Feasibility analysis and development of on-road charging solutions for future electric vehicles

D3.3.2 Gap Analysis

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
AC	Alternating Current
CAN	Controlled Area Network
CEDR	Conference of European Directors of Roads
CWD	Charge While Drive
DC	Direct Current
DfT	Department for Transport
DMRB	Design manual for Roads and Buildings
DSO	Distribution System Operator
DTITM	Direction Technique Infrastructures de Transports et Matériaux (French technical directorate of transport infrastructure and materials) – formerly known as Sétra
E/E	Electrical and Electronic
ECU	Electronic Control Unit
EMF	Electromagnetic field
ESS	Energy Storage System
EV	Electric Vehicle
HA	Highways Agency
HGV	Heavy Goods Vehicle
I2I	Infrastructure to Infrastructure
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEC	International Electrotechnical Commission
IPV	Inductively Powered Vehicle
ISO	International Organization for Standardization
KAIST	Korea Advanced Institute of Science and Technology
LGV	Light Goods Vehicle
LTA	Local Transport Authority
LTP	Local Transport Plan
LV	Low Voltage
MfS	Manual for Streets
MIDAS	Motorway Incident Detection and Automatic Signalling
MOVA	Microprocessor Optimised Vehicle Actuation

ABBREVIATION	DESCRIPTION
MV	Medium Voltage
NEDC	New European Drive Cycle
POLITO	Politecnico di Torino
PV	Photo Voltaic
RCC	Regional Control Centre
SAE	Society of Automotive Engineers
SCOOT	Split Cycle Offset Optimisation Technique
SROH	Specification of the Reinstatement of Openings in Highways
TSRGD	Traffic Signs Regulations and General Directions
UNECE	United Nations Economic Commission for Europe
UV	Ultraviolet
V2G	Vehicle to Grid
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VMS	Variable Message Sign
VRS	Vehicle Restraint system
WPT	Wireless Power Transfer

REVISION CHART AND HISTORY LOG

REV	DATE	REASON
1	01/09/2014	Template
2	19/11/2014	Integration of input from project partners
3	4/12/2014	Partner review
4	15/12/2014	Internal technical review
5	8/1/2015	Final draft for peer review
6	15/2/2015	Final following peer review
7	15/5/2015	Final following client review

EXECUTIVE SUMMARY

This deliverable D.33.2 is a report on the gap analysis task undertaken in the FABRIC project. The report identifies the gaps between the current state of the art solutions and the needs and requirements of users and stakeholders. The user and stakeholder needs and requirements which were developed in work package 3.2 and reported in deliverable D32.1 have been compared with the state of the art review task in work package 3.3 and reported on in deliverable D33.1 in order to identify the gaps.

The main objective is to assess the existing solutions' ability to meet the requirements and expectations of the users and stake holders. The assessments consider performance, reliability, stability, robustness, effectiveness, efficiency, scalability, safety and usability. This analysis can be used to determine the next steps, design implications, priorities and possible problems that must be resolved in order to provide technologically and economically feasible solutions.

The gap analysis has been carried out from the perspective of the following entities:

- Road operator
- Grid/Distribution
- Local and transport authority
- Vehicle systems
- Electromagnetic safety

The road operator is mainly concerned with the effect of the installation of dynamic charging systems on both the structural integrity of the road itself, as well as the effect of implemented these services on the operation of the road, for example any adverse effects on traffic flow, safety, convenience etc.

Significant gaps were found regarding the standards and practices of installing and maintaining this kind of equipment under the road surface. Standards for construction and testing will need updating. Further work on the effect on traffic flows, including the potential to induce congestion and reduce traffic throughput, is required. Communications between the vehicles and road operators' systems will require standardisation.

The grid and power distribution system requirements address the ability of the grid to safely and reliably supply power to charging systems. Simulations have shown that the power drawn by dynamic charging systems is very variable, with large peaks and troughs in power drawn.

Smoothing systems to compensate for power transients will have a significant beneficial effect. While the power regulations already have strict specifications on the robustness of power distribution, additional work will be required to ensure these meet the requirements of dynamic charging systems. There is also a strong case for making use of renewable power sources to supplements the traditional sources of power. The integration of, for example solar power, needs additional work.

Local authorities are primarily concerned with policy, regulation and providing guidance to ensure that technical and planning issues are considered.

In this deliverable, the UK was primarily used as an example of how local authority policy and regulations need consideration in the planning, installation and maintenance of dynamic charging systems. A number of gaps were found and discussed, but these should only be seen as an illustration as only a single country was considered, and significant differences will exist between the situations in other nation states. Each country and/or region will need to consider their own local conditions when creating regulations on dynamic charging.

Issues on signage need to be dealt with at a national level, though harmonisation is dealt with under the auspices of the United Nations Economic Commission for Europe (UNECE) as well as the signatories to the Vienna Convention.

The chapter on vehicle requirements considers how dynamic charging system will be integrated into vehicles, minimum performance requirements and how existing regulations and standards will be affected.

The performance of charging systems in terms of efficiency need definition. Standards for frequency of operation, voltages and power levels, size and positioning of coils etc. are required to ensure interoperability between equipment from different suppliers. Differences in the power requirements between different classes of vehicle will complicate this.

Finally, updates to standards on electro-magnetic emissions and safety are required. These should take into account the existing standards on maximum levels of electro-magnetic radiation, as well as standards addressing electro-magnetic interference. This is particularly relevant given the high power levels involved and the increasing level of complexity of in-car electronic systems.

1 INTRODUCTION

This deliverable D.33.2 is a report on the gap analysis task undertaken in the FABRIC project. The report identifies the gaps between the current state of the art solutions and needs and the requirements of users and stake holders. The user and stakeholder needs and requirements developed in work package 3.2 and reported in deliverable D32.1 were compared with the state of the art review task in work package 3.3 and reported on in deliverable D33.1 in order to identify the gaps. This report also ranks the importance of the gaps and their priority for the development of the systems, identifying what needs to be done to bridge the gaps and the stakeholder(s) responsible to ensure the requirements are met.

The main objective is to assess the existing solutions ability to meet the requirements and expectations of the users and stake holders. The assessments consider performance, reliability, stability, robustness, effectiveness, efficiency, scalability, safety and usability. This analysis can be used to determine the next steps, design implications, priorities and possible problems that must be resolved in order to provide technologically and economically feasible solutions.

The gap analysis has been carried out on the following subsystems:

- Road operator
- Local and transport authority
- Grid/Distribution
- Vehicle and power transfer solutions
- Electromagnetic safety

Figure 1 shows the inputs to and outputs from the gap analysis deliverable. As shown, work package 3.2, tasks 3.3.1 and task 3.3.2 are the inputs, and the gap analysis is the comparison between WP3.2 and tasks 3.31 and WP3.32. The results from this report will feed into work package 3.4 which aims to develop a specification to meet the project scope that is interoperable with the test sites capability.

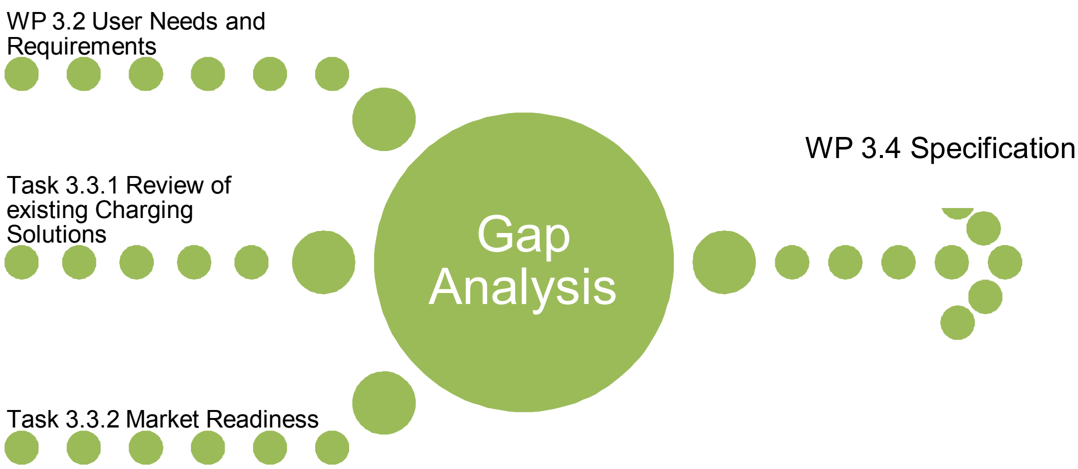


Figure 1: Deliverable dependencies

It should be noted that the purpose of this deliverable is to identify those gaps that need to be closed in order to install the on-road power transfer solutions on public roads. As the FABRIC project is developing solutions to a prototype level, and these will be tested on specific test tracks rather than public roads, not all of the gaps identified in this work package will be addressed by the solutions in FABRIC. It is expected that those gaps which are relevant to the technical operation of the system will need to be addressed in FABRIC, as well as fundamental safety issues. Other gaps, for example those affecting installation in the road surface, robustness and maintainability are unlikely to be fully addressed in this project.

It is up to the solution providers to use this document to identify those gaps which must be addressed to achieve FABRIC's aims.

2 METHODOLOGY

This deliverable extracts all the requirements for each sub-system by studying the user needs and requirements (WP3.2), which includes standards, guidelines, regulations and good practice. WP 3.2 includes needs and requirements for following subsystems:

- Task 3.2.1- Road authority/ owners requirements- Road infrastructure
- Task 3.2.2- Grid/ Distribution Requirements
- Task 3.2.3- Local Authorities/ City governance requirements- Transport and urban planning.
- Task 3.2.4- Vehicle manufacturer requirements- Vehicle platform
- Task 3.2.5 – Safety – EM environment

The requirements have been compared against the state of the art, and in order to identify the gaps; The comparison was undertaken by experts from within the project, using the wide range of expertise available within the diverse project team to ensure a sufficient coverage was achieved. TRL has developed a template for the gap analysis shown in Table 1. The requirement field is the extract from the user needs and requirements task from WP3.2. The second field ranks the importance of meeting mentioned requirement; the priority is ranked from low to very high. The priority terminologies defined as;

- **Low:** The needs and requirements are not essential to the systems operation or safety, usually guidelines or “nice to have” recommendations. These can be considered once the system is fully developed. For example, meeting connector requirements: this standard can be considered as low priority, because the solution can be modified with small design improvements. If the requirement is safety related it should not be a low priority.
- **Medium**: These are the needs, requirements, standards and regulation that the system should comply with, but are not essential for the fundamental operation of the system. However, the requirements must be fulfilled in order to install and use the systems in public domain. For example; requirements on location of the road side equipment, connection between roadside equipment and on road infrastructure. These standards aim to ensure that safety and drive quality are not compromised; however, it is not essential to meet these requirements during test track trials. It is important to recognise the effect of the standard on the performance of the equipment, for example, if there is a

requirement for minimum distance between the roadside equipment and the on road modules, the design should consider conductor size, voltage drop and losses due to larger distances.

- **High:** These are the needs and requirements that are important to meet; these are the standards, regulations or design requirements that will take the system from the test tracks to the actual road trials. For example; EM exposure, cost, connection to grid, weight of on vehicle systems, size etc.
- **Very High:** These are essential needs and requirements that must be addressed immediately in order to make sure the solution is technically feasible, For example, the ability to transfer power at motorway speeds, efficiency, length of the ground loops, misalignment tolerances and fundamental safety issues.

The "gap" field identifies the gap between the state of the art and needs and requirements. This field is completed by the responsible stakeholder, where they describe what the gap is. For example if the requirement is to meet a specific quantitative parameter, the responsible party indicates their system's parameter value and states if the system meets the requirement.

Severity of gap is an indication of the level of work required to meet the requirement. The ranking is stated below:

- **Need for further development**: The current system fails to meet the requirement but with minor modifications and developments, the system should meet the requirement. For example, connector requirements: the solutions may not meet the standard at this stage but by adopting approved connector the solution should meet the requirement. These are usually either minor changes to the design or upgrade on equipment that is easily available in the market.
- **Need for innovation:** New specifically designed equipment, a new protocol or a new standard is required to meet the requirements. For example a requirement for smoothing the fluctuations in power supply from the grid may require bespoke batteries or capacitors.
- **Major work required:** The system exceeds current limits or does not meet requirements. Either the other stakeholders need to improve their systems, for example; demand from the chargers exceeding the grid capacity would result in need for possible

upgrades in generation, transmission and distribution. Another example of major work can be the improvements in charging system to meet efficiency requirements. If the efficiency of the system has to be above a specific value, the efficiency the system may require major modifications, or may not be possible with the current technology. To maximize the efficiency, the vehicle needs to be aligned with the primary power transfer infrastructure, which may require automated guidance, which may not be legal in some countries and would therefore require a change in the law.

The recommendation field aims to provide high level description on what needs to be done in terms of development and modifications in order to meet the requirement. The recommendations field was completed by the responsible stakeholder.

The final field includes the responsible party, who is accountable to ensure that the subsystem meets needs and requirements. The responsible party can be a single organisation such as solution provider or it can be multiple stakeholders, each of whom has responsibility to close the gap between state of art and needs and requirements.

Table 1: Gap analysis template

Requirement:	Enter Requirement
Priority:	What is the importance to meet the requirement (low, medium, high, very high)
Gap:	What do existing systems provide and what is the gap when compared with the requirement
Severity of Gap:	Need for further development/ Need for Innovation/ Major work required
Recommendations:	What needs to be done to meet the requirement
Responsible Party:	Responsible stakeholder to ensure that the requirement are met/
Comments	Any issues not identified above

The report was developed by TRL, and FABRIC partners have provided inputs in their area of expertise. The responsible parties in each chapter were:

- The road authority gap analysis has been developed by TRL with support from the solution providers
- The grid requirements gap analysis was completed by CIRCE
- The Local authorities gap analysis was completed by TRL

- The vehicle requirements gap analysis completed by SAET, POLITO, SCANIA, VOLVO and FKA
- The EM safety requirements gap analysis was completed by CRF

The templates were completed by all the responsible partners. TRL analysed the results and identified the gaps, priorities, recommendations and responsibilities based on feedback from the partners. Any conflicts on a specific gap were communicated back to the partners to ensure an agreement was reached on identified gaps.

The final results were taken from the table format in the template, and gap analysis was written in textual format for this deliverable report, where each table in the template is a subtitle in the deliverable report.

3 ROAD REQUIREMENTS

This chapter compares the needs and requirements of stakeholders from D.3.2.1 against the current state of the art. The gap analysis covers physical size of the systems, consequences of operating the systems in the road, performance and installation and maintenance.

3.1 Physical size

This sections aims to find the gaps in physical parameters of the systems, such as size, weight, strength, robustness, heat and fire resistance.

3.1.1 Size

The current regulations on what equipment can be installed in roads have been not formulated with charging systems in mind. For example, in the UK the SROH (Specification of the Reinstatement of Openings in Highways) 1.8.1 requires that any equipment installed in roads with a diameter greater than 20mm requires special permission. This is clearly designed to allow the easy installation and maintenance of loop detectors, telecommunications cables and the like, and implies that any installation of a charging system would require special permission.

It is very likely that on road power transfer solution dimensions will be greater than 20mm in diameter; the power solutions are generally fabricated in sealed concrete/ plastic modules. These modules are usually installed few centimetres below road surface, each module can be up to 80 cm in depth, 80cm in width and it can be up to 24 metres in length. These dimensions are manufacturer dependent.

All countries have their own standards and regulations on road building, and it is likely that few if any will at this stage cover installation of this size of in-road infrastructure. Therefore, the size of the equipment can be considered as high priority. Regulations on road building standards will need amendment to allow in-road charging infrastructure to be installed without requiring special permission for each specific installation. To ensure that any updated standards do not negatively affect the installation of charging systems, road operators, solution providers and standards agencies should work in collaboration to facilitate smooth rollout of the systems.

3.1.2 Weight

There are no specific requirements at present for the weight of an on road dynamic power transfer system. However, a road owner would not expect the weight of the system to

accelerate the ageing of the structure of the pavement, since this would result in the increase of frequency of maintenance operation and consequently significant costs. The weight of on road system is based on what is included in the module; for example coils, cooling, power electronics etc. The weight of the system also includes a concrete casing to protect the system. The amount of concrete used can be a determinant factor on total weight of the module.

This requirement is considered as medium priority. The effect of the weight of systems on the integrity of the road has not been investigated to date. The weight of the solution should ideally be no heavier than the road layer it is replacing. As this is unlikely, it is not seen as a problem that could affect the system operation or development, although it could be an important factor in large scale take up scenarios. The transportation and installation machinery costs could be higher due to heavy weight of the power transfer equipment.

It is desirable to manufacture the road equipment to be of a similar weight and strength to the road layer it is replacing as this will mean existing lower layers can be used, without having to comprise on structural integrity and health and safety aspects.

3.1.3 Component

There are no specific requirements or standards regarding materials that can be used in construction. However, the material used to build the system must not chemically interact with the components of the pavement, salt and gritting.

The material used in power transfer equipment is considered as medium priority. The chemical stability of the systems, when subjected to normal operating conditions in a road, will need to be investigated. If this is not found to be acceptable, the choice of construction material for the system will need to be altered.

It is important to understand the impact of installations on the pavement. Therefore the road operators and solution providers should test the systems to ensure no chemical reaction takes places that can damage the equipment, road surface and cause a health and safety risk to the drivers.

3.1.4 Strength

User needs and requirements suggest that the system must be strong enough to withstand weight and vibrations of following parameters:

- The passage and possible stop of heavy vehicles of 44 tons, with a limit from 10 tons to 13,5 tons per axle, depending on the country.
- The passage and possible stop of the construction vehicles (finisher, compacter) during the implementation of the pavement layers.
- The passage and possible stop of abnormal load vehicles when authorised on the road.

This requirement is considered as medium priority. It is important to ensure that once the systems are installed, they do not deform due to vehicle loads. The results from the review (Deliverable 3.3.1) show that some of the power transfer solution providers could meet this standard; however, no test results are available from the majority of the suppliers. A solutions provider's static system has been successfully tested under a specific load of 6000 kg per wheel.

The solutions providers and road operators should carry out structural analysis of the "case" of the system and develop non-conductive reinforcement in collaboration with road operators during development stage. The solution providers should test and develop their system using relevant standards.

3.1.5 Environmental robustness

The system is expected to operate under extreme temperature conditions from sub-zero to extreme heat as found in real-world road environment, as well as other environmental conditions such as rain, humidity, UV etc. Environmental needs and requirements are:

- The system should be able to within stand heat of the pavement during re-surfacing 120 ^{0}C- 200 ^{0}C.
- The system must withstand the impact of de-icing salt: corrosion and thermal shock generated by their applications (for information: the temperature gradient is around 60°C in 3 minutes. Normal pavement of a motorway is able to withstand a gradient from -25°C to 60°C over a few minutes).
- The temperature generated by the operation of the system must not alter the structure of the pavement. The temperature of the system combined with the natural temperature of pavement must be under 40°C

This is a medium priority requirement. The system should be resilient to a range of temperature and other environmental variations. Also the heat generated by the system should not deform

the pavement which could be a health and safety risk to the surrounding environment and road users. The systems currently under consideration have varying operational temperature ranges. The majority of the systems can operate at temperatures low as -40 ^{0}C. The maximum temperatures are variable depending on the system from 40 ^{0}C, to as high as 120 ^{0}C.

The results show that all the systems meet the minimum temperature requirement of -25 ^{0}C, however there are number of the solutions fail to meet maximum temperature requirement of 60 ^{0}C. The insulator degradation and system integrity reduction due to different thermal expansion coefficients could result in solutions' failure to meet the requirement. The systems should be designed to operate at required temperature range. The solutions require further development to ensure safe operation in required temperature range.

The solution providers are responsible to design the systems to be fully operational within temperature range of -25 ^{0}C to 60 ^{0}C. It is also important to test the system to ensure that the heat generated by the primary infrastructure do not have negative impact on the pavement.

The solution providers and road operators should test their systems under exhaustive environmental conditions to ensure that the systems function safely under different conditions. Also, there is a need for an environmental testing standard or a guideline to ensure the systems are safe and robust to operate in road environment.

3.2 Consequences of the operation of the system

The requirements for the safety of road and footpath users suggest that the systems, whether online or off-line, must not affect the driving ability of the drivers (for all types of vehicles: electric and non-electric, charging or not, motorbikes, bicycle). The requirement also states that the solutions should not affect the health and safety of the drivers, passengers and pedestrians nearby.

This is a very high priority, as it is a safety critical requirement. It is essential to ensure the health and safety of road users and at same not have a negative impact on the efficiency of the system. The wireless and conductive system does not affect the driver's ability to control the vehicle.

However, in order to improve the efficiency of the system, it is possible that vehicles may operate semi-autonomously to optimally align the secondary coils with the primary power

transfer infrastructure. In this case the solution providers should ensure that the driver can interrupt autonomous drive to take full control of the vehicle at any time.

The primary infrastructure should only switch on when the suitable vehicle is requesting power; and switched if there is a possibility of affecting other vehicles, cyclists and pedestrians. The solution providers should carry out extensive tests to ensure that the system functions as intended. The tests should include scenarios where there is an equipped vehicle as well as an unequipped vehicle/cyclist/pedestrian etc. on one electrified segment to ensure the unequipped user is not exposed to unsafe levels of electromagnetic radiation.

The solution providers should carry out a complete electromagnetic compatibility analysis and extensive testing on driver behaviour during power transfer and develop their systems accordingly. A multi organisational working group is required to identify in which scenarios the system should be switched off. To realise this requirement, the systems may have to contain high speed active foreign object detection systems.

3.3 Performance of the services

This section compares the requirement on how the system should perform and the performance of the existing state of the art. The performance of the services is compared under the following headings:

- Speed of the vehicles
- Other sensors and motorway implantations
- Communications
- Mix of the vehicles
- Vehicle headway
- Wearing course
- Remote ON/OFF switch

3.3.1 Speed of vehicles

The vehicle speeds at which power transfer should or can occur are one of the important factors for system acceptance and take up. Lower speeds result in shorter overall electrified sections to transfer a specified amount of energy, but at same time leads to longer journey durations. The stakeholder's needs and requirements on vehicle speed and traffic are:

- The system should work at motorway speeds up to 130 km/h
- The vehicles should not be forced to slow down as they approach to power transfer section.
- For urban and other non-motorway implementations, it is acceptable to operate at a lower maximum speed, as long as this falls within the prevailing speed on the road being used.

This is a medium priority requirement for the core 130 km/h speed. It is considered a high priority that systems are able to work at the prevailing speed of the traffic, i.e. it does not cause traffic to slow down. It is essential that the system is able to operate efficiently at the speed limit of the road on which it is installed. Inability to solve this problem could be a barrier towards large scale takes up. The review of the state of art in section 3.3.1 states that the solutions are designed to operate up to a maximum speed of 90km/h. This is well below motorway speed requirements, therefore the power transfer systems further development to meet the requirements.

An increase in speed results in demand for higher power from the vehicle and it also means energy transferred from a given on-road power transfer section is less because the vehicle spends less time on that specific power section. This results in longer on-road power transfer sections, higher costs, and longer installation times in order to provide same amount of energy.

An investigation into the impact of speed against electrification length would provide useful information on trade-off between length of electrified road and speed of the vehicle; the study should carry out technical and economic feasibility analysis on various speeds.

The solution providers should develop their systems to operate at higher vehicle speeds but at the same time maintaining high power transfer efficiency. Also the traffic flow in power transfer sections needs to be investigated to understand and prevent congestion due to power transfer units. The solution providers are responsible for developing their systems to operate at specified speeds.

3.3.2 Other sensors and smart motorway implementation

In the UK, traffic data is collected remotely in real-time and used to set automatic signalling. The data is also stored for research purposes. The majority of this data is obtained from MIDAS inductive loops in the road surface, which are located every 500m and supplemented by radar

sensors at a few sites. Similar systems operate in other countries. The power transfer sites should not affect the functionality of the inductive loops, else they would need to be located away from the inductive loops.

