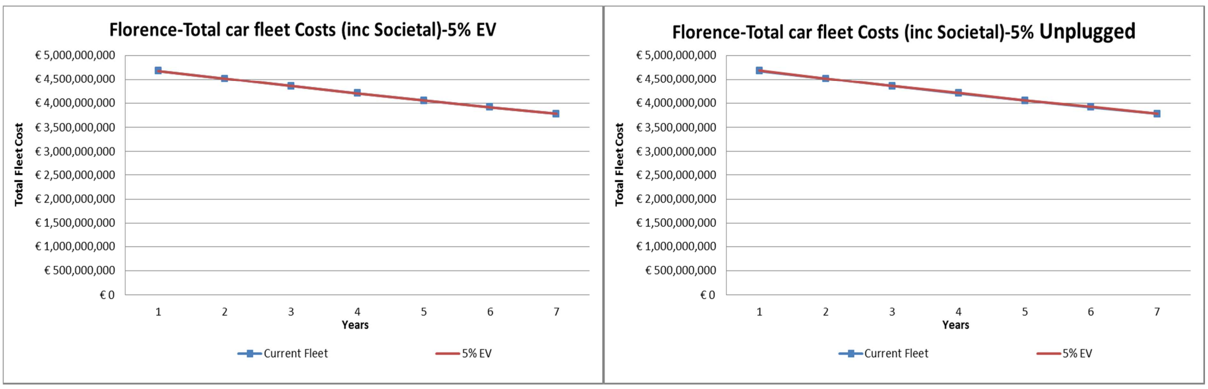


Figure 85 - *Total costs per year for electric (a) and UNPLUGGED (b) Florence cars 5%*

Overall benefits for the total car fleet if 5% cars are electric estimated at €1.0 million per year in year one, reducing to €0.8 million per year lower in year seven, giving a total estimated benefit of €6.5 million. Against current total costs of approximately €4.7 billion per year this is calculated to be 0.02% (-0.02%) lower. The benefit per car is thus estimated to be €23 over the seven year period.

Overall, Unplugged cars are estimated to cost €7.7 million more in year one dropping to €6.3 million more in year seven, which gives a total estimated increased cost of €49.0 million. Against current total costs of approximately €4.7 billion per year this is estimated to be 0.17% (+0.17%) higher costs per year and an increased cost per car of €177 over seven years.

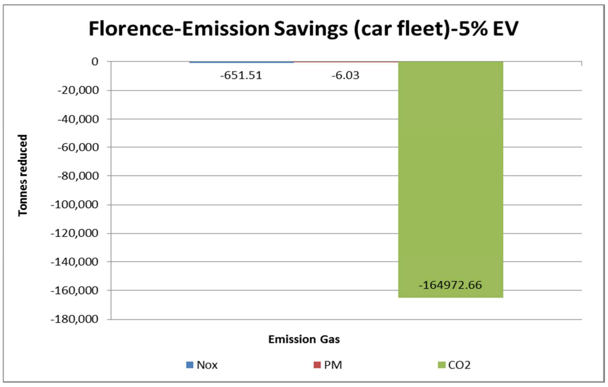


Figure 86 - *Reduced emissions if EV NO_x and PM only generated at power plant - Florence cars 5% EV*

Assuming that NO_x and Particulate Matter is generated primarily from tailpipe emissions, and that switching the vehicle fleet for 5% EVs removes some of these emissions from the city, NO_x is reduced by 650 tonnes per year and PM is reduced by 6.0 tonnes per year.

5.3.1.4 **20% Electric cars**

If 20% of cars were replaced by electric cars the analysis suggests that capital costs would be greater by approximately €31.3 million per year in the first year dropping to €25.3 million greater in year seven. This is mostly offset by the reduction in operating costs: €29.6 million lower in the first year and €23.9 million lower in year seven. Societal benefits are €931,000 in the first year and drop to €752,000 by year seven.

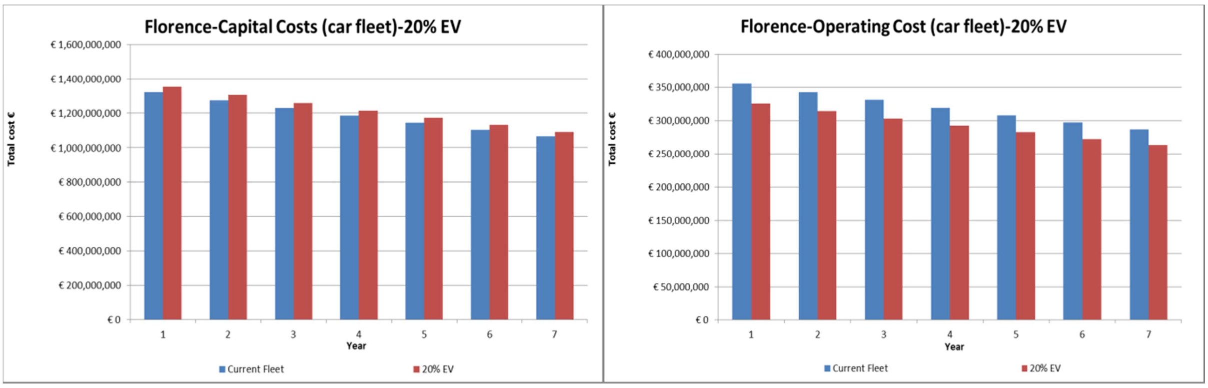


Figure 87 - *Fleet impact on capital (a) and operating costs (b): 20% EV - Florence cars*

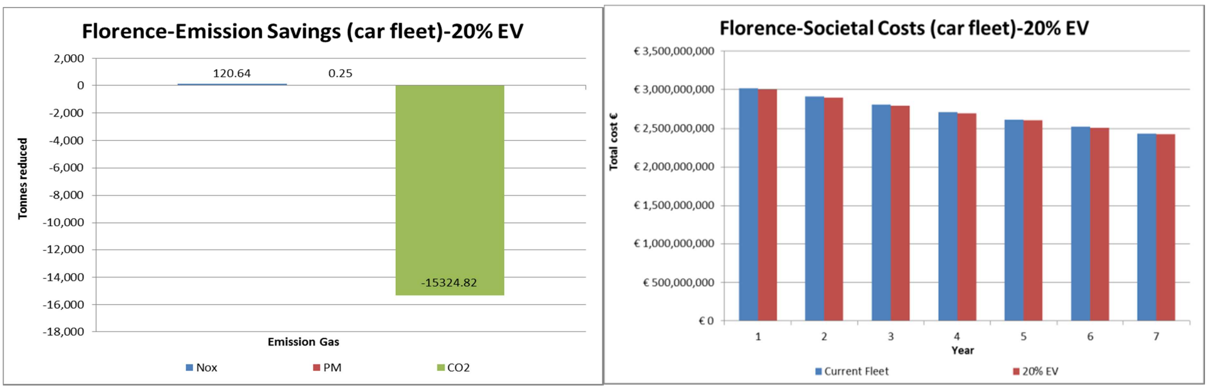


Figure 88 - *Reduced emissions (a) and resulting societal cost reductions (b) - Florence cars 20% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by 153,000 tonnes per year. Particulate matter increases by 0.25 tonnes per year. NO_x increases by approximately 120 tonnes per year.

5.3.1.5 20% Unplugged cars

If in Florence 20% of cars were replaced by Unplugged electric cars the analysis suggests that capital costs would be greater by approximately €67.5 million per year in the first year dropping to €54.5 million greater in year seven. This is partly offset by the reduction in operating costs: €29.6 million lower in the first year and €23.9 million lower in year seven. Societal benefits are €931,000 in the first year and drop to €752,000 by year seven.

Figure 89 - *Fleet impact on capital (a) and operating costs (b): 20% Unplugged - Florence cars*

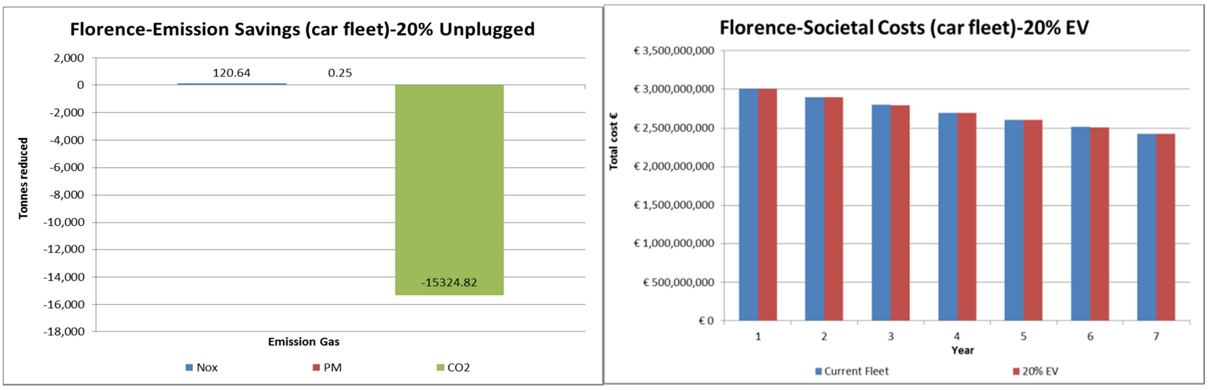


Figure 90 - *Reduced emissions (a) and resulting societal cost reductions (b) - Florence cars 20% Unplugged*

Emissions savings are considered to be the same as for 20% electric cars.

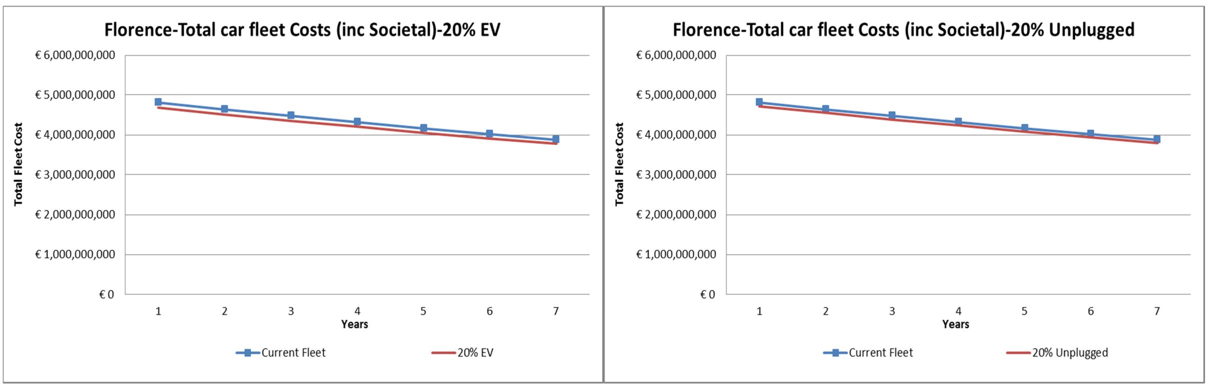


Figure 91 - *Total costs per year for electric (a) and UNPLUGGED (b) - Florence cars 20%*

Overall benefits for the total car fleet if 20% electric cars are estimated at €815,000 per year in year one, reducing to €658,000 per year in year seven, giving a total estimated benefit of €5.14 million. Against current total costs of approximately €4.7 billion per year this is calculated to be 0.02% (+0.02%) higher costs. The added cost per car is estimated to be €19 over the seven year period.

Overall, Unplugged cars are estimated to cost €37.0 million more in year one dropping to €29.9 million in year seven, which gives a total estimated increased cost of €233 million. Against current total costs of approximately €4.7 billion per year this is estimated to be 0.78% (+0.78%) higher costs per year and an increased cost per car of €845 over seven years.

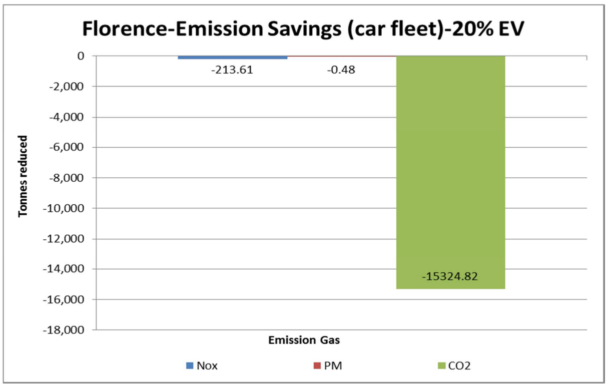


Figure 92 - *Reduced emissions if NO_x and PM only generated at power plant - Florence cars 20%*

Assuming that NO_x and Particulate Matter is generated primarily from tailpipe emissions, and switching the vehicle fleet for 20% EVs removes some of these emissions from the city by, NO_x is reduced by 213 tonnes per year and PM is reduced by 0.5 tonnes per year.

5.3.2 Florence van information

This model uses an estimated vehicle fleet of 17,400 vans. The vehicle fleet is assumed to have similar diesel-to-petrol van ratio as London. The London van fleet is 95% diesel vans. The model uses some London emissions data to compensate for incomplete information. The data uses NEDC average emissions data for CO_2 and average emissions factors from AEA-Ricardo Life Cycle analysis work quoted by TfL.

