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2018SP04EN

ELECTRIC ROAD SYSTEMS: A SOLUTION FOR THE FUTURE?

A PIARC SPECIAL PROJECT

WORLD ROAD ASSOCIATION
MONDIALE DE LA ROUTE
AIPCR PIARC

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International Standard Book Number: 978-2-84060-496-9

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PIARC and TRL would like to express their deepest appreciation to all those who provided inputs, time and data for this project. We thank all those that took the time to complete our online questionnaire, participate in workshops and interviews. In particular, we thank: Trafikverket, Highways England, Sanef Group, Uganda National Roads Authority, SANRAL, IMT, Scania AB, Siemens AB, Dongwon Inc, Alstom Group, Electreon, BASt, J-N-J Miller Design PLLC, Oxford Policy Exchange, the UK Department for International Development, M. Lamb Consulting, and all those who provided permissions, data, and shared their experiences of ERS with us.

EXECUTIVE SUMMARY

2018SP04EN

ELECTRIC ROAD SYSTEMS: A SOLUTION FOR THE FUTURE?

It is looking increasing likely that electric vehicles will play a major role in the future of road transport. While commercial electric vehicles exist their uptake has been limited due to high purchase costs, limited battery range, and a lack of charging convenience. Furthermore, while developments are underway, electric and hybrid drive trains are yet to be efficiently integrated with heavy goods vehicles (HGVs). A novel way to overcome such challenges are Electric Road Systems; a branch of technologies that allow vehicles to charge while in motion. Limited information exists regarding the comparative performance of ERS solutions, market readiness, costs, and implementation issues. To this end, the World Road Association (PIARC) commissioned TRL to undertake a state-of-the-art review and feasibility study of ERS concepts; focusing on ERS implementation from the perspective of a road administration.

The study had three interlinked phases:

(1) state-of-the-art review and stakeholder engagement,

(2) technological and implementation feasibility assessment, and

(3) exploring the business model for ERS uptake.

A review of stationary charging and other alternatives to fossil fuel propulsion technologies was also undertaken. The study adopted a global perspective, engaging with key stakeholder (road administrations, researchers, ERS developers, freight industry) from countries across the economic spectrum through an online survey and interviews with relevant experts. This informed the review, highlighting stakeholder views on benefits, limitations and barriers to development/implementation. A total of 17 viable ERS systems were identified. These are split into three categories: inductive (wireless); conductive rail; and conductive overhead. The majority of inductive ERS have a technology readiness level (TRL) between TRL3-4; with few systems advancing beyond TRL6. Conductive counterparts are more mature, typically between TRL4-5, with some systems between TRL6-8. All three types of ERS are undergoing road trials of some form, with rapid advancements in the last 5 years.

All three concepts are technologically feasible, providing comparable and unique advantages/limitations. For instance, conductive systems are more able and ready to support the power requirements of heavy goods vehicles. Whereas inductive ERS are generally more suited to vehicles with lower power requirements and cannot deliver at efficiencies equal to conductive systems. Risk assessments of each technology were undertaken, with results suggesting the majority of risks are ‘low to very low’. Conductive rail solutions however were inherently more risky due to: the presence of an open live conductor on high speed roads; and their impact on road maintenance activities. Concerns arise over the impact of any type of system that is integrated into the pavement structure, regarding durability, future maintenance and safety. Interoperability, within and across ERS categories does not currently exist.

Stakeholder engagement results suggest that despite uncertainties regarding ERS performance and barriers to implementation, the majority viewed the technologies positively and believed that ERS would be key to decarbonising road transport. Approximately half of the survey participants were actively involved in ERS research (from desktop studies to road trials). The majority of research is being undertaken in Europe, South Korea, Japan and the USA. Discussions with road administrations and developers emphasised that different ERS concepts should be viewed as solutions for given scenarios, rather than as ‘rivals’. Instead, the overall aim of all solutions is to better improve the sustainability of road transport networks and mitigate current levels of environmental impact. Stakeholders identified freight industry and public transport operators to be the likely first adopters of ERS. Stakeholders identified the key barriers to implementation as being high capital cost (for installation, maintenance and administration), alongside the risks associated with relatively immature technology. A key message from stakeholders was that government support is critical to ERS development and in addressing industry concerns.

As part of the study, a workshop was held, with relevant experts, to discuss potential implementation challenges of ERS in Low and Middle Income Countries (LMIC). Regarding installation, the following challenges were identified: existing infrastructure construction type, fleet composition, lack/availability of skills and resources, and limited grid infrastructure and capacity. However, LMIC have some unique opportunities, such as combining the construction of both new roads and grid infrastructure with ERS installations. The overall consensus from the workshop was that ERS would have to be established first in high income countries before it could be realistically considered for implementation in LMIC. Also, given the high capital costs associated with ERS and the many other priorities in LMIC that require investment and support, ERS is not likely to be installed in the near future. It may be possible in the long term that ERS could be installed on transnational freight routes if external funding was made available.

The bulk of current research is focused on functionality and installation. However other aspects required further attention, such as economic viability and the development of attractive business models. The study presents a UK specific cost-benefit analysis for a case study motorway. Assumptions, based on Phase 1 and 2 findings, were made on installation prices, technology take-up, and vehicles types suitable for ERS concepts. The results suggested that some types of ERS could be economically viable with sufficient electricity mark-up and technology penetration. However, there needs to be a clear understanding of who the main customer basis is. The ERS concept type affects the potential market, as the conductive overhead system can only be used by taller vehicles such as HGVs and buses, whilst in-road systems could be used by both light vehicles and HGVs. However, for light vehicles, ERS would be competing with other charging solutions; it is likely that private EV owners will use mainly plug-in or static charging solutions. Advances in other low carbon technologies, such as bio-fuels, fuel-cells, and electric batteries may also influence the take-up of ERS. As yet there is no clear evidence to suggest that it would either promote or limit ERS implementation. With respect to delivery, it is still unclear as to where the responsibility for ownership and operation of ERS technology should fall. It seems most likely that some form of private public partnership would be needed for implementation. This will require modifications to the existing regulatory framework and concessions between road administrations and operating contractors.

Overall the study concluded that ERS has the potential to play a major role in the decarbonisation of road transport, but in the short term is most likely to be adapted by specific parties to meet localised needs rather than a universal solution.

Recommendations for road administrations are provided in two stages:

(i) intermediate steps for ERS implementation which include: identifying potential routes for ERS implementation; identifying relevant standards and policy that require modification in order to plan future integration; to participate in international forums and technical committees; and to share knowledge with international road administrations and research organisations;

(ii) long term objective should be to support and take part in road trials that aim to better understand the benefits and impacts of ERS for a given transport network.

NRAs in LMIC should continue to monitor developments in ERS; engage in international discussions; identify country specific challenges; and consider ERS solutions in future green-fund opportunities, particularly for new road construction and on international freight corridors. It was also suggested that PIARC could support its members by seeking opportunities to partner with other key stakeholders and co-hosting an international conference on ERS development; establishing an alternative fuel task force in the next work cycle; and representing road administrations in global discussions on ERS.

CONTENTS

1. INTRODUCTION

1.1. PROJECT BACKGROUND

In order to keep the global temperature rise below 2°C and avoid the most severe climate change, it was estimated by the Intergovernmental Panel on Climate Change (IPCC) that world-wide emissions of greenhouse gases (GHGs) must be cut by 40% to 70% by 2050 compared to 2010 levels[164] As transport, particularly road transport is a major contributor of GHGs there is a clear need for accelerated introduction of Low Carbon Vehicles. Although government policies are technology neutral and focus on supporting any technologies that are able to meet their objectives, particular attention has recently been placed on electrified vehicles. For example, the European Commission Directive on the deployment of alternative fuels infrastructure[165] has particularly high targets for Electric Vehicle (EV) charging infrastructure. At the same time, many of the world's leading automotive manufacturers are making significant long-term investments into electro-mobility, which are indicative of a growing and maturing market. EVs are being increasingly viewed as having a key role to play in both reducing global carbon emissions and improving local air quality.

Whilst recent improvements have increased battery range and decreased charging time, these remain concerns for users, deterring uptake. One method of addressing this is by utilising dynamic charging or Electric Road Systems (ERS). ERS is defined as a system that provides dynamic electric vehicle charging through either conductive or inductive (wireless) means for various types of vehicles on roads and highways. Dynamic on-road charging also enables the use of electric powered Heavy Goods Vehicles (HGVs) which is currently not feasible with statically charged battery technology (although vehicle manufacturers are working on this). There are a number of different types of ERS technology being developed and trialled, all of which will require the participation of the road infrastructure owners for deployment. Note that for this study, HGVs are defined as commercial vehicles that have a gross vehicle weight (GVW) of over 3,500 kg. Vehicles less than 3,500 kg are referred to as Light Vehicles (LVs).

Each of these systems vary in terms of the type of charging system they employ (static or dynamic) relative to the road surface (overhead catenary, in-road conductive, or in-road inductive), the types of vehicles that can be charged (cars, buses, freight), and the type of pavements that they are installed in (asphalt or concrete). With each system there are challenges and opportunities that require careful planning and consideration. There is a need for road administrations to understand the types of ERS being developed, what each technology means for their network and what role they will need to play in implementation. This project was commissioned by PIARC to provide this information for their members.

1.2. PROJECT OBJECTIVES

This six-month project aims to provide a comprehensive summary of the development and implementation of ERS technology around the world. This enables consolidation of the current knowledge base and experience in this field so that the fundamental understanding of how ERS systems can benefit transport systems worldwide can be widely shared. In particular, so that road administrations are informed of the relative feasibility of implementing ERS technology on their road networks and how a safe road environment can be provided for the projected growth in low carbon vehicles. High level recommendations are provided in this report to support decision-making on infrastructure investment, innovation support, trials and partnerships.

Specifically, the project report includes:

- A description of the state of development of different types of ERS and an estimated timeline for deployment;
- A summary of the potential benefits and limitations of each system, considering economic, social and environmental impacts;
- An evaluation of the potential implementation of ERS from both a technical perspective and in terms of regulation and the business model (including factors external to ERS such as static charging, electric batteries capacities, and other alternative sources of power for vehicles);
- Proposed recommendations for infrastructure owners including specific recommendations for those from Low- and Middle-Income Countries (LMIC), and for PIARC on additional steps to support their members in this area.

Other deliverables from this project that will help raise awareness of issues relating to ERS include:

- A presentation on the findings for the PIARC Council meeting in October 2018; and
- An article for ROUTES/ROADS magazine in issue 379.