If Smart Motorways technology is in use, then the average speed of all lanes can be controlled (e.g. in UK: controlled at either 80 or 95 km/h). The power transfer solution should not impede the use of additional lanes or obeying of speed limits. For example the hard shoulder might be used as a running lane, either dynamically or permanently.

This is low priority, the requirement is not essential to the development of the solution or EV take up, however it could be high priority if the authorities decide to enforce lower the speeds on electrified sections to maximise the energy transferred to the vehicle by given length of electrified lane, in that case, the smart motorway schemes can be used to slow the vehicles and also to ensure only electric vehicles are on electrified lanes to maximise its capacity.

The existing solutions are in their early development stage, therefore integration with the Smart Motorways technology has not been considered. The systems can be installed in smart motorway areas, if they are designed to operate at low speeds and the smart motorway system can be used to ensure that the vehicles are on the correct lane and moving at specified speeds.

3.3.3 Communications

The solutions expected to meet following needs and requirements:

- The charging system should be able to communicate with the Smart Motorways system to select the most appropriate operational regime
- The traffic flow must not be affected by vehicles wanting to change their lane to use the system on the charging lane

These requirements are medium priority as they are not an essential factor for the technical feasibility of the system. The systems are not currently able to communicate with the Smart Motorways technology, but this requirement can be realised with improvements in ICT and communication technologies of the systems. The vehicle to power transfer infrastructure communication can be extended into I2I and V2G. The solution provider, grid and the road operator are responsible to establish a communication between different subsystems.

3.3.4 Mix of vehicles (electric and non-electric/charging or not)

If not all lanes are equipped with power transfer segments, then the scheme could have an adverse effect on network management, depending on the number of power transfer vehicles in total motorway vehicle mix. If the proportion of charging vehicles is high, then the number of vehicles wanting to use the power transfer lanes could exceed the capacity of that lane, causing congestion in the power transfer lanes. Even when there are sufficient power transfer lanes for the vehicle mix, vehicles might still be required to change lane on the approach to the power transfer zone. This would reduce the capacity of the road, making flow breakdown more likely.

This requirement can be considered as low priority for early adopters but it becomes a very high priority as the dynamic charging capable vehicle takes up increases. The ideal case is to electrify all three lanes. However during early stages of the take up single lane electrification can be a feasible option, and electrified motorway lanes can be increased in proportion to the number of vehicles equipped with the power transfer system.

The gap is that road electrification has not been taken on motorways, and there is no clear understanding of operation of the system in the motorway environment. Issues include:, how to differentiate between suitable and non-suitable vehicle, whether there would be lane changes prior to a power transfer section to group all electrified vehicle within the power transfer lanes (and the rest of the fleet on remaining lanes), and how the mix of vehicles be managed.

The road operator should investigate the relationship between road electrification requirements and electric vehicle take-up. This study needs to be based on number of electric vehicles in the motorway fleet and lane capacity. The road operator should predict the breakpoint where the numbers of electric vehicles that require power exceed the capacity of electrified lane, and hence determine when more lanes should be electrified.

3.3.5 Vehicle headway

The power transfer system should allow for two vehicles travelling close together, and potentially collecting power at same time. The needs and requirements indicate that the system must be able to cope with vehicles travelling within a 4m of each other. This is considerably less than the minimum legal following distance at motorway speeds (under EU law, the minimum distance allowed at a speed of 130 km/h this distance is 36 m), and hence is disputed by some.

This requirement is high priority. The system can be designed to operate at coordinated traffic, where the vehicles move at constant speed and follow the vehicle ahead at a determined headway, but implementation of coordinated traffic in real world application is not clear. There will be situations where vehicles follow each other very closely, especially at low speeds. It is essential to provide power to the entire vehicle fleet that require power at all times regardless of vehicle speed or traffic density. Clearly, on a congested motorway headways of less than 4m are possible.

The majority of the solutions are designed to utilise one loop to transfer power to one vehicle at a time, and these power transfer segments can be up to 24 metres for wireless systems, so the headway between two vehicles must be greater than 4 metres, and ideally the gap between two vehicles should be greater than the length of the power transfer loop. Therefore, major work is required to develop existing systems to meet this requirement.

The solution providers have to develop their systems either to provide power from single segment to multiple vehicles or reduce the length of the segment so that only one vehicle can be charged from one segment. At the same time, the solution providers should maintain the power transfer rate and efficiency at the highest level regardless of the length of the segment. The road operator can provide guidance on headway in power transfer sections, so the vehicles can follow each other with a safe headway. Also, coordinated traffic scenarios can be investigated in detail, including during on-road trials.

3.3.6 Wearing course

The thickness of the wearing course directly affects the (air) gap between the primary and secondary coils and, as this gap has a direct effect on power transfer efficiency, it follows that the thickness of the wearing course has a direct effect on efficiency. There are no specific requirements for system efficiency but it is likely that low efficiency (e.g. below 80%) would raise questions as to whether the energy is being used sustainably and responsibly.

The needs and requirements for wearing course of the system are:

- The system should work through a wearing course of at least 4 cm thickness
- The system should work when the wearing course is water-soaked

This is medium priority, the air gap between primary and secondary coil should operate within tolerance values and it should not be affected by water on the road. All the systems have

tolerance to operate at various air gap variations, and there are systems that tune the secondary coil to maximise the power transfer during misalignments and variable air gaps. Inductive power transfer systems are not affected by water, ice, standard road construction material etc. Since power transfer is affected by metallic debris, it is important to identify any object that can reduce the power transfer efficiency or can be a health and safety risk to the surroundings.

The solution providers are responsible for ensuring that the systems efficiency is not affected by the variations in the air gap within specified tolerance. The systems should be remain functional when there is a non-harmful object in the air gap, and the systems should be able to detect foreign objects in the air gap (and is all surrounding areas where bodies are vulnerable to radiation) and switch off if one is detected.

3.3.7 Switch on/off

The system should be able to be switched off remotely, e.g. in case of an incident. Regional control centre (RCC) operators could be responsible for switching of the system, or a dedicated power transfer operator could be placed in each RCC to provide additional resource. The switching requirements are:

- It should be possible to switch the system off remotely
- Switching off the system must not generate an abrupt decrease in the speed of charging vehicles, for example when the power transfer is terminated, this action should not have an effect on traction.
- Individual charging lanes can be switched on/off remotely according to traffic conditions and/or speed limits and/or whether the hard shoulder is in use as a running lane.

This is high priority for solutions providers. The power supply to the traction motors should be steady, and at no point should the vehicle experience power glitches due to connection/disconnection of power source. This is a safety critical requirement, especially at motorway speeds.

The remote switching will require communication links between the command centre and power transfer infrastructure. The gap is that communication and control infrastructure and protocols are not yet fully developed or standardised. The solutions providers and the road operators should work in collaboration to develop a communication infrastructure. The solution providers are expected to integrate control subsystems into the power transfer infrastructure and to

develop relevant communication protocols to enable remote switching. All the stakeholders should work towards developing communication standards for on road power transfer.

3.3.8 Other sensors

The systems should be placed in locations where they do not impede the operation of other sensors such as inductive loops. This can be a challenge as inductive loops are often located at short regular interval, for example every 500m the UK. If the power transfers systems are installed on long sections, it may require gaps for locations where inductive loops are located. This approach could add complexity to the installation of the systems.

This is medium priority; the effects on other sensors of operating on road power transfer systems in the same environment are unknown. The solutions have not been tested in the presence of inroad sensors.

The solutions providers and road operators should test power transfer solutions in the presence of inductive loops and investigate the impacts of one system on the other. The road operator or infrastructure owners are expected to develop a deployment plan, which should include measures taken to minimise or eliminate the adverse effects of power transfer infrastructure on the other sensors in/on the road, and solution providers should develop their systems to make sure they do not interfere with those other systems.

3.4 Installation and maintenance

This section of the report is the gap analysis on installation and maintenance procedures. The gap analysis is carried out on positioning of the infrastructure, skid resistance, structural integrity, drainage, road side equipment, programme, waste and visual integration.

3.4.1 Positioning

The lane on which the system is implemented must be chosen according to the kind of road traffic expected to use the system. For example, if only HGVs use the system then it would make sense for the power transfer units to be installed in the near side lane. The needs and requirements for the location of the chargers on the road network are:

- The system should not be installed where it would increase the risk of congestion.

- Installation of systems that are flush with the surface, where the skid resistance of the surface is lower than that of the surrounding pavement should be avoided at high risk locations e.g. on roundabouts, roads with tight curves.
- The positioning of the system in the pavement must not weaken the structure. Especially, it must not generate cracks or other distortions of the upper pavement layers (wearing course and binding course)

The efficiency of power transfer is generally better at lower speeds. Further, at lower speeds less infrastructure is required per unit of energy transferred as vehicles travel a shorter distance per unit time. Hence it may be financially and operationally advantageous to install charging systems in areas of high congestion, such as near junctions. However, the driver to not install in these areas derives from the increased danger and further congestion that will potentially result, particularly if only a single lane is electrified, by vehicles changing lanes and blocking junctions to get to the charging infrastructure. It is recognised that these two effects are in conflict, and further study will be required. Simulations have shown that, in terms of power transfer, installation near junctions and in other areas of high congestion are advantageous.

These requirements are considered to be medium priority. There are no fully developed deployment plans, standards or procedures on where to install the power transfer units. Therefore the road operators should undertake surveys and identify suitable power transfer locations on the road network. The investigation should consider capacity and speed at various locations, and the results from the study should be used to identify ideal power transfer positions on the road. Ideal spots can be described as areas where power transfer infrastructure:

- No effect on traffic flow
- Minimal health and safety risk
- Maximum energy can be transferred per unit length
- Minimum power is lost due to distance between distribution and roadside equipment

Taking account of the arguments above, some of these requirements may be in conflict with each other.

3.4.2 Skid resistance

Many countries have requirements for the skid resistance of road surfaces. This is usually achieved by ensuring that the texture of the surface provides sufficient skid resistance and also that any aggregate used in the surfacing does not polish too quickly.

This is High priority; the new system must not affect the skid resistance of the pavement. In the UK for example, the systems should meet the requirements set out in section 2.6 of the SROH. The underground solutions are resurfaced with asphalt, so these systems meet the skid resistance requirement automatically, however the flush systems should be designed to meet skid resistance requirement.

Either the system will need to be developed to work efficiently through a standard wearing course or the exposed surface of the system should be manufactured so as to provide similar skid resistance to the surrounding road surface. The road operator is responsible for testing skid resistance on power transfer sections; however the solution provider is responsible for meeting skid resistance requirements if the power transfer modules are flush with the road.

3.4.3 Structural integrity

Installation of the system should not detrimentally affect the structural integrity of the road pavement within which it is placed.

A road is constructed in layers (Figure 2) for optimum load distribution, and allows the stress and resultant strain from the vehicles above to be transmitted through the road structure, which then spreads and lessens with depth (Figure 3). In order to achieve this, stronger and consequently more expensive materials are used in the upper levels, with relatively low strength materials being used in the lower layers. It is also important that a good bond is achieved between all of the layers to ensure the road structure acts as a single structural entity with good bearing capacity.

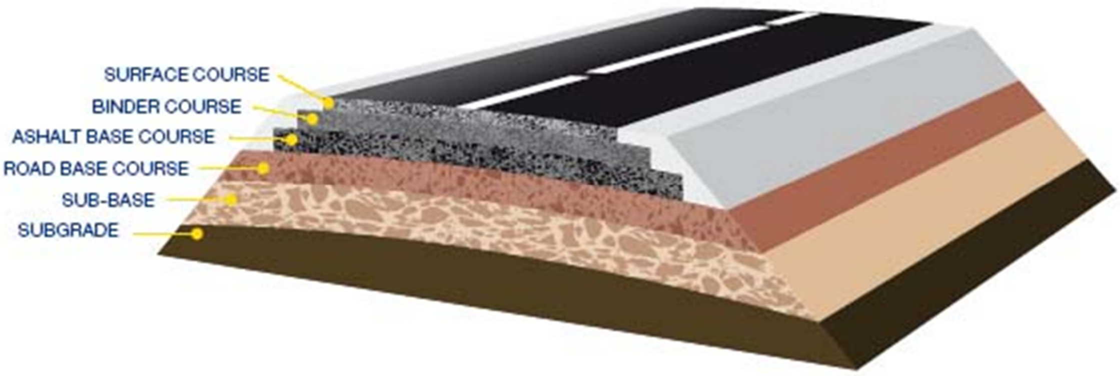


Figure 2: Structural design of a typical asphalt road[1]

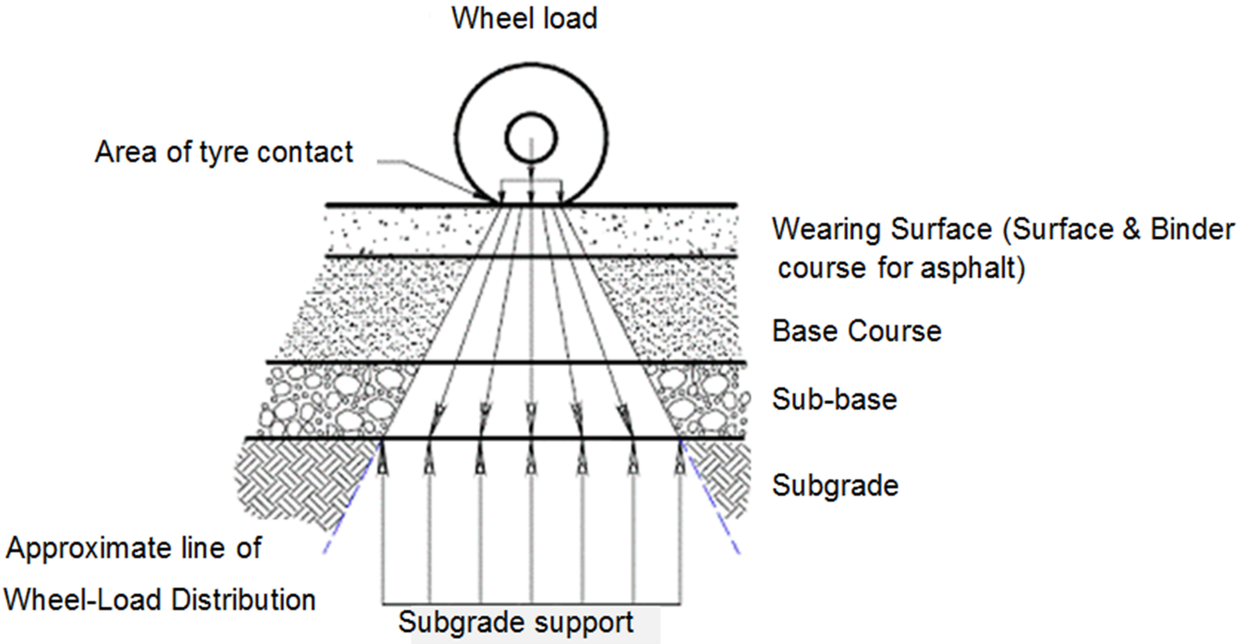


Figure 3: Transmission of stress and strain through the road's structure[2]

Installing equipment within the road structure can change the way that stresses and strains are transmitted through the structure. This can lead to stresses and strains within the road structure that it was not designed to cope with, thus leading to fatigue within the road structure and shortening of its structural life. For example, if equipment was placed into the road structure that

[1] Taken from http://www.eurobitume.eu/bitumen/applications/roads

[2] Taken from http://civilengineertech.blogspot.co.uk/2013/07/pavement-design-pavement-provides.html

was more rigid than the surrounding material, greater strain will be placed on the lower, weaker layers of the road structure (Figure 4). This is likely to cause cracking in the upper layers of the pavement and potential collapse of the lower layers.

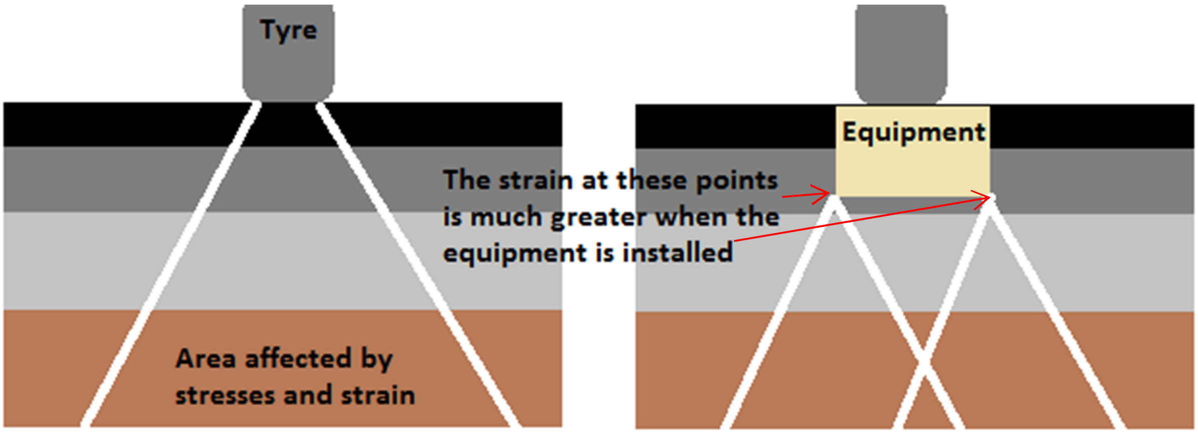


Figure 4: Potential effect of inserting a stiff box on the distribution of vehicle load within the road structure

Since most equipment currently installed in roads is buried much deeper than charging equipment is likely to be, no standards or requirements currently exist governing the effect of the installed equipment on the road's structural integrity and the only relevant guidance relates to settlement of reinstatements. Most road authorities / owners will have limits on the amount of settlement allowed for reinstatements, and will have a guarantee period for which these limits are applied. For example, in the UK, the following applies:

- The installations should meet the limits defined Table S2.1, S2.2 and S2.4 of the SROH
- A reinstatement of 1000mm depth or less requires an intervention if the cumulative settlement is greater than 30mm or 1.5% of the unbound layer thickness (whichever is greater)
- Construction tolerances at the edges of the reinstatement shall not exceed ± 6mm
- Edge depression intervention shall be required where the depth of any edge depression exceeds 10 mm over a continuous length of more than 100 mm in any direction

These requirements are minimum standards in the UK, so they are considered as medium priority. Procedures to make sure power transfer infrastructure does not affect the integrity of the road and the ride quality must be developed for all systems installed in the running lanes of public highways, irrespective of the system's position within the lane. This may include design of materials used for the system which ensure that it behaves similarly to the surrounding road

structure under vehicle load; or a redesign of the road structure in which it is to be installed. Therefore the solution providers and road operators are responsible for meeting this requirement.

3.4.4 Drainage

Some moisture is always present in the subgrade (see Figure 2) and unbound paving materials due to capillary moisture movement controlled by the environment. If this becomes excessive the subgrade and road structure can be weakened appreciably. Consequently it is important to minimise ingress of water into the road structure and subgrade. Thus, surface and sub-surface drainage arrangements are designed to prevent water entering the lower layers of the road structure, either from the surface or from the sides.

Continuity of drainage through the upper layers of the road structure and across the carriageway is also important: An obstacle to this flow can cause water to pond on the surface of the road (a safety issue) and, in severe cases, can cause flooding of the road. Thus, surface and sub-surface drainage arrangements are also designed to ensure continuity of drainage, both in and below the layers of road structure and across the carriageway.

In the UK, the SROH states that all reasonably practicable measures should be taken to prevent the permanent disturbance of artificial or natural drainage systems/paths.

Thus, the existence of power transfer solutions must not compromise the drainage, nor allow water ingress into the lower layers of the road structure, such as in the example in Figure 5. This is medium priority; the gap is that the impacts of the equipment on drainage has not been tested or considered. Therefore drainage will need to be considered by solution providers during system design. It is important to include a drainage section in the deployment plan, which includes measures taken to meet the standards and requirements. The road operator or infrastructure owner is responsible to meet the requirement to ensure that drainage is not compromised, whilst it is the solution providers' responsibility to ensure that the equipment doesn't cause water ingress.

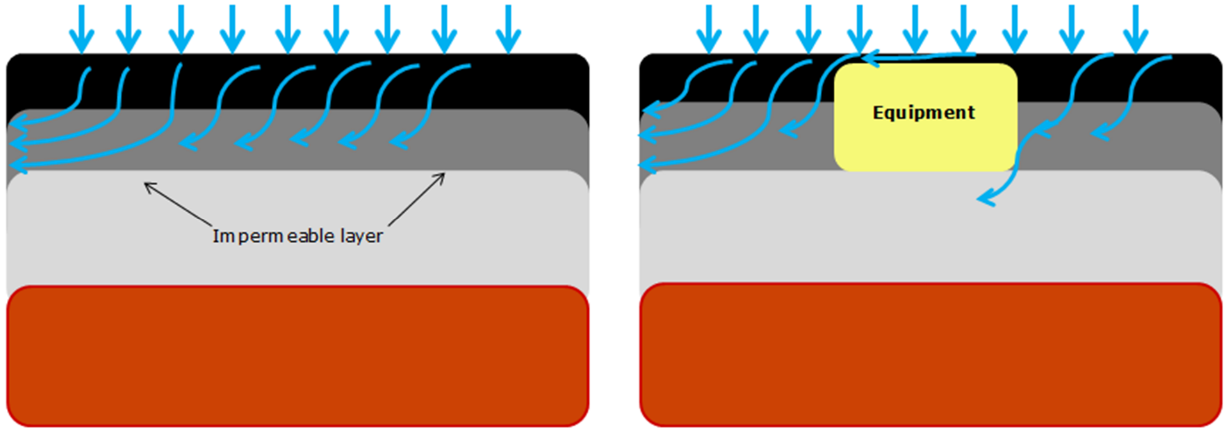


Figure 5: Obstruction of pavement drainage caused by installation of equipment, allowing water to get into the lower layers of the road structure.

3.4.5 Interaction with other equipment

Before installing the equipment, the exact position of any other publicly and privately owned apparatus, services and supplies affected by the works, should be identified.

This requirement is considered as medium priority. Neither services nor supplies shall be interrupted without the written consent of the appropriate authority or owner, and the equipment installer shall provide a satisfactory alternative before interrupting any existing service or supply. The system should be shielded to reduce the interference with other telecommunications and power conductors, and solutions providers should test their system in presence of other underground equipment and investigate the impacts.

The solutions providers along with road operators are expected to take precautionary actions to ensure the solution does not have negative effect on surrounding infrastructure. The protective measures are expected to be taken during system manufacture and installation.

3.4.6 Equipment life time

It is difficult to estimate the life time of the solutions without prior experience and detailed test plan and execution; however, the user needs are requirements are listed:

- The life time of the system should be greater than 12 years
- There should be no need to access the components buried into the road, therefore inroad power transfer equipment should not require disruptive maintenance for at least 12 years

This is a medium priority; the state of the art review shows that there are systems that are designed to operate for 12 years without maintenance but that there is a need for accelerated age testing. The solution providers are responsible to design the systems to operate to the specified life expectancy. In addition, the solution providers should provide maintenance schedules which should include information on how often road side and on-road equipment needs to be maintained.

3.4.7 Time schedule for installation & maintenance

The time frame taken to install any equipment will have an effect on the capacity of the road network during the installation works. Reduced capacity could cause congestion on heavily trafficked roads, particularly where a good quality diversion is not available. It will also affect journey times and road availability. The requirements on time scales and installation are:

- It should be possible for the road works to be conducted in low traffic hours (22h-05h)
- A dedicated procedure (deployment plan) for implementation must be defined

This is medium priority, there is no installation plan stating the duration of the construction works to install the power transfer equipment in the road. The solution providers have installed their systems in test tracks by adopting their own installation methods; however, in test track installations, the time constraint was not an issue. It is important install power transfer systems safely and consistently in shortest possible time to avoid delays. Therefore the power transfer infrastructure owners are expected to develop a deployment plan (programme) outlining installation steps and the time periods associated with each step.