The current fleet has capital costs of approximately €75 million in year one reducing to €60 million per year in year seven.

5.3.2.1 5% Electric vans

If in Florence 5% of vans were replaced by electric vans the analysis suggests that capital costs would be higher by approximately €852,000 per year in the first year dropping to €688,000 higher in year seven. This is more than offset by the reduction in operating costs: €7.7 million lower in the first year and €6.2 million lower in year seven. Societal benefits are €1.1 million in the first year and drop to €896,000 by year seven.

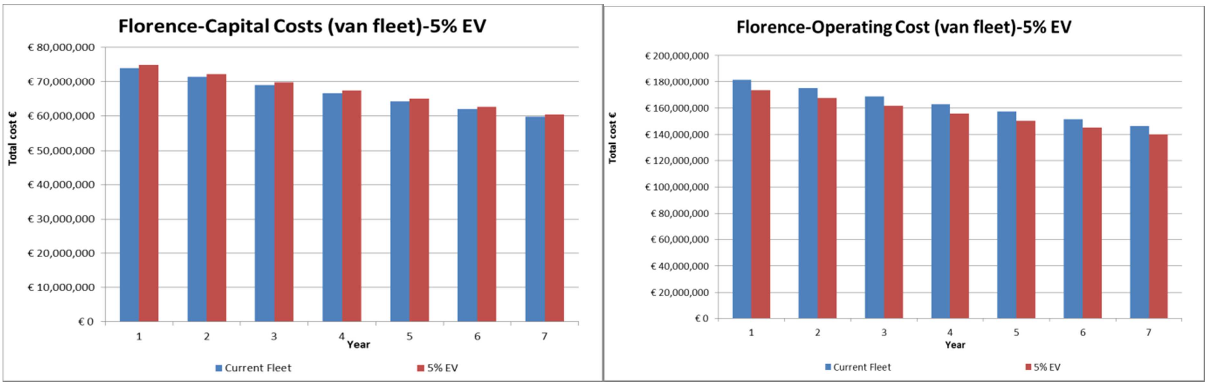


Figure 93 – *Fleet impact on capital (a) and operating costs (b): 5% EV - Florence vans*

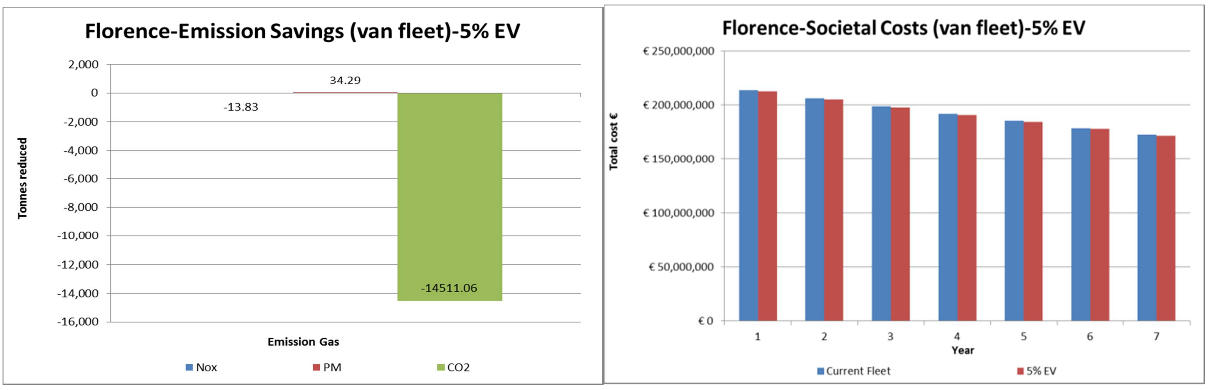


Figure 94 - *Reduced emissions (a) and resulting societal cost reductions (b) Florence vans 5% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by 14,500 tonnes per year. Particulate matter increases by 34 tonnes per year. NO_x decreases by approximately 14 tonnes per year.

5.3.2.2 **5% Unplugged electric vans**

If in Florence 5% of vans were replaced by Unplugged electric vans the analysis suggests that capital costs would be greater by approximately €1.4 million per year in the first year dropping to €1.1 million greater in year seven. This is more than offset by the reduction in operating costs: €7.7 million lower in the first year and €6.2 million lower in year seven. Societal benefits are €1.1 million in the first year and drop to €896,000 by year seven.

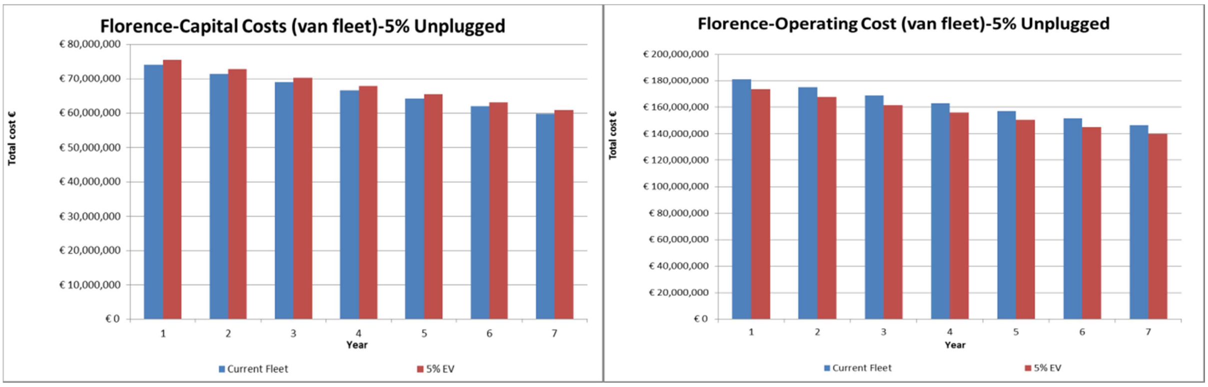


Figure 95 - *Fleet impact on capital (a) and operating costs (b): 5% Unplugged - Florence vans*

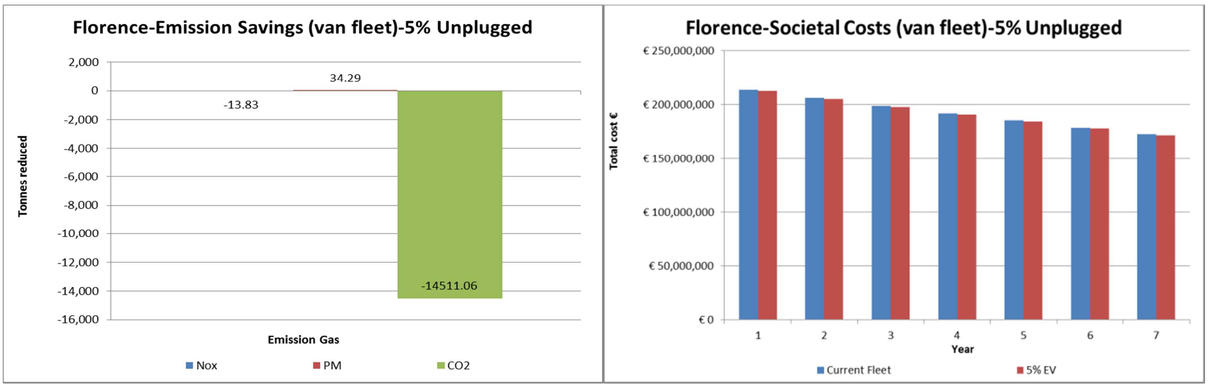
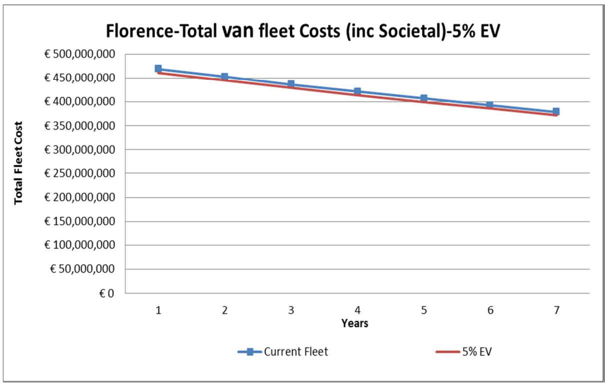


Figure 96 - *Reduced emissions (a) and resulting societal cost reductions (b) Florence vans 5% Unplugged*

This change in fleet composition would reduce Carbon Dioxide emissions by 14,500 tonnes per year. Particulate matter increases by 34 tonnes per year. NO_x decreases by approximately 14 tonnes per year.

5.3.2.3 **5% van fleet take-up comparison**



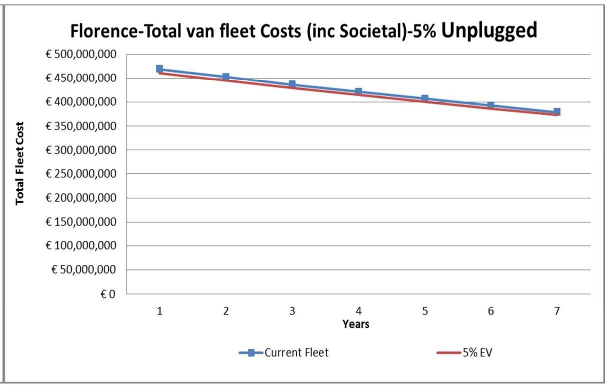


Figure 97 - *Total costs per year for electric (a) and UNPLUGGED (b) Florence vans 5%*

Overall benefits for the total van fleet if 5% of vans are electric are estimated at €7.96 million per year less in year one, reducing to €6.4 million per year in year seven, giving a total estimated benefit of €50.2 million per year. Against current total costs of approximately €462 million this is calculated to be 1.7% (-1.7%) lower. The benefit per van is thus estimated to be €2884 over the seven year period.

Overall Unplugged vans are estimated to cost €7.41 million less in year one dropping to €5.98 million less in year seven, which gives a total estimated benefit of €46.7 million. Against current total costs of approximately €462 million per year this is estimated to be 1.6% (-1.6%) reduced costs per year and reduction in cost per van reduction of €2684 over seven years.

Assuming that urban NO_x and Particulate Matter is generated primarily from tailpipe emissions, and that switching the vehicle fleet for 5% EVs removes some of these emissions from the city, NO_x is reduced by 14 tonnes per year and PM is reduced by 0.1 tonnes per year.

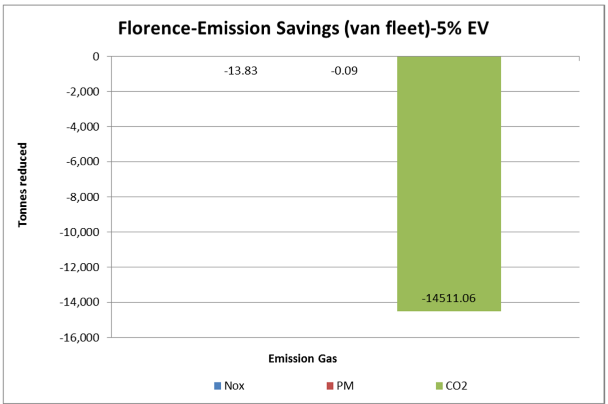


Figure 98 - *Reduced emissions if EV NO_x and PM only generated at power plant - Florence vans 5%*

5.3.2.4 **20% Electric vans**

If in Florence 20% of vans were replaced by electric vans the analysis suggests that capital costs would be higher by approximately €3.8 million per year in the first year dropping to €3.1 million greater in year seven. This is more than offset by the reduction in operating costs: €30.8 million lower in the first year and €24.8 million lower in year seven. Societal benefits are €4.2 million in the first year and drop to €3.4 million by year seven.