1.3. Project scope

This project focuses on Electric Road Systems (ERS). Although ERS refers to dynamic charging, the relevance of ERS is impacted by the development of other technologies such as static charging, battery technology development, and alternative power sources such as hydrogen and biofuels. Therefore, although the project is specific to ERS it takes into account the impact of other developments and technologies on ERS.

The project reviews ERS technologies, developments and their implementation from a road administration perspective. When considering implementation, the team reviewed the requirements and challenges in different countries including LMIC.

The project objectives were achieved through the following tasks:

Task 1: Description of ERS with regard to their TRL and the players involved in the development

In this task, a state-of-the-art review of ERS based on information available in the public domain (at the time of submission of this report) was carried out and the views of the key stakeholder groups captured. This included estimating the TRL and the expected timeframe until the technology is market ready. Task 1 also identified the key parties involved in the development of the systems and the target markets being considered.

Task 2: Comparison of different ERS technologies with their pros and cons

Task 2 considered the ERS technologies identified in Task 1 and provided a high-level overview of the potential advantages and disadvantages of each type of system based on the information gathered. A qualitative risk assessment of the risks associated with each ERS was also carried out.

Task 3: Business model from a Road Administration perspective

In Task 3 the business model of ERS was assessed from a road administration perspective. This task reviewed potential business models that might be employed and used a previously developed cost-benefit analysis (CBA) model to explore the economics of ERS.

The project report summarises the results of the three tasks and provides conclusions and recommendations that aim to answer the question of whether ERS is a solution for the future. The main content of the report is provided in Sections 1-7; more detailed information including case studies of different ERS is included in the appendices.

The report is divided into the following sections:

Section 1 provides an introduction and background to the project, outlines the project objectives, and sets out the scope of the report.

Section 2 describes the methodology and approach employed and the activities undertaken by the project team.

Section 3 presents the findings from Task 1. This includes a description of the various types of ERS concepts, and the results from the literature search, stakeholder survey and interviews, and the LMIC workshop.

Section 4 presents the findings from Task 2 which is an evaluation of ERS technologies and their perceived advantages and disadvantages.

Section 5 presents the business model from a road owner's perspective. This includes the results from a UK-focussed cost-benefit analysis and discussion on how it could vary for different countries and scenarios.

Section 6 presents the project conclusions based on the work undertaken on Tasks 1, 2 and 3.

Section 7 presents recommendations for PIARC, road administrations and LMIC based on the conclusions found from this study.

Appendix A provides a copy of the survey questions and interview topics.

Appendix B contains details of the case studies reviewed in this project.

Appendix C compares the advantages and disadvantages of the different ERS technologies.

Appendix D provides a risk assessment of each ERS concept.

Appendix E summarises the findings from the LMIC workshop.

Appendix F describes the cost-benefit analysis model used in Task 3.

Appendix G presents summary sheets for each ERS concepts.

Appendix H is a bibliography for further study of ERS.

2. METHODOLOGY AND APPROACH

2.1. Overall approach

The overall approach to the project was to gather and review available information on ERS technology that is currently being trialled on public roads or being developed through various research studies. This project did not create any new data or models but summarised the existing state-of-play of ERS and tried to capture the views from various stakeholders.

The World Road Association (PIARC) has established a Special Project mechanism which aims to respond to emerging issues within the road sector within a short time frame (less than 12 months). Several National Road Administrations (NRA) had identified the Electric Road Systems as an emerging issue for which they would like to have a global perspective and learn from other countries experience. Therefore, after a thorough selection process including the representatives of the 121 PIARC Government members as well as the PIARC Technical Committees, the ERS topic was selected by PIARC Executive Committee to develop a PIARC Special Project in 2018.

Following an international call for proposals PIARC awarded TRL to develop the ERS Special Project.

Prior to the award of the PIARC ERS Special Project, the TRL Academy approved funding for a similar project on ERS. TRL is a non-profit distributing research institution and reinvests in its own self-funded research programme managed through the TRL Academy. Therefore, by combining resources the project team have provided a more comprehensive study of ERS, which has benefited both projects.

All project activities were carried out by the TRL project team with guidance from the PIARC Project Oversight Team (POT). POT included representatives from different PIARC bodies: Strategic Planning Commission, Technical Committees, member countries and General Secretariat.

2.2. Task 1 activities

The objective of Task 1 was to conduct a state-of-the-art review on ERS, the key players involved and TRL of ERS technologies.

2.2.1. Literature review

A literature review was carried out to gather and summarise the most recent information and research findings on ERS from around the world. Relevant information from past TRL projects on ERS was reviewed; this knowledge base was updated and enhanced through a comprehensive evaluation of more recent journal papers, research project reports, trial results and manufacturer information.

2.2.2. Manufacturer discussions

In addition to a review of published information, the project team sourced additional information on emerging technology developments though telephone and video interviews with various stakeholder groups. This helped provide a complete picture of the current state of knowledge on ERS technology.

2.2.3. Stakeholder engagement

The development and implementation of ERS occurs within a complex sphere of diverse stakeholders and actors; each of which has differing priorities, needs and concerns. The current environment and key actors are illustrated below in illustration 1. It should be noted individuals and organisations within this space manoeuvre against industry and time specific conditions. Capturing the thoughts, concerns and experiences of informed stakeholders, in order to build a clear picture of the state of ERS around the world, was a key part of this project. As such engagement activities were undertaken across three platforms: an online survey; telephone interviews, and a workshop focusing on LMIC. Interactions were focused on five primary groups of actors:

- National Road Administrations & Government Bodies
- Technology Manufacturers & Developers
- Researchers & Academics
- Freight Operators
- Power Suppliers

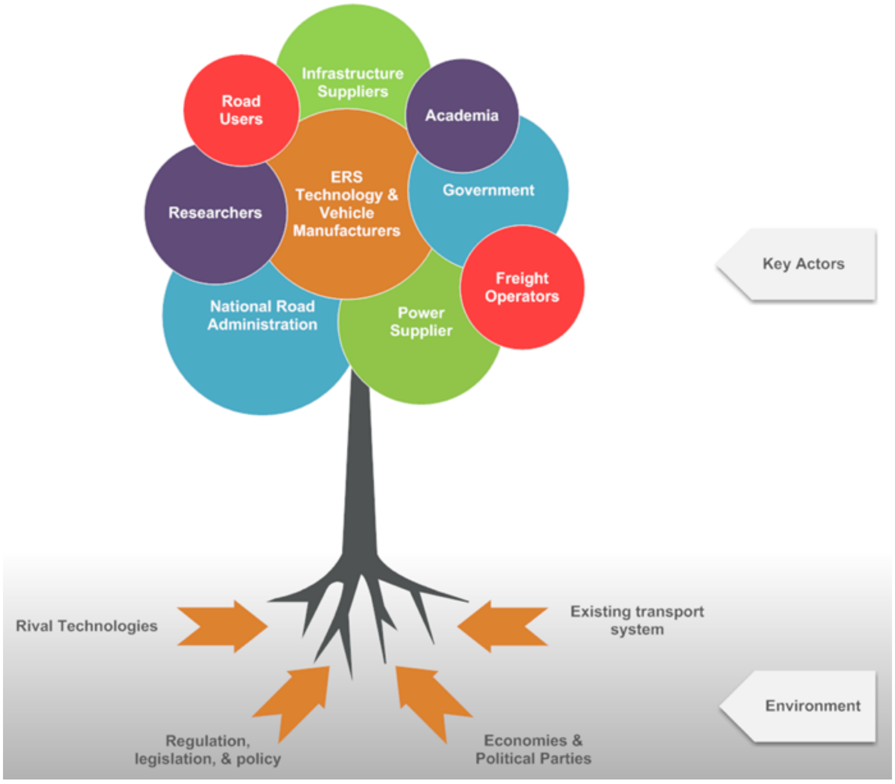

Illustration 1: Key stakeholders involved in ERS development

2.2.3.1. Stakeholder survey

Stakeholder engagement began with the development and dissemination of an online survey. The aim of the online survey was two-fold; firstly to capture general perceptions/data on global ERS developments, and secondly to secure participation for later engagement activities. The survey questions are provided in Appendix A. The survey was made available in English, French, Spanish, and Portuguese. In total, the project team contacted over 400 informed stakeholders, across 55 countries, to gain their participation and insight.

In total, 119 participants from 39 countries responded to the survey. Please refer to Section 3.3 for the survey results. Table 1 describes the stakeholder groups contacted in different countries and the number of responses from each group. It can be seen here that the majority of responses came from NRAs and researchers/academics (>70%); there was good feedback from the technology manufacturers with 17 responses; whilst responses from freight operators and energy suppliers was lower than expected. The 'Other' group consisted mostly of independent engineers and consultants.

Stakeholder Group	No. of Responses	Representative Country
NRA/Government	40	Austria, Australia, Belgium, Brazil, Burkina Faso, Canada, Chile, Columbia, France, Germany, Ghana, Japan, Kenya, Mozambique, Netherlands, Nigeria, Norway, Portugal, Romania, Sweden, Uganda, United Kingdom, United States, Zambia
Researchers/Academics	46	Australia, Bangladesh, Belgium, France, Germany, Greece, India, Italy, Malaysia, Nepal, Netherlands, Norway, Pakistan, Poland, Portugal, Slovenia, Spain, South Korea, Sweden, Switzerland, United Kingdom, United States
Freight Operators	6	UK, Sweden
Technology Manufacturers	17	France, Germany, Israel, Japan, Portugal, South Korea, Sweden, United States
Electricity Suppliers	2	Greece, South Korea
Other	8	Cyprus, France, Ireland, Sweden, United Kingdom, United States, Nepal
Total	119	38 Countries

Table 1: Stakeholder engagement through online survey

2.2.3.2. Stakeholder interviews

In addition to the survey, a number of telephone or video-linked interviews were conducted with key stakeholders representing each stakeholder group. Of the 119 participants, 56& (66 stakeholders) agreed to further engagement with the project team. Given the budgetary and time constraints of the project, a shortlist of candidates was drawn based on representatives from different stakeholder groups, types of ERS (conductive rail/catenary, inductive concepts), and different countries of operation or potential participation (capturing the views from LMIC and HIC).