3.4.8 Waste of components

Often during road maintenance, involving replacement of the surface layers of the road, the road will be scarified or planed before the new surfacing is applied. The materials used to secure and protect the in-road power transfer infrastructure should not result in debris,from planing the pavement,requiring special treatment before landfilling or recycling. Thus, the system must not interact with the materials of the road structure in such a way as to contaminate them with environmentally harmful substances, or leach contaminants into the road structure, due to the ageing of the system, or the effects of weather. This is medium priority, as it is illegal in most countries to dispose of contaminated material without treating it first. The solution provider is responsible for ensuring that the system will not cause contamination of the

road structure. Note that this only refers to the materials above the in-road infrastructure. It is assumed that a road will be able to be resurfaced without removal or destruction of the power transfer equipment.

3.4.9 Visual integration

Good integration of visible equipment in the landscape is crucial for the social acceptability of the charging solution. Attention has to be focused on urban areas, when a significant variety of equipment is already installed in a narrow space, and where the residents may be very reluctant with another installation that may modify or alter their usual landscape.

This is medium to high priority, the road side equipment has to integrate with the surrounding, and it should be possible to install the power transfer modules in built up areas without roadside equipment taking a lot of kerb space. The size and location of the road side equipment is a critical factor in system take up.

At this stage, installing road side equipment in built up areas can be an issue, as this equipment is quite large in size and located in regular intervals. The solution providers along with road operators or local councils should develop the system in such a way that it does not impede vision or require large spaces.

4 GRID REQUIREMENTS

This section studies the gap analysis for grid requirements. It compares the current grid arrangements against needs and requirements from the stakeholders. The gap analyses are carried out on:

- Supply characteristics
- Harmonics
- Energy demand requirements
- Energy storage for smoothing requirements
- Integration of solar PV into on-road power transfer solution

In this chapter, low voltage (LV) distribution is typical European 230/400V connection. Although "low voltage" more generally includes all systems with nominal voltages below 1000 V, in this section typical values for European distribution grids are assumed. Medium voltage (MV) refers to typical distribution system voltages of 10-20 kV. High voltage (HV) in this context refers to typical European electricity transport lines of 110 kV or above. For example, if a HV/MV substation is mentioned, in Spain this would mean transformation from 132 kV to 15 kV while in Germany it is 110/20 kV. In other European countries voltage levels are similar. The gap analysis is not intended to study each possible voltage configuration in detail and it refers to the different voltage levels by name (LV, MV and HV).

Applicable standards are only cited for LV systems (< 1000 V), as this was the focus of grid requirements in deliverable D32.1 of the FABRIC project. Also, all existing power transfer solutions described in D33.1 are connected to the LV grid. In this document the gap analysis also considers a possible alternative with direct connection to the MV grid. However, applicable standards are not studied as it is out of scope.

4.1 Power supply characteristics

This section describes the power supply characteristics such as voltage range, operational frequencies and tolerances.

4.1.1 The power supply characteristics tolerances

The power supply characteristics tolerances are given below:

- Nominal voltage below 1000V must operate within ±10% of the standard nominal voltage

- The voltages at all nodes should be above 95% of nominal voltage
- Frequency should be 50Hz and 60Hz at ± 1 %

It is important that the power supply tolerances are not exceeded due to the demand from on road power transfer infrastructure. This is prioritized as very high, because the grid and distribution standards should be met, and it is important to protect equipment.

Especially under and over voltages are not tolerable, as network protection systems may shut down the power supply.

The power supply must be designed according to existing standards. Depending on the existing infrastructure, new lines and distribution transformers might be required to be installed.

There is no gap regarding technical feasibility. However, high power supply may be costly, especially if power lines must be reinforced. Therefore, controllability of power demand is proposed in this project in order to reduce costs and improve grid stability.

4.1.2 Power supply voltage range for French grid

The power supply range for voltage levels for the French grid listed below. The supply voltage requirements for rest of Europe can be considered to be similar to France.

- LV 230 V single phase for 3-18kVA systems
- LV 400V three phase for 12-250kVA systems
- MV 15/20 kV three phase for power supply to systems above 250kVA

This is high priority, because the voltage level of the supply must be chosen according to the required power demand. As a result, for low to medium scale take up (below 250 kVA) the supply may be connected to LV (400V three phase), so there is no gap for the equipment and the grid. In the case of high scale take up, a connection at MV level (15/20 kV) is mandatory; in order to cope with power levels of several MVA, and this may require consideration of new connection architecture for MV or HV.

Expected installations will be over 100 kVA, which demands a dedicated power transformer, for the LV supply. For higher demand (>250 kVA) direct connection to MV distribution grid is preferable. The converter might be connected directly to MV which reduces complexity (no need for MV/LV transformer).

If the existing power grid is weak, costs may be very high, as a separate MV power line from the HV/MV substation might be necessary, or at worst a new substation may be required. Again, this is no technical gap, but may be an economic obstacle for sparsely populated regions.

Connection to the grid

As reported in the French contribution, loads >250 kVA are recommended to connect directly at MV level. Direct connection to the HV grid is very unlikely as this would only be required for very high power systems; for example, in Germany large wind or solar farms with power levels of >50 MW are currently connected to the 110 kV network. Offshore wind parks are connected to the 380 or 220 kV transport network. Connection to the HV would require a dedicated sub-station which only provides power to the on-road power transfer system. A distribution network of several MV/LV distributions transformers are then connected to HV in order to provide power to the on-road power transfer sections.

From the technical grid connection point of view, there is no gap. Current installations of renewable energy are connected by following existing procedures. Even though there are no gaps from a grid and distribution point of view, each connection requires individual planning and it is not clear which connection architecture is the best option, so the infrastructure owners and DSO should simulate connection to the grid scenarios and develop a connection plan.

4.2 Harmonics

For LV systems, the harmonics standards state that the systems must meet IEC standard 61000-3-2 which specifies the limits for current below 16A, and 61000-3-4 which specifies the limits for currents equal to and above 16A. There are similar standards applicable for MV systems.

This requirement is a very high priority because high power devices that produce high level of harmonic distortion can have serious impact on other consumers. Therefore, the standards identified above are mandatory for any equipment which is connected to the grid.

Even for the case of an isolated test track, there may be more appliances connected to the LV grid, which could be affected by large harmonic distortions from on-road power transfer equipment. If there is a dedicated distribution transformer for the test track, the compliance with the standard may be less critical, but still should be kept in mind.

Most of the current on-road solutions do not have results for harmonics tests but some solutions, especially static solutions, do meet the required standards. So, the gap is that there is no extensive testing to this standard at this stage, but the solutions are expected to meet the standards if they are to be connected to the grid. This gap can easily be closed with minor

developments, as harmonics will be tested during the project and all the solutions are expected to comply with the standards.

The power electronic devices are switching devices which, by their nature, produce harmonics. Therefore, grid-tied converters always include harmonic filters. A proper filter design will make sure that standards are met, but, as a consequence, may reduce the efficiency of the system. With higher switching frequencies and multi-level architectures, the amplitude of harmonics and the associated filter size can be reduced. It should be noted that higher frequencies produce harmonics of higher order but with lower amplitudes therefore they can be filtered out by physically smaller filter circuits which results in reduction in cost and increase in efficiency. The solution providers are responsible to ensure their equipment meets the harmonics standards.

Filters should be designed carefully with simulation software, in order to make sure that even prototypes will not exceed permitted levels, or at least do not exceed the limits too much.

In a testing scenario, the standards may not always be satisfied, but harmonics may have negative impact on communication and measurement equipment, so harmonic filters should always be present.

4.3 Additional equipment / Infrastructure by roadside including potential renewable generation

This section outlines gaps for the power demand and smoothing requirement for urban and interurban scenarios. It is important to understand the power demand and fluctuations for different scenarios, identify gaps and suggest possible solutions to bridge the gaps.

4.3.1 Power demand

The power supply equipment should be designed to cope with fluctuations for urban and interurban scenarios. The vehicles must be tested for small headways and in situations where there is more than one vehicle on a power transfer loop.

The demand from the grid could have high power fluctuations depending on the intensity of the traffic. The model developed for this project indicates that in coordinated scenario at speeds of 36km/h, the power demand is up to 13MW. The coordinated scenario consists of 500 cars on an 8.01km route with 30m headway and with 267 power transfer modules, each of which transfer power at 50kW.

Table 2 show the uncoordinated scenario power demand for urban and interurban scenarios. As shown, in the urban case the power demand can range from 6 MW to 37 MW, which is a large gap, and the distribution systems should be designed to fully function within this specified range.

Table 2: Power demand in uncoordinated urban and interurban scenario

Environment	**Scenario**	**Average [MW]**	**STDEV [MW]**	**MAX [MW]**
Urban	Light traffic	6.33	1.07	12.05
Urban	Medium traffic	20.61	2.18	31.05
Urban	Heavy traffic	30.80	1.88	37.50
Interurban	Light traffic	3.92	0.42	4.75
Interurban	Medium traffic	13.39	0.59	14.35
Interurban	Heavy traffic	20.00	0.47	21.00

The power demand fluctuation can range between 2-8 MW several times over 5 second periods. This will cause serious problems for the grid; therefore, the system should include smoothing equipment to balance the demand to an acceptable level.

This is a very high priority. High and fast power peaks are expected to have possible negative impact on the grid. Additional equipment is needed in order to mitigate the impact and reduce installation costs.

The power transfer demand models should be developed to simulate and study the impact on the grid and also to analyse the requirements for smoothing methods. This has been addressed theoretically in D32.1. The results during testing will provide further information on the impacts the solutions will have on the grid. This gap is important, but with traffic coordination and storage systems, there are feasible solutions to the problem, as shown in D32.1. Nevertheless, those solutions are still subject to development.

Design of power transfer infrastructure must aim to reduce power fluctuations. For example:

- No gaps should be present between power transfer pads. A continuous charging zone benefits the grid but also the vehicle.

- Traffic coordination can reduce fluctuations by creating a continuous flow of vehicles with reasonably constant headways.
- Steep power steps should be smoothed with storage systems, which are ideally connected to the DC bus of the power transfer infrastructure in order to reduce losses.
- Independently, the power transfer infrastructure should be able to limit power levels and ramps according to the distribution system operator (DSO) settings (which may change during the day).

Several parties are responsible for minimising power fluctuations. In the first place, solution providers are responsible to design a suitable system. The solutions should avoid large gaps between power transfer pads in order to control the power flow. Also, the solution providers are responsible for integration of storage solutions and communication with the DSO for power limitation. The traffic coordination methods or procedures can be developed by either the road operator or power transfer infrastructure owner. The solution providers are responsible for traffic coordination if the speed and headway are automatically controlled by the vehicle whilst on power transfer sections.

The need for additional equipment depends strongly on the strength of the grid connection point. The grids of large cities are often quite strong, which means less additional equipment will be needed. Although network congestions may occur, reinforcement might be easy, as distances to the HV grid are short. The cost of reinforcement may be far higher and additional equipment would be sized larger, if the solution is to be installed in a rural environment (inter-urban roads). Every specific case must be studied.

4.3.2 Energy storage system requirements in urban case

There is a need for energy storage systems in order to minimise the fluctuations. Smoothing windows from 1 second to 60 seconds have been tested. As shown in Figure 6a, a 5 second smoothing window captures most of the fluctuations in urban scenario, which corresponds to 11.4MW and 8.2kWh energy storage system. This system has a typical discharge time of 2.6 seconds.

In the inter-urban traffic case, fluctuations are much lower, hence the storage requirement for smoothing is lower. On the other hand, a smoothing window of 60s is needed to obtain some smoothing effect. As shown in

Figure 6b, the required storage system has to be 2 MW with 8 kWh of energy capacity, which results in a typical discharge time of 20s.

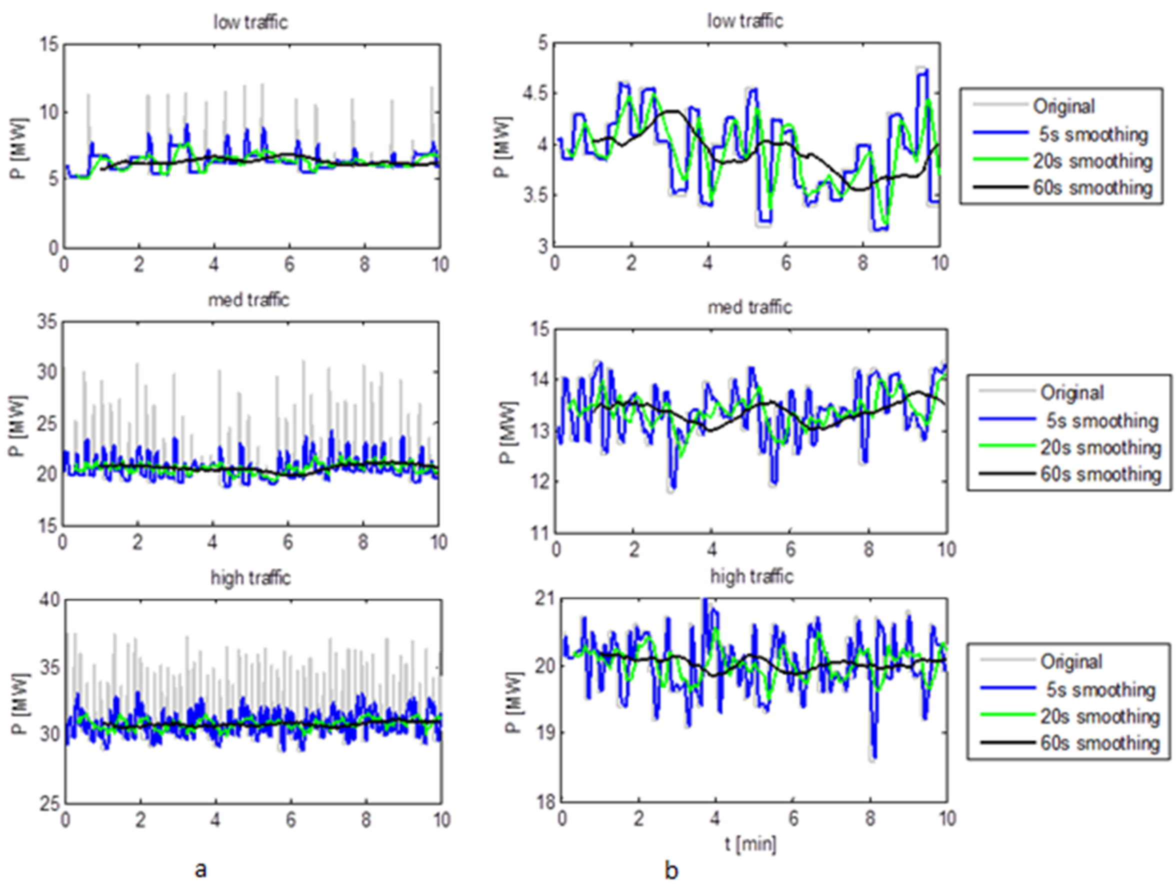


Figure 6: a) Charging power demand for urban case (36 km/h) with low, medium and high traffic for different window widths of moving average smoothing. b). Charging power demand for inter-urban case (108 km/h) with low, medium and high traffic for different window widths of moving average smoothing.

This is very high priority, as the storage systems for mitigating fast demand fluctuations are the central objective of FABRIC feasibility analysis.

Actual demand patterns are still unknown. Only simplified models are available at the moment (D32.1). As a result, storage requirements are not defined in detail at this stage. It is not clear who will own the storage equipment. Furthermore, an improved understanding of the affect of aging on the ability of storage systems to accept charge need improved understanding.

Storage solutions which meet the preliminary requirements do exist, but may be expensive. Typical discharge times in the range of seconds can be obtained with commercially available Supercapacitors and/or Flywheels. Supercapacitors may have some advantages when compared with flywheels, as they can be easily integrated into the DC bus, even as passive elements. These solutions will require additional space, which needs to be taken into account during solution design. The smoothing equipment could be located in the grid-tied converter cabinet, where the DC bus connections are.

The storage requirements should be minimised, or possibly eliminated, by system design and/or by adopting traffic coordination methods (see 4.4.1). If storage devices are required, they should be integrated into the DC bus of the power transfer equipment in order to reduce losses and simplify their integration. This results in highly distributed storage which makes the solution scalable. As a fully integrated solution, the storage device should be owned by the infrastructure provider.

The power transfer equipment and storage equipment will be distributed along the road. As a result, the system is scalable. Units of 100 kVA or above are technical feasible without the need for special developments. However, if a road of several km is equipped, many of those units may sum up to a total power of several MVA, but this does not compromise the feasibility of each individual unit.

4.3.3 Integration of solar PV power

This section investigates the gaps for the integration between PV generation and power transfer infrastructure. Making use of solar PV power supports the use of more renewable power generation in transport.

The results obtained in D32.1 of this project show that significant amounts of energy can be generated by a well-sized solar PV installation. As shown in Table 3, 10 MW PV power in Spain can supply 20% of the demand over a one year period. This installation does not need additional storage for self-consumption, as generation peaks are below demand levels. If installed power is increased to 20 MW, the solar share implies some net-metering scheme or additional storage if back-feeding of energy to the grid needs to be avoided.

This requirement is low priority. The preliminary study in D32.1 shows that integration of distributed solar PV generation is an interesting option, because traffic intensity is similar to

sunlight patterns. Therefore, as the majority of vehicles are active during the day, it is possible to supply cheap solar PV power to those vehicles. However, this is an additional and optional scenario which is not decisive for the feasibility in general. Also, solar power is not always available and maximum power demand from the vehicles cannot be reduced.

Table 3 Daily solar PV generation and corresponding share of solar energy for self-consumption.

	Mean daily solar energy Epv (MWh)			PV share (%)		
Pinst (MW)	1000 kWh/kWp	1500 kWh/kWp	2000 kWh/kWp	1000 kWh/kWp	1500 kWh/kWp	2000 kWh/kWp
1	3	4.5	6	1.4	2.1	2.8
5	14	21.0	28	6.8	10.2	13.6
10	27	40.5	54	13.5	20.3	27.0
20	55	82.5	110	27.0	40.5	54.0

The main interest with this scenario is to show the compatibility of generation and demand and demonstrate that typical power transfer demands are in favour of solar PV integration.

Solar PV is state-of-the-art technology which is able to produce low cost clean energy. Nevertheless, its integration with the DC bus to high power equipment is not a common approach. No demonstration systems exist.

In urban areas, there may be not enough space to install large solar generators which are directly connected to the system. Nevertheless, existing distributed solar generation may be beneficial in order to support additional demand.

DC integration of solar PV is straightforward. Although special DC/DC converters must be developed, the technological feasibility is proven. Material costs are lower because DC/DC converters are cheaper than AC/DC. Like storage, solar PV generation should be distributed and integrated with the DC bus of the power transfer infrastructure.

Depending on the business model, any entity may be the owner of the solar PV system.

In principle, solar-battery systems are fully market ready and no gap is identified from a technological point of view. Nevertheless, the application studied here is new and the entire control system must be designed and tested.

5 LOCAL AUTHORITIES AND TRANSPORT SYSTEMS

This chapter compares the user needs and requirements of local and city authorities against current policy to support on road power transfer systems, and the comparison has been used to identify gaps. This chapter is divided into five sections:

- Policy
- Regulation
- Guidance
- Technical
- Integration

It should be noted that the gaps identified in this chapter are mainly based on UK needs and requirements. However, it is believed these gaps can be applicable to other EU countries.

5.1 Policy

A policy is a principle to guide decisions and achieve desired outcomes. A policy is a statement of intent, and is implemented as a procedure e.g. enforcement of regulations. This section identifies the gaps in policy and economic planning. Policy and finance play very important roles in large infrastructure projects and promotion of new technologies.

Whether on-road power transfer is supported by policy or not depends on the policy towards promoting EV use in general and electric vehicle use may be supported as a tool to reduce pollution. On the other hand, urban authorities are interested in reducing traffic overall (replacing ICE vehicles with EVs does not reduce congestion) so EV promotion might be reserved for essential vehicles (public transport, delivery and utility vehicles). The level of policy support in different organisations for traditional plug in charging points could be a good indicator of potential support for on-road charging, as both contribute to the same policy goal of facilitating EV take-up.

5.1.1 Transport plans

The Local Transport Plans (LTPs, also called Sustainable Urban Mobility Plans) should include installation of on-road power transfer systems in order to support the reduction of greenhouse emissions and to provide “green” economic growth. As an example in the UK, Local Transport Authorities (LTAs) must demonstrate their support for the following five national goals:

- Supporting economic growth
- Reducing carbon emissions
- Promoting equality of opportunity
- Contributing to better safety, security & health
- Improving the Quality of Life and a healthy natural environment

Electro-mobility has the potential to contribute towards several of these goals, so if a local authority deems that it is a priority, then the existence of appropriate and convenient public charging facilities is a necessary step. In this case, the priority for policy and financial support for the introduction of on-road power transfer systems is high. Although these requirements do not have an effect on the fundamental operation of the systems, government support could speed up the development of the systems and it could provide financial incentives for organisations to manufacture, install and manage on-road power transfer systems at larger volumes or, once on-road electrification becomes government policy, it could also encourage automotive manufacturers to increase their investment in EVs.

Samples of LTPs do not indicate specific references to on-road power transfer, but do refer to greener travel. Local transport plans do not have specific reference to plans for on-road power transfer; this could be due to very little knowledge about the solutions, the complexity of the project and/or the high costs associated with the infrastructure.

Major work is required to meet the requirements and innovative business cases are needed to identify the monetisation options in order to minimise the commercial risks due to the high cost of infrastructure and the complexity of these projects to make on-road electrification a feasible investment. The policies and incentives can be specifically aimed at road electrification at a national level, rather than a local authority level, because the projects would require infrastructure with national coverage.

On-road power transfer infrastructure must comply with transport policy, once the policies are updated to include on-road power transfer requirements. There would need to be government support at a national level for the installation of on-road power transfer systems. The policy and incentives would need to aim to install and operate power transfer modules until the length of electrified road has a noticeable effect on EV take up (that means a standard electric vehicle

with a standard battery can meet user requirements for the range that they would expect for all of their journeys).

The primary responsible party for defining national policies is either the national government or the regional/devolved/state government (depending on the country). Local authorities are responsible for preparing LTP's to support national goals. Solution providers are responsible for developing systems that comply with the policy.

5.1.2 Economic & financial planning

Economic planning is a mechanism for economic coordination by interventions, often by governments, in contrast to a reliance on market mechanisms. Financial planning involves a comprehensive evaluation of the current and future financial states by using currently known variables to predict future cash flows, asset values and withdrawal plans. This often includes a budget which organizes finances and sometimes includes a series of steps or specific goals for spending and saving in the future. The requirements for an on-road charging system are:

- The cost of the system should be calculated
- Government financial support and incentives to kick start large scale deployment
- Consideration of monetisation options and a feasible business plan

These are very significant requirements; all of the on-road power transfer solutions are currently in their development stage and therefore there is no clear indication of the total cost of the system. The solution providers should estimate the cost of the systems including cost of installation and connection to the grid. The relevant Ministry should carry out an economic feasibility study on power transfer infrastructure.

Major infrastructure budgets are, in general, provided by central government, but how these funds are then spent is often a local decision. Large amounts of funding would be required for large scale installation of on-road power transfer infrastructure and would encourage the public to purchase new electric vehicles to use this infrastructure.

Government funding already plays a huge role in research, development and the deployment of large infrastructure projects; therefore the government should have clear long term policy on the installation of on-road power transfer solutions and it should consider leading system development with an initial investment.

Currently, it is not clear who will fund the costs of on-road power transfer systems - government and/or the private sector. Furthermore, there is no plan for how to integrate current and new EV vehicles so that these vehicles can draw power from the infrastructure.