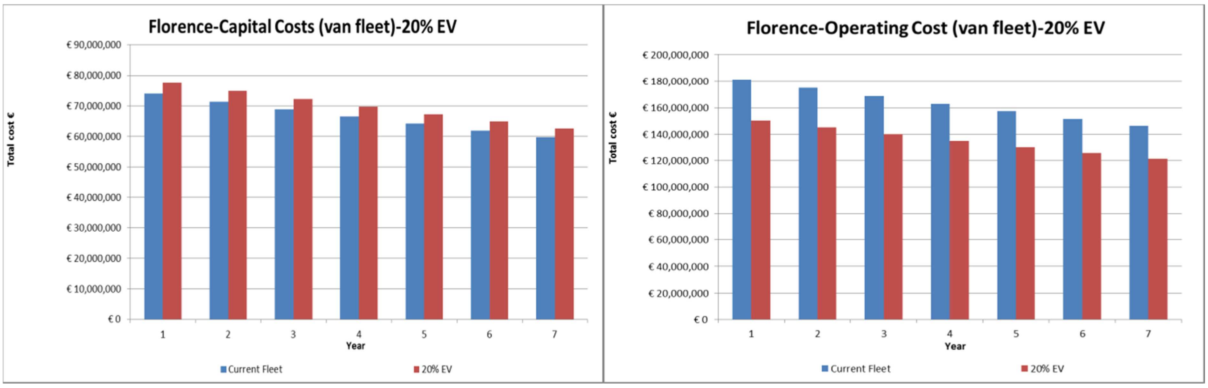


Figure 99 - *Fleet impact on capital (a) and operating costs (b): 20% EV - Florence vans*

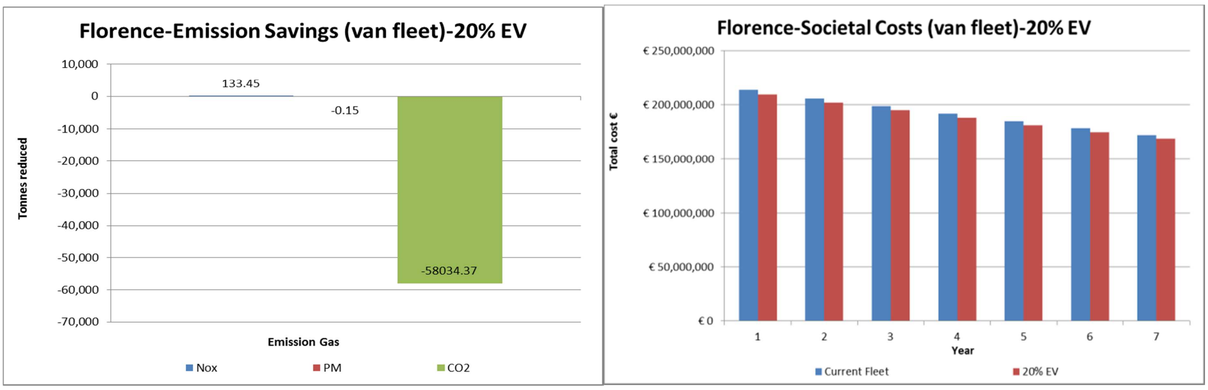


Figure 100 - *Reduced emissions (a) and resulting societal cost reductions (b) Florence vans 20% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by 58000 tonnes per year. Particulate matter decreases by 0.15 tonnes per year. NO_x increases by approximately 133 tonnes per year.

5.3.2.5 **20% Unplugged vans**

If 20% of vans in Florence were replaced by Unplugged electric vans the analysis suggests that capital costs would be greater by approximately €6.0 million per year in the first year dropping to €4.9 million greater in year seven. This is more than offset by the reduction in operating costs: €30.8 million lower in the first year and €24.8 million lower in year seven. Societal benefits are €4.2 million in the first year and drop to €3.4 million by year seven.

Figure 101 - *Fleet impact on capital (a) and operating costs (b): 20% Unplugged - Florence vans*

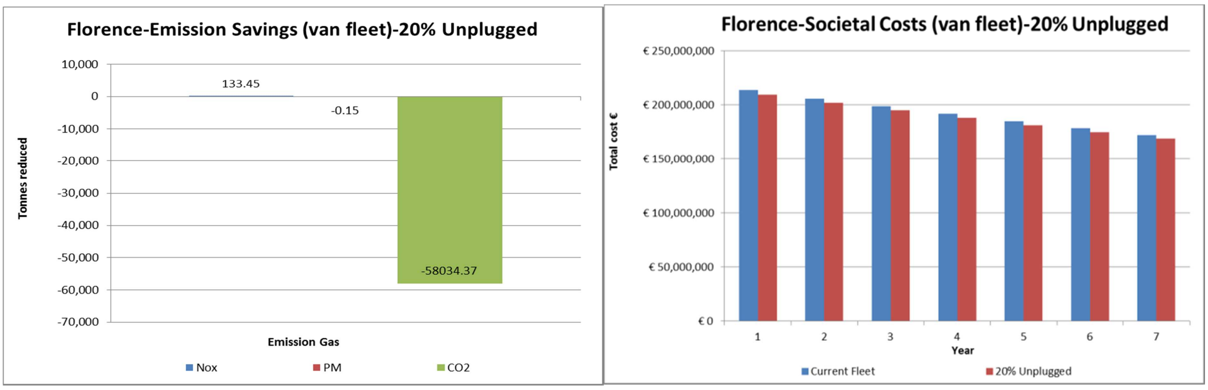


Figure 102 - *Reduced emissions (a) and resulting societal cost reductions (b) - Florence vans 20% Unplugged*

This change in fleet composition would reduce Carbon Dioxide emissions by 58000 tonnes per year. Particulate matter decreases by 0.15 tonnes per year. NO_x increases by approximately 133 tonnes per year.

5.3.2.6 **20% van fleet take-up comparison**

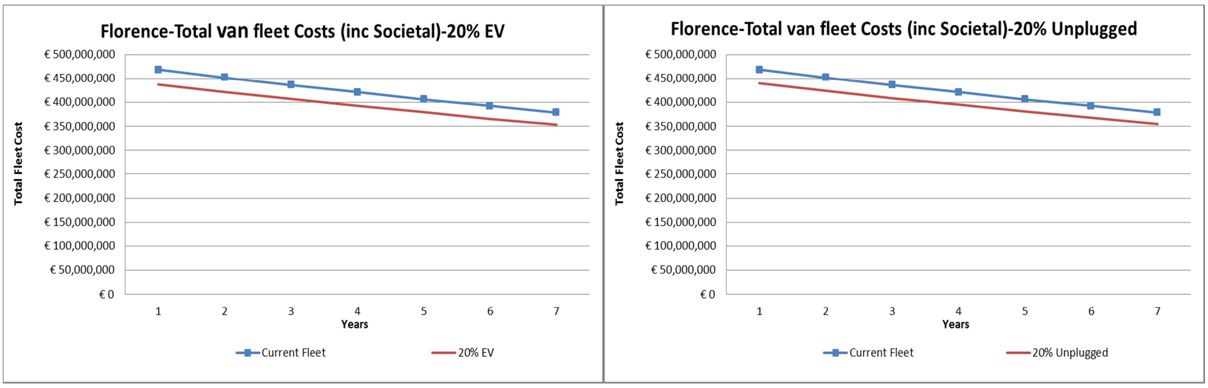


Figure 103 - *Total costs per year for electric (a) and UNPLUGGED (b) Florence vans 20%*

Overall benefits for the total van fleet if 20% are electric vans are estimated at €31.2 million per year in year one, reducing to €25.2 million per year in year seven, giving a total estimated benefit of €196.8 million. Against current total costs of approximately €462 million per year this is calculated to be 7.1% (-7.1%) lower. The benefit per van is thus estimated to be €11,306 over the seven year period.

Overall Unplugged vans are estimated to cost €28.9 million less in year one dropping to €23.3 million less in year seven, which gives a total estimated benefit of €182.5 million. Against current total costs of approximately €462 million per year this is estimated to be 6.6% (-6.6%) reduced costs per year and a reduction in cost per van of €10480 over seven years.

Assuming that NO_x and Particulate Matter is generated primarily from tailpipe emissions and that switching the vehicle fleet for 20% EVs removes some of these emissions from the city, NO_x is reduced by 330 tonnes per year and PM is reduced by 0.8 tonnes per year.

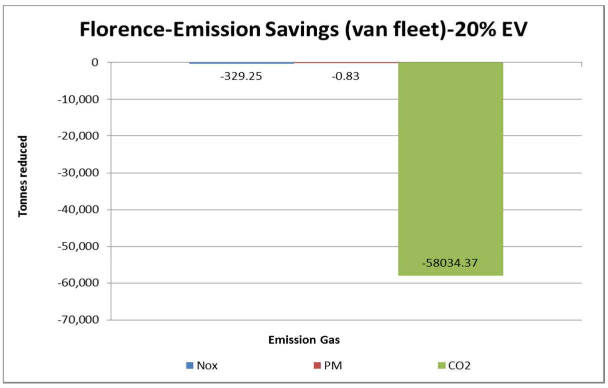


Figure 104 - *Reduced emissions if EV NO_x and PM only generated at power plant - Florence vans 20% EV*

5.3.3 Florence Taxi information

This model is based on a vehicle fleet of 650 taxis. At time of data collection the fleet is made up of the following:

- 378 diesel taxis
- 196 petrol taxis
- 80 range extended electric taxis

The model uses some London emissions data to compensate for incomplete information. The data uses NEDC average emissions data for CO_2 and average emissions factors from AEA-Ricardo Life Cycle analysis work quoted by TfL.

The current fleet has capital costs of approximately €3.1 million in year one reducing to €2.6 million per year in year seven.

5.3.3.1 **5% Electric taxis**

If in Florence 5% of taxis were replaced by electric taxis the analysis suggests that capital costs would be higher by approximately €11,000 per year in the first year dropping to €8,800 higher in year seven. This is more than offset by the reduction in operating costs: €164,000 lower in the first year and €133,000 lower in year seven. Societal benefits are €34,000 in the first year and drop to €28,500 by year seven.

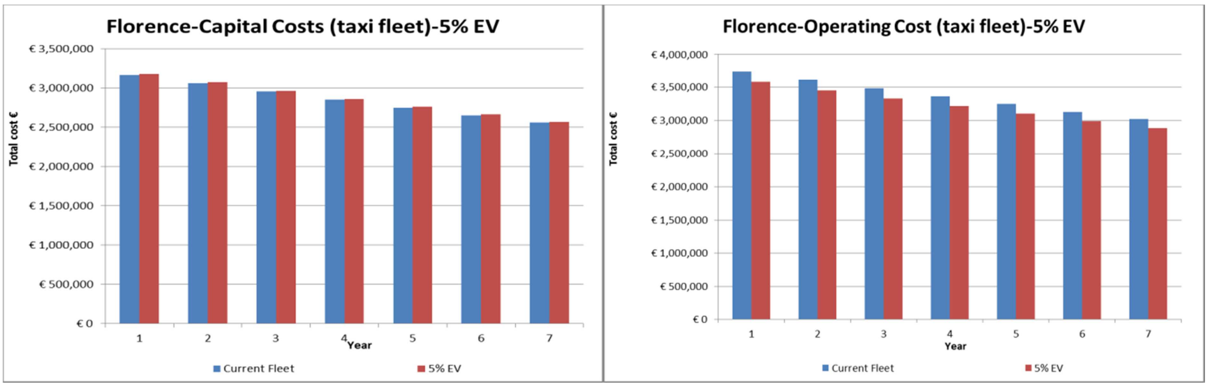


Figure 105 - *Fleet impact on capital (a) and operating costs (b): 5% EV - Florence taxis*

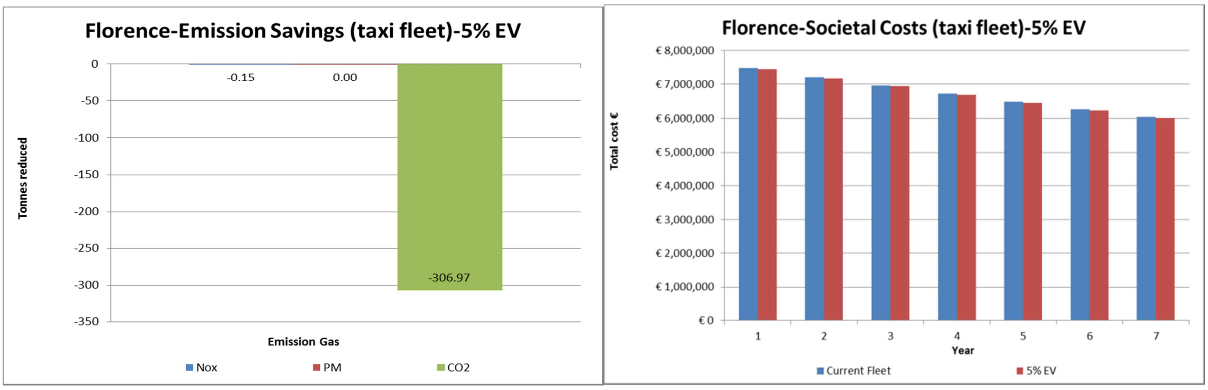


Figure 106 - *Reduced emissions (a) and resulting societal cost reductions (b) Florence taxis 5% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by 300 tonnes per year. Particulate matter does not decrease measurably. NO_x decreases by approximately 0.15 tonnes per year.

5.3.3.2 **5% Unplugged Electric taxis**

If in Florence 5% of taxis were replaced by Unplugged electric taxis the analysis suggests that capital costs would be higher by approximately €31,200 per year in the first year dropping to €25,200 higher in year seven. This is more than offset by the reduction in operating costs: €164,000 lower in the first year and €133,000 lower in year seven. Societal benefits are €34,000 in the first year and drop to €28,500 by year seven.