The aim of each interview was to provide a forum for a richer discussion on ERS developments, benefits and challenges. Each interview was recorded and transcribed for analysis. Interviews were conducted with representatives from the following organisations:

- Trafikverket, Sweden (National Road Administration)
- Highways England, UK (National Road Administration)
- Sanef Group, France (National Road Administration)
- National Roads Authority, Uganda (National Road Administration)
- SANRAL National Road Authority, South Africa (National Road Administration)
- IMT Instituo Mexicano del Transporte, Mexico (National Road Administration)
- Scania AB, Sweden (ERS Vehicle Manufacturer)

- Siemens AB, Sweden (ERS Technology Manufacturer)
- Dongwon OLEV, South Korea (ERS Technology Manufacturer)
- Alstom Group, France (ERS Technology Manufacturer)
- ElectReon, Israel (ERS Technology Manufacturer)
- BASt Federal Highway Research Institute, Germany (Researcher)
- J-N-J Miller Design PLLC, USA (Researcher/Consultant for Oak Ridge National Laboratory and Momentum Dynamic Corp.)

2.2.4. Summarising and presenting the information collected

The information from the literature review and stakeholder engagement was collated and summarised in various formats:

- Published project report.
- Summary sheets that provide a brief description of the ERS technology, the key players involved, estimated TRL, timeline for deployment, and identification of any case studies or trials (available in Appendix F).
- Interactive timeline and map that:
    - describes ERS development over the past 20 years;
    - includes development milestones for each ERS concept; and
    - locations of various ERS trials and research activities.

Both the timeline and interactive maps are available online in addition to being included as images within the report.

2.3. Task 2 activities

The objective of Task 2 was to evaluate the information gathered in Task 1 and compare the advantages and disadvantages of the different ERS concepts.

2.3.1. Evaluation of advantages, disadvantages, and potential impacts

Each ERS concept was assessed in relation to the areas listed below. Based on the information available the perceived advantages, disadvantages, and potential impacts of each system were identified, highlighting the elements relevant to road administrations and LMIC. The main areas for evaluation were:

- Technical feasibility and installation challenges.
- Impact on road infrastructure and maintenance.
- Safety and security.
- Environmental and social impacts.

As part of the deployment and uptake evaluation, the project team identified the requirements that could be drivers or impediments to the deployment of each of the ERS.

2.3.2. Low- and Middle-Income Countries (LMIC) Workshop

A key aspect of this project was to establish the suitability and practicality of implementing ERS concepts in all countries including low-middle income countries. While the online survey and interviews captured responses from a number of LMIC, an informal workshop was chosen as the most appropriate platform to facilitate a deeper discussion on ERS implementation in LMIC. The information generated from this activity fed into the evaluation of ERS technologies and the business models.

The workshop was held in early June 2018 and had 15 participants. Attendees included representatives from the UK's Department for International Development, Oxford Policy Management, and TRL experts and associates who were experienced in working on road infrastructure projects in LMIC. This included experts from a variety of disciples – e.g. intelligent transport systems, e-mobility, infrastructure construction and maintenance, project managers, and sustainability experts). Telephone interviews were also held with a number of NRAs from LMICs.

The aim of the workshop was to inform participants about ERS, the potential benefits/disadvantages of ERS and the environments they operate within; and to discuss the major challenges and opportunities that might come with ERS implementation in LMIC. The main topics for discussion, in terms of potential challenges and opportunities, were as follows:

- ERS Installation and maintenance;
- Impact on road infrastructure and maintenance;
- ERS Expertise and equipment requirements;
- Energy supply and reliability;
- Social and environmental impacts;
- Impact of competing technologies;
- Business case and operational costs;

The results from the workshop were used as a basis for wider discussion within the project and can be found in Section 0.

2.3.3. Analysis of the impact of static electric charging and other developments

The project team reviewed other emerging technologies that could affect ERS development and uptake. This included a high-level assessment of advancements in other technologies that could promote or constrain ERS development in the near future. This included the potential development of alternative power sources such as hydrogen and biofuels to power low carbon vehicles.

2.3.4. Risk assessment

A qualitative risk assessment was conducted based on the information gathered in Task 1. The potential risk posed by a wide range of hazardous events was considered for each of the ERS technologies (inductive, conductive overhead and conductive rail) and also plug-in and static inductive charging as a baseline comparison. The risk assessment considers the hazardous event, persons affected, and the level of concern regarding the potential risk posed. Consideration is also given to high level risk mitigations.

2.3.4.1. Assumptions

In order to focus the risk assessment, a number of assumptions were made:

- When deployed, the technology would work in the way that would be intended.
- The road types considered in the assessment vary between the different ERS technologies :
    - Both plug-in charging system and static inductive will be deployed in public areas as well as secure locations such as bus depots.
    - Inductive ERS will be deployed in both urban and motorway environments.
    - Conductive overhead will be deployed in motorways and closed environments such as large distribution areas like ports and industrial routes.
    - Conductive rail will be deployed in both urban and motorway environments.

2.3.4.2. Lifecycle

The following lifestyle stages are considered in the assessment:

- Installation of ERS on or adjacent to the carriageway.
- Use of the ERS.
- Routine maintenance of ERS on or adjacent to the carriageway as well as routine maintenance of the carriageway in the vicinity of the ERS.
- Emergency maintenance of ERS on or adjacent to the carriageway as well as emergency maintenance of the carriageway in the vicinity of the ERS.
- Removal/ replacement of ERS on or adjacent to the carriageway.

2.3.4.3. Persons affected

- Plug-in vehicle user/ERS vehicle operator
- Pedestrians
- Vulnerable road users (e.g. motorcyclists)
- Other road users (ORU)
- Road workers (workers involved in installation and removal of temporary traffic management (TTM)
- Operatives (workers installing, removing or maintaining equipment, possibly within a road closure)
- Emergency services (fire service, police, ambulance service)
- Traffic officers
- Vehicle recovery organisations

2.3.4.4. Levels of concern

The actual level of risk posed by a system (typically expressed in terms of likelihood and severity of harm) cannot be established at this stage. Detailed design considerations, for example whether equipment is raised or flush with a surface, can have a substantial effect on the level of risk. In this assessment, levels of concern are used instead of levels of risk: these reflect TRL's opinion regarding whether the risk could be effectively managed. Table 2 shows the levels of concern used in this assessment:

Level of concern	Definition
Very low/ low	Risks are likely to be acceptable. Risk controls required are understood and may already be in place. High level of confidence that these risks can be reduced to a tolerable level with reasonably practicable mitigations.
Medium	Likely to be tolerable but will require careful management to ensure risks are as low as reasonably practicable.
High/very high	Level of risk could be intolerable. Further design work, investigation or testing likely to be required to provide evidence that the level of risk is tolerable.

Table 1: Levels of concern used in risk assessment

2.4. Task 3 activities

The objective of Task 3 was to consider the business model from a road administration perspective.

2.4.1. Types of business models

The information gathered from the literature and stakeholders was used to review potential business models and discuss the main considerations in developing a business model for ERS.

2.4.2. Scenario development

A series of potential future scenarios were defined for evaluation. This included different ERS systems, installation costs, electricity mark-up, take-up of technology etc.

2.4.3. Evaluation

A cost-benefit analysis model developed by TRL for a previous project was modified to explore the potential costs and benefits associated with implementing different ERS in the UK for the defined scenarios. The model produced payback times and Net Present Value (NPV) for different ERS concepts under different scenarios. Estimates of carbon and energy savings for the user (private cars and HGVs) were also presented. The types of costs and benefits that need to be considered are transferable to other countries, but the details of the payback times and specific costs will vary by country. A discussion is provided on how the inputs may differ for other countries, particularly LMIC.

2.5. Development of conclusions and recommendations

The findings from all three tasks were reviewed and used to produce the conclusions of the study and develop specific recommendations for road administrations, LMIC and PIARC in regard to future implementation of ERS.

3. TASK 1: DESCRIPTION OF ERS WITH REGARD TO THEIR TRL AND THE PLAYERS INVOLVED IN THE DEVELOPMENT

This section provides a summary of the different ERS technologies (both conductive and inductive solutions) based on the information available in the public domain. This includes estimated TRL and the expected timeframe until they are market ready. The key parties involved in the development of the systems and the target markets being considered are also described.

3.1. ERS CONCEPTS

ERS is a relatively new concept that has emerged over the last decade. Although there is no general consensus as to their definition, it is widely understood as a system that enables dynamic power transfer between a vehicle and the roads they are travelling along. ERS is generally classified into three groups:

- Inductive (wireless)
- Conductive (catenary/overhead)
- Conductive (in-road rail)

These three ERS concepts use different forms of technology to provide the same principle function and service – providing on-demand power transfer for electric vehicles, automatically, whilst travelling at low and normal traffic speeds (quasi dynamic and dynamic). Power is either transferred to the vehicles on-board battery unit or can directly power its propulsion system. All three concepts can also be applied to static (stationary) applications; however for the purpose of this report static capabilities are not designated as ERS systems. Instead they are seen as supporting or complementary technologies for EV charging. Static systems also include traditional cable connections – the most widely used mature method of EV charging. Each ERS concept is illustrated in Illustration 2.

There are numerous actors developing and commercialising ERS including: research institutes and academia, automotive manufacturers, freight industry, road administrations, small start-ups and spin-off enterprises, construction companies and technology manufacturers.