Government should include consideration of on-road power transfer within their decarbonisation policies. Infrastructure manufacturers (solution providers) should provide possible costs for the installation and maintenance of the systems.

5.2 Regulatory

Regulatory instruments, specifically laws and regulations, are commonly used policy instruments. For example, to achieve the desired effect of fewer traffic accidents, governments pass laws which regulate driving. Regulatory instruments are used in conjunction with the provision of information and other policy instruments. Note that regulation is normally used as a last resort.

A regulation is a legal norm intended to shape conduct and behaviour or set a technical requirements for example setting headlamp beam pattern. A regulation may be used to prescribe conduct. It can be extended to monitoring and enforcement of rules as established by primary and/or delegated legislation. In general, regulations are written by executive agencies as a way to enforce laws passed by the legislature.

This section describes the regulatory gaps which should be addressed during development of the systems. It should be noted that there are large number of regulatory requirements such as standards, installation methods, health and safety etc., but this section only concentrates on requirements with regard to local authorities.

5.2.1 Signage

The user needs and requirements indicate the need for an internationally recognisable signage for on-road power transfer infrastructure.

Signage is developed and approved at a national and international level and should comply with relevant national standards, e.g. in the UK it should meet the Traffic Signs Regulations and General Directions (TSRGD) law, and in France any changes to the prescribed list of signs, signals and markings must be subject to a central government decree following recommendations from the Ministry of the Environment, Sustainable Development and Energy

(responsible for transport) and the Ministry of the Interior (responsible for traffic regulation, police and enforcement). Harmonisation at European level is undertaken through consultation among the relevant national authorities under the auspices of the United Nations Economic Commission for Europe (UNECE). In particular, most European countries as well as numerous countries in the Middle East, Africa and Central Asia are signatories to the 1968 Vienna Convention on Road Signs and Signals. This means that although there are national variations, the style and pictograms used on most signs are harmonised (e.g. red-bordered triangles for warning signs, red-bordered circles for proscriptive signs, rectangles for informative signs, etc.). In Europe, only Ireland, Iceland, Moldova, Andorra, Malta and Liechtenstein are not signatories to the Vienna Convention, and of these, only Ireland deviates significantly from European standards (using instead yellow diamond style warning signs, as in North America and Australia).

In Europe, the need for new signs and their harmonisation is discussed at an international level by the Conference of European Directors or Roads (CEDR), which comprises the national road directorates of 25 of the EU member states (all except for Bulgaria, Croatia and Slovakia) plus additionally Iceland, Norway and Switzerland. CEDR has either carried out or monitored studies (for example within the Easyway programme) on aspects such as harmonisation of message styles on Variable Message Signs (VMS), and can make recommendations for changes to the Vienna Convention. Other areas of discussion have included a sign for ramp metering (motorway access control) as different approaches had been adopted e.g. in France, the Netherlands, Germany and the UK. Standardisation of advisory diversionary signs has also been a topic worked on. This is medium priority, the road signs and markings should be clear and recognisable everywhere. No current set of iconography exists for on-road power transfer infrastructure. Increasingly, recognisable icons exist for plug-in charging (depicting a vehicle with a flex and plug coming out of it), but clearly this is not appropriate for the types of power transfer considered in FABRIC.

In the UK, the DfT Traffic Signs group would have responsibility for developing signs and markings for use with wireless EVs, distribute widely and update the traffic signs manual. In France it would be the DTITM (technical directorate of transport infrastructure and materials), which then makes a recommendation for a legal decree by the relevant ministries. Sign development should also include communication with European partners (through CEDR) in order to compare any existing ‘on-road power transfer’ signs or markings elsewhere and, if

appropriate, a small international study to recommend best practice (as has been done for VMS and other new signage). Signs should aim to be consistent and recognisable in different countries. Compatibility with standards must be met, once signage and markings are developed.

5.3 Guidance

This section of the report identifies requirements for guidance in order to stimulate installation of on-road power transfer equipment and EV take up. This section studies:

- Design Manual for Roads & Bridges
- Guidance from the Government
- Manual for Streets

5.3.1 Infrastructure design, planning and construction

The solutions and installation should be in compliance with infrastructure planning and construction tools (e.g. in the UK, the Design Manual for Roads & Bridges [DMRB]).

This requirement is medium/high, since the main tools used for the design of roads do not mention on-road power transfer infrastructure. Planning and constructing new transport infrastructure includes many aspects: civil or public works, design and engineering, construction and installation and integration even at local level. It is not clear if new institutional bodies will be required for the regulation, security and safety arrangements of the EV infrastructure either nationally or locally.

There is a need for further development to update the infrastructure, planning & construction tools. (N.B. – In the UK, some updates can be made in the form of Interim Advice Notices for highways and trunk roads [IANs]). The regulatory bodies should fully understand the impact of installation, integration and management; this may require working in collaboration with the stakeholders to redefine the requirements.

Various transport organisations/agencies at national/federal, devolved or regional level (depending on the country) are responsible for defining planning and construction 'tools' for contractors to use.

5.3.2 Guidance from central government

The government should produce guidelines to address the points stated below in relation to on-road power transfer in order to increase the length of the electrified road and encourage EV take up. The guideline should aim:

- To help local and city authority officers interpret advice in a practical manner
- To provide advice and information to authorities
- To direct authorities to pursue specific policy initiatives
- To provide a framework for assessing authority performance
- To ensure consistency between different tiers and types of authority

The function of guidance is to provide direction and promote aspects of policy, then to clarify policy implementation and good practice. The priority is high; the government policy, guidance and standardisation are crucial stages for system development, reliability and feasibility as well as take up. There is little current guidance from government regarding on-road power transfer infrastructure. This guidance is either currently unwritten or unfinished.

Central government must first publish guidance documentation before compliance can be achieved. For this to happen, the government should work with stakeholders to develop guidance to promote policy, implementation and good practice. New infrastructure is likely to impact property owners along the proposed roads; therefore local authorities should also be involved in the development of the guidance to minimise the adverse impacts of the installation process and operation on local residents.

The government has the primary responsibility for defining the guidance for local and city authorities. Solution providers need to make available key information in order for guidance to be produced.

5.3.3 Compliance with Manual for Streets

In the UK, on road power transfer should be in compliance with the Manual for Streets (MfS) and other documentation (once up to date). Sympathetic design needs to be incorporated into infrastructure placement.

EV infrastructure should be in compliance with:

- Street furniture

- Crossings (raised or otherwise, tactile paving)
- Impedance of pedestrian footways
- Surfacing of footways

This is medium/high priority; the Manual for Streets (MfS) does not consider on-road power transfer solutions. In urban scenarios, integration with the environment, street furniture and the health and safety of pedestrians are important factors in determining the feasibility of installation. Connection from the road infrastructure to the high voltage grid and the size of the roadside equipment can be important issues which need to be resolved in order to install power transfer solutions.

The local authorities should clearly define their requirements for the size of the road side infrastructure, suitable locations in the street, health and safety requirements and connection to the grid. Ministry of transport and local authorities should develop guidelines for on road power transfer infrastructure within the MfS. Solution providers are responsible for designing their system to meet the MfS requirements.

5.4 Technical

This section includes technical gaps such as in the installation of electrical equipment, suitable locations, constraints, and suitable measures to protect equipment.

5.4.1 Installation

The solutions should consider road users (motorists) and non-motorists when undertaking roadwork's to install the equipment in urban areas. The infrastructure, deployment method and the proposed programme should be in compliance with the most up to date road works practices.

This is medium priority, as there are no current implementation plans for installation of power transfer solutions. Plans must be developed in order to reduce disruption to motorists, and other road users, and any local residents when installing the equipment.

Road owners, distribution operators and contractors are responsible for developing roadwork plans for installations. The installation/deployment plan for urban areas must address health and safety risks during installation, maintenance and while the system is in operation. The solution providers should design the system to be a “plug and play” in order to speed up the

installation process, and to minimise the health and safety risks during installation. The system should be fully tested in simulated urban areas to observe the impacts on all road users.

5.4.2 Infrastructure location

This section of defines the gaps in the selection of power transfer infrastructure locations in urban areas. During the planning process the solution should consider:

- Urban freight deliveries, including when/where they are made – Loading bays must not be blocked by charging equipment (or other loading provisions must be considered)
- Strict parking measures where on-road power transfer unit are located (i.e. to stop vehicles parking there and preventing wireless vehicles from being able to use that unit)
- Ideally on-road locations should comply with technical requirements and should provide maximum energy transfer efficiency (e.g. near junctions, constant speed sections, mid ways between two junctions etc.)

This is medium priority. These requirements have not yet been considered; however, suitable or unsuitable power transfer locations should be included in an urban area deployment plan. There is need for major work in this area. The infrastructure owner along with the road operators and local authorities should carry out surveys on selected locations and identify if that specific location is suitable for infrastructure installation.

5.4.3 Physical design constraints

The equipment must be able to be used almost anywhere on the road network, which means it must comply with existing infrastructure. Examples of physical & design constraints are:

- Fixed building lines
- Shallow services and utilities
- Extensive and unmapped statutory undertakers equipment (on road and way side locations)
- Conflicts over allocation of space and priority from a wide number of users
- Access to property
- High cost of remodelling or rehabilitation of streetscape
- Maintaining service access

This requirement is medium/high priority. The physical design constraints may not be an essential issue during the development of the system; however, in order to install these systems in urban areas, the solution must be in compliance with the physical and design constraints. The constraints for the installation of power transfer systems have not been identified and the points stated above have not been considered at this stage of system development.

There is a need for an investigation to examine whether on-road power transfer infrastructure and utilities supply are compatible. This will require collaboration between the solutions provider and the utility operators.

Environmental constraints are often fixed (e.g. buildings, bridges etc.). Possible novel alternatives should be devised in case of environmental limitations. For example, the constraint may require the resizing of power transfer units or increasing the distances between the on-road and roadside power units due to space limitations for road side equipment.

The road operator and local authorities must define the constraints and the solution providers must develop their systems to operate within specified limits. The constraints may differ based on the location but should be possible to identify all the constraints by considering multiple locations and it is also necessary to provide guidelines on solutions for how to design the system to meet the requirements.

5.4.4 Protection of power transfer equipment

The on-road infrastructure will be safely located under the ground. However, in flush systems road systems road side equipment could be at risk of vandalism and theft. Therefore the power transfer equipment should be protected from malicious damage.

This is low priority. The protection from theft and vandalism has not yet been considered but it is believed that during installation necessary measures will be taken to protect the equipment.

Infrastructure owners should obtain up to date information from solution providers regarding the testing & standardisation of equipment, and must ensure that the equipment meets safety standards before installation. Regular maintenance checks should be carried out by local authorities and power distribution companies. The solution providers and infrastructure owners are responsible for meeting these requirements.

5.5 Integration

This section outlines the gaps in:

- Compatibility with public utilities and electricity supply
- Communication between the stakeholders
- Operation of the system
- Management of traffic flow and congestion

5.5.1 Compatibility with public utilities and electricity supply

The on-road power transfer solution should integrate into the road and it should be compatible with public utilities and the electricity supply, including safety, dimensions, power requirements, interference etc.

This is a high priority, as the system should be interoperable with the entire surrounding infrastructure. The gaps are:

- No safety standards as equipment is currently only in prototype form
- Dimensions are known for some charging equipment, but utilities are often located at unknown depths and infrequent interval;
- Power requirements vary per unit
- Interference with other electrical supplies is unknown. (see also Grid Requirements)
- Interference with signalling systems etc. is unknown

There is need for major development in order to meet the requirements; the gaps can be closed by taking following measures:

- Examine existing requirements for the utility supply i.e. space/clearance required
- Make use of ‘Grid requirements’ section (chapter 2) to establish whether supplying power to power transfer units could overload the grid (at local and national level i.e. is more power generation required)
- Ensure that safety requirements are met and testing undertaken before user interaction e.g. EMF effects, public interaction with electricity supply etc.
- The distribution operator should state the spare capacity in their network and state whether the capacity can meet the demand from the power transfer infrastructure; the

distribution operator should also recommend alternative connection solutions if it proves to be lower cost, more efficient and/or where it can meet the demand

Utility providers are responsible for providing information on feeder locations; however, these gaps require collaborative working of road operators, solution providers and distribution network operators.

5.5.2 Communications between stakeholders

This section describes the gaps between institutions who should be working collaboratively to install, operate and maintain the on road power transfer infrastructure.

All the stakeholders should be able to exchange information regarding their equipment, requirements and constraints in order to minimise the accidental damage during installation and maintenance, ensure the systems do not interfere with each other and resolve issues with regards to conflict of interest. Examples of physical & design constraints are:

- Extensive and unmapped statutory undertakers equipment (on road and way side locations)
- Conflicts over allocation of space and priority from a wide number of users
- Variety of players, influencers and interested parties

These gaps can be considered as medium priority. The physical design constraints may not be an essential issue during the development of the system; however, it becomes a major issue if these systems are to be deployed in public places. Various stakeholders are responsible for different items of infrastructure. For example: the road surface – road owners, utility providers – gas, electricity, communications etc. (Installation environment belongs to the road owner, but many other groups have equipment in the road, above and around it). Each party is likely to lack communication channels to exchange information.

Solutions providers and infrastructure owners must develop communication channels to exchange information with all other stakeholders. This could be achieved by setting up a central cloud based IT infrastructure to exchange information.

The stakeholders should be informed about the locations of the on-road power transfer systems, installation method, electrical parameters, mechanical parameters, environmental

factors and installation time. A wide range of information can be, and needs to be, communicated between different stakeholders.

5.5.3 Operation

The solutions should consider the impact of power transfer infrastructure on cyclists or motorcyclists whom may share a lane with inductively charged vehicles. Therefore the system:

- Must work at the speed of a cyclist (low) (i.e. if a vehicle is following a cyclist)
- Must not affect other users in any way (see also EMF Safety)

This is high priority; the solutions have not been tested in built up areas. In a number of cases the primary loops could be longer than the vehicle length and could emit EM waves into the open air which could be hazardous to the public.

Major work is needed in order to meet the requirement and to control EM exposure without having to reduce the power transfer rate. The systems should be designed to operate at all speeds, which may require solution providers to include additional subsystems to monitor the speed and re-tune the power transfer circuit to provide maximum power.

The loops should be safe to operate in urban areas, so solution providers have to ensure that their system doesn’t have any health and safety effects on pedestrian, cyclists, etc.

5.5.4 Managing congestion & traffic flow

On-road power transfer infrastructure would need to be compatible and should;

- Not interfere with the existing traffic management system; this could restrict the installation of on road power transfer infrastructure near any junction that has traffic signals.
- Be compatible with junction sensors & systems. For example, SCOOT traffic light control has most detection and cabling within 20m of junctions, but a typical set up is only at ~50% of junctions. MOVA control has a detection sensor on the stop line and two more about 3.5s and 8-9s journey times from this point.
- Consider the max/min vehicle speeds when using inductive charging lanes i.e. will vehicles hold up other users (e.g. in dual purpose bus/taxi/cycle lanes). (See also the impact on other road users). Additionally, to consider whether the number of WPT vehicles will eventually clog these lanes.

- Consider the effect of driver behaviour as this may affect both traffic flow and routing choices.

This is medium priority; the solutions have not been tested in the presence of traffic management sensors, and the impact of on-road power transfer infrastructure on traffic management sensors is unknown.

There is a need for further development; the solution providers and infrastructure owners should:

- Develop a test plan to investigate the impacts of charging infrastructure on traffic sensors
- Develop solutions to minimise or eliminate the effects
- Develop standards and regulations to minimise or eliminate the effects
- Investigate the tolerances needed to be undertaken. MOVA junctions may not be able to have a charging plate/unit at the stop line
- Investigate the capacity of roads at various speeds/vehicle mix, identify capacity for various road types
- Identify the equipment's capability to meet the maximum requirements

It should be noted that the power transfer solutions could be most efficient near junctions or traffic signals where vehicles move at low speed; therefore the solution must be interoperable with the traffic management infrastructure in order to maximise, energy transfer to the vehicles.

6 VEHICLE REQUIREMENTS

The scope of this section is to perform a gap analysis on the main vehicle manufacturer needs and requirements.

6.1 General standards and guidelines

There are currently no specific published standards for on road power transfer solutions. A number of standards for on-road power transfer solutions are being developed and some are currently in draft form. The systems are expected to meet following guidelines and standards once they are finalised and published:

- ISO 19363 (Electrically propelled road vehicles -- Magnetic field wireless power transfer -- Safety and interoperability requirements)
- IEC 61980 (Electric equipment for the supply of energy to electric road vehicles using an inductive coupling)
- SAE J2954 (Wireless Charging of Electric and Plug-in Hybrid Vehicles)

These are Medium priority; however, as majority of the on-road power transfer solutions standards are not published, there is gap in standard development as well as equipment meeting standards.

It is recommended that the standards for on-road power transfer should be published soon as possible.

All the stakeholders, such as standards agencies, solution providers, vehicle manufacturers, road operators are responsible for development, approval, adaptation and development of these standards. They are also responsible to design and develop their systems to ensure that solutions meet the guidelines and the standards.

6.2 Operation needs and requirements

6.2.1 Power

The requirements suggest that the power demand required to maintain a constant cruising speed from a car or LGV at speed range of 70-90km/h should be between 20-30 kW. Power demand from an HGV at 90km/h is approximately 125 kW. A higher rate of power transfer will be required to provide additional energy to charge the batteries. All systems currently under development are rated at speeds up to 90 km/h. While this is likely to be sufficient for HGVs, higher operating speeds will be required for smaller vehicles like cars and LGVs. As stated in

Deliverable D3.3.1, there is no fundamental operational speed limit for inductive power transfer systems, the limits on current systems are design limits based on market perception and practical testing limitations. It is reasonable to expect that operational speeds will increase as the technology matures.

The rate of power received by the vehicle is very high priority, as it can be the decisive factor on how much of the road should be electrified. Existing on-road power transfer solutions provide power between 20-100kW, therefore the power transfer units meet the vehicle traction demand for light vehicles but the demand from heavy vehicles are too high for the supply.

There is an interoperability issue with primary and secondary coils/loops: the primary coils are capable of providing power up to 100kW but the size and the weight of 100kW secondary coil can be too high to integrate under light vehicles. With that said, 100kW power transfer does not provide sufficient power to the HGV to operate in purely electric mode on power transfer sections.

High power secondary coils on light vehicles will provide larger amounts of energy over shorter electrified sections. As a result, the total length of the electrified sections can be shorter. So, there is a need for innovation to develop high power, lightweight, compact secondary coils for light vehicles.

There are number of solutions to improve power transfer rate, one of which is the reduction in air gap between primary and secondary coil. This will require optimisation of the system design. There could be a limitation on minimum distance between the road surface and the vehicle, so the solutions should not breach existing standards and regulations.

The solution providers are responsible for developing high power systems and overcoming interoperability issues. And the vehicle manufacturers are responsible for integrating the power transfer solutions into their vehicles.

6.2.2 Efficiency

Inductive power transfer to moving vehicles is still the subject of research and development, and it is expected that transfer efficiencies will improve.

The minimum power transfer efficiency, defined from the AC grid side to the vehicle DC side, shall be higher than 85% for the private cars and LGV. For the HGV a lower efficiency (80%) could be considered given the higher power value (>200kW), although this will exacerbate heat

management issues. This difference between small and larger systems recognises that it is more difficult to achieve high efficiencies at high power transfer levels.. Note that efficiencies are measured under ideal conditions, i.e. optimum alignment and air gaps between primary and secondary coils.

The majority of the on road systems do not meet the target requirement at this stage. The efficiency of the test systems is approximately 70-75%. However, there are few on-road solutions that are capable of 80% or greater power transfer efficiency. It should be noted that the efficiency should be measured from the distribution feeder to the output of the in-vehicle power converter.

The power transfer efficiency needs to be improved by at least 10 %, without having a negative impact on health and safety and meeting all the necessary standards. Therefore major work is needed to achieve this higher efficiency value.

All systems should make real-time measurements of the transfer efficiency, and turn off when the efficiency drops below a pre-set level.

There is also need for a standardised test method to measure efficiency of the system. The test method should consider the movement of the vehicle, and should state at which points efficiency measurements should be taken (for example are the measurements taken to calculate efficiency from coil to coil or grid to battery).

6.2.3 Frequency

From a health perspective, the frequency used for power transmission should be in the induction band: 10 kHz to 150 kHz.

This is very high priority. The on road wireless systems operate below 150 kHz, usually in the 20-30 kHz range; therefore the solutions meet the requirement. However, the solutions providers are aiming to increase the frequency in order to improve efficiency, but the trade-off between increases in frequency is a technological problem in relation to the ability to keep the losses in conductors, ferromagnetic and conductive materials low and, of course, in relation to the technology of the power electronic. The increase in frequency also results in higher EM exposure which could results in health and safety concerns; however, it should be noted that high frequencies are suitable for suppressing EMC effects as it is easier to design shielding for high frequencies when compared with low frequencies.

The increase in frequency is only possible with innovative to contain the magnetic fields within a restricted area, while the vehicle is in motion. The electronics also have to be developed to ensure that efficiency gained due to frequency increased is not lost in other parts of the system due to switching losses, skin effect in conductors etc.

6.2.4 Battery voltage

There are requirements on voltage levels on the vehicles, usually based on safety aspects, these requirements are:

- The, typical voltage range for a car or LGV is between150V and 400V
- The typical voltage range for HGV is higher than 400V

The voltage at the secondary coil pick up could be higher than 400V, to increase the power transfer rate. However, the batteries can be designed to operate at below 400V but the voltage limits for the pickup coils needs to be clarified.

The voltage level on the output of the secondary coils needs to be clarified via guidelines or standards. There is a trade-off between power transfer rate and voltage; a higher induced voltage would result in higher power transfer, but the batteries for the light vehicles are required to be below 400V.

6.3 The pickup coil

In the current draft standards for the wireless power transfer (IEC 61980), the maximum mechanical size of the secondary device are defined as a function of the power transfer classes as shown in the table 5:

Table 4: Mechanical size of secondary coil

Power class / **Direction**	**MF-WPT1 (<3.7kW)**	**MF-WPT2 (3.7 to 7.7kW)**	**MF-WPT3 (7.7 to 22kW)**
X(direction of travel)	350 mm	600 mm	750 mm
Y (transverse)	300 mm	450 mm	600 mm
Z (height)	22 mm	22 mm	35 mm

It should be noted that these values are for static power transfer, and only up to power transfer rates of 22kW. Higher power rates are currently not covered. Table 5 shows the pickup coil weight and dimensions for the current state of the art.

Table 5: Pick up coil mechanical parameter

Parameter	CWD	IPV	Volvo	Scania Primove	UNPLUGGED	KAIST
On-vehicle equipment Dimensions	70x30 cm (20 kw)	80x100 cm (100 kW)	50x150x50 cm (120kW conductive)	200x100 cm (200 kW)	29 x 33 cm (3.7 kW) 185 x 84 x 13 cm (50 kW, dual coil pack))	80*170*8 cm (100 kW)
Weight			80 kg plus 40kg power electronics	330 kg plus 60kg power electronics		80 kg per coil (20-25kW per coil) plus weight of power electronics

This is very high priority. The state of the art secondary coils are within specified values but integration of large power systems (100 kW and over) onto a commercial vehicle could be mechanically difficult. For example there may not be available space under the vehicle to integrate 100x200 cm equipment. Also the weight of the coil system is very high, as shown above, and a 100 kW pick up coil could weigh more than 320kg.

Even though dimensions meet the requirements, very high power systems are not feasible to be installed in a car due to their dimensions and the weight. Therefore, the solution providers must reduce the weight and the dimensions of the system in order to enable high power transfer to the vehicles.

Closely related to weight issues is that of electromagnetically induced forces between components of the wireless power transfer systems. Two forces can be identified:

- Forces between the coils
- Forces between the primary coil and the vehicle.