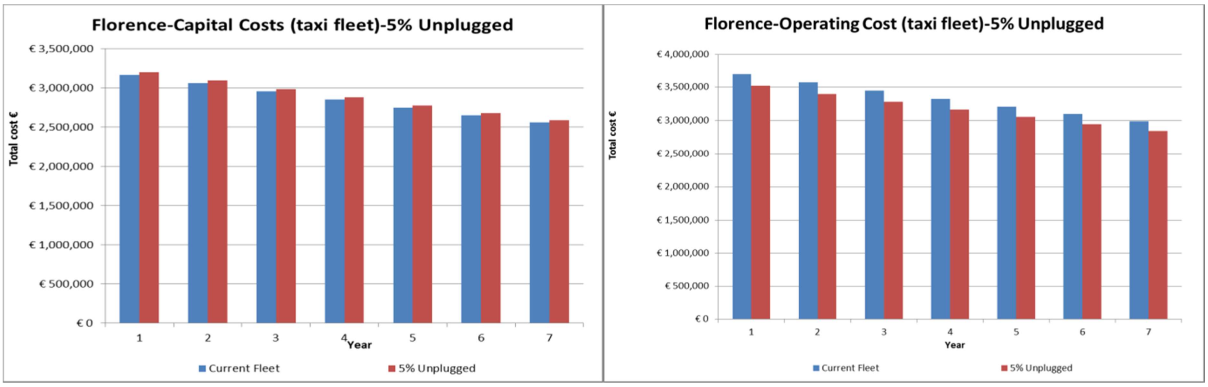


Figure 107 - *Fleet impact on capital (a) and operating costs (b): 5% Unplugged - Florence taxis*

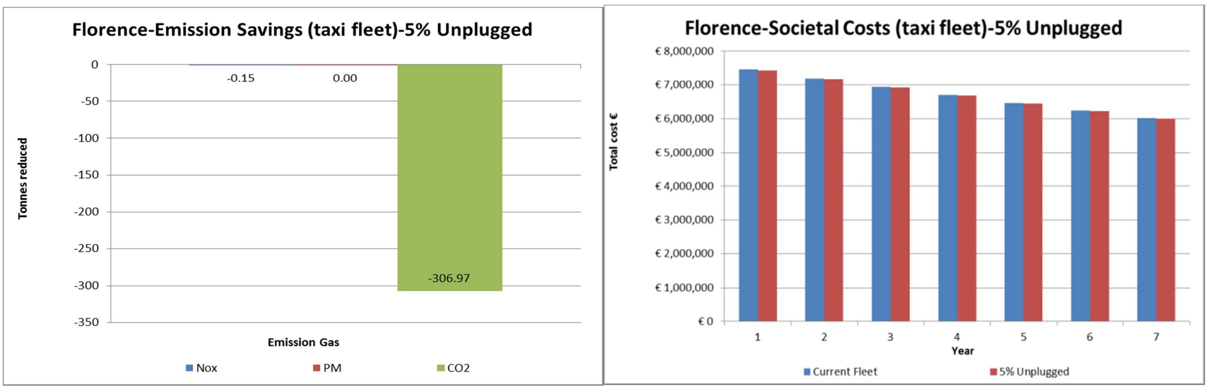


Figure 108 - *Reduced emissions (a) and resulting societal cost reductions (b) Florence taxis 5% Unplugged*

This change in fleet composition would reduce Carbon Dioxide emissions by 58000 tonnes per year. Particulate matter decreases by 0.15 tonnes per year. NO_x increases by approximately 133 tonnes per year.

5.3.3.3 **5% taxi fleet take-up comparison**

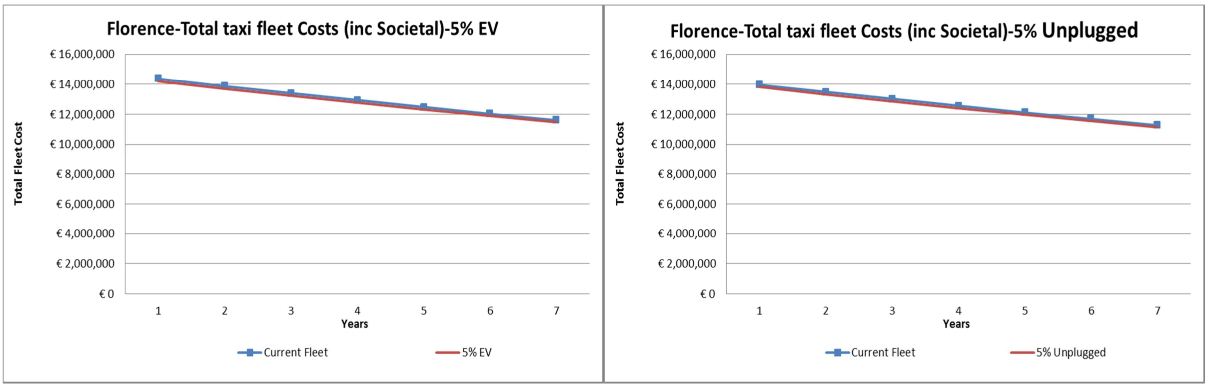


Figure 109 - *Total costs per year for electric (a) and UNPLUGGED (b) Florence taxis 5%*

Overall, benefits for the total taxi fleet if 5% are electric taxis are estimated at €188,000 per year in year one, reducing to €152,000 per year in year seven, giving a total estimated benefit of €1.18 million. Against current total costs of approximately €14.4 million per year this is calculated to be 1.3% (-1.3%) lower. The benefit per taxi is thus estimated to be €1804 over the seven year period.

Overall, Unplugged taxis are estimated to cost €167,000 less in year one dropping to €135,000 in year seven, which gives a total estimated benefit of €1.05 million. Against current total costs of approximately €14.4 million per year this is estimated to be 1.2% (-1.2%) reduced costs per year and a reduction in cost per taxi reduction of €1608 over seven years.

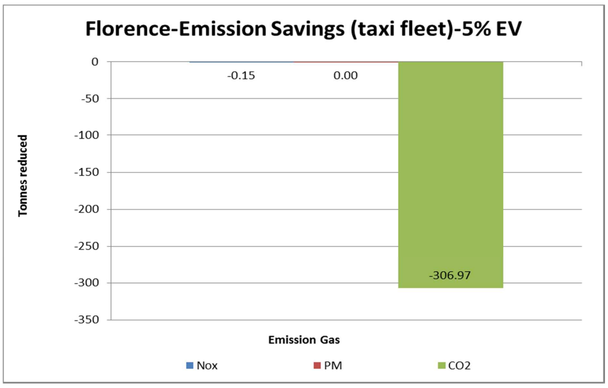


Figure 110 - *Reduced emissions if EV NO_x and PM only generated at power plant - Florence taxis 5% EV*

Assuming that NO_x and Particulate Matter is generated primarily from tailpipe emissions and that switching the vehicle fleet for 20% EVs removes some of these emissions from the city, NO_x is reduced by 0.15 tonnes per year and PM is not reduced at all.

5.3.3.4 **20% Electric taxis**

If in Florence 20% of taxis were replaced by electric taxis the analysis suggests that capital costs would be higher by approximately €72,000 per year in the first year dropping to €58,000 higher in year seven. This is more than offset by the reduction in operating costs: €649,000 lower in the first year and €524,000 lower in year seven. Societal benefits are €102,000 in the first year and drop to €83,000 by year seven.

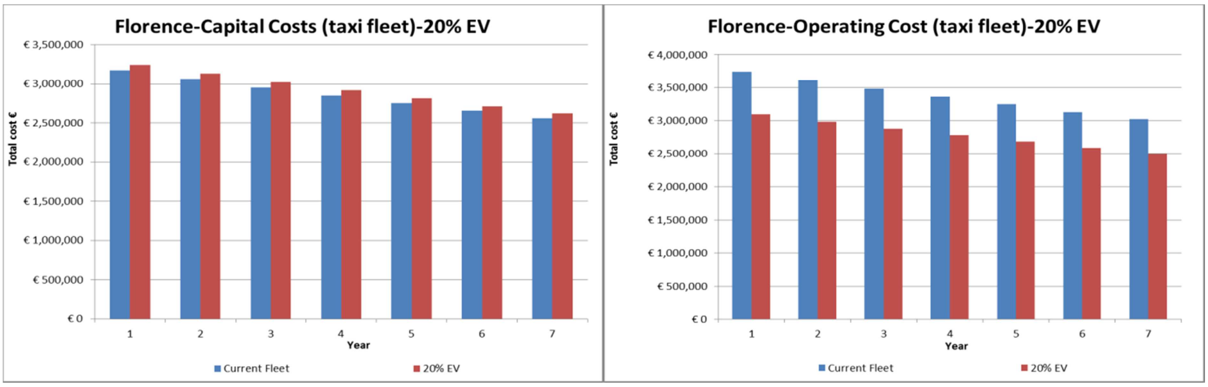


Figure 111 - *Fleet impact on capital (a) and operating costs (b): 20% EV - Florence taxis*

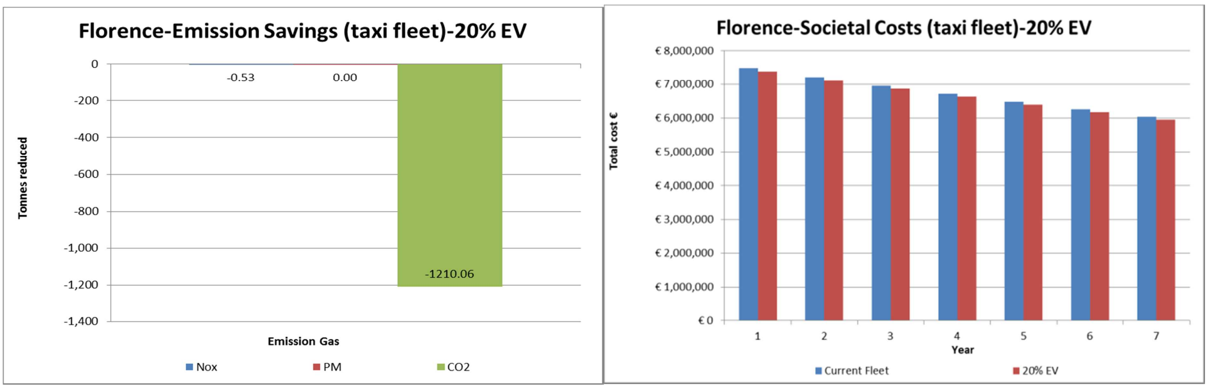


Figure 112 - *Reduced emissions (a) and resulting societal cost reductions (b) - Florence taxis 20% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by 1200 tonnes per year. Particulate matter does not decrease measurably. NO_x decreases by approximately 0.5 tonnes per year.

5.3.3.5 **20% Unplugged Electric taxis**

If in Florence 20% of taxis were replaced by Unplugged electric taxis the analysis suggests that capital costs would be higher by approximately €157,000 per year in the first year dropping to €127,000 higher in year seven. This is more than offset by the reduction in operating costs: €649,000 lower in the first year and €524,000 lower in year seven. Societal benefits are €102,000 in the first year and drop to €83,000 by year seven.

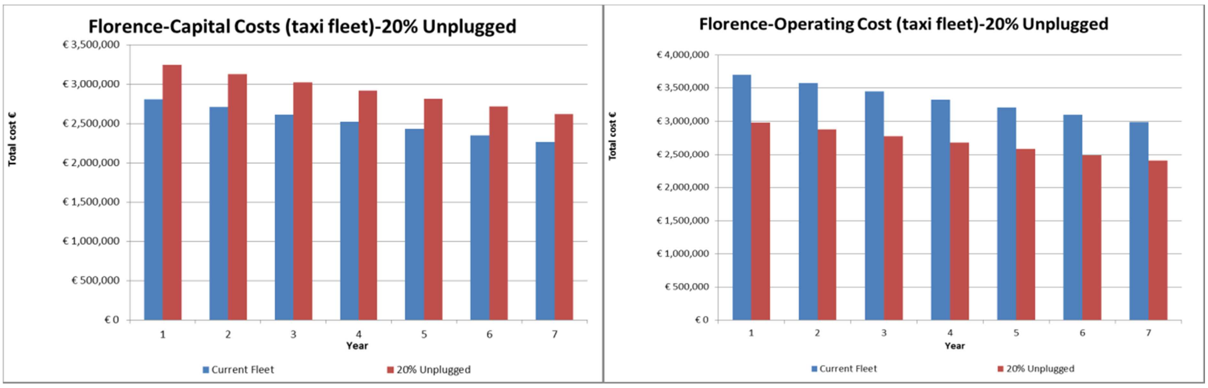


Figure 113 - *Fleet impact on capital (a) and operating costs (b): 20% Unplugged - Florence taxis*

Figure 114 - *Reduced emissions (a) and resulting societal cost reductions (b) Florence taxis 20% Unplugged*

5.3.3.6 **20% taxi fleet cost comparison**

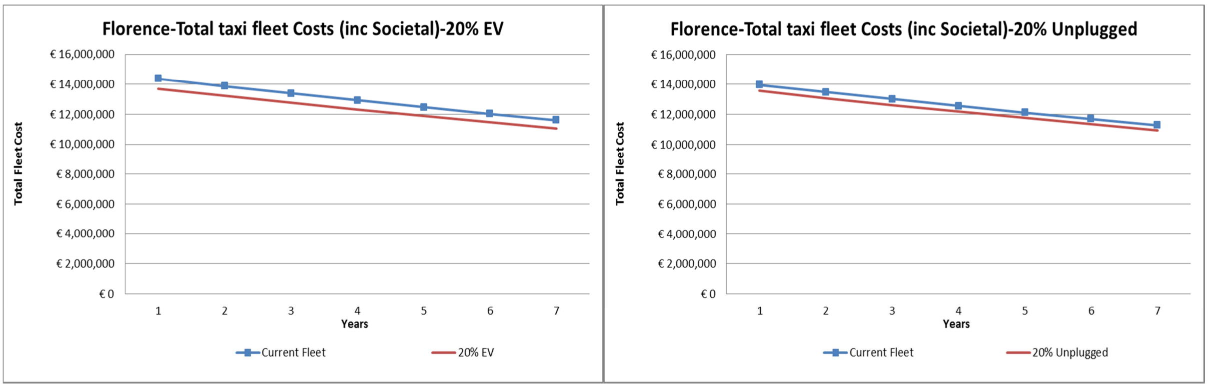


Figure 115 - *Total costs per year for electric (a) and UNPLUGGED (b) - Florence taxis 20%*

Overall, benefits for the total taxi fleet if 20% are electric taxis are estimated to be €679,000 per year in year one, reducing to €549,000 per year in year seven, giving a total estimated benefit of €4.28 million.