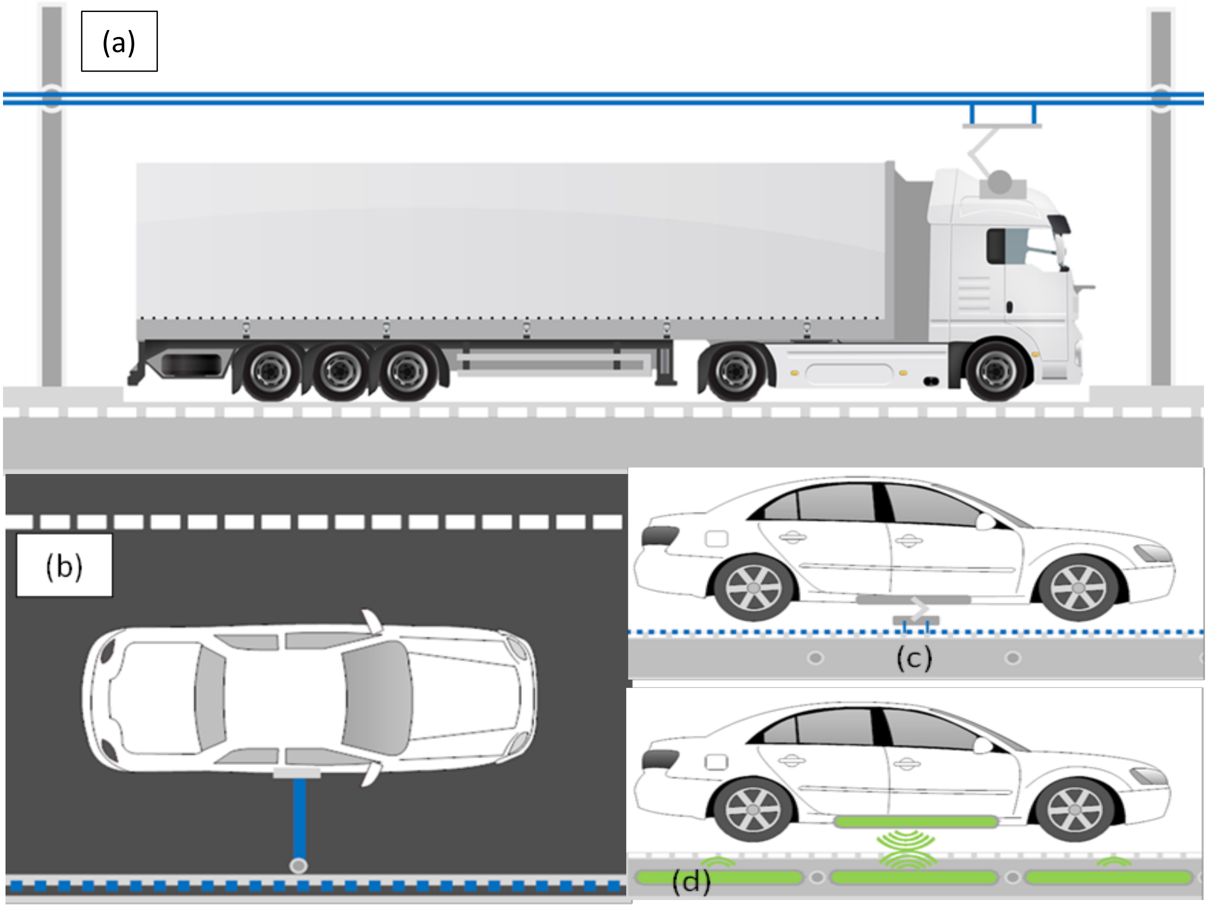

Illustration 2: Types of ERS; [a] Conductive Overhead, [b] Conductive Rail (Side Rail), [c] Conductive Rail (Ground Rail), [d] Inductive (Wireless In-Road)

3.1.1. Inductive (wireless)

The concept of dynamic inductive power transfer applied to transport is not new; it was first proposed by M. Hutin and M. Leblanc in their 1894 US patent (No. 527,857) for a current collector for electrically propelled vehicles without mechanical contact between the collector and the power line (as applied to railways)[131]. However, it wasn't until the late 1990s that the development and application of this concept was applied to modern road transport, with the first public demonstration taking place in New Zealand for static shuttle bus charging[132]. During the early 2000s a number of manufacturers emerged, commercialising the concept for static applications, namely start/end-route and opportunistic mid-route bus and shuttle charging. In parallel to this, alongside the market introduction of electric vehicles and buses, research and development of inductive power transfer began to gain momentum; with manufacturers, academia and various research institutes contributing to the developing field, building upon earlier research[137].

Throughout the last eight years the development of inductive systems has grown enormously, with advances being driven a number of factors. These include, but are not limited to, concerns over:

- road transport's impact on climate change and subsequent legally binding/voluntary greenhouse gas reduction targets adopted in some form by most countries around the world
- mass production and affordability of HEVs and EVs
- inconvenience and availability of static charging

- the range (km) limitations of current EV battery technologies
- the cost, size and weight of EV batteries
- rising fossil fuel costs and their efficiency per tonne/km compared to electrified transport
- local air quality, pollution and noise generated by internal combustion engines
- long term operational savings compared to fossil fuels
- technological advances and cost reductions in renewable electricity (wind, hydro, solar PV)

The concept of inductive ERS is based on the transfer of power from coils embedded in the road (primary) to the coils located in the vehicle (secondary) without any wired connection between vehicle and the road. The power from the grid is converted to high frequency AC power to develop a varying magnetic field, which is picked up by the coil under the vehicle. The magnetic field creates an induced voltage on the pick-up coil and results in flow of electric current on the pickup coils, hence inductive transfer of power.

This type of ERS is contactless and can transfer power across a variable air gap. Generally, inductive systems have three groups of components: in-road, on-vehicle, and roadside. In-road components refer to the primary coils (typically copper litz turnings with a ferrite core) and power cables laid beneath the road surface. In dynamic applications, multiple coils are laid in segments of variable length. On-vehicle components include secondary coil (also referred to as the pick-up unit) and control electronics. In addition, the vehicle must have electric drive train components such as battery and electric motor. Roadside components include grid connections, power inverters, transformers, cooling units and communication systems.

Power from the roadside unit is delivered to the primary coil segment automatically when a compliant vehicle, travelling above a certain speed along the track, is detected. The action of the secondary coil passing over the primary coil induces the electromagnetic current between the two and power is transferred. Depending on the system, power can directly drive the propulsion system or charge the vehicles battery. Illustration 3 provides a simplified schematic of the inductive ERS layout. The principle and components are essentially the same for static applications, however smaller in scale and infrastructural requirements.

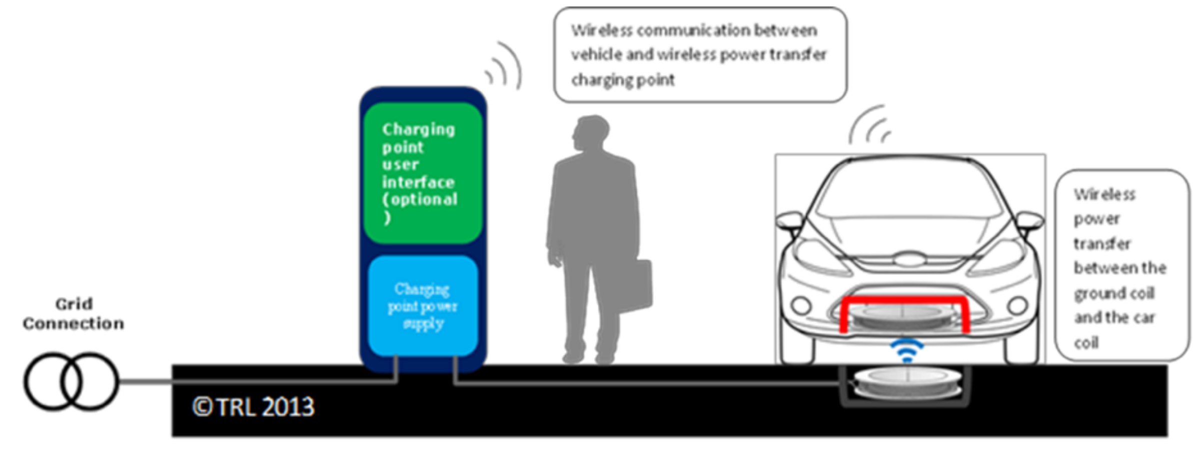

Illustration 3: Inductive (Wireless) ERS Concept

3.1.2. Conductive (catenary/overhead)

Overhead conduction is the most established and mature principle of the ERS solutions, dating back over 100 years. It was first applied to road transport in 1882 with the invention of Siemens Elektromoto in Berlin, Germany, a trolley bus system. Trolley bus systems (where a pantograph is permanently attached to the overhead cables) gained popularity in the 70s with over 300 installations in operation today across the wold[142]. The conductive overhead ERS is essentially an evolution of overhead rail and trolley bus technologies. This type of system relies on a direct and constant connection (normally using a pantograph) between the vehicle and power supply for energy to be transferred. Similarly, overhead conductive concepts have two groups of components: on-vehicle, and roadside. On vehicle components typically include: extendable pantograph (pick-up unit) and control electronics, and as stated in the inductive case the vehicle should have an electric drive train component such as battery and electric motor. Roadside equipment includes: continuous masts supporting tensioned power cables, and substations equipped with switchgear, power transformers, rectifiers, controlled inverters, and communication systems.

Power to the overhead lines is delivered from the roadside unit when a vehicle travelling at a threshold speed is detected beneath the track. The vehicles pantograph, located on the roof, automatically extends to make contact with the overhead lines. Power is transferred through the pantograph and supplies the vehicles battery or propulsion system. Static applications operate using similar principles; however, they are generally smaller in scale and requires less infrastructure. An illustration of the conductive overhead concept is given in illustration 4. During the last 8 years the concept of dynamic conductive charging for highway use has rapidly developed and evolved into two broad categories of system. These are the catenary overhead system and the ground level rail systems. They're development over the last decade has been driven by many of the same factors discussed in Section 3.1.1.

Illustration 4: Conductive (catenary/overhead) ERS Concept (Source: Maple Consulting)

3.1.3. Conductive (in-road rail)

Conductive in-road rail ERS is similar in principle to the overhead concept in that it relies on direct contact (via a mechanical arm/pantograph) between the power source and vehicle to transfer energy. However, it uses segmented electrified rails embedded in or on top of the road surface. Its components generally fall into three groups: in-road, on-vehicle, and roadside. In-road refers to the rail, power cables, and drainage systems. On-vehicle concern the pick-up unit (pantograph or mechanical arm) and control electronics, battery and electric motor. Roadside equipment includes transformers, grid connections, and communications.

A vehicle is detected moving along the rail track, after which the segments are electrified by the roadside units. Once the vehicle is aligned with the track a mechanical arm automatically extends from the vehicles rear/underside to connect with the rail. Power is then transferred to the battery or directly to the propulsion system. An illustration of the conductive in-road rail concept is given in illustration 5.