Two forces exist between the coils, namely Lorentz force (caused by a moving charge in a magnetic field) and the reluctance force. As the coils can be treated as circular, there is no net Lorentz force. The reluctance force between the coils exists, but has been calculated to be a small fraction of the force exerted by the weight of the coil, and can thus be ignored.

As the coils are electromagnets, there will be a force between the primary coil (when operating) and the magnetic parts of the vehicle. However, it can be shown that while the currents in the primary coil are high, the resultant electromagnet is very weak and hence the attractive force between the primary coils and vehicle is very low. This is further minimised as the underside of the vehicle must be shielded to prevent circulating currents from being induced in the vehicle structure.

Note that the forces to which the coils are subjected will be investigated in T3.6.1.

6.4 General requirements

All vehicle mounted equipment will need to meet existing standards for temperature, vibration, EMC, IP-rating etc. These are a combination of regulatory requirements and requirements placed on suppliers by vehicle manufacturers. As these requirements are well established, it is not considered that there is a significant gap.

In-vehicle equipment will need to be integrated into the vehicle communications systems. It is to be expected that connection to the CAN bus will be required. As CAN standards are well established, this is not a gap. The specific messaging to be used is outside the scope of this work, and will be defined by individual manufacturers.

There is a significant gap in the vehicle to infrastructure communications subsystem. Dynamic charging systems will need to have available a secure, reliable, high speed and low latency communications channel to communicate with the charging infrastructure, both to the roadside equipment and charging back offices. This has yet to be defined.

As the performance of charging systems is often critically dependent on the alignment between the primary and secondary coils, guidance systems are required to ensure optimal alignment. These may be either manual (indicating to the driver when optimal alignment has been achieved) or automatic (the system control the vehicle’s steering to achieve optimal alignment). Automated systems fall within the remit of automated driving systems and have significant regulatory constraints. Clearly a guidance system standard will be required to ensure interoperability between systems from different suppliers.

7 EMF SAFETY REQUIREMENTS

This chapter performs a gap analysis on EM safety. The gaps are identified in three areas:

- Protection from electromagnetic field- human health and safety
- EMC requirements
- Electrical safety

7.1 Protection from electromagnetic field- human health and safety

The safety limits for human exposure to electromagnetic fields are determined by reviews of scientific evidence of the impact of electromagnetic fields on human health. The scientific evidence is used by most national regulations to recommend the human exposure guidelines. The current evidence indicates that there is no causal link between human exposure to radio frequency (RF) electromagnetic fields and cancer. However, there is established evidence showing that RF electromagnetic fields may increase a person's body temperature or may heat body tissues and may stimulate nerve and muscle tissues.

The EM exposure from the solutions should not affect the health and safety of the driver, passenger, pedestrians and other motorists. There are no statutory standard or regulation to limit the EM exposure; however, there are guidelines designed to limit the EM exposure. The solutions are expected to meet the following guidelines:

- IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, IEEE Std. C95.1-2005
- Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (Up to 300 GHz)", ICNIRP Guidelines, International Commission.
- Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz - 100 kHz). Health Physics 99(6):818-836; 2010
- IEC62311: Assessment of electronic and electrical equipment related to human exposure restriction for electromagnetic fields (0Hz 0 300 GHz)
-

This is very high priority as this is a safety critical requirement. The solution providers are responsible to ensure their solutions do not have short and long term health effects on the public principally caused by exposure to electromagnetic waves.

There are no standards to regulate EM exposure, and as the solutions are still in their development stage, the EM exposure is not fully controlled in dynamic solutions. The solution providers are responsible for designing their system to meet the guidelines. Governments are responsible for exploring the effects of EM exposure from wireless on-road power transfer solutions and drafting regulations while the standards bodies are responsible for drafting standards to limit the EM exposure based on results from the research.

Control of magnetic exposure can result in fundamental design changes. Therefore, the solutions potentially require major development in order to close this gap. The EM exposure could require changes or developments in frequency, voltage, coil/loop length, cable type, shielding and magnetic field shaping.

7.2 EMC requirements

This section outlines the gaps in electromagnetic compatibility for on-board and off-board equipment.

7.2.1 Electromagnetic compatibility (EMC) requirements - on board

EMC requirements for on-board equipment are under consideration in IEC 61851-21-1. The devices which fall under the standard shall conform to the applicable component level EMC requirements. EMC requirements for installation of E/E components in vehicles can be classified in two categories, referring to tests and requirements at component level and at vehicle level. Required standards and guidelines are listed: here

- ISO 11451 - Road vehicles - Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy
- ISO 11452 - Component Test Methods for Electrical Disturbances in Road Vehicles Package
- CISPR 12 - Vehicles, boats and internal combustion engine driven devices - Radio disturbance characteristics - Limits and methods of measurement for the protection of receivers except those installed in the vehicle/boat/device itself or in adjacent vehicles/boats/devices

- CISPR 25 - Vehicles, boats and internal combustion engines - Radio disturbance characteristics-Limits and methods of measurement for the protection of on-board receivers

These requirements are medium priority. The solutions should meet the requirements if they are to be installed in vehicles for public use. It is not possible to evaluate on-board EMC at this point as the power transfer solutions are not available to be integrated into the vehicles.

The on-board solutions should meet the standards at component and vehicle level, the testing should be carried out on both cases. The EMC aspects should be considered from the design phase through virtual analysis to validation. Vehicle manufacturers and solution providers are responsible for meeting EMC standards.

7.2.2 Electromagnetic compatiblity (EMC) requirements - off board

The main standard for electric vehicle inductive charging is the IEC 61980-x suite of standards. IEC 61980-1 (with current status: circulated as committee draft with vote) includes a chapter regarding EMC of the off-board WPT module with analysis of two fundamental EMC considerations; namely, electromagnetic immunity and emission limits.

This is medium priority, the standard mentioned is still in draft form, so the IEC should release the standards soon as possible and the solution providers should take measures the meet the standard. Again, as stated in previous gap, the power transfer solutions are not fully developed to carry out EMC testing.

There are no standards to regulate on-road power transfer infrastructure. It is essential for all the stakeholders to work towards standardisation of infrastructure.

7.3 Electrical Safety Requirements

This section outlines the electrical safety requirements for on-board and off board systems.

7.3.1 Electrical safety - on board

Class B circuits refer to working voltages between 25 V AC and 1000 V AC, or 60 V DC and 1500 V DC. All class B circuits shall be protected against direct and indirect contact. For this reason, the requirements in this section shall apply only to systems belonging to Class B family (according to classification in ISO 6469 and ISO 17409 (under development)). The on-board equipment should meet following standards:

- ECE R100 - Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train
- ISO 20653 - Degrees of protection (IP code) -- Protection of electrical equipment against foreign objects, water and access
- ISO 6469-2 - Electrically propelled road vehicles -- Safety specifications -- Part 2: Vehicle operational safety means and protection
- ISO 6469-3 - …Part 3: Protection of persons against electric shock
- ISO 23273-3 - Fuel cell road vehicles -- Safety specifications -- Part 3: Protection of persons against electric shock
- SAE J2344 - Guidelines for Electric Vehicle Safety
- SAE J2578 - Recommended Practice for General Fuel Cell Vehicle Safety Reference Information
- IEC 60364-7-726 – Electrical Installations for buildings – Part 7 Special Installations
- ISO 20653 - Degrees of protection (IP code) -- Protection of electrical equipment against foreign objects, water and access
- IEC Guide 117 - Electrotechnical equipment - Temperatures of touchable hot surfaces
- IEC 61439-1 - Low-voltage switchgear and control gear assemblies - Part 1: General rules
- IEC 60364-4-42:2010-05 - Low-voltage electrical installations - Part 4-42: Protection for safety - Protection against thermal effects

These are high priority. The solutions are expected to meet these requirements. Most of the on-road power transfer solutions meet these requirements, but the solution providers that do not should identify the standards that their solution fails to meet. Solutions providers are responsible to meet these standards, and the vehicle manufacturers should approve the equipment prior to vehicle integration.

7.3.2 Electrical safety – off board

The off-board requirement aims to regulate on-road and road side equipment. The requirements are listed here:

- IEC 60364-7-726 – Electrical Installations for buildings – Part 7 Special Installations
- ISO 20653 - Degrees of protection (IP code) -- Protection of electrical equipment against foreign objects, water and access
- IEC Guide 117 - Electrotechnical equipment - Temperatures of touchable hot surfaces
- IEC 61439-1 - Low-voltage switchgear and control gear assemblies - Part 1: General rules
- IEC 60364-4-42:2010-05 - Low-voltage electrical installations - Part 4-42: Protection for safety - Protection against thermal effects

These are high priority. The solution providers are expected to take the necessary steps to protect the public from direct contact or thermal incidents and are expected to meet the standards for electrical safety.

The solution providers are responsible for meeting the requirement. There could be need for further development and minor modifications to meet electrical safety requirements.

8 GAP SUMMARY

In this section we summarise the gaps found in the analysis.

Table 6: Summary of Gaps

Gap	Priority	Severity of the gap
Road Operator		
The size of the infrastructure exceeds current standards therefore, it may require special permission to install	High	Need for further development
The effect of the weight of systems on the integrity of the road has not been investigated to date	Medium	Need for further development (Further testing)
The chemical stability of the systems, when subjected to normal operating conditions in a road, will need to be investigated.	Medium	Need for further development (Further testing)
No strength test results are available from the majority of the suppliers	Medium	Need for further development (Further testing)
The solutions are not fully tested for robustness to withstand weather conditions	Medium	Need for further development (Further testing)
Number of solutions fail to meet high temperature requirement of 60 C	Medium	Need for further development (Further testing)
The heat generated by the solution and its effect on the pavement has not been studied	Medium	Need for further development (Further testing)
Impact of power transfer solution on driving ability has not been studied in detail	Very high	Innovative method required
The solutions do not operate at speeds up to 130km/h	High	Major work required
integration with the Smart Motorways technology has not been considered	Low	Need for further development
The systems are not currently able to communicate with the Smart Motorways technology	Low	Need for further development

The systems do not operate at headways as low as 4m	High	Major work required
communication and control infrastructure and protocol is not yet fully developed or standardised to enable remotely switching the system on/off	High	Need for further development
Unknown effects on other sensors by operating on road power transfer systems in the same environment. The solutions have not been tested in presence of inroad sensors.	Medium	Need for further development
There is no fully developed deployment plan or procedure on where to install the power transfer units	Medium	Need for further development
No standards or requirements currently exist governing the effect of the installed equipment on the road's structural integrity	Medium/High	Need for further development
Skid resistance only applies to systems that are to be installed flush with the surface of the road and are not covered with a wearing course	High	Need for further development
Impact of infrastructure in drainage of the road has not been considered	Medium	Need for further development
The size, location and frequency of the road side equipment have not been considered at this stage of the project	High	Innovative method required
life time testing procedures should be developed and implemented	Medium	Need for further development
The installation pace should be stated, for example how long would it take to electrify X km of lane.	Medium	Major work required
Maintenance procedure and periods should be stated	Medium	Need for further development
No disposal procedure for any harmful substance	Medium	Need for further development
The installation strategy for built up areas, it is not clear whether series of cabinets can be located in built up areas	Medium	Major work required
Grid		
Most of the current on road solutions do not have results for	Very High	Need for further

harmonics tests		development
Mitigation for power fluctuations require smoothing method or equipment	High	Major work required
The demand pattern is unknown	Very high	Major work required
Integration of solar photovoltaic technology into on-road power transfer solution	Low	Major work required
Local Authority		
Local transport plans do not have specific reference to plans for on-road power transfer.	Very High	Major work required
The cost of the infrastructure is unknown	Very High	Need for further development
There are no funding or incentives for on-road power transfer	Very High	Major work required
There is no road signage for on-road power transfer infrastructure	Medium	Need for further development
the main tools used for the design of roads do not mention on-road power transfer infrastructure	Medium	Need for further development
There is little current guidance from government regarding on-road power transfer infrastructure. This guidance is either currently unwritten or unfinished.	High	Major work required (Detailed study needed)
the Manual for Streets does not consider on-road power transfer solutions	Medium	Need for further development
There are no implementation plans for installation, maintenance and operation	Medium	Major work required
There is no detailed study on suitable or unsuitable locations for on-road power transfer installation	Medium	Need for further development
The constraints for the installation of power transfer systems in urban areas have not been identified	Medium	Major work required (Detailed study needed)
It is unclear what measures have been taken to protect the equipment from theft or vandalism	Low	Need for further development
Interoperability of power transfer solutions with the public	High	Major development

utilities and electricity supply		required
The stakeholders are likely to lack communication channels to exchange information	Medium	Need for further development
The impact of the infrastructure on motorists and non-motorist in urban areas is not known	Very High	Major work required
Impact of power transfer infrastructure on traffic flow and traffic signals and sensors are not known	Medium	Need for further development
Vehicle Requirement		
There are no standards for on-road power transfer solutions	Very High	Need for further development
Number of power transfer solutions are not capable of supplying above 100kW power which is required by HGV	Very High	Need for further development
There is a interoperability issue with providing power to the car and a HGV	Very High	Major Work Required
Majority of the solutions do not meet at least 80% efficiency requirement	Very High	Major work required
High power secondary coils are too large and heavy to be integrated into car or LGV	Very High	Need for innovation
Standards fro guidance systems are required to optimise alignment between the primary and secondary coils	High	Detailed work required
EM Safety		
The results of EM exposure is not available	Very High	Major work required
There are no regulatory standards for EM exposure	Very high	Major work required
The are no standards for EMC off-board	High	Need for further development
The solution providers have not fully tested off-board their solutions for electrical safety	High	Need for further development

9 CONCLUSIONS

The report identified the gaps between the current state of the art solutions and needs, and the requirements of users and stakeholders. The report also outlines the priority of the gaps for development and take up of on-road power transfer solutions and provides recommendations for possible measures to be taken to meet the requirements. This section summarises the findings.

9.1 Road operator

The road operator chapter outlined the gaps in the state of the art with regards to installation and integration into the public roads. There are number of gaps that should be closed before safe installation.

There are requirements for standards, regulations and guidelines with regards to physical size of the on-road installation equipment. The standards documentation should include guidance on volume, weight, chemistry, strength, and operation in all weather conditions and operational temperature range.

There is a need for standards, regulations and guidelines with regards to performance of the system. This document should define operational speeds, recommended headway between two vehicles and how to enforce and manage these regulations. The performance documentation should also provide guidelines on integration with other sensors and infrastructure as well as procedures and scenarios for remote switching of the system and regulations on skid resistance, structural integrity and drainage.

There is no installation deployment plan; the deployment plan should include all the necessary information to carry out installation such as:

- Ideal installation locations
- Installation method or architecture
- Communication with the stakeholder including other infrastructure owners
- Installation programme
- Road closure durations and locations

There is also need for a maintenance plan. This is a separate requirement from the installation and the responsible party should identify:

- Equipment life time
- The equipment to be maintained
- Maintenance interval
- Duration of the work
- Identification of road closure locations and times

The road operator gap analysis identified the main gaps to be lack of standardisation, little guidance on the performance of the systems and nonexistence of installation and maintenance plans/methods.

9.2 Distribution system operator

The main gap in the DSO section was smoothing the power fluctuations. This could be a decisive factor for installation of in-road power transfer solutions. The fluctuation can range between 6 MW to 37 MW for urban and between 4 MW to 21MW for interurban environments depending on traffic conditions.

For the urban scenario, most of the fluctuations can be captured by using a 5 second smoothing window which corresponds to 11.4MW and 8.2 kWh energy storage systems. For inter-urban scenarios, most of the fluctuations can be captured by using a 60 second smoothing window, which corresponds to 2 MW with 8 kWh of energy capacity.

Actual demand patterns are still unknown. Only simplified models are available at the moment (D32.1). As a result, storage requirements are not defined in detail and it is not clear who will own the storage equipment.

Storage solutions which meet the preliminary requirements do exist, but may be expensive. Typical discharge times in the range of seconds can be obtained with commercially available supercapacitors and/or flywheels. Supercapacitors may have some advantages when compared with flywheels, as they can be easily integrated to the DC bus, even as passive elements. These solutions will require additional space, which needs to be taken into account during solution design.

The storage requirements should be minimised, or possibility eliminated, by system design and/or by adopting traffic coordination methods.

The gap analysis also studied solar PV power. For 1-min smoothing only 13 kWh is needed, and in case of 3-h smoothing, almost 23 MWh is required. The results show that significant

amounts of energy can be generated by a well-sized solar PV installation. Solar PV is state-of-the-art technology which is able to produce cheap energy. Nevertheless, its integration with the DC bus for high power equipment is not a common approach and no demonstration systems exist.

The integration of solar PV within on-road power transfer infrastructure requires large batteries, which may not be economical. There is a need for space to install solar panels (in urban areas this could be difficult) and special DC/DC converters.

9.3 Local authority

This chapter compared the user needs and requirements of local and city authorities against current policies to support on road power transfer systems, and the comparison has been used to identify gaps.

The gap analysis shows that there is very little interest in on-road power transfer. Local transport plans, design manuals, government guidance documents, standards and regulations do not have specific reference to on-road power transfer. This could be due to very little knowledge about the solutions, immaturity of the solutions, the complexity of the projects and/or the high costs associated with the infrastructure. There needs to be government support at a national level for installation of on-road power transfer systems with policy and incentives to install and operate power transfer modules.

All of the on-road power transfer solutions are currently in their development stage and therefore, there is no clear indication of the total cost of the systems. The solution providers should estimate the cost of the systems including cost of installation and connection to the grid. Large amounts of funding will be required for large scale installation of on-road power transfer infrastructure and incentives would also need to be in place to encourage the public to purchase new electric vehicles to use this infrastructure.

No current set of iconography exists for on-road power transfer infrastructure. In the UK the DfT Traffic Signs group would have the responsibility for developing signs and markings for use with wireless EVs, distribute widely and update the traffic signs manual. Signs should aim to be consistent and recognisable in different countries. Compatibility with standards must be met.

The constraints for the installation of power transfer systems have not been identified and the points stated above have not been considered at this stage of system development. There is a

need to examine whether on-road power transfer infrastructure and utilities supply are compatible. This will require collaboration between the solutions provider and the utility operators. Environmental constraints are often fixed (e.g. buildings, bridges etc.), and possible novel alternatives should be devised in case of environmental limitations. For example, the constraint may require the resizing of power transfer units or increased distances between the on-road and roadside power units due to space limitations for road side equipment.

9.4 Vehicle

The vehicle requirements gaps are identified as lack of standards and regulations with regards to on-road power transfer solutions.

The majority of the dynamic systems are incapable to provide power as high as 125kW dynamically, which results in failure to meet the HGV power requirement. The on-road power transfer solutions fail to meet the minimum requirement of 80% efficiency. The majority of the solutions are approximately 70-75% efficient; therefore, the solution providers should aim to meet at least the 80% efficiency target. Use of higher frequencies can increase the efficiency but the solution provider should consider EM exposure effects when designing high frequency solution.

The solutions meet the existing secondary coil dimension requirements mentioned in IEC 61980, but these requirements are primarily designed for static system with lower power transfer rates when compared with the on-road power transfer solutions. 100kW solutions can weigh 320kg and they could be 2x1m in area - coils of this size and the weight is very difficult to integrate into a car or LGV, so it is difficult to provider high power (as high as 100kW) to the light vehicle at this point in time. The high power transfer could result in shorter electrified road sections for given energy requirement; hence it has an impact on technical and economic feasibility of the primary power transfer infrastructure.

9.5 EM safety

The EM safety standards, regulation, guidelines and requirements are considered to be a high priory. The results of EM exposure are not available. There are no standards or regulations for on-road power transfer EM exposure. There is a need for independent and detailed study on impacts on EM exposure from the power transfer units on humans. The IEEE and ICNIRP conclude that there is no evidence to show EM fields causes cancer; however, both institutions

have concluded that EM fields may increase human body temperature and these studies should results in standardisation of EM exposure. These standards should guide solution providers to design safe on-road power solutions.

The solutions have not been tested for on-board and off board EMC. The solutions are not fully developed and integrated into the vehicle to carryout EMC testing. This requirement should be one of the priorities to meet once full integration is achieved.

The solution providers are expected to meet electrical safety requirements - these are high priority requirements to ensure the safety of the systems at all times.

ANNEX

This annex contains the completed analysis tables, wherein project partners evaluated the requirements against the current state of the art.

As described in section 2, the partners were asked to use the table below to assess each requirement as identified in the deliverable D32.1 against the capabilities of the current state of the art as described in deliverable D33.1 in order to identify where there are gaps in the current knowledge or capabilities which will need addressing before dynamic charging systems can be widely implemented.