Against current total costs of approximately €14.4 million per year this is calculated to be 5.0% (-5.0%) lower. The benefit per taxi is thus estimated to be €6532 over the seven year period.

Overall, Unplugged vehicles are estimated to cost €594,000 less in year one dropping to €480,000 less in year seven, which gives a total estimated benefit of €3.7 million. Against current total costs of approximately €14.4 million per year this is estimated to be a 4.3% (-4.3%) cost reduction per year and cost per taxi reduction of €5714 over seven years.

5.3.4 Florence buses

This model uses a vehicle fleet of 396 buses. At time of data collection the fleet was made up of 202 diesel buses, 160 CNG buses (treated as petrol for the purposes of the model) and 31 electric buses (minibus size). The model uses some London emissions data to compensate for incomplete information. The data uses NEDC average emissions data for CO_2 and average emissions factors from AEA-Ricardo Life Cycle analysis work quoted by TfL.

The current fleet has capital costs of approximately €23 million in year one reducing to €19 million per year in year seven. Operating costs start at €20 million per year, reducing to €16.5 million in year seven. Societal costs start at €1.9 million in year one and reduce to €1.6 million in year seven.

Comparisons have not been made for 5% electric and Unplugged fleet sizes as Florence has more than 7% electric buses in its current fleet. This would make comparisons between the current fleet and a 5% Unplugged fleet challenging.

5.3.4.1 **20% Electric buses**

If in Florence 20% of buses were replaced by electric buses the analysis suggests that capital costs would be higher by approximately €1.8 million per year in the first year dropping to €1.5 million higher in year seven. This is almost offset by the reduction in operating costs: €1.7 million lower in the first year and €1.4 million lower in year seven. Societal benefits are €644,000 in the first year and drop to €520,000 by year seven.

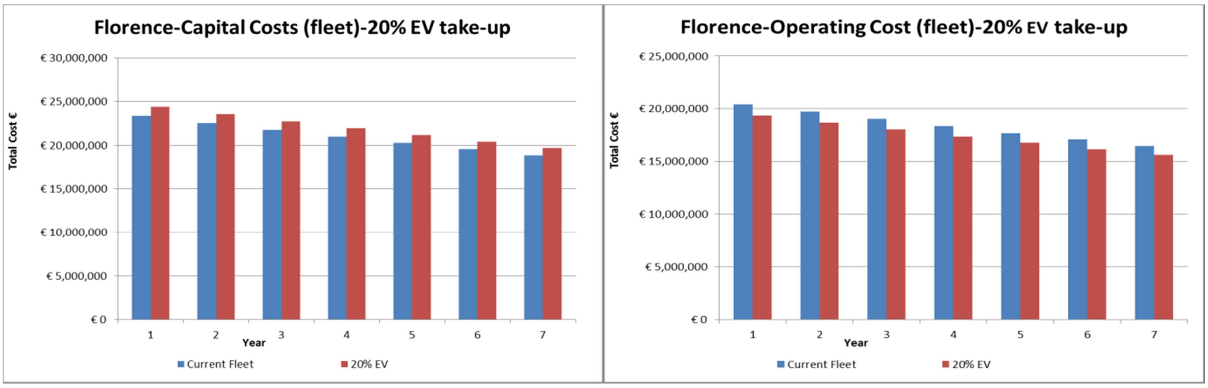


Figure 116 - *Fleet impact on capital (a) and operating costs (b): 20% EV - Florence buses*

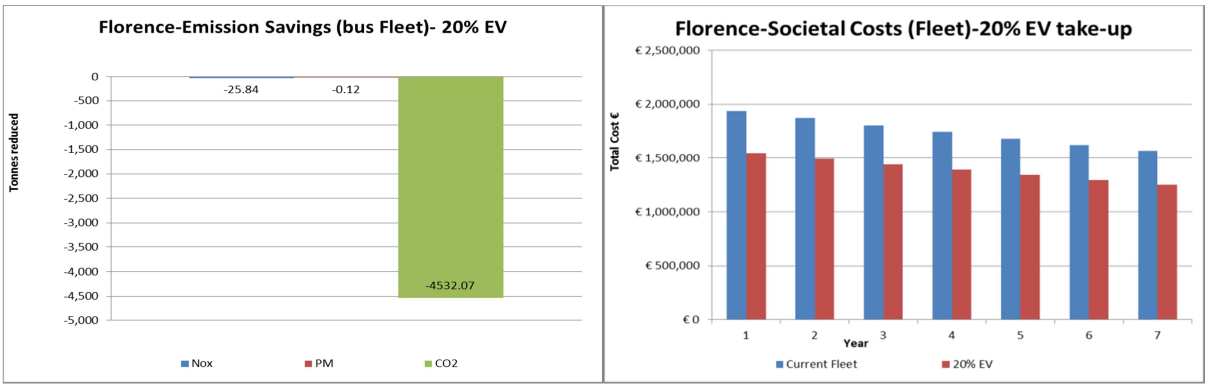


Figure 117 - *Reduced emissions (a) and resulting societal cost reductions (b) Florence buses 20% EV*

This change in fleet composition would reduce Carbon Dioxide emissions by 4500 tonnes per year. Particulate matter decreases by 0.12 tonnes per year. NO_x decreases by approximately 26 tonnes per year.

5.3.4.2 20% Unplugged Electric buses

If in Florence 20% of buses were replaced by Unplugged electric buses the analysis suggests that capital costs would be greater by approximately €1.9 million per year in the first year dropping to €1.6 million greater in year seven. This is offset by the reduction in operating costs: €1.7 million lower in the first year and €1.4 million lower in year seven. Societal benefits are €644,000 in the first year and drop to €520,000 by year seven.

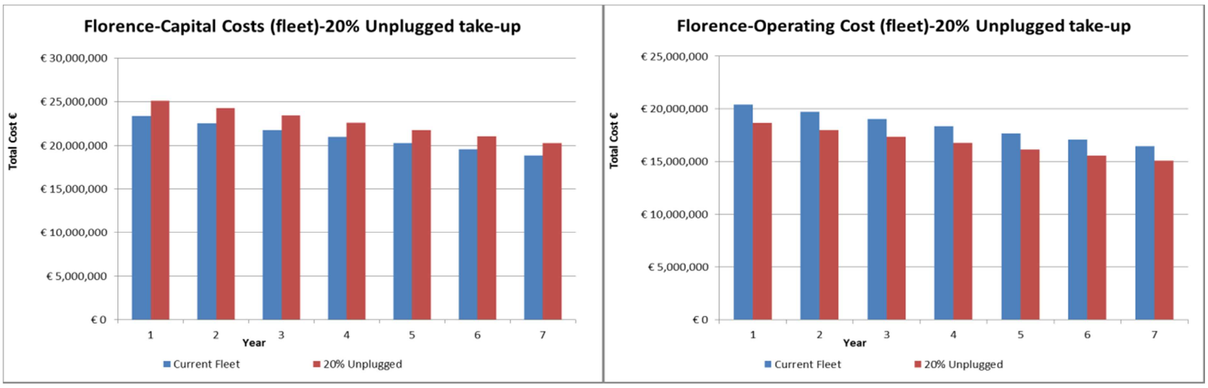


Figure 118 - *Fleet impact on capital (a) and operating costs (b): 20% Unplugged - Florence buses*

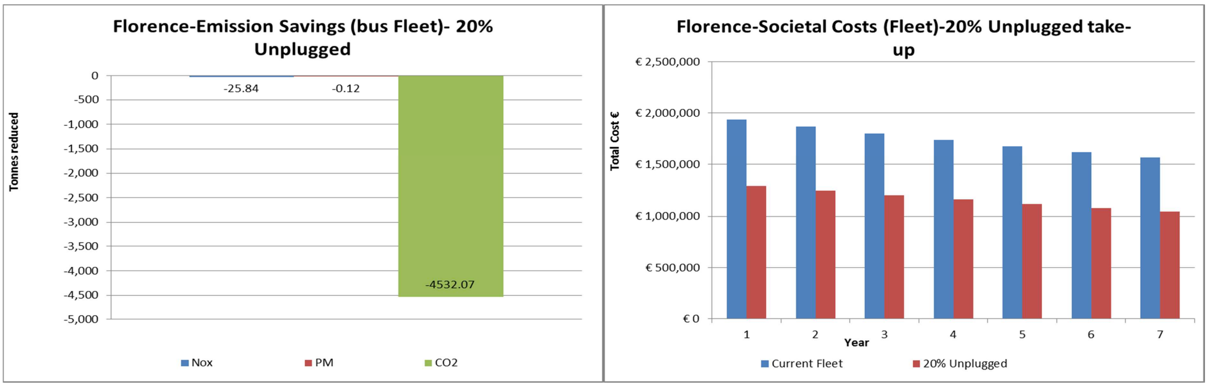


Figure 119 - *Reduced emissions (a) and resulting societal cost reductions (b) Florence buses 20% Unplugged*

This change in fleet composition would reduce Carbon Dioxide emissions by 4500 tonnes per year. Particulate matter decreases by 0.12 tonnes per year. NO_x decreases by approximately 26 tonnes per year.

5.3.4.3 20% bus fleet take-up comparison

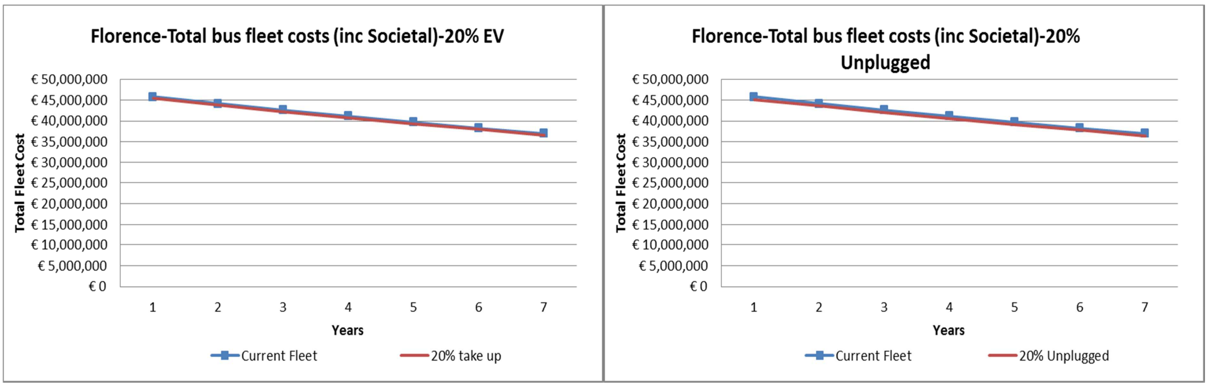


Figure 120 - *Total costs per year for electric (a) and UNPLUGGED (b) - Florence buses 20%*

Overall benefits for the total bus fleet if 20% of buses were electric are estimated to be €560,000 per year in year one, reducing to €452,000 per year in year seven, giving a total estimated benefit of €3.5 million. Against current total costs of approximately €45.8 million per year this is calculated to be 1.2% (-1.2%) lower. The benefit per bus is thus estimated to be €8937 over the seven year period.

Overall Unplugged vehicles are estimated to cost €447,000 less in year one dropping to €360,000 less in year seven, which gives a total estimated benefit of €2.8 million. Against current total costs of approximately €45.8 million per year this is estimated to be 0.99% (-0.99%) reduction in costs per year and a reduction cost per bus of €7130 over seven years.

5.4 Summary

The following summary gives indications of how much might be saved or how much additional cost might be incurred over a seven year period vehicle fleets were to change to include 5% or 20% electric vehicles or Unplugged electric vehicles.

The results are not intended to provide comprehensive analysis as the information is modelled and certain assumptions have been made.

5.4.1 Cars

When comparing the two fleets below it should be noted that London has approximately ten times as many cars as Florence. This may make a difference to some of the comparative results. The total number of vehicles and their respect fleet make up could cause differences. London has 60% diesel cars in its fleet, while Florence has only 35% diesel cars. Barcelona information was not provided and has not been included in the comparison below.