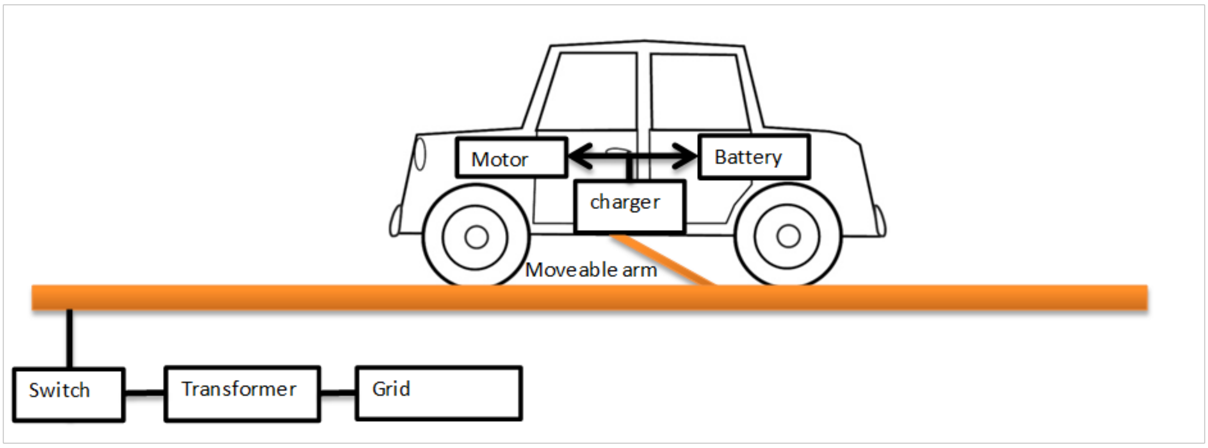

Illustration 5: Conductive (in-road rail) ERS Concept

3.1.4. Closed/Open-Loop Systems

Implementation can occur for two basic scenarios, closed-loop and open-loop. A closed loop system is where there is a high degree of control over the installation and typically over shorter distances along a set route. For instance, a closed-loop ERS could be implemented on an industrial estate, mining site, ports, and metropolitan bus schemes. In these applications vehicles typically travel along the same route, carrying constant loads. Routes are generally separate from interactions with the public, i.e. bus lanes separate from the main highway, on private land. Operators have more control over vehicle movements within a closed-loop system; the same brand of vehicles are used and only one type of ERS manufacturers system is used, minimising the need for interoperability. An open-loop ERS system is where different ERS compatible vehicles can all use the same installation and there is no fixed route, only strategically placed dynamic sections. Different brands/classes of vehicle, ERS systems, charging requirements, and communication protocols must all be able to operate within the same space. In open-loop scenarios the need for interoperability between different systems and payment communications is a critical prerequisite. For instance, this could be an ERS installation along a highway where any [ERS compatible] vehicle can use the infrastructure. The operator of the open-loop infrastructure has less control over who uses the system and when they use it.

3.2. Case studies

Examples of each type of ERS were identified and evaluated as part of the study. A total of 24 case studies were found, with varying levels of development and amounts of information available. Systems that have demonstrated dynamic capabilities are listed in Tables 2 and 4; and discussed in more detail in Appendix B. Tables 5 and 6 summarize inductive and conductive static systems. The case studies were used to develop a 20 year timeline depicting the major advances in the different types of ERS systems (please refer to illustrations 6 to 9).

A map illustrating geographically where research studies and trials on ERS have taken place or are currently underway is provided in illustration 10. The interactive version can be accessed here.

Table 2: Global overview of existing inductive ERS

Name	Organisations (Country)	Concept	Type Proven	TRL (1-9)	Cost	Vehicle Application
OLEV	Dongwon Inc. / KAIST (South Korea)	Inductive	Dynamic	9	€500,000/lkm[197]	Buses, Passenger vehicles, Light Duty Goods, Tram/Rail
CWD	Politecnico di Torino / CRF (Italy)	Inductive	Dynamic	3-4	N/A - Research Project	Passenger Vehicles, Light Duty Goods
IPV	Seat Group (Italy)	Inductive	Dynamic	3-4	N/A - Research Project	Passenger Vehicles, Light/Heavy Duty Goods, Buses & Shuttles
PRIMOVE	Bombardier / Scania (Germany/Sweden)	Inductive	Dynamic (under testing)	5-6	€3.25m-6.15m/lkm[45] (€1.7m/lkm final expectation)[5]	Passenger Vehicles, Light Duty Goods, Buses
HALO	Vedecom / Qualcomm (France/Germany)	Inductive	Dynamic	3-4	N/A	Passenger Vehicles, Light Duty Goods
WPT	Oak Ridge National Laboratories / OEM's (USA)	Inductive	Dynamic	3-4	€1.32m/lkm[50]	Passenger Vehicles
INTIS	Integrated Infrastructure Solutions (Sweden)	Inductive	Dynamic (under testing)	3-4	N/A	Small Plant, Passenger Vehicles
Momentum Dynamics	Momentum Dynamics (USA)	Inductive	Dynamic (under testing)	3-4	N/A	Buses and Shuttles
Electreon	Electreon Inc. (Israel)	Inductive	Dynamic	5-6	>€1m/lkm	Passenger Cars & Buses
Victoria	CIRCE (Centre of Research for Energy Resource and Consumption) (Spain)	Inductive	Dynamic	7-8	N/A – Research Project	Buses & Shuttles
WPT	University of California, Berkeley, (USA)	Inductive	Dynamic	3-4	€1.05m/lkm[5]	Passenger Cars, Light/Heavy Duty Vehicles

Table 3: Global overview of existing conductive ERS

Name	Organisations (Country)	Concept	Type Proven	TRL (1-9)	Cost	Vehicle Application
eHighway	Siemens / OEMs (Sweden/Germany)	Conductive	Dynamic (overhead)	7-8	€1.07m-2.06m/lkm[5, 67, 71]	Heavy Duty Goods/Large Plant, Buses & Trams
Elways	eRoadArlanda / Elways AB (Sweden)	Conductive	Dynamic (rail)	6-7	€390k-1m/lkm[5, 79, 83]	All types
Slide-In/APS for Roads	Alstom / Volvo (Sweden)	Conductive	Dynamic (rail)	4-5	€1.08m/lkm[5]	All types
ElonRoad	Elon Road Inc. / Lund University (Sweden)	Conductive	Dynamic (rail)	4-5	€600k-€1.5m/lkm[112, 113]	All types
HPDC	Honda R&D Ltd.	Conductive	Dynamic (rail)	4-5	N/A	All types

Table 4: Global overview of novel static charging inductive systems

Name	Organisations (Country)	Concept	Type Proven	Vehicle Application
OLEV	Dongwon Inc. / KAIST (South Korea)	Inductive	Static	Buses, Passenger vehicles, Light Duty Goods, Tram/Rail
PRIMOVE	Bombardier / Scania (Germany/Sweden)	Inductive	Static	Passenger Vehicles, Light Duty Goods, Buses
HALO	Vedecom / Qualcomm (France/Germany)	Inductive	Static	Passenger Vehicles, Light Duty Goods
WPT	Oak Ridge National Laboratories / OEM's (USA)	Inductive	Static	Passenger Vehicles
INTIS	Integrated Infrastructure Solutions (Sweden)	Inductive	Static	Small Plant, Passenger Vehicles
Momentum Charger	Momentum Dynamics (USA)	Inductive	Static	Buses and Shuttles
IPT	North Carolina State University (USA)	Inductive	Static	Passenger Cars
Victoria	CIRCE (Centre of Research for Energy Resource and Consumption) (Spain)	Inductive	Static	Buses & Shuttles
Unplugged	European Consortium / European Commission (UK, Spain, France, Italy, Germany, Sweden, Netherlands, Belgian)	Inductive	Static	Passenger Vehicles, Light Duty Goods

Name	Organisations (Country)	Concept	Type Proven	Vehicle Application
IPT	IPT Technologies (Germany)	Inductive	Static	Passenger Cars and Buses
WiT-3300, Drive-11	Witricity Corp (USA)	Inductive	Static	Passenger vehicles, Light Duty Goods, Shuttles
WAVE IPT	Wireless Advanced Vehicle Electrification Inc. (USA)	Inductive	Static	Passenger Vehicles, Light/Heavy Duty Goods, Buses & Shuttles
Plugless Power	Evatran	Inductive	Static	Passenger Cars
Magneto DC	University of British Columbia (Canada)	Inductive	Static	Passenger Cars
Inverto	Inverto GmbH (Belgium)	Inductive	Static	
Inductives	Daimler (Germany)	Inductive	Static	Passenger Cars
Wireless Charging	BMW (Germany)	Inductive	Static	Passenger Cars
Wireless Charging System	Nissan (Japan)	Inductive	Static	Passenger Cars
Inductive Charging System	Fraunhofer IISB (Germany)	Inductive	Static	Passenger Cars

Table 5: Global overview of novel static charging conductive Systems

Name	Organisations (Country)	Concept	Type Proven	Vehicle Application
Busbaar. All-in-One	Furrer + Frey / Opbrid SL (Spain)	Conductive	Static (pantograph)	Buses & Coaches
Overhead Fast Charger	Proterra (USA)	Conductive	Static (pantograph)	Buses & Coaches
Fast Charge Systems	Heliox (Netherlands)	Conductive	Static (pantograph)	Buses & Coaches
Opp-Charge	Volvo Bus Corporation (Sweden)	Conductive	Static (pantograph)	Buses & Coaches
Flash Charging	ABB (Switzerland)	Conductive	Static (pantograph)	Buses & Coaches
Quick-POINT	Eko Energetyka (Poland)	Conductive	Static (pantograph)	Buses & Coaches
Charging-Panto	Faiveley Transport - Wabtec Company (France)	Conductive	Static (pantograph)	Buses & Coaches
eBus Charger	Siemens	Conductive	Static (pantograph)	Buses & Coaches