Requirement:	Enter Requirement
Priority:	What is the importance to meet the requirement (low, medium, high, very high)
Gap:	What do existing systems provide and what is the gap when compared with the requirement
Severity of Gap:	Need for further development/ Need for Innovation/ Major work required
Recommendations:	What needs to be done to meet the requirement
Responsible Party:	Responsible stakeholder to ensure that the requirement are met/
Comments	Any issues not identified above (if required)

1. ROAD REQUIREMENTS

1.1 Physical Characteristics

1.1.1 On road infrastructure Size

Requirement:	There may be limits on the size of equipment that can be installed in a road, without obtaining special permission. For example, any system installed in UK roads may not exceed 20mm diameter without special permission of the road operator/owner
Priority:	**High** The special permission may require additional modifications or improvements to the system, these requirements are not clear, therefore uncertainty in installation procedure make the size requirement a high priority.
Gap:	This limitation comes from the installation of traffic loops, enabling the installation of small diameter traffic loops without requiring special permission for each installation. As the on road equipment consists of power transfer loops, sensors, connectors and depending on the system control electronics, the overall size of the ground system is always greater than 20mm in diameter; therefore special permission is required from the road operator or the local authorities to install the equipment in the road.
Severity:	Need for further development: The special permission may require additional modifications or improvements to the system, these requirements are not clear, therefore uncertainty in installation procedure make the size requirement a high priority.
Recommendation	Standards for approval/type approval of in-road systems will be required, as well as processes for (type) approval to ensure the future smooth roll-out of charging infrastructure.
Responsible Party:	Solution provider
Comments:	

1.1.2 Weight

Requirement:	The weight of the system must not accelerate the ageing of the structure of the pavement. The road equipment should not be heavier than the road layers it is replacing.
Priority:	**Medium**
Gap:	The effect of the weight of systems on the integrity of the road has not been investigated to date. It may be that some systems will need to be made lighter, in order to not accelerate the ageing of the pavement.
Severity of the gap:	Need further development/testing
Recommendations:	• Testing for impact of weight, • Feasibility study on transportation of the equipment
Responsible Party:	Solution providers, Infrastructure owner
Comment	

1.1.3 Component

Requirement:	The material composing the system must not chemically interact with the components of the pavement, salt and gritting
Priority:	**Medium**
Gap:	The chemical stability of the systems, when subjected to normal operating conditions in a road, will need to be investigated. If this is not found to be acceptable, the choice of construction material for the system will need to be altered.
Severity of the gap:	Need further development
Recommendations:	Test the systems to ensure no chemical reaction takes places that could damage the equipment, road surface and be a health and safety risk to the drivers
Responsible Party:	Solution Provider, road operator
Comment	

1.1.4 Strength

Requirement:	The system must be strong enough to withstand pavement construction and normal traffic conditions (weight, vibrations) • The passage and possible stop of heavy vehicles of 44 tons, with a limit from 10 tons to 13,5 tons per axle, depending on the country • The passage and possible stop of construction vehicles (finisher, compacter) during the implementation of the pavement layers. For information, the pressure of a compacter is around 100-300 kg/cm². • The passage and possible stop of extra-large vehicles when authorised on the road.
Priority:	**Medium**
Gap:	The results from the review (Deliverable 3.3.1) show that there are power transfer solution providers meet this standard; however, no test results are available from the majority of the suppliers
Severity of the gap:	Need further development
Recommendations:	Structural analysis and tests
Responsible Party:	Solution provider, Road operator
Comment	

1.1.5 Environmental Robustness

Requirement:	The system is expected to operate under extreme temperature conditions from sub-zero to extreme heat as found in real-world road environment, as well as other environmental conditions such as rain, humidity, UV etc. Environmental needs and requirements are: • The system should be able to within stand heat of the pavement during re-surfacing 120 ^{0}C- 200 ^{0}C. • The system must withstand the impact of de-icing salt:

	corrosion and thermal shock generated by their applications (for information: the temperature gradient is around 60°C in 3 minutes. Normal pavement of a motorway is able to withstand a gradient from -25°C to 60°C over a few minutes). • The temperature generated by the operation of the system must not alter the structure of the pavement. The temperature of the system combined with the natural temperature of pavement must be under 40°C
Priority:	**Medium**
Gap:	The systems meet the minimum temperature requirement of -25 ^{0}C, however there are number of the solutions fail to meet maximum temperature requirement of 60 ^{0}C. The polymeric insulator degradation and system integrity due to different thermal expansion coefficients could result in solutions failure to meet the requirement.
Severity of the gap:	Further development
Recommendations:	• Design the systems to be fully operational within temperature range of -25 ^{0}C to 60 ^{0}C. • Test the system to ensure that the heat generated by the primary infrastructure do not have negative impact on the pavement. • Need for environmental testing standard to ensure the solutions are safe and robust to operate in the road.
Responsible Party:	Solution provider, road operator
Comment	

1.2 Consequences of the operation of the system

Requirement:	The system on or off-line must not affect the driving abilities of the drivers (for all types of vehicles : electric or not, charging or not, motorbikes, bikes and health of the passengers)
Priority:	**Very High**
Gap:	Wireless and conductive system does not affect the driver's ability to control the vehicle. However, in order to improve the efficiency of the system, it is possible that vehicles may operate semi-autonomously to optimally align the secondary coils with the primary power transfer infrastructure. In this case the solution providers should ensure that the driver can interrupt autonomous drive to take full control of the vehicle at any time.
Severity of the gap:	Need for further development
Recommendations:	Development of test procedure and testing to analyse the operation of the system
Responsible Party:	Solution provider
Comment	

1.3 Performance of the services

1.3.1 Speed of vehicles

Requirement:	• The system should work at motorway speeds up to 130km/h • The system should not force vehicles to slow down when approaching power transfer segment
Priority:	**High** It is essential that the system is able to operate efficiently at the speed limit of the road on which it is installed. Inability to solve this problem could be a barrier towards mass scale take up, therefore

	vehicle speed requirements are high priority.
Gap:	The review of the state of art in section 3.3.1 states that the solutions are designed to operate up to a maximum speed of 90km/h, which is too low for motorway speed requirements. Therefore there is Major work required to meet the requirements. The increase in speed may result in requirement for longer power transfer segments, as each vehicle spends less time on the power transfer units.
Severity of the gap:	Major work required. Development of a power electronic working at high frequencies but also with relevant power level. (this can represent a problem for the voltage drops over the compensation capacitance)
Recommendations:	The solution providers should develop their systems to operate at higher vehicle speeds but at the same time maintaining high power transfer efficiency. Also the traffic flow in power transfer sections needs to be investigated to understand and prevent congestion due to power transfer units.
Responsible Party:	Solutions providers
Comment	

1.3.2 Other sensors and smart motorway implementation

Requirement:	If Smart Motorways technology is in use, then the average speed of all lanes will be controlled (e.g. in UK: controlled at either 80 or 95 km/h). Charging solutions should not impede the use of additional lanes or obeying of speed limits. E.g. the hard shoulder might be used as a running lane, either dynamically or permanently
Priority:	**Low** This requirement is not essential to the development of the solution or its take up, however it could be useful if the authorities have limited budget and they choose to reduce to speed of the vehicle to maximise the energy transferred to the vehicle. In that scenario, smart motorway schemes can be used to slow the vehicles and

	ensure only electric vehicles are travelling in charging lanes.
Gap:	The existing solutions are in their early development stage, therefore integration with the Smart Motorways technology has not been considered
Severity of the gap:	Need further development
Recommendations:	The systems can be installed in smart motorway areas, if they are designed to operate at low speeds and the smart motorway system can be used to ensure that the vehicles are on the correct lane and moving at specified speeds.
Responsible Party:	Solution provider, Road operator
Comment	

1.3.3 Communication

Requirement:	• The charging system should be able to communicate with the Smart Motorways system to select the most appropriate operational regime • The traffic flow must not be affected by vehicles wanting to change their lane to use the system on the charging lane.
Priority:	**Medium**
Gap:	The systems are not currently able to communicate with the Smart Motorways technology, however this requirement can be realised with improvements in ICT and communication technologies of the systems
Severity of the gap:	Need further development
Recommendations:	Improvements in ICT and communication technologies of the system
Responsible Party:	Solution provider, Road operator

Comment	

1.3.4 Vehicle headway

Requirement:	The system must be able to cope with vehicles travelling within 4m of each other
Priority:	**High** This requirement is considered as high priority, the system can be designed to operate with coordinated traffic, but in real life the traffic is not coordinated and there could be situations where vehicles follow each other very closely, especially at low speeds. It is essential to provide power to the entire vehicle fleet at all times regardless of vehicle speed or traffic density.
Gap:	The majority of the solutions are designed to utilise one loop to transfer power to one vehicle at the time, and these power transfer segments can be up to 24 metres for wireless systems, so at this stage the headway between two vehicles must be greater than 4 metres, and ideally the gap between two vehicles should be greater than the length of the power transfer loop. Therefore major work is required to develop existing systems to meet the requirement
Severity of the gap:	Major work required
Recommendations:	Systems should either to provide power from single segment to multiple vehicles or reduce the length of the segment so that only one vehicle can be charged from one segment. At the same time the solution providers should maintain the power transfer rate and efficiency at the highest level regardless of the length of the segment. The road operator can provide guidance on headway in power transfer sections, so the vehicles can follow each other with a safe headway, also, coordinated traffic scenarios can be investigated in detail, including on-road trials.
Responsible Party:	The solution providers has to develop their systems either to provide power from single segment to multiple vehicles or reduce the length of the segment so that one vehicle can be charged from

	one segment, however the solution providers should maintain the power transfer rate and efficiency at highest level regardless of the length of the segment. The road operator can provide guidance on headway in power transfer sections, so the vehicles can follow each other with a safe headway.
Comment	

1.3.5 Wearing course

Requirement:	• The system should work through a wearing course of at least 4cm thickness. • the system should work when the wearing course is water-soaked
Priority:	**Medium**
Gap:	All the systems have tolerance to operate at various air gap variations, there are systems that tune the secondary coil to maximise the power transfer during misalignments and variable air gaps. Inductive power transfer systems are not affected by water, ice, standard road construction material etc.
Severity of the gap:	Need further development
Recommendations:	Systems efficiency is not affected by the variations in the air gap within specified tolerance. The systems should be remain functional when there is a non-harmful object in the air gap, and the systems should be able to detect foreign objects in the air gap
Responsible Party:	Solution providers
Comment	

1.3.6 Switch on/off

Requirement:	• It should be possible to switch the system off remotely • Stopping the system must not generate an abrupt decrease of the speed of the charging vehicles • Individual charging lanes can be switched on/off remotely according to traffic conditions and/or speed limits and/or whether the hard shoulder is in use as a running lane

Priority:	**High / Very High** The power supply to the traction motors should be steady, and at no point should the vehicle experience power glitches due to connection/disconnection of power source. This is a safety critical requirement, especially at motorway speeds.
Gap:	Solutions must have switching off capability at the inverter level, but it is not clear in which scenarios it is necessary to switch off.
Severity of the gap:	Need further development
Recommendations:	The level of switching should also be specified, for example; possibility of switching at segment, section or entire network.
Responsible Party:	The solutions providers and the road operators should work in collaboration to develop a communication infrastructure. The solution providers are expected to integrate control subsystems into the power transfer infrastructure and develop relevant communication protocols to enable remote switching. All the stakeholders should work towards developing communication standards for on road power transfer.
Comment	

1.3.7 Other sensors

Requirement:	The systems should be placed in locations where they will not impede the operation of other sensors such as inductive loops
Priority:	**Medium**
Gap:	The effects on other sensors by operating on road power transfer systems in the same environment are unknown. The solutions have not been tested in presence of inroad sensors.
Severity of the gap:	Need further development
Recommendations:	Test power transfer solutions in presence of inductive loops and investigate the impacts of one system on the other. The road operator or infrastructure owners are expected to develop a deployment plan which should include measures taken to minimise or eliminate the adverse effects of power transfer infrastructure on

	the other sensors on the road, and solution providers should develop their systems to make sure it does not interfere with other systems.
Responsible Party:	Solutions providers and road operators
Comment	

1.4 Installation and maintenance

1.4.1 Positioning

Requirement:	• The system should not be installed near bottlenecks (congestion hotspots), where it would increase the risk of congestion. Typically, this means installing the system at least 1.5km away from a junction*. • Installation of systems that are flush with the surface, where the skid resistance of the surface is lower than that of the surrounding pavement should be avoided at high risk locations e.g. on roundabouts, roads with tight curves. • The positioning of the system in the pavement must not weaken the structure. Especially, it must not generate cracks or other distortions of the upper pavement layers (wearing course and binding course)
Priority:	**Medium**
Gap:	There are no fully developed deployment plans, standards or procedures on where to install the power transfer units. Therefore the road operators should take surveys and identify suitable power transfer locations on the road network. The investigation should include suitable locations in the urban areas and motorways
Severity of the gap:	Need further development

Recommendations:	Ideal locations can be described as areas where power transfer infrastructure has; • No effect on traffic flow • Minimal health and safety risk • Maximum energy transfer per unit length • Minimum power loss due to distance between distribution and roadside equipment
Responsible Party:	Solution provider, Road operator
Comment	

1.4.2 Structural integrity

Requirement:	Requirements for the structural integrity of the system may exist. For example, in the UK, the following applies: • The installations should meet the limits defined Table S2.1, S2.2 and S2.4 of the SROH • A reinstatement of 1000mm depth or less requires an intervention if the cumulative settlement is greater than 30mm or 1.5% of the unbound layer thickness (whichever is greater) • Construction tolerances at the edges of the reinstatement shall not exceed ± 6mm. • Edge depression intervention shall be required where the depth of any edge depression exceeds 10 mm over a continuous length of more than 100 mm in any direction. • The system must be firmly attached to the road in order not to be torn away
Priority:	**Medium/High** These requirements are standards in the UK, therefore in order to

	install the systems into the road solution providers, along with the road operators, should meet the standards. The situation may be similar in other countries.
Gap:	Impacts of power transfer infrastructure onto the road structure have not been considered for long term.
Severity of the gap:	Need for development
Recommendations:	Procedures to make sure power transfer infrastructure does not affect the integrity of the road and the ride quality must be developed for all systems installed in the running lanes of public highways, irrespective of the system's position within the lane. This may include design of materials used for the system which ensure that it behaves similarly to the surrounding road structure under vehicle load; or a redesign of the road structure in which it is to be installed. Therefore the solution providers and road operators are responsible to meet this requirement
Responsible Party:	Solution Provider, Road operator
Comment	

1.4.3 Skid resistance

Requirement:	The new system shall not affect the skid resistance of the pavement. In the UK, the systems should meet the requirements set out in section 2.6 of the SROH.
Priority:	**High**
Gap:	This only applies to systems that are to be installed flush with the surface of the road and are not covered with a wearing course.
Severity of the gap:	Need further development
Recommendations:	Either the system will need to be developed to work efficiently through a standard wearing course or the exposed surface of the system should be manufactured so as to provide similar skid resistance to the surrounding road surface.
Responsible Party:	The solution provider is responsible to meet the skid resistance requirements, if the power transfer modules are in flush with the

	road.
Comment	

1.4.4 Drainage

Requirement:	• Surface and sub-surface drainage arrangements should be designed to prevent water entering the lower pavement layers, either from the surface or from the sides. • Charging system and maintenance design must ensure continuity of drainage, both in and below the pavement layers and across the carriageway • The existence of power transfer solutions must not compromise the drainage.
Priority:	**Medium**
Gap:	Has not been considered
Severity of the gap:	The gap is that the impacts of the equipment on drainage has not been tested or considered, therefore drainage will need to be considered by solution providers during system design. It
Recommendations:	• It is important to include a drainage section in the deployment plan, which includes measures taken to meet the standards and requirements. • Meet the requirement to ensure that drainage is not compromised and the equipment doesn't cause water ingress.
Responsible Party:	Solution Provider to make sure the drainage is not effected as results of installing systems in/on the road.
Comment	

1.4.5 Road side Equipment

Requirement:	• No substantial fixed equipment should obstruct user sightlines, particularly at junctions.

	• The roadside equipment should not cause obstruction to road users, including footpath users • The roadside equipment must be installed behind the guard rail on motorways. The safety distance between the edge of the pavement and the road side unit must be 10m for motorways, 7m for other new roads and 4m for other existing roads • For highways: Passively safe furniture placed a minimum of 600mm from the back of the safety barrier with larger objects placed at a minimum of 2m from the back of the safety barrier. • The wires connecting the charging unit to the roadside equipment must not prevent the traffic of the vehicles for winter maintenance (snow removal) and the traffic of the vehicles for the maintenance of the shoulder (sweepers, mowers, trimmers…).
Priority:	**Medium**
Gap:	There is no gap, location and frequency of the road side equipment is not considered as a gap. But, in high level take-up scenario, large number of road side equipment could be an issue in urban environments.
Severity of the gap:	Need further development
Recommendations:	Understand the impact of the road side equipment on urban and rural areas in different take up scenarios
Responsible Party:	Solution Providers, Local Authorities, Road operator
Comment	

1.4.7 Equipment life time

Requirement:	• The life time of the system should be greater than 12 years. • There should be no need to access the components buried into the road during its lifetime. Therefore inroad power transfer equipment shall be robust for at least 12 years, without requiring change or repair.
Priority:	**Medium**
Gap:	There are systems that are designed to operate for 12 years without maintenance; but there is a need for accelerated age testing.
Severity of the gap:	Need further development
Recommendations:	• Design the systems to operate to the specified life expectancy. • Provide maintenance schedule which should include information on how often road side and on-road equipment needs to be maintained
Responsible Party:	Solution providers
Comment	

1.4.8 Time schedule for installation and maintenence

Requirement:	• The road works shall be conducted in low traffic hours (22h-05h) • A dedicated procedure for implementation must be defined.
Priority:	**Medium**
Gap:	There is no installation plan outlining the process and duration of the construction works to install the power transfer equipment in the road
Severity of the gap:	Low
Recommendations:	To develop a deployment plan (programme) outlining installation steps and the time periods associated with each step

Responsible Party:	The solution providers, Infrastructure owner
Comment	

1.4.9 Waste of components

Requirement:	Debris resulting from the planning of the pavement must not require special treatment before landfilling or recycling
Priority:	**Medium**
Gap:	Expected to meet the requirements, but need for testing.
Severity of the gap:	Some work required
Recommendations:	Ensure that the system will not cause contamination of the road structure.
Responsible Party:	Solution providers
Comment	

1.4.10 Visual integration

Requirement:	Good integration of visible equipment in the landscape is crucial for the social acceptability of the charging solution. Attention has to be focused on urban areas, when a lot of various equipment are already installed in a narrow space, and where the residents may be very reluctant to accept a new installation that may modify or alter their usual landscape
Priority:	**Medium/High** The road side equipment has to integrate with the surrounding, and it should be possible to install the power transfer modules in built up areas without roadside equipment taking lot of kerb space. The size

	and location of the road side equipment is a critical factor in system take up.
Gap:	The installation strategy for built up areas, it is not clear whether series of cabinets can be located in built up areas.
Severity of the gap:	Major work required
Recommendations:	Develop the system in the way that it does not impede with the vision or take large spaces.
Responsible Party:	Solution providers, road operators, local authorities
Comment	

2. GRID REQUIREMENTS

2.1 Power supply characteristics

Requirement:	• Nominal voltage below 1000V must operate within ±10% of the standard nominal voltage • The voltages at all nodes should be above 95% of nominal voltage. • Frequency of 50Hz and 60Hz at ± 1 %
Priority:	**Very High** This is prioritized as very high, because the grid and distribution standards should be met, and it is important to protect equipment. Especially under and over voltages are not tolerable, as network protection systems may shut down power supply.
Gap:	No gap.
Severity of the Gap:	N/A
Recommendations:	The power supply must be designed according to current standards. Depending on the existing infrastructure, new lines and distribution transformers might be necessary to be installed.
Responsible Party:	Distribution Grid Operator (DSO).
Comment	Here is no gap regarding technical feasibility. Still, high power supply may be costly, especially if power lines must be reinforced. Therefore, controllability of power demand is proposed in this project in order to reduce costs and improve grid stability.

Requirement:	• LV 230 V single phase for 3-18kVA • LV 400V three phase for 12-250kVA, • MV 15/20 kV three phase for power supply above 250kVA.
Priority:	**High** This high priority, because the voltage level of the supply must be

	chosen according to the required power demand. As a result, for low to medium scale take up (below 250 kVA) the supply may be connected to LV (400V three phase). In the case of high scale take up, a connection at MV level (15/20 kV) is mandatory, in order to cope with power levels of several MVA.
Gap	No gap.
Severity of the Gap:	N/A
Recommendations:	Expected installations will be over 100 kVA, which demands for a dedicated power transformer, for LV supply. For higher demand (< 250 kVA) direct connection to MV distribution grid is preferable. The converter might be connected directly to MV which reduces complexity (no need for MV/LV transformer).
Responsible Party:	DSO
Comment	If the existing power grid is weak, costs may be very high, as a separate MV power line from the HV/MV substation might be necessary, or even a new substation should be built. Again, this is no technical gap, but may be an economical obstacle for thinly populated regions.

2.2 Harmonics

Requirement:	The harmonics must meet IEC standards 61000-3-2 which specifies the limits for current below 16A and 61000-3-12 which specifies the limits for currents equal to and above 16A.
Priority:	**Very high** The priority is very high because high power devices can have serious impact on other costumers if they produce high harmonic distortion. Therefore, the mentioned standards are mandatory for any equipment which is connected to the grid. Even for the case of an isolated test track, there may be more appliances connected to the LV grid, which may be affected by large harmonic distortions. If there is a dedicated MV/LV transformer for the

	test track, the compliance with the standard may be less critical, but still should be kept in mind.
Gap:	Most of the current on road solutions do not have results for harmonics tests, but some solutions especially static solutions do meet these requirements So, the gap is that there is no extensive testing on this standard at this stage, but it is expected to meet the standards if it is to be connected to the grid.
Severity of the Gap:	This gap is easy to be overcome, as harmonics will be tested during the project and compliance with the standards is expected.
Recommendations:	Power electronic devices are switching devices which by its nature produce harmonics. Therefore, grid-tied converters always include harmonic filters. A proper filter design will make sure that standards are met, but may reduce the efficiency of the system. With higher switching frequencies and multi-level architectures harmonics and the associated filter size are reduced.
Responsible Party:	Solution provider
Comment	Filters should be designed carefully with simulation software, in order to make sure that even prototypes will not exceed permitted levels, or at least do not exceed them too much. In a testing scenario, standards may not always be met, but harmonics may have negative impact on communication and measurement equipment, so harmonic filters should always be present.

2.3 Grid connection elements

2.3.1 Connections

Requirement:	Connections must comply with • ITC-BT-11 • ITC-BT-07 • ITC-BT-10 • Conductors shall be isolated aluminium or copper.
Priority:	**Low/Medium** Proper cable dimensions are important, but the above mentioned standards will be part of the design and no specific priority is considered here.
Gap:	No gap. Conventional grid connection procedures are valid.
Severity of the Gap:	N/A
Recommendations:	None
Responsible Party:	Solution provider/DSO.
Comment	Standards are based on Spanish grid and distribution, similar standards exists for other EU states

2.3.2 Circuit breaker panels

Requirement:	Circuit Breaker Panels must comply with : • ITC-BT-13 • UNE-EN 60439-1 • Flammability degree according to UNE-EN 60439-3 • Protection level IP43 according to UNE-EN 20324 • IK08 and IK10 according to UNE-EN50102 • The system must be externally covered, protected against

	corrosion, and must have a standardised lock. Only two boxes can be placed in the same place, • must have fuses in all the phase conductors,
Priority:	**Low/Medium**
Gap:	No gap. Existing standard systems meet requirements.
Severity of the Gap:	N/A
Recommendations:	None.
Responsible Party:	Solution Provider
Comment	Standards are based on Spanish grid and distribution, similar standards exists for other EU states

2.3.3 The general feeding line

Requirement:	• The isolated wires and tubes must follow ITC-BT-07 and ITC-BT-21. • Wires shall be made from aluminium or copper, the isolation level should be 0.6kV-1kV. • Minimum cross section of the wires should be $10mm^2$ for Copper and $16mm^2$ for Aluminium
Priority:	**Low/Medium**
Gap:	No gap. Existing standard systems meet requirements.
Severity of the Gap:	N/A
Recommendations:	N/A
Responsible Party:	DSO
Comment:	Standards are based on Spanish grid and distribution, similar

	standards exists for other EU states

2.3.4 The protection measurement boxes

Requirement:	• ITC-BT-13 (in Spain, similar standards exists for other EU states) • The reading devices shall be located at the heights between 0.7m to 1.8m from the ground level. • UNE-EN-60439-1 • Flammability degree according to the UNE-EN-60439-3 • Protection level of IP43 according to UNE 20324 and IK 08 according to UNE-EN-50102 and must be saleable.
Priority:	**Low** Proper protection is crucial in order to ensure security for equipment and any person. Nevertheless, protection installation is standard procedure and no specific priority is considered here.
Gap:	No gap. Existing standard systems meet requirements.
Severity of the Gap:	N/A
Recommendations:	None
Responsible Party:	Solution provider, DSO
Comment	Equipment may be installed near motorways or road side which could pose some risks.

2.3.5 Meters

Requirement:	Meters must meet: • ITC-BT-16 • UNE-EN 60.439 parts 1, 2 and 3 • The minimum protection level that those groups have to

	possess, according to UNE 20324 and UNE-EN 50102, respectively are: • Indoors installations: IP40; IK 09 • Outdoors installations: IP43; IK 09 • Walls should be at least 15 cm thick; or in a prefabricated concrete box, having walls 5 cm thick. • The box will be closed with a door, preferable metallic, with IK 10 protection level according to UNE-EN 50102 • Externally covered following the environmental characteristics and protected against corrosion, having a standardized lock. It will be located at such a height that metering devices are located between 0.7 m and 1.8 m from the ground. • Cables should be rated at 450-750V made from copper class 2 according to UNE 21022 with dry insulation, extruded based on thermo stable or thermoplastic mixtures, identified according to the colours described in ITC MIE-BT-26 • Cables should be non-fire propagators, low opacity and smoke generation, similar to cables that meet UNE 21027 -9 and UNE 211002. • The cable should have identification colour as read and it should have cross sectional area of 1.5mm^2
Priority:	**Low** Proper installation of meters at the grid connection point is important. Nevertheless, this is standard procedure and no specific priority is considered here.
Gap:	No gap. Existing standard systems meet requirements.
Severity of the Gap:	N/A
Recommendations:	None
Responsible Party:	DSO, Solution provider
Comment:	These requirements are for low-voltage (LV) connections. For medium voltage (MV), other standards are applicable, but still no gap is identified.

2.3.6 Concentration of control and protection devices

Requirement:	Concentration of Control and Protection Devices must comply with; • ITC 17,22,23 and 24 • UNE20451 and UNE-EN-60439-3 for the housing • Minimum IP30 according to UNE 20324 • Minimum IK07 according to UNE-EN- 50102 • The system also require at least : • One power control switch • One automatic general switch to break all poles. • One general differential switch, protection from indirect contacts • All Pole breakers, protection from overloads and short circuits • One Overvoltage protection device according to ITC-BT-23
Priority:	**Low** This is standard procedure. No specific priority is considered here.
Gap:	No gap. Existing standard systems meet requirements.
Severity of the Gap:	N/A
Recommendations:	None.
Responsible Party:	Solution provider
Comment:	None.