The term car ‘fleet’ should be treated with caution because purchasing decisions are made by private individuals rather than companies. The fleet composition is not controlled by one (or more) organisation (e.g. TfL and its suppliers in London). This means that take-up of electric vehicles is likely to be dependent on factors that may not have been considered within the model.

Comparing the two data sets with car fleets, we can see similar trends. The chart below shows the difference between the total current fleet and the modelled uptake fleets. The percentage variation is for total costs, including capital cost, operational cost and societal benefit. Over the seven year modelling period costs comparison shows that electric cars are more favourable when comparing against Unplugged electric fleets, though the actual percentage difference is small.

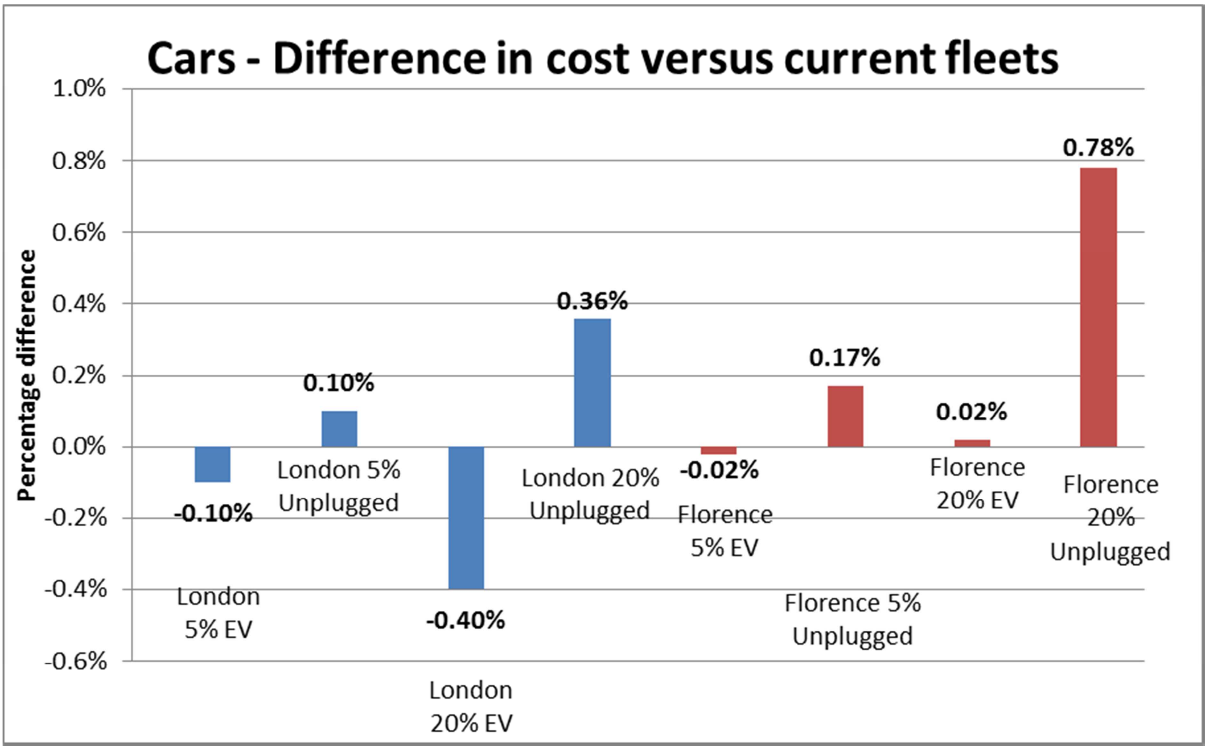


Figure 121 – *Percentage difference in total cost of modelled fleets versus current total fleet cost (cars)*

Table 2: Summary table - Cost benefits compared to diesel (over 7 years) for London cars. Negative values indicate saving against current costs. Values in € millions unless indicated.

% of vehicles in fleet	Capital Cost		Operating Cost (saving)		Societal Cost (saving)		Total	
	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED
5	€562	€1182	-€845	-€845	-€42	-€42	-€-325	€295
20	€2,248	€4728	-€3,380	-€3,380	-€168	-€168	-€1,301	€1180

Table 3: Summary table - Cost benefits compared to diesel € millions (over 7 years) for Florence cars. Negative values indicate saving against current costs. Values in € millions unless indicated.

% of vehicles in fleet	Capital Cost		Operating Cost (saving)		Societal Cost (saving)		Total	
	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED
5	€42.5	€98.0	-€44.9	-€44.9	-€4.1	-€4.1	-€6.5	€49.0
20	€198	€426	-€187	-€187	-€5.8	-€5.8	€5.1	€233.2

5.4.2 Vans

In comparing van fleets below it should be noted that London has a van fleet approximately forty times greater than Florence, based on supplied information. This might be the cause of some differences between the fleets.

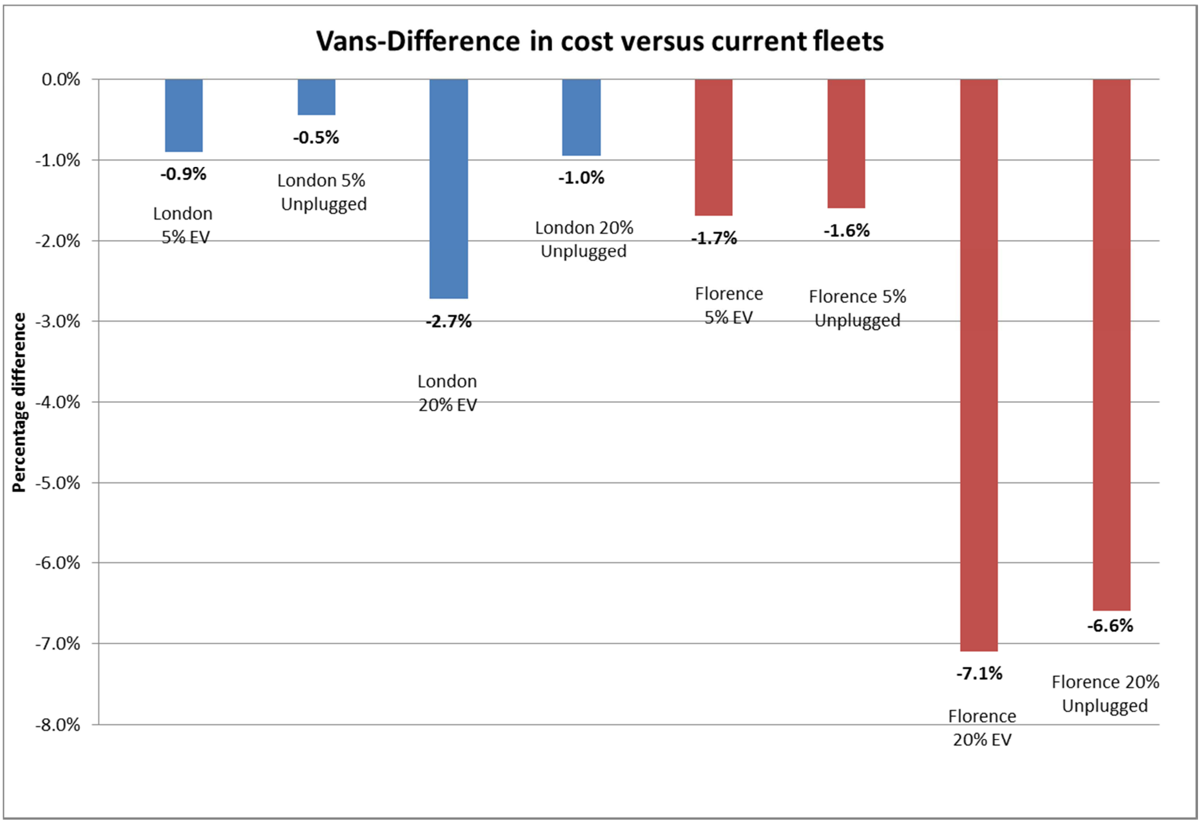


Figure 122 - *Difference in cost versus current fleet (vans)*

The clearest pattern discerned from the above chart is that either electric or electric Unplugged vehicles are shown to reduce van fleet costs. At 5% penetration of EVs, there is a percentage gain of approximately 1% against current fleets. For 20% EVs, the costs can be reduced by approximately 3% to 7%. Estimated percentage reductions are greater in Florence than London.

Table 4: Summary table - Cost benefits compared to diesel € millions (over 7 years) for London vans. Negative values indicate saving against current costs

% of vehicles in fleet	**Capital Cost**		**Operating Cost (saving)**		**Societal Cost (saving)**		**Total saving**	
	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED
5	€412	€470	-€481	-€481	-€229	-€229	-€298	-€239
20	€1935	€2517	-€1923	-€1923	-€916	-€916	-€903	-€322

Table 5: Summary table - Cost benefits compared to diesel € millions (over 7 years) for Florence vans. Negative values indicate saving against current costs

% of vehi-cles in fleet	**Capital Cost**		**Operating Cost (saving)**		**Societal Cost (saving)**		**Total saving**	
	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED
5	€5.4	€8.9	-€48.6	-€48.6	-€7.0	-€7.0	-€50.2	-€46.7
20	€23.9	€36.2	-€194.3	-€194.3	-€26.4	-€26.4	-€196.8	-€185

5.4.3 Taxis

In comparing taxi fleets below it should be noted that London has a taxi fleet approximately thirty times greater than Florence, based on supplied information. This might be the cause of some differences between the fleets.

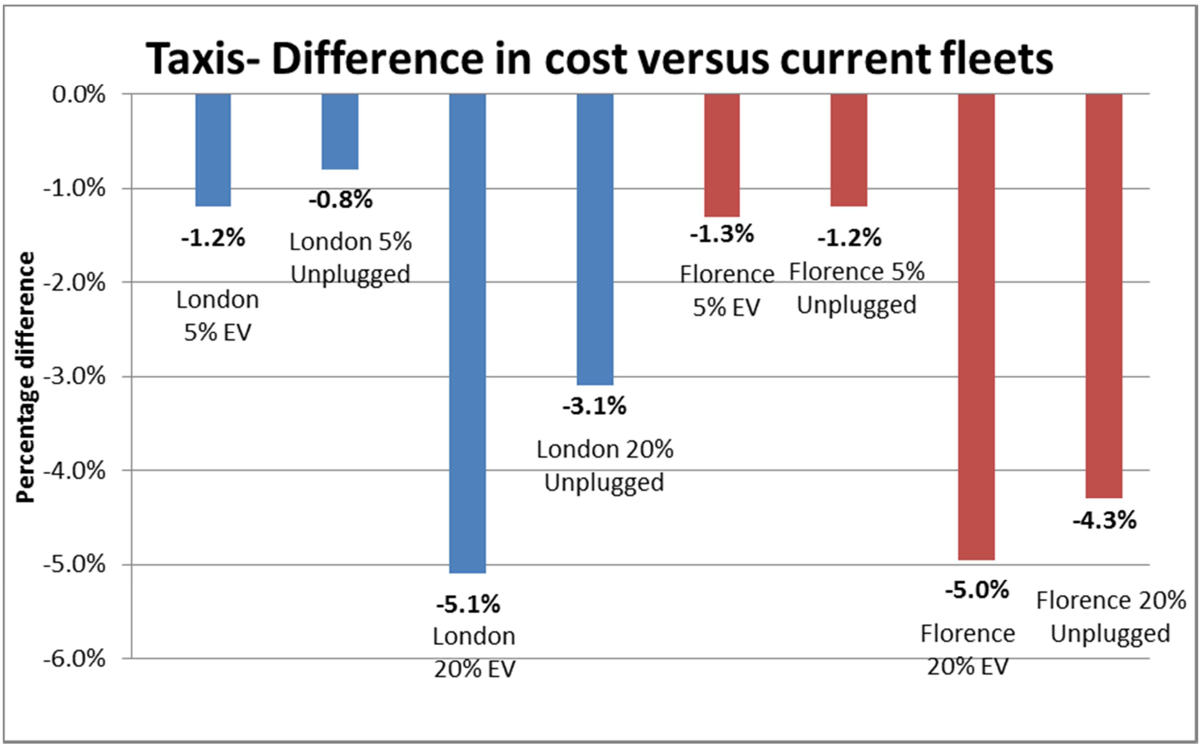


Figure 123 - *Difference in cost versus current fleet (taxis)*

The clearest pattern discerned from the above chart is that either electric or electric Unplugged vehicles are shown to reduced taxi fleet costs. At 5% penetration of EVs, there is a percentage gain of approximately 1% against current fleets. At 20% of the fleet savings vary between 3% and 6% against current fleet costs.

Table 6: Summary table - Cost benefits compared to diesel € millions (over 7 years) for London taxis

% of vehicles in fleet	Capital Cost		Operating Cost (saving)		Societal Cost (saving)		Total saving	
	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED
5	€8.5	€23.8	-€46.7	-€46.7	-€5.6	-€5.6	-€43.8	-€28.5
20	€34.1	€98.9	-€187	-€187	-€22.1	-€22.1	-€175	-€110

Table 7: Summary table - Cost benefits compared to diesel € millions (unless stated) (over 7 years) for Florence taxis.