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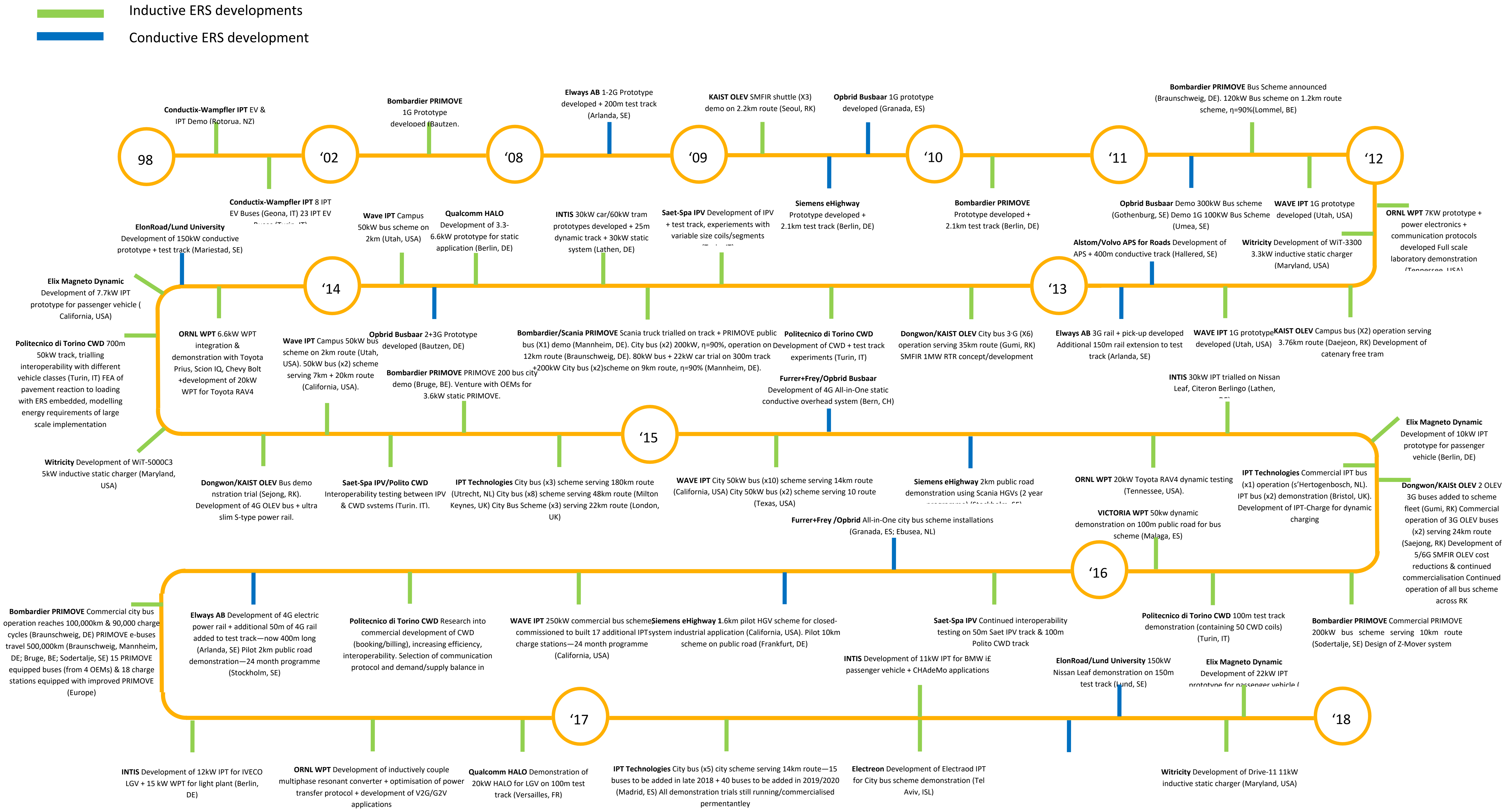

Illustration 6: Key ERS Development Timeline

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Illustration 7: ERS Key Players Overview

An online interactive version of the complete map can be found at: https://cloud.smartdraw.com/editor.aspx?depoId=9986319&credID=-22760890&pubDocShare=CCC83F020404C2727928C6829BECBEF354E

Europe

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Key

Illustrations 8 and 9 illustrate key ERS developments across the world to date. Countries with ERS developments are highlighted in Green (inductive only), Blue (conductive only) and Red (inductive and conductive). These maps identify (1) key ERS technology manufactures developments, (2) stakeholder questionnaire results identifying the types of ERS research activities taking place in that country (again these follow the same colour coding as above). A number of countries have not been included for two primary reasons, (1) there are no developments taking place in that country, (2) questionnaire responses did not highlight any dynamic ERS related research activities.

Belgium

Bombardier PRIMOVE

(Inductive Static/Dynamic) Refer to Germany

- Flanders, Belgium Track Testing (300m Long Inductive Track, 80kW Bus & 22kW Car) (2010-12)
- Lommel City Bus Scheme (1 PRIMOVE bus, 1.2km route, 40-80kW, 90% efficiency, Since 2012)
- Bruge City Bus Scheme (1 PRIMOVE 200 Bus, 5.6km route, 200kW, >90% efficiency, Since 2015)

Questionnaire Responses

United Kingdom

IPT Technologies—Inductive Power Transfer

(Inductive Static) Refer to Italy, Netherlands, New Zealand & Spain

- Milton Keynes Bus Scheme (8 IPT buses, 150kW, 24km route, 93% efficiency, operating since 2014)
- London Bus Scheme (3 IPT buses, 60kW, 11km route, 93% efficiency, operating since 2015)
- Bristol Bus Scheme (2 IPT buses, 60kW, operating since 2016)

Qualcomm/Renault—HALO IPT

(Inductive Static) Refer to France

- London demonstration (10-20 3.3kW charging stations, trialled with 50 vehicles since 2012)

Questionnaire Responses

NRAs: 1 response (Desktop Study)

Freight Operators: 5 responses (No Research Activities)

Researchers: 4 responses (Desktop Study x3, Desktop Study x1, Laboratory Trial x1, Road Trials x1)

France

Qualcomm/VEDECOM - HALO IPT

(Inductive Static & Dynamic)

- Development of HALO for Static Charging (3.3-20kW, >90% Efficiency)
- Development and Track Testing 20kW HALO for LDVs (100m Inductive Track) (Since 2015)

Questionnaire Responses

NRA: 3 responses (Desktop Study x2, Laboratory Trial x1, No Research Activities x1)

Portugal

Questionnaire Responses

Technology Manufacturer: 1 response (No Research Activities)

Researcher: 3 responses (Desktop Study x1, No Research Activities)

Spain

IPT Technologies - Inductive Power Transfer (IPT)

(Inductive Static) Refer to Italy, Netherlands, New Zealand & UK

- Madrid Bus Scheme (5 IPT Buses, 14km Route, Since 2017) - Plans to Add 15 Buses + 18 Minibuses in 2018, Plans to Add 40 Buses in 2019/20

Furrer + Frey - Busbaar

(Conductive Overhead/Static) - Refer to Netherlands & Sweden

- CAF Demonstration

Victoria/CIRCE/International Energy Agency

(Inductive Dynamic)

- Public Road Bus Scheme Demonstration (1 Bus, 100m Track, 20kW, 83-92% efficiency)
- Demonstration on Test Track (210m, 240kW, 90-97% Efficiency)

Questionnaire Responses

Researcher: 3 responses (Desktop Study x1, No Research Activities x2)

Netherlands

IPT Technologies - Inductive Power Transfer (IPT)

(Inductive Static) Refer to Italy, New Zealand, Spain & UK

- Utrecht City Bus Scheme (3 IPT Buses, 86kW, 180km Route, Since 2014)
- sHertogenbosch City Bus Scheme (1 IPT Bus, 120kWh, 289km Route, Since 2016)

Furrer + Frey - All-In-One

(Conductive Overhead Static) Refer to Sweden

- Ebusea Demonstration

Questionnaire Responses

NRA: 1 response (Desktop Study x1)

Technology Manufacturers: 1 response (Desktop Study x1,

Denmark

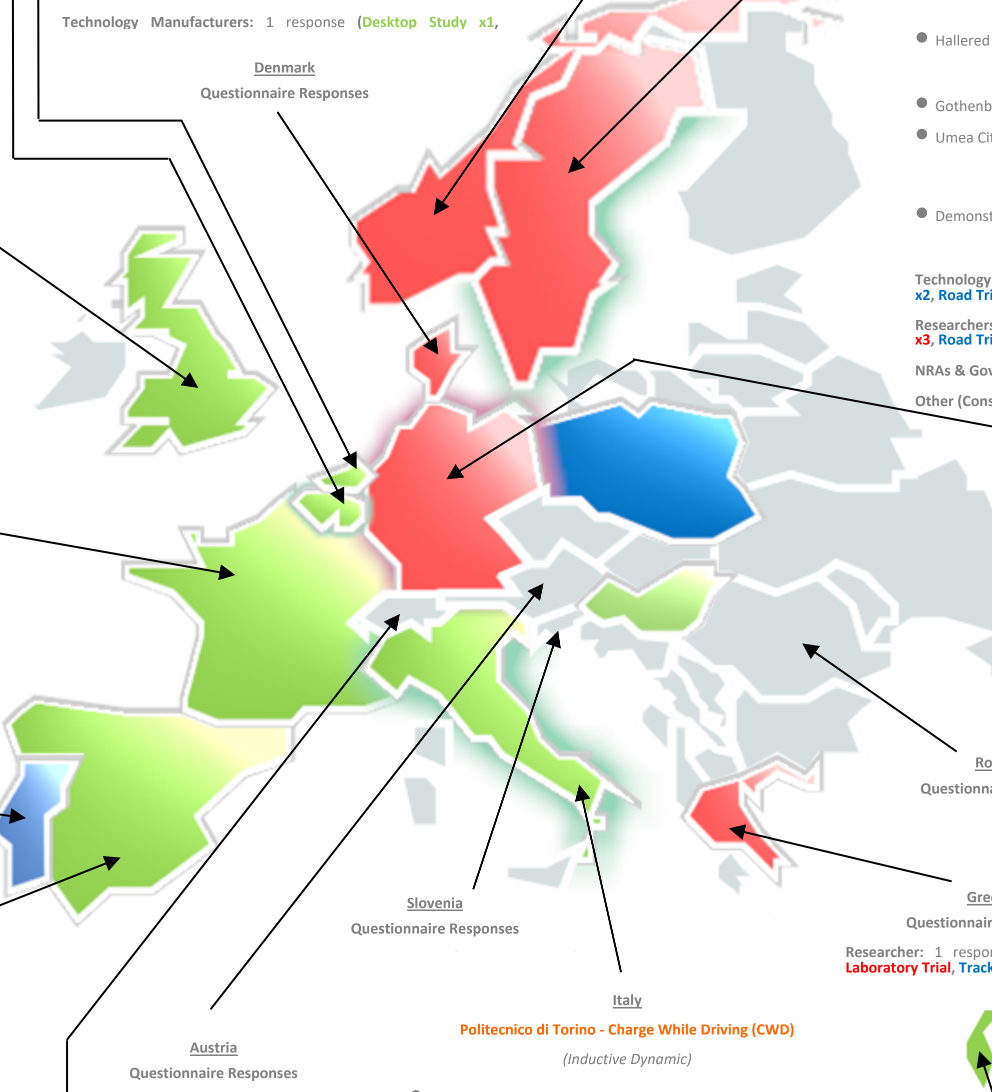
Questionnaire Responses

Norway

Questionnaire Responses

NRA: 1 responses (Desktop Study x1)

Researcher: 2 responses (Desktop Study x2)



Austria

Questionnaire Responses

Switzerland

Questionnaire Responses

Slovenia

Questionnaire Responses

Italy

Politecnico di Torino - Charge While Driving (CWD)

(Inductive Dynamic)

- Susa Test Track Demonstrations (Light Duty Vehicle Testing, 100m long track, 20kW, 20cm air gap, 75-85% efficiency)

SAET-SPA Induction Powered Vehicles (IPV)

(Inductive Dynamic)

- Susa Test Track Demonstrations (Light Duty Vehicles, 50m long track, 30-100kW, 25cm air gap, 70-80% efficiency)

IPT Technologies - Inductive Power Transfer (IPT)

(Inductive Static) Refer to Netherlands, New Zealand, Spain & UK

- Turin City Bus Scheme (23 IPT buses, 63kWh, 200km route, operating since 2003)
- Geona City Bus Scheme (8 IPT buses, 63kWh, operating since 2002)

Questionnaire Responses

Researcher: 3 responses (Desktop Study x3, Laboratory Trial x2, Track Trial x2, Road Trial x2)

Romania

Questionnaire Responses

Greece

Questionnaire Responses

Researcher: 1 response (Desktop Study, Laboratory Trial, Track Trial, Road Trial)

Israel

Electreon

(Inductive Dynamic)

- Development of 5-20kW System (24-27cm Air Gap, 88-90% Efficiency)
- Tel Aviv Bus Scheme Demonstration Planned

Sweden

Bombardier PRIMOVE

(Inductive/Static & Dynamic) Refer to Belgium & Germany

- Sodertaje City Bus Scheme (1 PRIMOVE 200 Bus, 10km route, 200kW, >90% efficiency, since 2017)

Siemens - eHighway

(Conductive Overhead/Dynamic) - Refer to Germany & U.S.A.