2.3.7 Conductors of the Inner Installation

Requirement:	Conductors of the inner installation must comply with ITC-BT-09 or

<table>
<tr><td></td><td>ITC-BT-29

<table>
<tr><th>Cross section area of phase or polar conductors of the installation
(mm²)</th><th>Minimum cross section area of the protection conductors
(mm²)</th></tr>
<tr><td>$S \leq 16$</td><td>S (*)</td></tr>
<tr><td>$16 < S \leq 35$</td><td>16</td></tr>
<tr><td>$S > 35$</td><td>S/2</td></tr>
<tr><td colspan="2">(*) With a minimum of:
• 2.5 mm^2 if protection conductors are not part of the supply wiring and have mechanic protection.
• 4 mm^2 if protection conductors are not part of the supply wiring and do not have mechanic protection.</td></tr>
</table>
</td></tr>
<tr><td>Priority:</td><td>Low/Medium
Proper cable dimensions are important, but the above mentioned standards will be part of the design and no specific priority is considered here.</td></tr>
<tr><td>Gap:</td><td>No Gap. Existing standard systems meet requirements.</td></tr>
<tr><td>Severity of the Gap:</td><td>N/A</td></tr>
<tr><td>Recommendations:</td><td>None</td></tr>
<tr><td>Responsible Party:</td><td>Solution provider</td></tr>
<tr><td>Comment:</td><td></td></tr>
</table>

2.3.8 The protection tubes and envelopes

Requirement:	The Protection Tubes and envelopes are used to protect the conductors feeding in to the EV fast charge point and must comply with the ITC-BT-21 or ITC –BT-29. If the conductors are located underground, the protection tubes must comply with UNE-EN-50086-2-4.

Nominal section of the unipolar conductors (mm^2)	**Tube external diameter (mm)**				
	Conductor number				
	≤ 6	7	8	9	10
1.5	25	32	32	32	32
2.5	32	32	40	40	40
4	40	40	40	40	50
6	50	50	50	63	63
10	63	63	63	75	75
16	63	75	75	75	90
25	90	90	90	110	110
35	90	110	110	110	125
50	110	110	125	125	140
70	125	125	140	160	160
95	140	140	160	160	180
120	160	160	180	180	200
150	180	180	200	200	225
185	180	200	225	225	250
240	225	225	250	250	--

Priority:	**Low** This is standard procedure. No specific priority is considered here.
Gap:	No Gap. Existing standard systems meet requirements.
Severity of the Gap:	N/A
Recommendations:	None
Responsible Party:	Solution provider
Comment:	None

2.4 Additional equipment / infrastructure by roadside including potential renewable generation

2.4.1 Power demand

Requirement:	The power supply equipment shall be designed to cope with the fluctuations in urban and interurban scenarios. The vehicles must be tested for small headways, in the situations where there are more than one vehicle on a power transfer loop. The demand from the grid can have high fluctuations depending on the traffic. The model developed for the project indicate in controlled scenario, where there are 500 cars in space of 8.01km and head way is 30m and there are 267 power transfer modules, each charging at 50kW Coordinated scenario at speed of 36km/h: the demand is up to 13MW Uncoordinated scenario demand of urban and interurban:

<table>
<tr><td></td><td>
<table>
<tr><th>Environment</th><th>Scenario</th><th>Average [MW]</th><th>STDEV [MW]</th><th>MAX [MW]</th></tr>
<tr><td>Urban</td><td>Light traffic</td><td>6.33</td><td>1.07</td><td>12.05</td></tr>
<tr><td>Urban</td><td>Medium traffic</td><td>20.61</td><td>2.18</td><td>31.05</td></tr>
<tr><td>Urban</td><td>Heavy traffic</td><td>30.80</td><td>1.88</td><td>37.50</td></tr>
<tr><td>Interurban</td><td>Light traffic</td><td>3.92</td><td>0.42</td><td>4.75</td></tr>
<tr><td>Interurban</td><td>Medium traffic</td><td>13.39</td><td>0.59</td><td>14.35</td></tr>
<tr><td>Interurban</td><td>Heavy traffic</td><td>20.00</td><td>0.47</td><td>21.00</td></tr>
</table>
The power demand fluctuation can range between 2-8 MW for several times over 5 second periods. This will cause serious problems for the grid, therefore the system should have smoothing equipment to balance the demand to an acceptable level.
</td></tr>
<tr><td>Priority:</td><td>Very high

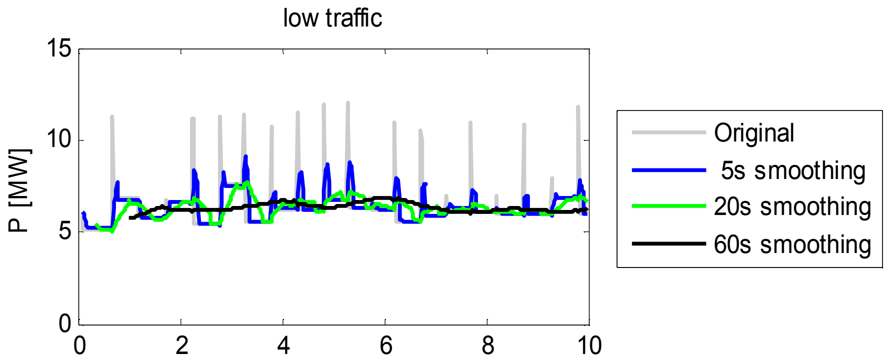
High and fast power peaks are expected to have possible negative impact to the grid. Additional equipment is needed in order to mitigate the impact and reduce installation costs.</td></tr>
<tr><td>Gap:</td><td>It is still unknown, what will be the actual power transfer demand, as it depends strongly on traffic patterns and power transfer infrastructure configuration. Preliminary models indicate that power transfer demand will show high and fast peaks.</td></tr>
<tr><td>Severity of the Gap:</td><td>Power transfer demand models need to be developed in order to study the impact on the grid and also requirements for smoothing options. This has been addressed theoretically in D32.1. Results from test sites will give more information.

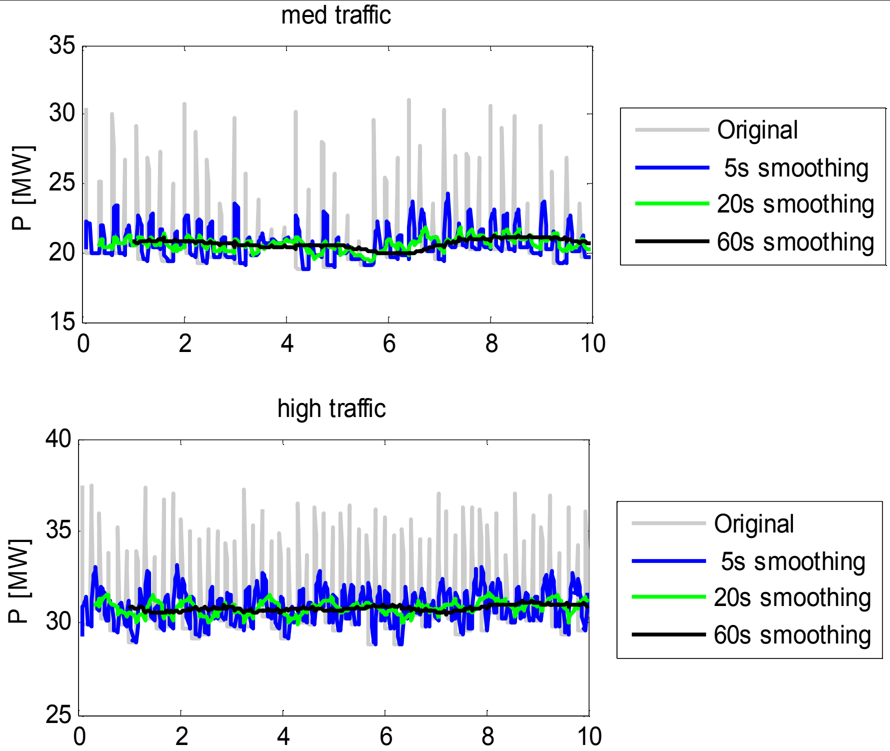
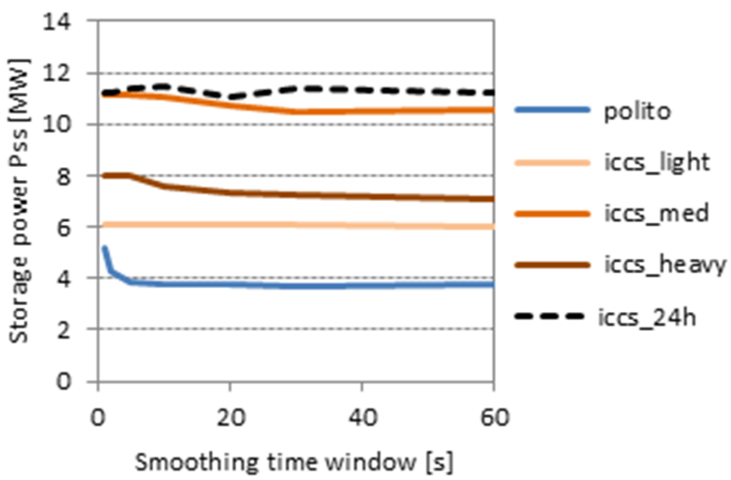
The gap is important, but with traffic coordination and storage systems, there are feasible solutions to the problem, as has been shown in D32.1. Nevertheless, those solutions are still object of development.</td></tr>
<tr><td>Recommendations:</td><td>Design of power transfer infrastructure must aim to reduce power fluctuations. For example, no gaps should be present between power transfer pads. A continuous charging zone benefits the grid but also the vehicle.

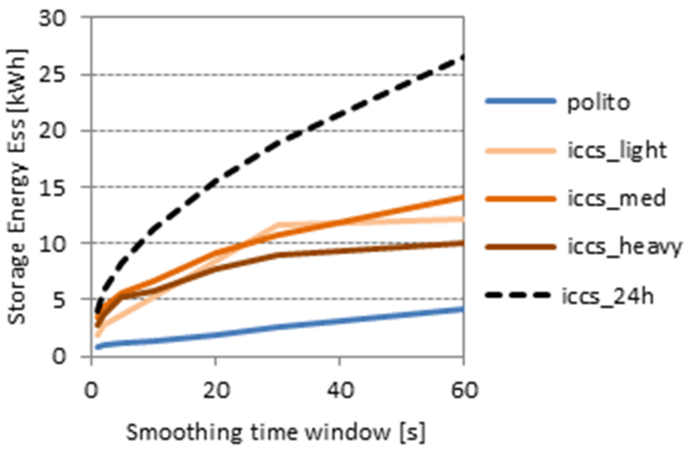
Traffic coordination can reduce fluctuations by creating a continuous</td></tr>
</table>

	flow of vehicles with rather constant headways. Even with traffic control, steep power steps should be smoothed with storage systems, which are ideally connected the DC bus of the power transfer infrastructure, in order to reduce losses. Independently, the charging infrastructure should be able to limit power levels and ramps according to DSO settings (which may vary over the day).
Responsible Party:	Solution provider
Comment:	The need for additional equipment depends strongly on the strength of the grid connection point. The grids of large cities are often quite strong, which means less additional equipment will be needed. Although network congestions may occur, reinforcement might be easy, as distances to the HV grid are short. If the solution is to be installed in a rural environment (inter-urban roads), the cost of reinforcement may be far higher and additional equipment would be sized larger. Every specific case must be studied.

2.4.2 Energy storage system requirements in urban case

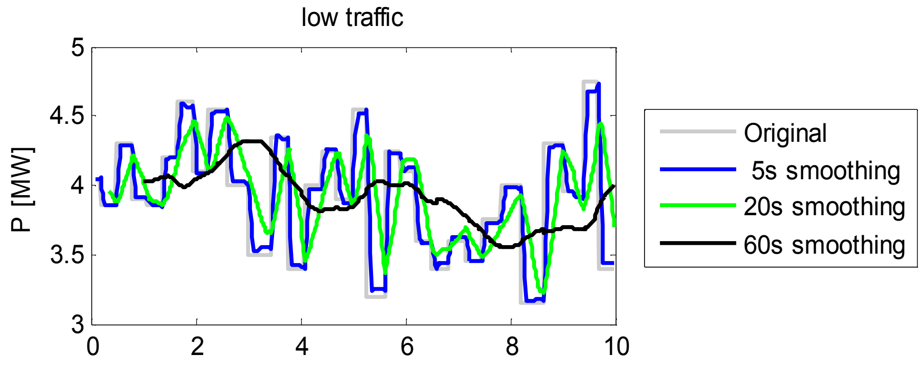
Requirement:	There is a need for energy storage systems to in order to minimise the fluctuations. Smoothing Windows from 1 second to 60 seconds have been tested. 

	 **Figure 7: Charging power demand for urban case (36 km/h) with low, medium and high traffic for different window widths of moving average smoothing.**  **Figure 8: power supply at different smoothing window**

	 **Figure 9: Energy demand for different smoothing windows** 5 second smoothing window captures most of the fluctuations, which corresponds to 11.4MW and 8.2kWh energy storage system. This system has a typical discharge time of 2.6 seconds.
Priority:	**Very high** Storage systems for mitigating fast demand fluctuations are a central objective of FABRIC feasibility analysis.
Gap:	Actual demand patterns are still unknown. Only simplified models are available at the moment (D32.1). As a result, storage requirements are not defined in detail. It is not defined who will own the storage equipment.
Severity of the Gap:	Storage solutions which meet the preliminary requirements do exist, but may be still expensive. Typical discharge times in the range of seconds can be obtained with Supercapacitors and Flywheels which are commercially available. Supercapacitorss may have some advantages as they can be easily integrated at the DC bus, even as passive elements. These solutions will occupy important space, which needs to be taken into account during solution design. Its location will be the grid-tied converter cabinet, where the DC bus is created.

Recommendations:	Storage requirements should be reduced by system design and traffic coordination (see 4.4.1). Storage devices should be integrated at the DC bus of the power transfer equipment in order to reduce losses and simplify its integration. This results in highly distributed storage which makes the solution scalable. As a fully integrated solution, the storage device should be owned by the infrastructure provider.
Responsible Party:	Solution provider
Comment:	Power transfer equipment will be distributed along the road. Therefore, storage devices will be distributed also. As a result, the system is scalable. Units of 100 kVA or more are technical feasible without the need of special developments. If a road of several km is equipped, many of those units may sum up to a total power of several MVA, but this does not compromise the feasibility of each individual unit.

2.4.3 Energy storage system requirement: interurban case

Requirement:	There is a need for energy storage systems to in order to minimise the fluctuations. Smoothing Windows from 1 second to 60 seconds have been tested. 

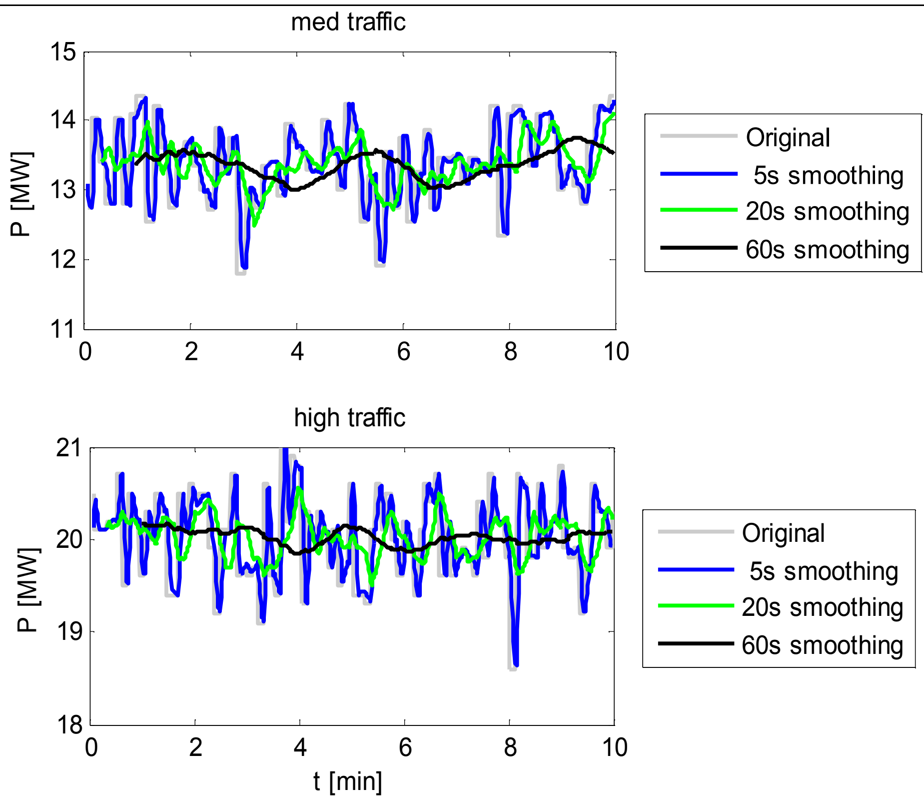


Figure 10: Charging power demand for inter-urban case (108 km/h) with low, medium and high traffic for different window widths of moving average smoothing.

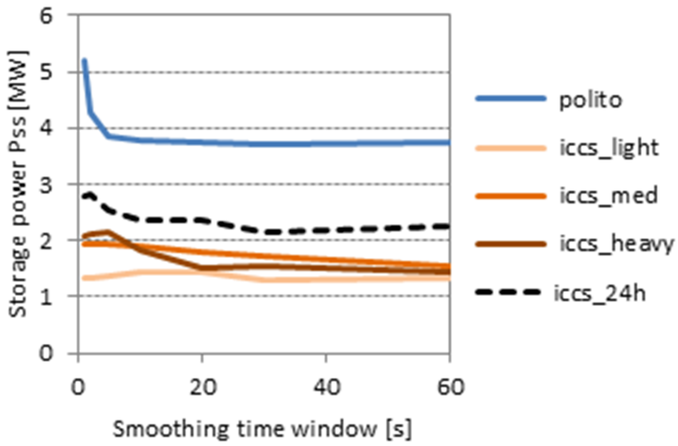
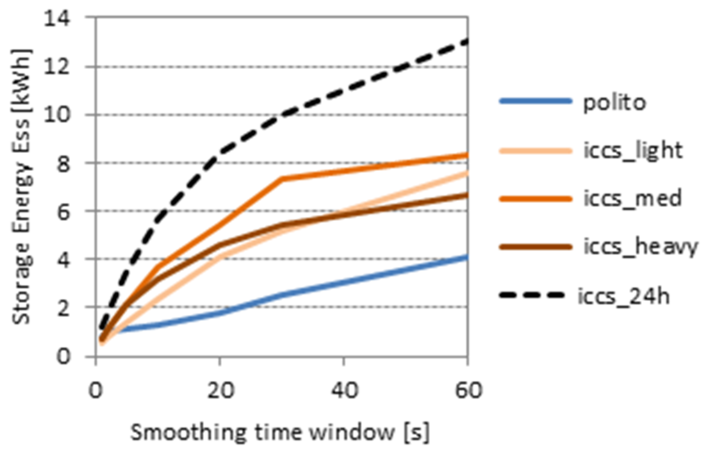


Figure 11: power supply at different smoothing windows

	 Figure 12: energy demand at different smoothing windows In the inter-urban traffic case, fluctuations are much lower hence storage requirement for smoothing is lower. On the other hand, a smoothing window of 60s is needed to obtain some smoothing effect. In this case, the required storage system has to be 2 MW with 8 kWh of energy capacity, which results in a typical discharge time of 20s.
Priority:	**Very High**
Gap:	Further work is required on the specification, design and deployment of energy storage systems for smoothing
Severity of the Gap:	Major work required
Recommendations:	Undertake further research on the use of storage systems, including capacity use of alternative power sources, battery aging etc
Responsible Party:	DSO / Solution provider / independent entity
Comment	

2.4.4 Sizing of a storage system Including solar PV power

Requirement:

Pinst (MW)	Pmax (MW)	Pss (MW)	Ess (kWh)
1	17.2	2.24	12.9
2	17.2	2.24	12.9
5	17.2	2.24	12.9
10	17.2	2.24	12.9
20	17.2	2.24	13.0

Table 7: Daily peak power demand (inter-urban case) and ESS size for 1-min smoothing and different values of installed PV power Pinst (sunny day case).

As shown in Table 8, storage power increases with larger smoothing intervals, reaching 12 MW for 3-h smoothing, up from 2.2 MW for 1.min smoothing. On the other hand, energy capacity is very high, mainly due to the steep ramps in the demand curve. While for 1-min smoothing only 13 kWh where necessary, in case of 3-h smoothing, almost 23 MWh are required.

Smoothing (h)	Pmax (MW)	Pss (MW)	Ess (MWh)
1	16.8	8.0	7.9
2	16.3	11.1	15.5
3	15.9	12.1	22.8

Table 8: Daily peak power demand (Pmax) and ESS size for different large smoothing intervals, assuming 10 MW of installed PV power.

Table 9 Daily solar PV generation and corresponding share of solar energy for self-consumption.

Pinst (MW)	Mean daily solar energy Epv (MWh)			PV share (%)		
	1000 kWh/kWp	1500 kWh/kWp	2000 kWh/kWp	1000 kWh/kWp	1500 kWh/kWp	2000 kWh/kWp
1	3	4.5	6	1.4	2.1	2.8
5	14	21.0	28	6.8	10.2	13.6
10	27	40.5	54	13.5	20.3	27.0
20	55	82.5	110	27.0	40.5	54.0

	The results show that significant amounts of energy can be generated by a well-sized solar PV installation. In this case, 10 MW PV power in Spain can supply 20% of the demand over one year period. This installation doesn't need additional storage for self-consumption, as generation peaks are below demand levels. If installed power is increased to 20 MW, the solar share implies some net-metering scheme or additional storage in order to avoid back-feeding of energy to the grid.
Priority:	**Low/Medium** The preliminary study in D32.1 show that integration of distributed solar PV generation is an interesting option, because traffic intensity is similar to sunlight patterns. This means that when cheap solar power is available, there will be probably also demand for it as many vehicles are circulating during daylight hours. Nevertheless, this is an additional and optional scenario which is not decisive for the feasibility in general. Also, maximum power demand cannot be reduced, as solar power is not always available. The main interest of this scenario is to show the compatibility of generation and demand and show that typical power transfer demands are favouring the integration of solar PV.
Gap:	Solar PV is state-of-the-art technology which is able to produce cheap energy. Nevertheless, its integration at the DC bus of high power equipment is not a common solution. No demonstration systems exist. In urban areas, there may be not enough space for large solar systems which are directly integrated in the system. Nevertheless, existing distributed solar generation may be beneficial in order to support the additional demand. Storage for smoothing fluctuations of solar generation is typically large battery systems which may be uneconomical. Nevertheless, battery costs are expected to go down and take up of EVs will produce a large amount of second life batteries at very low cost which can be integrated.
Severity of the	DC integration of solar PV is easy. Although special DC/DC converters must be developed, the technological feasibility is given. Costs are lower because

Gap:	DC/DC converters are cheaper than AC/DC.
Recommendations:	Such as storage, solar PV generation should be distributed and integrated at the DC bus of the power transfer infrastructure.
Responsible Party:	DSO / Solution provider / independent entity Depending on the business model, any entity may be the owner of the solar PV system.
Comment:	In principal, solar-battery systems are fully market ready and no gap is identified from a technological point of view. Nevertheless, the application studied here is new and the entire control system must be designed and tested.