% of vehicles in fleet	Capital Cost		Operating Cost (saving)		Societal Cost (saving)		Total	
	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED
5	€0.07	€0.20	-€1.04	-€1.04	-€0.21	-€0.21	-€1.18	-€1.05
20	€0.45	€0.99	-€4.1	-€4.1	-€0.64	-€0.64	-€4.3	-€3.75

5.4.4 Buses

When comparing the two fleets below it should be noted that Barcelona has approximately two and a half times as many buses as Florence. This may make a difference to some of the comparative results.

No comparison was made for 5% fleet in Florence as the fleet is already made up of more than 5% electric buses. Differences in the 20% comparative results might be due to the Florence fleet being made up of 7.8% electric buses. No model was created to compare a theoretical fleet without this proportion of electric buses (i.e. 0% EVs), the current fleet and, 5% and 20% fleets.

The remaining models show reduction in costs over the seven year period. The values are from a smallest 0.2% reduction of up to a maximum 2.1% reduction in costs. Barcelona is the only city modelled which show an increase in costs for each percentage modelled.

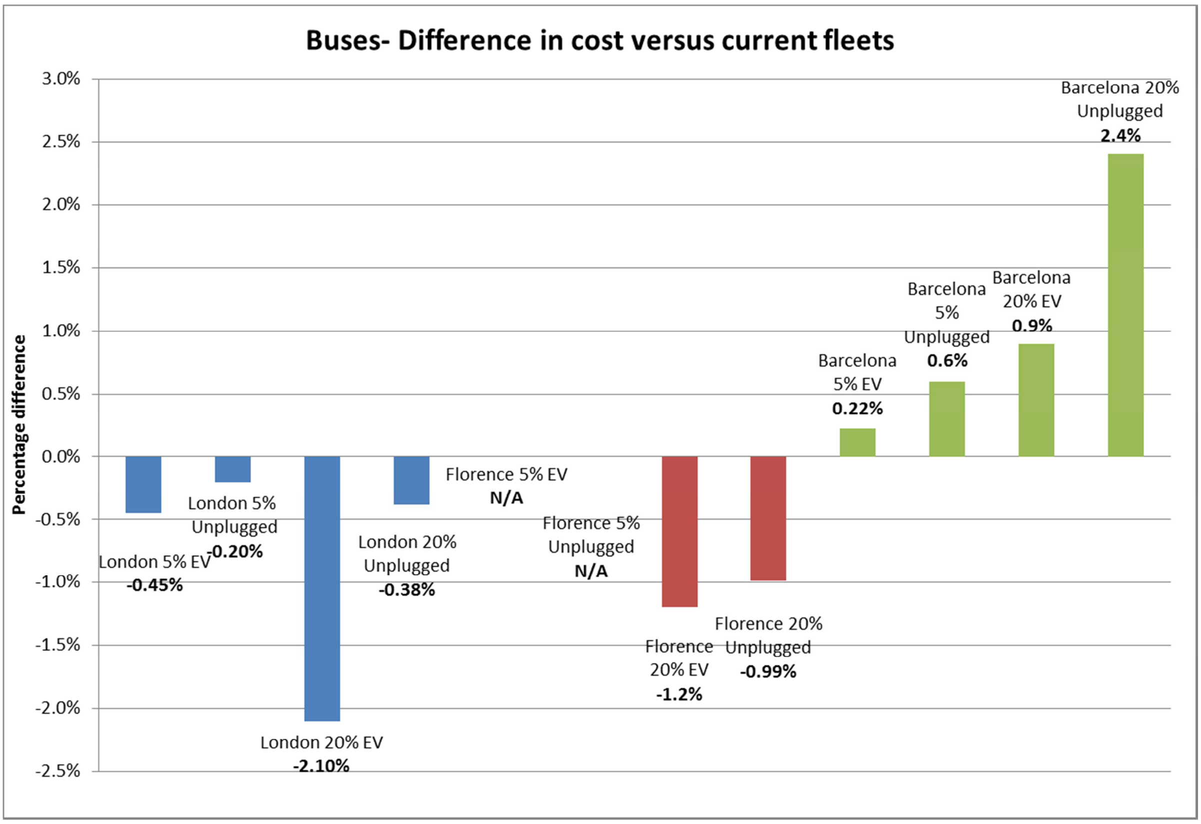


Figure 124 - *Difference in cost versus current fleet (buses)*

Table 8: Summary table - Cost benefits compared to diesel € millions (over 7 years) for Barcelona buses

% of vehicles in fleet	Capital Cost (saving)		Operating Cost (saving)		Societal Cost (saving)		Total	
	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED
5	€10.9	€13.2	-€7.1	-€7.1	-€2.4	-€2.4	€1.4	€3.7
20	€44.7	€54.2	-€28.8	-€28.8	-€10.1	-€10.1	€5.8	€15.3

Table 9: Summary table - Cost benefits compared to diesel € millions (over 7 years) for Florence buses

% of vehicles in fleet	Capital Cost		Operating Cost (saving)		Societal Cost (saving)		Total	
	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED
5	No comparison made							
20	€11.5	€11.1	-€11.0	-€11.0	-€4.1	-€4.1	-€3.5	-€2.8

Table 10: Summary table - Cost benefits compared to diesel € millions (over 7 years) for London buses

% of vehicles in fleet	Capital Cost		Operating Cost (saving)		Societal Cost (saving)		Total	
	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED	electric	UNPLUGGED
5	€9.0	€11.4	-€12.2	-€11.8	-€1.0	-€1.0	-€4.2	-€1.2
20	€36.9	€50.4	-€49.2	-€49.2	-€4.9	-€4.9	-€17.1	-€3.7

5.5 Socio-economic impact assessment conclusions

The models show that in most cases, there is a financial gain to society that can be made from switching a vehicle fleet to electric vehicles and Unplugged electric vehicles. This financial gain is not accrued by individual vehicle owners, but by wider society as an environmental benefit.

The benefits are clearer for vans, buses and taxis than they are for cars. For each of the cases above, vans, buses and taxis show all negative cost difference indicating savings. Only the Barcelona bus fleet shows an increase in costs for all modelled percentages. For cars there are some cost increases, noticeably for 20% penetration of Unplugged vehicles in Florence. It is possible that this is due to car fleets being composed of a smaller percentage of diesel powered vehicles. The large majority of non-car fleets were composed of diesel vehicles, whilst the car fleets were composed of more petrol than diesel vehicles, so the air quality benefits of replacing them with EVs are lower.

As expected savings are modelled to be greater in real terms when fleets are modelled to have 20% EV or Unplugged EV.

The highest potential saving is modelled to be in Florence for the van fleet, where approximately 7% cost savings may be obtained by switching to 20% EV or 20% Unplugged fleets.

When fleets are modelled to be 5% EV and 5% Unplugged, savings tend to be approximately 1%. Depending on the size of the fleet and the capital costs these can still be significant amounts.

Comparing standard EVs with Unplugged EVs, the differences in the modelling figures are derived from the initial capital costs, which are currently estimated to be higher than for standard EVs. Therefore savings are generally lower for Unplugged EVs than for standard EVs.

As discussed previously, it is difficult to isolate the impact of WPT charging technology on the cost-benefit of EVs. Although it is clear that the capital costs are likely to be higher and the benefits derived in terms of running cost and societal cost savings are the same on per mile basis, unlike conventional EVs, UNPLUGGED EVs are able to opportunistically change en-route, therefore maximising the electric-only range and total electric miles driven, thus increasing the overall benefits. UNPLUGGED technology can be best thought of as facilitating higher proportion of EVs in fleets and therefore, allowing to meet theoretical savings calculated which would otherwise not be possible due to EVs not being able to achieve the same duty cycles, as conventional ICE vehicles in some cases.

6 Overall Conclusions

In reviewing the two parts of the report, it can be seen there are some important links that can be made.

Stakeholders responding to the questionnaire stated that 'CO_2 reduction' and 'air quality improvement' are two of the more important factors to them. Using the modelling updates for the various fleets, we can see that even with low (5%) EV take-up, that emissions can be reduced. The emissions reductions are greater when considered on a purely local basis. That is, if ICE vehicles are removed from a city fleet and replaced with EV equivalents, then the local exhaust emissions are reduced. These emissions are of course transplanted to the power stations (assuming the grid is not completely non-fossil fuel based). Emissions at a remote power station are not as detrimental as in the city, which is where the majority of the societal benefits are obtained.

When respondents in the questionnaire were asked about costs, private users indicated that reduced running costs were important to them. Stakeholders were more concerned with who would pay for the charging infrastructure. The modelling shows that savings can be made in the long term, provided a certain percentage of the fleet is switched to EVs.

Responding to the questionnaire, respondents in both stakeholder and the private user group stated that 'improved practicality/simplicity of charging' was one of the most important things in their opinion. With WPT to vehicles, this eliminates the requirements for charging via plug sockets. If inductive charging also became widespread, this could reduce range anxiety amongst EV users.

High level modelling of possible costs for converting fleets to UNPLUGGED vehicles showed that in most cases for vans, taxis and buses converting 20% of vehicles to UNPLUGGED vehicles leads to overall cost reductions when considering the monetised reductions in emissions. The savings are slightly lower than for standard EVs due to higher vehicle and charging infrastructure capital costs. However, it should be noted that standard EVs may not be able to meet the practical requirements of van, bus and taxi operation all the time. Constraints such as having time to plug in, larger batteries lack of automated charging process with regular EVs means that in some cases, these could only be addressed through opportunistic wireless charging. Therefore, without wireless power transfer, high-level penetration of EVs into these types of vehicles may not be possible.

For cars, the relatively large increase in capital costs and comparatively lower reductions in running and societal costs due to lower annual mileage driven and lower average emissions than for other vehicle types considered in this study, resulted in converting vehicle to UNPLUGGED vehicles as having a net cost. However, it can be seen that when considering standard EVs, overall reductions can be achieved. Therefore, if the cost of wireless charging infrastructure and on-vehicle components can be reduced to be comparable with plug-in charging, then overall cost-reductions could be achieved. Analysis suggests that if combined charging infrastructure and on-vehicle component costs for wireless chargers can be reduced by around 50% then parity with standard EVs could be achieved.

7 Figures

8 Tables

8.1 Reference

[1] Dziekan, K., Gehlert, T. & Gärling, T. (2011). User acceptance of guided charging: results of a field study. 9th Biennial Conference on Environmental Psychology. September 26-28 2011. Eindhoven, The Netherlands.

[2] P. Ballon, J. Pierson & S. Delaere (2005). Test and experimentation platforms for broadband innovation: examining European practice in: Conference Proceedings of 16th European Regional Conference by the International Telecommunications Society (ITS), Porto, Portugal, 4-6 September, 2005.

[3] Coosemans, T., Lebeau, K., Macharis, C., Lievens, B. & Van Mierlo, J. (2012). Living Labs for Electric Vehicles in Flanders. Paper submitted for EVS 26, Los Angeles, California.

[4] Project Unplugged (2014), Deliverable 3.2-Power grid power request and grid management strategies technical report-rev1- APP v140729.01, 29 July 2014

[5] Department for Transport – WebTAG Transport analysis Guidance website

Appendix A – TRL survey WPT information sheet

WPT Information Sheet

Electric vehicles (EV) can be charged in different ways, with different technologies. The conventional charging method is using a cable (also known as *conductive charging* or *plug-in charging*) to connect the EV to the charging infrastructure. This method requires the EV to be compatible with the charging infrastructure (also known as *charging point*) by having a compatible connector (consisting of *plugs* and *sockets*). There is a number of charging point types, each able to deliver different levels of power to the EV and therefore charge it in different amount of time but will typically take from around 7-8 hours to charge a fully depleted battery from a slow/domestic-type charger to 20-30 minutes to charge a battery to 80% from a rapid charger. The construction of the charging point will differ depending on the power supply it is designed to provide to the EV, and therefore the price and complexity also varies considerably. Charging points are usually part of various charging schemes and require users to gain access to the charger by using some form of smart card or a pin number. Then, the user is able to plug in their EV. See examples of charging equipment in Figure 1 below.

Figure1: Examples of plug-in charging vehicles and chargers

The other method of charging is wirelessly, using wireless power transfer (WPT), also sometimes referred to as inductive charging or inductive power transfer (IPT). It should be noted that WPT is not a complete replacement for plug-in charging but is an additional method of charging. When using WPT to charge an EV there is no physical connection or contact between the vehicle to be charged and the power supply. As there is no need for the user to plug in, the process is also typically fully automated, requiring no interaction from the user other than from the vehicle dashboard to confirm the start of the charging process. The charging process automatically stops when the user drivers away. Although the technology for WPT is well developed and has been applied in industrial applications for many years, its application in the transport sector is still new. The general concept of a WPT system is illustrated in Figure 2 below and some examples can be seen in Figure 3. The system consists of two sets of coils, a ground coil (the infrastructure component) and the vehicle coil. The ground coil is connected to the grid (or other power supply) via a set of power electronics, and generates a magnetic field. This magnetic field is then transmitted to the vehicle coil which converts the magnetic field back to electricity, which then chargers the EV battery.