- Sweden Public Road Demonstration (2km route, HGVs testing Only, since 2016)

Elways AB - Elways

(Conductive Rail Dynamic)

- Development of 1st-2nd Gen Prototype Systems (2009-12)
- Demonstration on 200m Arlanda Test Track (2012)
- Development of 3rd Gen System (2012-14)
- 150m Added to Arlanda Test Track (2014)
- Development of 4th Gen System (2017)
- 50m Added to Arlanda Test Track (2017)
- Stockholm Demonstration on Public Road (2km Route, Cars/LGVs Testing Only, Upto 200kW, 82-95% efficiency, since 2017)

Alstom/Volvo - Aesthetic Power Supply (APS) for Roads

(Conductive Rail Dynamic)

- Hallered Demonstration on 400m Test Track (126kW, >95% efficiency, since 2014)

Furrer + Frey - Busbaar

(Conductive Overhead/Static)

- Gothenburg City Demonstration Bus Scheme (100-240kW, 90% efficiency)
- Umea City Demonstration (100-240kW, 90% efficiency)

ElonRoad/Lund University - ElonRoad

(Conductive Rail/Dynamic)

- Demonstration on Test Track (210m, 240kW, 90-97% efficiency)

Questionnaire Responses

Technology Manufacturer: 4 responses (Desktop Study x2, Desktop Study x1, Laboratory Trials x2, Laboratory Trial x2, Track Trial x2, Track Trial x2, Road Trial x2)

Researchers: 4 responses (Desktop Study x2, Desktop Study x1, Laboratory Trial x2, Laboratory Trial x1, Track Trial x1, Track Trial x1, Road Trials x3, Road Trials x1)

NRAs & Government: 3 responses (Desktop Study x1, Laboratory Trial x2, Track Trial x3, Road Trials x3)

Other (Construction Company): 1 response (Laboratory Trial, Track Trial, Road Trial)

Germany

Bombardier PRIMOVE

(Inductive Static/Dynamic) Refer to Belgium & Sweden

- Prototype PRIMOVE developed - Track Testing in Bautzen (2008-9)
- Mannheim Test Track - SCANIA eTruck PRIMOVE 200, 140-180kW, 90% efficiency, operating since 2013
- Braunschweig City Bus Scheme (2 PRIMOVE buses, 12km route, 200kW, >90% efficiency, operating since 2014)
- Mannheim City Bus Scheme (2 PRIMOVE 200 buses, 9km route, 200kW, >90% efficiency, operating since 2014)
- Berlin City Bus Scheme (4 PRIMOVE 200 bus, 6.1km route, 200kW, >90% efficiency, operating since 2015)
- Development of 3.6kW EV Static Car Charger
- All Bus Schemes retrofitted with PRIMOVE Invisible Systems (operating since 2016)

Siemens - eHighway

(Conductive Dynamic) - Refer to Sweden & U.S.A.

- Berlin Proof of Concept - 2.1km Demonstration on Test Track (2010-12)
- Frankfurt Demonstration on Public Road - 10km Installation (Commisioned 2017, still under contraction until 2018/19)
- Holstein Demonstration on Public Road - 12km Installation (Since 2016)

Integrated Infrastructure Solutions (INTIS) - Wireless Power Transfer (WPT)

(Inductive/Static & Dynamic)

- Development of 30kW WPT for Artega Car and VW T5 Minivan (10-15cm air gap, >85% efficiency, since 2013-15)
- Development of 60kW WPT for TRam (10-15cm air gap, >85% efficiency, since 2013-15)
- Development of 30kW WPT for Nissan Leaf Gen 1/2 (88-93% efficiency, since 2016)
- Development of 12kW WPT for IVECO Daily Van (88-93% efficiency, since 2017)
- Development of 15kW WPT for P250 Luggage Hauler (88-93% efficiency, since 2017)

Questionnaire Responses

NRAs: 2 response (Desktop Study x1, Laboratory Trial x1, Track Trial x2, Road Trials x1)

Technology Manufacturers: 7 responses (Desktop Study x1, Desktop Study x1, Desktop Study x3, Laboratory Trials x1, Laboratory Trials x2, Laboratory Trials x4, Track Trial x3, Track Trial x3, Road Trial x2, Road Trial x4)

Researchers: 2 responses (Desktop Study x1)

Illustration 8: ERS Developments - Europe

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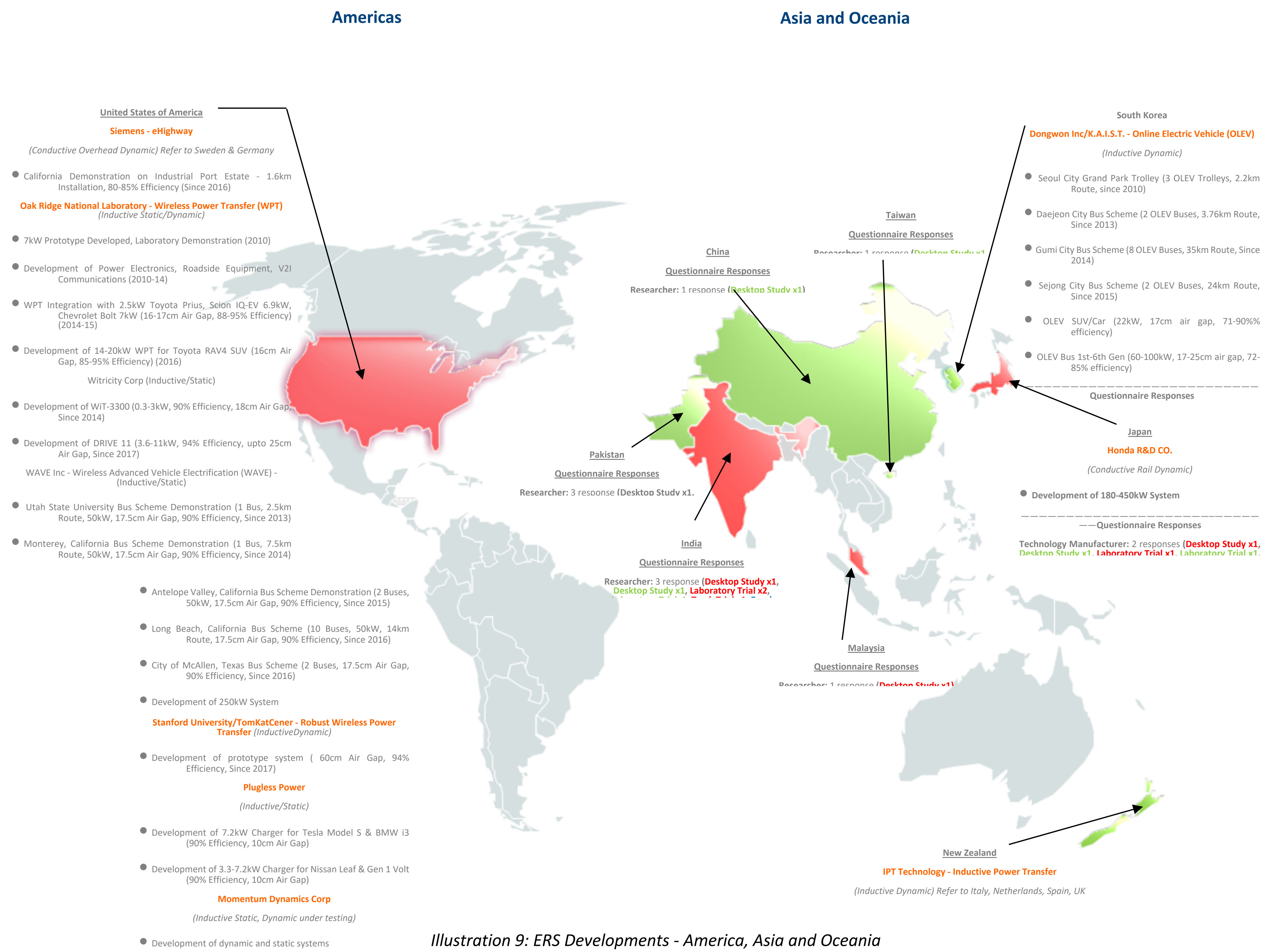

Illustration 9: ERS Developments - America, Asia and Oceania

3.3. Stakeholder perspective

This sub-section provides an overview of the views of stakeholders, based on the results from the online survey (Appendix A.1), stakeholder interviews (Appendix A.2) and the LMIC workshop (Appendix D).

3.3.1. Stakeholder activities in ERS

Survey participants were asked what type of ERS activities their organisation has been involved in. Responses included desktop studies, laboratory testing, track testing, road trials, and none. Participants provided the ERS concept that was their main focus: inductive only, conductive only, or both. The results indicated that both inductive and conductive ERS concepts have received similar levels of attention. Aside from those who have not undertaken any ERS activities, the most common activity was desktop studies for both systems. Laboratory testing was the most common activity associated with inductive ERS, while track testing was more common with conductive systems. This could be because inductive systems are much smaller than conductive and require less laboratory infrastructure for testing. Equally, track testing could be more favourable for conductive systems due to the necessary spatial requirements of the system and the lengths of installation required for dynamic testing. Responses also showed that 40 organisations had taken part in road trials, 24 of which were for conductive systems. An interactive map of ERS work can be found online at: https://www.zeemaps.com/map?group=3009510&add=1#. A snapshot of this is provided in illustration 10.