3. LOCAL AUTHORITIES AND TRANSPORT SYSTEMS

3.1 Policy

3.1.1 Transport plans

Requirement:	Policy-Compliance with Local Transport Plans (LTP)-UK {See also Sustainable Urban Mobility Plans (SUMPs)–Europe}. Local Transport Authorities (LTAs) must demonstrate their support for following five national goals: • Supporting economic growth; • Reducing carbon emissions; • Promoting an equality of opportunity; • Contributing to better safety, security & health; and • Improving the Quality of Life and a healthy natural environment.
Priority:	**Very high**
Gap:	A sample of LTPs does not indicate specific references to inductive charging, but do refer to greener travel. So the gap is that the local transport plans do not have specific plans for ion road power transfer. This could be due to very little knowledge about the solution, requirement of large infrastructure projects and high costs associated with the infrastructure.
Severity of the Gap:	The severity "Major work required" to meet the requirements and innovative business cases are needed to compensate for a high cost of infrastructure and complexity of the projects. The policies and incentives can be specifically aimed at road electrification at national level, rather than local authority level.
Recommendations:	• Innovative business cases • Policies and incentives specifically aimed at on road electrification • Government support at national level for the on-road power transfer installation

Responsible Party:	Government, Local Authorities, solution providers
Comment:	

3.1.2 Economic and financial planning

Requirement:	The requirements for an on-road charging system are: • The cost of the system should be calculated, • The government should provide initial financial support and incentives to kick start large scale deployment. • The monetisation options should be considered and a feasible business plan should be proposed.
Priority:	**Very high**
Gap:	All of the on-road power transfer solutions are currently in their development stage and therefore there is no clear indication of the total cost of the system. It is not clear who will fund the costs of on-road power transfer systems - the government and/or the private sector
Severity of the gap:	Innovative method needed
Recommendations:	• The government should include on-road power transfer into its decarbonisation policy. • The funds should be allocated to on-road electrification and the government should have a long term policy. Solution providers must provide possible costs for the installation and maintenance of the systems.
Responsible Party:	Government, Solution Providers,
Comment:	

3.2 Regulatory

3.2.1 Signage

Requirement:	The requirements indicate the need for an internationally recognisable signage for on-road power transfer infrastructure
Priority:	**Medium**
Gap:	No current set of iconography exists for on-road power transfer infrastructure
Severity of the gap:	Need for further development
Recommendations:	Support existing work on signage standardisation
Responsible Party:	United Nations Economic Commission for Europe Ministries for Transport
Comment:	

3.3 Guidance

3.3.1 Infrastructure design, planning and construction

Requirement:	The solutions and installation should be in compliance with infrastructure planning and construction tools (e.g. the Design Manual for Roads & Bridges [DMRB]).
Priority:	**Medium**
Gap:	It is not clear if new institutional bodies will be required for the regulation, security and safety arrangements of the EV infrastructure either nationally or locally
Severity of the gap:	Need for further development
Recommendations:	There is a need for further development to update the infrastructure, planning & construction tools. (N.B. - Some updates can be made in the form of Interim Advice Notices for highways and trunk roads

	[IANs]). The regulatory bodies should fully understand the impact of installation, integration and management; this may require working in collaboration with the stakeholders to redefine the requirements.
Responsible Party:	Various transport organisations/agencies (UK-Department for Transport, England-Highways Agency, Scotland - Transport for Scotland, Wales - Welsh Government, Northern Ireland - Department for Regional Development Northern Ireland)
Comment:	

3.3.2 Guidance from central government

Requirement:	The government should produce a guideline to address the points stated below in relation to on-road power transfer in order to increase the length of the electrified road and encourage EV take up. The guideline should aim: • To help local and city authority officers interpret advice in a practical manner; • To provide advice and information to authorities; • To direct authorities to pursue specific policy initiatives; • To provide a framework for assessing authority performance; and To ensure consistency between different tiers and types of authority
Priority:	**High**
Gap:	There is little current guidance from government regarding on-road power transfer infrastructure. This guidance is either currently unwritten or unfinished.
Severity of the gap:	Need for further development
Recommendations:	Central government must first publish guidance documentation

	before compliance can be achieved. For this to happen, the government should work with stakeholders to develop guidance to promote policy, implementation and good practice. New infrastructure is likely to impact property owners along the proposed roads; therefore local authorities should also be involved in the development of the guidance to minimise the adverse impacts of the installation process and operation on local residents
Responsible Party:	Government, Local and City authorities.
Comment:	

3.3.3 Compliance with Manual for Streets (MfS)

Requirement:	EV infrastructure should be in compliance with; • Street furniture; • Crossings (raised or otherwise, tactile paving); • Impedance of pedestrian footways; and • Surfacing of footways.
Priority:	**Medium/high**
Gap:	The Manual for Streets does not consider on-road power transfer solutions.
Severity of the gap:	Need for further development
Recommendations:	Clearly define their requirements for the size of the road side infrastructure, suitable locations in the street, health and safety requirements and connections to the grid.
Responsible Party:	Local Authorities, Transport Ministry and Solution providers
Comment:	

3.4 Technical

3.4.1 Installation

Requirement:	The solutions should consider road users (motorists) and non-motorists when undertaking roadwork's to install the equipment in urban areas. The infrastructure, deployment method and the proposed programme should be in compliance with the most up to date road works practices
Priority:	**Medium**
Gap:	There are no current implementation plans for installation of power transfer solutions.
Severity of the gap:	N/A
Recommendations:	Development of roadwork's plans
Responsible Party:	Road owners, distribution operators, contractors
Comment:	

3.4.2 Physical design constraints

Requirement:	The equipment must be able to be used on almost anywhere on the road network, which means it must comply with existing infrastructure. Examples of physical & design constraints:- • Fixed building lines; • Shallow services and utilities; • Extensive and unmapped statutory undertakers equipment (on road and way side locations); • Conflicts over allocation of space and priority from a wide number of users; • Access to property; • High cost of remodelling or rehabilitation of streetscape; • Maintaining service access.
Priority:	**Medium/High**

Gap:	The constraints for the installation of power transfer systems have not been identified and the points stated above have not been considered at this stage of the system development
Severity of the gap:	N/A
Recommendations:	Define constraints based on location
Responsible Party:	Solution providers
Comment:	

3.4.3 Protection of power transport equipment

Requirement:	The on-road infrastructure will be safely located under the ground. However in flush systems road systems road side equipment could be at risk of vandalism and theft; therefore the power transfer equipment should be protected from malicious damage.
Priority:	**Low**
Gap:	The protection from theft and vandalism has not yet been considered
Severity of the gap:	Need for further development
Recommendations:	Use of anti-theft paint
Responsible Party:	Solution providers
Comment:	

3.5 Integration

3.5.1 Compatibility with public utilities and electricity supply

Requirement:	The on-road power transfer solution should integrate into the road and it should be compatible with public utilities and the electricity supply, including safety, dimensions, power requirements,

	interference etc.
Priority:	**High**
Gap:	The gaps are: • No safety standards as equipment is currently only in prototype form; • Dimensions are known for some charging equipment, but utilities are often located at unknown depths and infrequent intervals; • Power requirements vary per unit; • Interference with other electrical supplies is unknown. (see also Grid Requirements); and • Interference with signalling systems etc. is unknown.
Severity of the gap:	
Recommendations:	There is need for major development in order to meet the requirements; the gaps can be closed by taking following measures: • Examine existing requirements for the utility supply i.e. space/clearance required. • Make use of 'Grid requirements' section (chapter 2) to establish whether supplying power to power transfer units could overload the grid (at local and national level i.e. is more power generation required). • Ensure that safety requirements are met and testing undertaken before user interaction e.g. EMF effects, public interaction with electricity supply etc. • The distribution operator should state the spare capacity in their network and state whether the capacity can meet the demand from the power transfer infrastructure; the distribution operator should also recommend alternative connection solutions if it proves to be lower cost, more efficient and/or where it can meet the demand
Responsible Party:	Utility providers are responsible for providing information on feeder locations; however these gaps require collaborative working of road operators, solution providers and distribution network operators.
Comment:	

3.5.2 Communications between stakeholders

Requirement:	Examples of physical & design constraints are:- • Extensive and unmapped statutory undertakers equipment (on road and way side locations); • Conflicts over allocation of space and priority from a wide number of users; • Variety of players, influencers and interested parties
Priority:	**Medium**
Gap:	Each party is likely to lack communication channels to exchange information
Severity of the gap:	Need for further development
Recommendations:	Develop communication channels to exchange information with all other stakeholders.
Responsible Party:	Solutions Providers
Comment:	

3.5.3 Operation

Requirement:	The solutions should consider the impact of power transfer infrastructure on cyclists or motorcyclists whom may share a lane with inductively charged vehicles. Therefore the system: • Must work at the speed of a cyclist (low) (i.e. if a vehicle is following a cyclist). • Must not affect other users in any way (see also EMF Safety)
Priority:	**High**
Gap:	The solutions have not been tested in built up areas
Severity of the gap:	Major work Needed

Recommendations:	The systems should be designed to operate at all speeds, which may require solution providers to include additional subsystems to monitor the speed and retune the power transfer circuit to provide maximum power.
Responsible Party:	Solution providers
Comment:	

3.5.4 Managing congestion & traffic flow

Requirement:	On-road power transfer infrastructure would need to be compatible and should; • Not interfere with the existing traffic management system; this could restrict the installation of on road power transfer infrastructure near any junction that has traffic signals. • Be compatible with junction sensors & systems. For example, SCOOT traffic light control has most detection and cabling within 20m of junctions, but a typical set up is only at ~50% of junctions. MOVA control has a detection sensor on the stop line and two more about 3.5s and 8-9s journey times from this point. • Consider the max/min vehicle speeds when using inductive charging lanes i.e. will vehicles hold up other users (e.g. in dual purpose bus/taxi/cycle lanes). (See also the impact on other road users). Additionally, will the number of WPT vehicles eventually clog these lanes?
Priority:	**Medium**
Gap:	The solutions have not been tested in the presence of traffic management sensors, and the impact of on-road power transfer infrastructure on traffic management sensors is unknown
Severity of the gap:	N/A
Recommendations:	There is a need for further development; the solution providers and infrastructure owners must;

	• Develop a test plan to investigate the impacts of charging infrastructure on traffic sensors; • Develop solutions to minimise or eliminate the effects; • Develop standards and regulations to minimise or eliminate the effects; • Investigation the tolerances needed to be undertaken. MOVA junctions may not be able to have a charging plate/unit at the stop line; • Investigate the capacity of roads at various speeds/vehicle mix, identify capacity for various road types; and Identify equipment's capability to meet the maximum requirements
Responsible Party:	Solution provider and Road operator
Comment:	

4. VEHICLE REQUIREMENTS

4.1.1 General standards and guidelines

Requirement:	• ISO 19363 • IEC 61980 • SAE J2954
Priority:	**Medium**
Gap:	Majority of the on-road power transfer solutions standards are not published, there is gap in standard development as well as equipment meeting standards.
Severity of the Gap:	Need for further development
Recommendations:	It is recommended that the standards for on-road power transfer should be published soon as possible.
Responsible Party:	Vehicle Manufacturer, solution provider, standards agencies
Comment:	

4.2 Operation needs and requirements

4.2.1 Power

Requirement:	The requirements suggest that the power demand required to maintain a constant cruising speed from a car or LGV at speed range of 70-80km/h should be between 20-30 kW. Power demand from an HGV at 70-80km/h is approximately 125 kW.
Priority:	**Very High**
Gap:	Existing on-road power transfer solutions provide power between 20-100kW, therefore the power transfer units meet the vehicle traction demand for light vehicles but the demand from heavy vehicles are too high for the supply

Severity of the gap:	Innovative development
Recommendations:	There are number of solutions to improve power transfer rate, one of which is the reduction in air gap between primary and secondary coil. This will require optimisation of the system design. There could be a limitation on minimum distance between the road surface and the vehicle, so the solutions should not breach existing standards and regulations.
Responsible Party:	Solution Providers
Comment:	

4.2.2 Efficiency

Requirement:	The power transfer efficiency, defined from AC grid side to the vehicle DC side, shall be higher than 85% for the private cars and LGV. For the HGV a lower efficiency (80%) could be considered given the higher power value (>200kW), although this will exacerbate heat management issues.
Priority:	**Medium/High**
Gap:	Majority of the on road systems do not meet this requirement at this stage. The efficiency of the test systems is approximately 70-75%
Severity of the gap:	Major work required
Recommendations:	Need for further development
Responsible Party:	Solution Providers
Comment:	

4.2.3 Frequency

Requirement:	The frequency used for power transmission should be in the

	induction band: 10 kHz to 150 kHz
Priority:	**Very high**
Gap:	The solutions meet the requirement
Severity of the gap:	Innovative development
Recommendations:	The increase in frequency is only possible with innovative methods to contain the magnetic fields within a restricted area, while the vehicle is in motion. The electronics also have to be developed to ensure the efficiency gained due to frequency increased is not lost in other parts of the system due to switching losses, skin effect in conductors etc.
Responsible Party:	Solution providers
Comment:	

4.2.4 Battery voltage

Requirement:	There are requirements on voltage levels on the vehicles, usually be based on safety aspects, these requirements are; • Typical voltage range for a car or LGV is between150V and 400V • Typical voltage range for HGV is higher than 400V
Priority:	**Medium**
Gap:	The voltage on secondary coil could be higher than 400V, to increase the power transfer rate. However the batteries can be designed to operate at below 400V, the voltage limits for the pickup coils needs to be clear
Severity of the gap:	
Recommendations:	The voltage level on the output of the secondary coils needs to be clarified via guidelines or standards. There is a trade-off between power transfer rate and voltage, higher induced voltage would result in higher power transfer, and however the batteries for the light

	vehicles are required to be below 400V.
Responsible Party:	Solution providers ,vehicle manufacturers
Comment:	

4.3 The battery

Requirement:	• The existing electric vehicles have an installed battery pack energy capacity from 20 to 30kWh which provides a range between 150-200km on real world conditions • For the light commercial vehicles shorter range could be acceptable for specific missions, for example urban goods delivery in traffic within limited range of less than 100 km could be considered as sufficient range. • Light commercial vehicle with a cargo compartment (up to total mass of 3.5 ton), energy capacity must be at least 40 kWh.
Priority:	**Medium**
Gap:	• State of the art electric cars usually contain battery capacity between 20-30 kWh, • The higher battery capacity should consider integration to the vehicle. It could be possible to integrate 40kWh battery to the light commercial vehicle
Severity of the Gap:	Need for further development
Recommendations:	The batteries are still very heavy, for example Nissan Leaf 24kWh (21kWh available) weights 294 kg. The energy density of the batteries must be improved. However the battery development no in the scope of this project.
Responsible Party:	Vehicle manufacturer
Comment:	

4.3.1 The pickup coil

Requirement:

In the current standard developments for the wireless power transfer (IEC 61980) the maximum mechanical size of the secondary device are defined as function of the power transfer classes as shown in the table below:

Table 10: Mechanical size of the secondary device

Power class	**MF-WPT1 (<3.7kW)**	**MF-WPT2 (3.7 to 7.7kW)**	**MF-WPT3 (7.7 to 22kW)**
Direction			
X(direction of travel)	350mm	600mm	750mm
Y (transverse)	300mm	450mm	600mm
Z (height)	22mm	22mm	35mm

Priority: **Very high**

Gap:

Parameter	**CWD**	**IPV**	**Volvo**	**Scania Primove**	**UNPLUGGED**	**KAIST**
On-vehicle equipment Dimensions	70x30 cm (20kw)	180x100 cm (100kW)	50x150x50 cm (120kW conductive)	200x100 cm (200kW)	29 x 33 cm (3.7 kW)	80*170*8 cm (100 kW)
Weight			80 kg plus 40kg power electronics	330 kg plus 60kg power electronics		80 kg per coil (20-25kW per coil) plus weight of

<table>
<tr><td></td><td><table><tr><td></td><td></td><td></td><td></td><td></td><td></td><td>power electronics</td></tr></table>
The system are within specified values, but integration of large power system (100 kW) onto a light commercial vehicle could be mechanically difficult, there may not be space available under the vehicle to integrate 100x200 cm equipment. Also the weight of the coil system is very high, as shown above 100 kW pick up coil weighs greater than 320kg</td></tr>
<tr><td>Severity of the Gap:</td><td>Need for Innovation</td></tr>
<tr><td>Recommendations:</td><td>The state of the art secondary coils are within specified values, but integration of large power systems (100 kW and over) onto a commercial vehicle could be mechanically difficult, for example there may not be available space under the vehicle to integrate 100x200 cm equipment. Also the weight of the coil system is very high, as shown above 100 kW pick up coil could weigh up to 320kg possibly more.

Even though dimensions meet the requirements, very high power systems are not feasible to be installed in a car due to its dimensions and the weight. Therefore the solution providers must reduce the weight and the dimensions of the system in order to enable high power transfer to the vehicles.</td></tr>
<tr><td>Responsible Party:</td><td>Solution Providers</td></tr>
<tr><td>Comment:</td><td></td></tr>
</table>

4.3.2 General requirements

Requirement:	The following minimum set off parameters need to be taken into account:

Environment
  - Temperature operating limits
  - Cooling requirements
  - Vibration
  - IP-classification
- Electrical installation
  - Electrical Operating Range
  - Electromagnetic Compatibility
  - Inputs
  - Outputs
  - Supply and Fuses
  - Cable harness, power and signal connectors
  - Insulation resistance
- Control
  - CAN communication with in vehicle ECUs (internal status, measurements, fault codes, enable/disable command, power/current request/limits, etc.)
  - Wireless communication with the primary on-road power transfer device (status, received power/energy, operating frequency etc.)
  - Current source behaviour with closed loop current control done by the in-vehicle secondary device (AC/DC)
  - Variable current/power regulation
  - Fault detection, recovery actions and system information

Priority:	**High**

Gap:

Parameter	CWD	IPV	Volvo	Scania	KAIST
Operating temperature limits		55	85		-30- 70
Cooling requirements					
Vibration					

IP-Classification					
Electrical operating Range					
Electromagnetic compatibility			Expected to meet	Below 6.25uT EM exposure Meets Harmonic standards	Meet ICNIRP
Inputs	400 C	400V	750	10kV	380-440 V
Outputs	600 VDC			750 VDC	
Supply and Fuses	34A		175A	400A	200A
Cable Harness, Power and Signal Connectors					
Insulation Resistance					
CAN communication within the vehicle	CAN on Wi-Fi		Vehicle to power box		
Wireless Communication to the Primary	WLAN		Power box to the APS		

	power transfer infrastructure.			cabinet		
	Current source behaviour with closed loop current control					
	Variable current and power regulation					
	Fault detection					
	Recovery actions					
	System information					
Severity of the Gap:	Need for further development					
Recommendations:	Ensure above issues are taken into account on development					
Responsible Party:	Vehicle manufacturers, solution providers					
Comment						

5. EMF SAFETY REQUIREMENTS

5.1 Protection from electromagnetic field: Health and safety

Requirement:	The solutions are expected to meet following guidelines: • IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz, IEEE Std. C95.1-2005 • Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (Up to 300 GHz)", ICNIRP Guidelines, International Commission. • Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz - 100 kHz). Health Physics 99(6):818-836; 2010. • IEC62311: Assessment of electronic and electrical equipment related to human exposure restriction for electromagnetic fields (0Hz 0 300 GHz).
Priority:	**Very High**
Gap:	There are no standards to regulate EM exposure, and as the solutions are still in their development stage, the EM exposure is not fully controlled in dynamic solutions. The solution providers are responsible to design their system to meet the guidelines. Governments are responsible to explore the effects of EM exposure from wireless on-road power transfer solutions and the standards bodies are responsible to draft standards and regulations to limit the EM exposure based on results from the research
Severity of the gap:	Major work required
Recommendations:	Control of magnetic exposure can result in fundamental design changes, therefore the solutions potentially require major development in order to meet close this gap. The EM exposure could require changes or developments in frequency, voltage,

	coil/loop length, cable type, shielding and magnetic field shaping.
Responsible Party:	Solution providers, Standards agencies

5.2 Electromagnetic compatibility (EMC) requirements

5.2.1 Electromagnetic compatibility (EMC) requirements - on vehicle

Requirement:	• ISO 11451 - Road vehicles - Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy • ISO 11452 - Component Test Methods for Electrical Disturbances in Road Vehicles Package • CISPR 12 - Vehicles, boats and internal combustion engine driven devices - Radio disturbance characteristics- Limits and methods of measurement for the protection of receivers except those installed in the vehicle/boat/device itself or in adjacent vehicles/boats/devices • CISPR 25 - Vehicles, boats and internal combustion engines - Radio disturbance characteristics-Limits and methods of measurement for the protection of on-board receivers
Priority:	**Medium**
Gap:	The solutions should meet the requirements if they are to be installed in vehicles for public use. It is not possible to evaluate on-board EMC at this point as the power transfer solutions are not available to be integrated into the vehicles.
Severity of the gap:	need for development
Recommendations:	The on-board solutions should meet the standards at component and vehicle level, the testing should be carried out on both cases. The EMC aspects should be considered from the design phase

	through virtual analysis to validation.
Responsible Party:	Vehicle Manufacturer ,Solution provider

5.2.2 Electromagnetic compatibility (EMC) requirements - off vehicle

Requirement:	IEC 61980-1 - Electric road vehicle-Electric vehicle wireless power transfer (WPT) systems
Priority:	**Medium**
Gap:	Not possible to evaluate today because we don't have the final charging solution devices available, but these aspects have to considered during the design phase through virtual analysis and validation.
Severity of the gap:	Need for further development
Recommendations:	
Responsible Party:	Infrastructure manufacturer – Must ensure that this standard for wireless power transfer is met

5.3 Electrical Safety Requirements

5.3.1 Electrical safety requirements - on vehicle

Requirement:	• ECE R100 - Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train • ISO 20653 - Degrees of protection (IP code) -- Protection of electrical equipment against foreign objects, water and access • ISO 6469-2 - Electrically propelled road vehicles -- Safety specifications -- Part 2: Vehicle operational safety means

	and protection against Major work requirements • ISO 6469-3 - …Part 3: Protection of persons against electric shock • ISO 23273-3 - Fuel cell road vehicles -- Safety specifications -- Part 3: Protection of persons against electric shock • SAE J2344 - Guidelines for Electric Vehicle Safety • SAE J2578 - Recommended Practice for General Fuel Cell Vehicle Safety
Priority:	**High**
Gap:	Expected to meet the requirements
Severity of the gap:	Further development needed
Recommendations: **What needs to be done to meet requirement?**	Most of the on-road power transfer solutions meet these requirements, but the solution providers that do not should identify the standards that their solution fails to meet. Solutions providers are responsible to meet these standards, and the vehicle manufacturers should approve the equipment prior to vehicle integration.
Responsible Party:	Solution Providers, Vehicle manufacturer

5.3.2 Electrical safety requirements - off vehicle

Requirement:	• IEC 60364-7-726 – Electrical Installations for buildings – Part 7 Special Installations • ISO 20653 - Degrees of protection (IP code) -- Protection of electrical equipment against foreign objects, water and access • IEC Guide 117 - Electrotechnical equipment - Temperatures of touchable hot surfaces • IEC 61439-1 - Low-voltage switchgear and control gear assemblies - Part 1: General rules • IEC 60364-4-42:2010-05 - Low-voltage electrical installations - Part 4-42: Protection for safety - Protection against thermal effects

Priority:	**High**
Gap:	Most of the current on road power transfer solutions meet these requirements
Severity of the gap:	Further development needed
Recommendations:	The solutions are expected to take necessary steps to protect public from direct contact or thermal incidents. However, the solution providers are expected to meet the standards for electrical safety.
Responsible Party:	Solution Providers

5.4 Dynamic conductive charging for HGV

Requirement:	DD CLC/TS 50502:2007 - Railway applications. Rolling stock. Electric equipment in trolley buses. Safety requirements and connection systems
Priority:	Medium (but only if the system is an overhead charging system)
Gap:	Not clear if standards are being adhered to
Severity of the gap:	N/A
Recommendations:	Ensure standards are followed on development
Responsible party:	Infrastructure manufacturer – Must meet requirements, but these currently only apply to railway type application such as trolley-buses.
Comments	