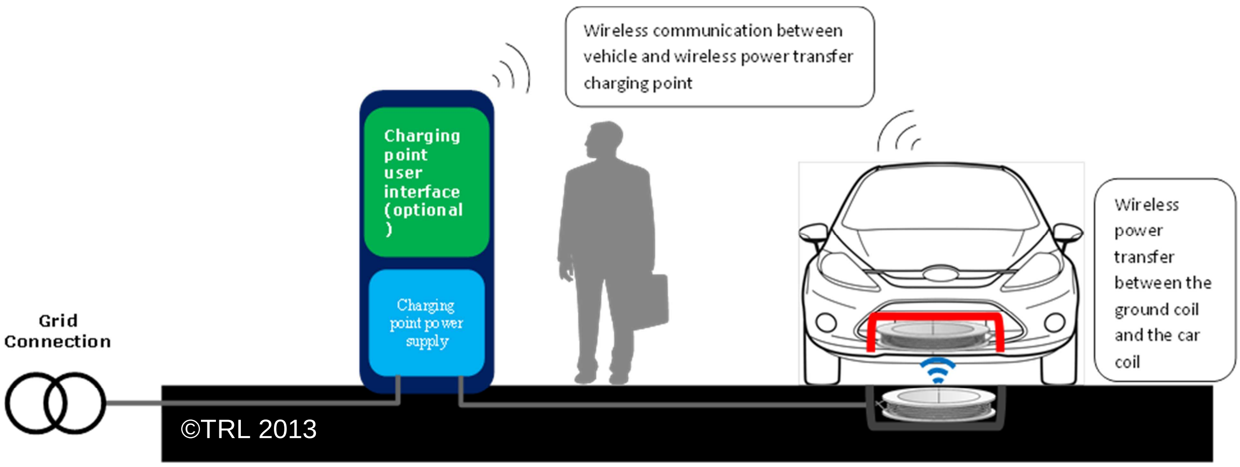


Figure 2: Diagram for a typical WPT charging point for a car

Figure 3: Examples of WPT Charging, for a car using a mat (left), WPT charging for a bus built into the road surface (right)

The two coils can operate very efficiently under optimal conditions and can transfer power at greater than 90% efficiency. The coil performance is not typically affected by rain or snow and the coils can even be placed on, or under the ground. As the charging process is automated and there is no need for the driver to get out of the vehicle or to physically connect to any device, WPT charging can be used while the vehicle is moving or is stationary for short periods of time at traffic lights or other stops (also known as ***en-route charging***). As the application of WPT charging in transport is till new, there are some possible disadvantages such as uncertainty over whether different manufacturers' systems will be interoperable, additional cost and weight of the vehicle coils and the cost of the ground coils. It is also likely that different types of coils will be required for different vehicle classes with larger coils necessary for higher power transfer in larger vehicles such as buses and trucks and smaller coils required for cars and vans.

The biggest possible impact of using WPT is that it allows much more opportunistic charging of EV batteries. **Opportunistic charging** is any charging process that takes place over a short period of time during the vehicle's typical use. This charging is typically done ad-hoc, as opposed to predetermined charging at work place or overnight at home. Opportunistic charging has the potential to significantly improve EV range without increasing the size and cost of the batteries. It may even allow for use of smaller batteries; therefore, reducing the price and weight of required EV batteries. By allowing more EVs to complete more electric miles, WPT charging (particularly en-route charging) could have an overall impact on reducing emissions, improving air quality and reducing running costs for EVs further. It may also allow for a greater variety of vehicles to be electric as battery size, weight and range may no longer be a constraint.

The table below summarizes the relative advantages and disadvantages of WPT / IPT. You can use this table and the information above to help you answer questions that follow. Please note that as the technology in the transport application is still maturing, many of these points are **theoretical** only.

Wireless Power Transfer (WPT)	
Advantages	**Disadvantages**
Automated charging process - does not require user intervention other than confirmation to start the process	
Does not require cables or complicated connectors to be handled	
Charging process can be started without driver leaving the vehicle	
Charging process can happen during short stops or even while the vehicle is moving	
Power level for charging is not restricted by the thickness of the available cable	Power (and therefore speed of charging) will depend on the size of the coils with more powerful systems requiring larger, heavier coils
Can have very high powered charging without increasing the risk of electrocution	
Connector (plugs and sockets) and charging point interoperability is not an issues	Interoperability between different manufacturers is still to be determined
Much less susceptible to vandalism or to accidental damage	
Largely unaffected by weather or environmental conditions	Location of the pad on the ground needs to be visible or in vehicle guidance system required for alignment (e.g. similar to automatic parking)
Reduces the amount of “street clutter”	
Improved electrical safety – no contacts so no risk of electrocution for users	
Allows more opportunistic charging and therefore can increase the range of EVs and reduce charging times	Generally more expensive than plug-in charging
Can lead to better EV utilization	
Can lead to reduced vehicle weight and battery pack size and cost	Vehicle coils will add weight and complexity to the vehicle
Can lead to better acceptance of EVs / higher EV mileage which have a positive impact on: Local air quality	

Green House Gas emissions Noise levels in cities Vehicle running costs.	

Appendix B – Stakeholders comments to TRL survey

- No information provided on the impact on heath of wireless charging, nor of the impact on other electronic devices.
- I think the idea of wireless charging is a genuinely good one. Following a trial I took part in to run a plug in EV for a few days, I found the experience highly stressful as to whether I'd have enough battery range to complete the journey's I currently use my car for, and it proved to be totally unsuitable for the journeys I undertake in my work van. A quick, fuss free wireless solution to top up on the way therefore makes total sense. However, all of this is somewhat irrelevant considering how long it takes to see any running cost saving compared to a tradition diesel vehicle. I have 2 diesel cars and 1 van, all can comfortably see more than 50mpg on a run, and 40+mpg locally. They are high spec, quality vehicles that suit my needs perfectly. The EV's on sale at the moment seem massively expensive for an inferior spec, they are not as nice to drive (mainly due to significant weight penalties), and the reliability and cost long term for the technology would concern me. I still think that EV's are a long way off replacing standard vehicles for anything other than inner city use.
- May have some concern about electrical radiation were coils to be more numerous and at every traffic light junction. Not sure of the safety factor over the long term.
- To facilitate speedy uptake the key issue will be costs. The system needs to be affordable and therefore central government need to make the infrastructure available and if taxes can't fund it then have a "small"; levy on the electricity metered. The electricity used should be paid for via home electricity supplier contract to prevent individual firms charging excessively the facility otherwise the technology will never take off.
- I don't think wireless charging on the entire road network is a great idea at present. too much of an outlay for too little payback. I do think it could be worthwhile in bus lanes though where buses/taxis are in higher concentration and you could focus the investment to where it would be most worthwhile. I'd eventually like to see wireless charging everywhere but don't imagine this would happen till the use of electric vehicles is much more common and the technology has progressed.
- Wireless power charging will be very convenient. However, efficiency, safety and cost will have to be acceptable.
- The principals of wireless charging are well understood, the technology is mature and is low technical risk. In order to ensure adoption any solution most use common architectural infrastructure, be a stable solution that remains available for decades, be widely available, cheap to install at home and overall costs must show a whole life cost benefit for the vehicle / no net cost increase in public transport fares.
- Sounds a brilliant idea. What would the installation of the charging points do to the durability of the road surface, I wonder? Also would there be more road works as these points are installed?
- I cannot see that the amount of charge received whilst stopped at a bus stop or traffic lights would be sufficient to make this type of charging economically viable, particularly when consideration is given to the technology needed to bill the user for the service .I would be against the installation of these chargers being laid into the road all over the place including outside people's houses and remain sceptical about the safety of them.
- Good idea in theory, practically difficult to implement and not as convenient as traditional fuel vehicles.
- A good idea
- Before this questionnaire I knew nothing about wireless electric cars but I think that it is a really positive change in transportation if the general public go for it. However I would expect to pay a lot less for buses and other public transport as in the past they have been marketed as "green"; and if driving a car on your own is just as Eco friendly for someone like me the idea of buses seem a bit obsolete.
- EV's need to be cheaper to buy in the first place to allow for less well off people to afford them. They are still too expensive for the average person to afford. Until then a Wireless Power Charging System will only be of use to the minority thus not proving all the environmental benefits pos-

sible. There is no point putting in the infrastructure if only 10% of people will own a car capable of using it.

- Q14a and 14b. Just because I expect the cost to be higher doesn't mean I think it actually should be higher. Electric vehicles, especially non wireless ones, are totally impractical outside of major cities due to their limited range. When used in a city environment, especially places such as London, unless the owner has secure off street parking (not common in big cities) a non wireless system is not viable. Then there is the question of cost. I simply cannot see the supply of electricity being cheap. A monopoly is likely to exist for which the motorist will pay the price. Also the actual vehicles will not be cheap, will probably wear out tyres quicker and no doubt have high maintenance costs. I simply can't see the batteries lasting the life of an average conventional vehicle and no doubt their replacements will cost an absolute fortune. This will make second hand vehicles unattractive and could potentially put off buyers of new vehicles because of high depreciation values. Modern conventional petrol and diesel vehicles are generally very economical and environmentally clean, therefore I see no real point in pursuing the use of electric vehicles for domestic use. Unless of course costs are regulated so that the motorist is better off. I somehow can't see that. What about the environment you ask? Well first tell the Russians and Chinese to go green and then I'll think about it............
- The more use of EVs throughout the country and world can only be beneficial. Vehicle makers MUST be made to use this technology in order to produce more ecologically efficient vehicles. Central Government must also make available funds to enable charging to be economical and effective
- On road charging may lead to irresponsible driving. Charging structure could be complicated. Given established technology no reason for increased cost of vehicle. Too little information/experience to understand how quickly charging of battery will take place.
- Question 10 is wrongly formulated - it should refer back to Q. 9 and NOT to Q. 7Would such magnetic wireless charging systems have any impact on peoples health in the vicinity? How could one avoid ”tampering”; i.e. avoid paying ... would charging be based on ”pay as you go”, or ???
- This has been quite a revelation to me - I did take part in the trial of electric car but would have found the charging quite onerous particularly in winter -going outside to garage to charge up -
- The introduction of WPCS to the infrastructure will accelerate the adoption of EV's as the problem of short distance capacity of EV's should be overcome as the vehicles can be ”topped up”; on the move.
- Why bother when the overall costs are prohibitive and aircraft emissions negate the majority of air quality savings, and all this extra electricity still needs to be generated....at what cost? The time and effort should be devoted to other forms of vehicle power, eg; hydrogen cells or water, we have more than enough of it at the moment. Has anyone thought of the effect upon mobile phones that already have wireless charging, would it blow their circuits?
- I really think the idea of this technology it the way all fuel for transport will go. Being able to constantly recharge you vehicle will increase the range for electric transport. It could also be linked with automated driving, which would reduce accidents and this technology could be fitted alongside at the same time This will make it a lot more appealing for long distance drivers, and will spur people to change their vehicles. It would be an excellent investment with the right mix of funding. It could be funded by the populace in return for a share of the company/s. I do have some concerns about the impact on birds etc. that use magnetic fields to navigate and whether or not this could affect people who have pacemakers etc.
- I think the whole concept should be trialled using buses only - both bus lanes and use at terminals and depots.
- The 2 main advantages I believe are: 1. The 'range' is likely to be much less of an issue. 2. The smaller battery should make the purchase price lower, the available useable space greater and the car weight lower thereby reducing the running power/cost needed.
- There are two issues that I believe may impact the take-up/value of WPT:- In order to increase efficiency, the two coils need to be very close. On buses this is currently done by lowering the coil on the bus when stationary. I'm not sure how viable this would be on a car, and a permanently lowered coil might make speed-bumps somewhat tricky.- How often are optimum power-transfer

conditions achieved (i.e. more than 90% efficiency) ? Unless high efficiency can be achieved, this could offset the total efficiency of EVs, possibly making them less efficient (well-to-wheel) than diesel technology.

- Concerns about EMC and radiation from wireless charging facilities need to be covered, and also the concerns about overlap control of charging elements to maximise charging capability have to have a robust solution - w.r.t. (with respect to) electro-magnetic flux field shape and the disproportionate reduction in charging capacity per unit of distance between charger and receiver centre lines.
- It is bound to have some useful applications. How many use cases and how widely it will be used, I really don't know.
- Believe all the Power generation companies, would have to supply the electric power required at an agreed and equal cost, only as approved by central government generally as outlined as per Q6
- I would never buy an electric vehicle while the environmental impact of their production and battery production and disposal is so high
- I don't think that wired EV charging will continue much after wireless charging is available. Wired charging is VERY inconvenient, unplugging the car on a cold morning, storing the cable, washing your hands (cats pee on it overnight) is a disgusting retrograde step in transport, compared with the clean dispensing of liquid fuel (even diesel) nowadays.
- I think WPT is a great idea but that the main issues surrounding the roll out are:1. How to get interoperability between manufacturers to allow multi vehicles types to use the same pads and 2. How to make a business case for it. For buses & Taxis there is a bigger and better argument as the opportunity charging can make a difference to the viability and therefore the business case of particular routes. Good luck
- The question is always buy an EV? For me the answer is which is why I lease an EV