Illustration 10: Participating countries in online survey - Black Pins: No Activities undertaken; Green Pins: Inductive Activities Only; Blue Pins: Conductive Only; Red Pins: Both Inductive and Conductive Activities

Illustration 11 provides a breakdown of the various activities that have been undertaken by the stakeholders that responded. Individual responses were reviewed to ensure static and dynamic research activities had not been confused. As such illustration 11 only considers dynamic ERS activities.

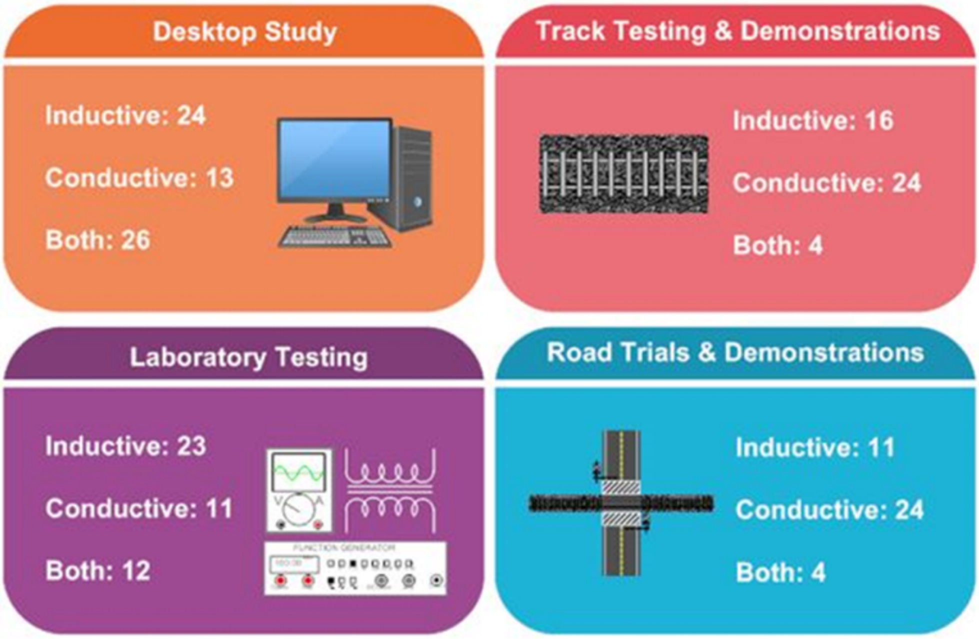

Illustration 11: ERS activities undertaken by survey participants

Survey participants were asked if their respective organisations were planning to continue involvement or participate in ERS research activities over the next 24 months – of the 119 responses, 63 participants (53%) indicated continued or future involvement; 52 participants (43%) indicated no planned involvement; and 4 said they were currently unsure. The types activities planned are summarised below:

- Pilot studies working towards large scale implementation;
- Monitoring, maintenance & operation of existing ERS demonstrations;
- Refining power and control strategies;
- Component testing and materials research;
- Modelling and traffic simulation studies;
- Market uptake and feasibility research;
- Emissions studies between ERS and conventional fuels;
- Life Cycle Analysis studies;
- Regulatory studies exploring ownership, procurement, business models, standards, legal issues;
- Development of ERS component production processes;
- Commercialising ERS products;
- System integration and vehicle retrofitting;
- Advising national road administrations;
- Securing funding for further research; and
- Stakeholder engagement & public opinion surveys.

3.3.2. Potential impact of ERS on selected aspects of transport system

Survey participants were presented with five general categories and asked to rate the potential impacts that ERS could potentially have on their current road transport system, should it be implemented. A five point scale was used to rate the potential impact: significant benefit (✓✓), minimal benefit (✓), neutral (--), negative impact (✕), significant negative impact (✕✕).Illustration 12 provides an overview of responses for each impact category. It can be seen that in general stakeholders believed that ERS could deliver gains across each category, with the exception of operational costs (capital, maintenance and administrative).

	Greenhouse Gas Emissions e.g. CO, CO_2	Local Air Quality e.g. NO_2, PM_{10}	Operational Costs e.g. $/km capital-upkeep cost	Vehicle Running Costs e.g. $/km fuel	Noise Emissions e.g. <dB
✓✓	78%	73%	15%	33%	48%
✓	15%	18%	16%	31%	31%
—	3%	4%	16%	16%	16%
✕	2%	1%	33%	17%	3%
✕✕	2%	4%	20%	3%	2%

Illustration 12: Overall perceived ERS benefits/drawbacks

Illustration 13 provides a breakdown of the results reported in illustration 11 by stakeholder group. It can be seen that all groups, aside from freight operators have an optimistic outlook regarding the potential benefits that ERS could deliver. All stakeholders believed that introducing ERS could have significant benefits to GHG emissions and local air quality. Electrified transport is typically zero emissions, thus GHG and local air quality emissions would not be produced at source. However, an important consideration, in terms of emissions, is how this energy is produced. If produced by renewable means then estimations of environmental gains can be assumed.

However, if electricity is produced from fossil fuels, then the environmental gains would be significantly reduced. In this scenario local emissions would be minimal but overall a significantly high volume of emissions is being generated, albeit at the point of production (as opposed to the point of use).

The survey results indicated that freight operators are slightly more pessimistic, believing that ERS would increase their capital and operating costs. Surprisingly governments and NRAs believed that there would be no gain or drawback for ERS regarding operational costs. During interviews NRAs were asked to comment on the benefits and limitations if ERS were to be implemented on their networks. Some NRAs framed their responses in terms of their preferred solution or the solution they had most knowledge on. For instance, in Sweden the majority of research activities are for conductive overhead and rail solutions, whereas France has knowledge of both conductive and inductive systems, due to the FABRIC demonstration track (with shared experience with Italy) and Alstom developments.

In terms of the main benefits, from an NRA perspective, these include:

- Conductive overhead:
  - The most mature solution (trials in Sweden and Germany on public roads);
  - Can provide higher levels of power suitable for HGVs;
  - Rail/tram industry stakeholders have years of experience installing, operating and maintain similar systems;
  - Does not impact the pavement structure;
  - For the most part they can be installed at the roadside leading to minimal disruptions;
  - Does not affect routine pavement maintenance activities.
- Conductive rail:
  - Can transfer higher levels of power;
  - Suitable for all types of vehicles;
  - A lot of transferable knowledge from rail/tram industry;
  - Can be easily inspected as most components are visible and accessible.
- Inductive solutions:
  - Does not impose on established winter maintenance activities;
  - Safer in terms of road user or worker interaction;
  - No visual impact as they are buried;
  - Suitable for a number of vehicle types; less vulnerable to damage or vandalism.

All NRAs commented that a key benefit of any type of ERS is that they could potentially act as a pathway for rapid decarbonisation of the transport fleet, helping them to achieve their national or transport specific GHG reduction targets within relatively short timeframes. Similarly all noted that this would also improve local air quality, reducing toxic emissions such as nitrogen dioxide and particulate matter.

In terms of limitations, from an NRA perspective, these include:

- Conductive overhead:
  - high visual impact on surrounding landscape;
  - only suitable for heavy duty vehicles;
  - potential hindrance to emergency responses (in cases of helicopter landings on the carriageway).
  - Impacts the roadside moreso than other solutions (greater spatial requirements)
  - Suseptable to damage and defects (from wear of overhead cable under heavy use, possible corrosion/defects at roadside supports)
- Conductive rail:
  - having an accessible and open conductor on the road;
  - safety for motorcycle users and road users travelling at speed passing over a rail system;
  - long-term impact on surrounding pavement;
  - susceptible to damage and defects (from wear, corrosion/contamination, debris build-up).
- Inductive:
  - lower power ratings than conductive (most systems are not currently suitable to power HGVs);

- not easily accessible;
- roadside equipment installations at frequent intervals.

NRAs commented that introducing ERS systems, with the exception of the conductive overhead ERS, could possibly cause more defects and lead to higher overall maintenance costs. Similarly all identified the installation times would be a limiting factor due to the level of disruption and congestion it could cause. Stakeholders from LMIC identified a number of limitations, the majority of which are highlighted above. However additional limitations from an LMIC NRA perspective include greater vulnerability to theft and vandalism, and the availability of skills required to install/ maintain ERS systems.

	Greenhouse Gas Emissions e.g. CO, CO_2	Local Air Quality e.g. NO_2, PM_{10}	Operational Costs e.g. $/km capital-upkeep cost	Vehicle Running Costs e.g. $/km fuel	Noise Emissions e.g. <dB
Technology Manufacturer	✓✓	✓	✓	✓	✓
Researchers & Academics	✓✓	✓✓	—	✓	✓
Governments & NRAs	✓✓	✓✓	—	✓	✓
Power Suppliers	✓✓	✓✓	✓	✓	✓✓
Freight Operators	✓	✓	✗✗	✗	✓✓

Illustration 13: Perceived ERS benefits/drawbacks by Stakeholder

Stakeholders had the opportunity to elaborate on their responses, alongside expressing some of the other potential benefits and drawbacks ERS could offer. These are shown in illustration 14, highlighting the most common responses.

Benefits	Drawbacks
+ Reduced EV range hesitation	-- Large up front capital costs
+ Increased energy efficiency	-- Relatively novel, immature technology
+ Reduction on fossil fuel reliance	-- Diffusion of many ERS types & interoperability between them
+ Reduction in EV battery size/costs	-- Requires high level cooperation & communication between many actors
+ Enhanced driving experience	-- Lack of large scale demonstrations
+ Potential to create new jobs	-- Capital cost of upgrading vehicle fleet
+ Increasing public awareness of air quality/pollution from transport	-- Gaining public & political support
+ Vehicle fuel cost savings	-- Government uncertainty in new tech and their pathways
+ Potential to increase cooperation & cross-industry communication	-- Loss of tax/VAT revenue from diesel
+ Highly automated, easy to adapt to	-- Complexity of ERS and skills required to implement and maintain
+ Promotes sustainable mobility	-- Producing clean, carbon free electricity
+ Promotes uptake of sustainable power generation technologies	

Illustration 14: Additional ERS benefits/drawbacks

3.3.3. Challenges in ERS implementation

One of the key questions asked in the survey was for stakeholders to rate the top challenges they foresee if ERS were to be implemented. A scale of 1-9 was used (with 1 being the most significant challenge, and 9 being the least challenging aspect). Data has been weighted and averaged accordingly. Illustration 15 highlights the aggregate results. Although the survey did not disclose estimates of the costs involved, the number one concern of stakeholders, as a whole, was the cost of an ERS installation and its associated maintenance. Concerns of how an installation would impact the pavement, directly and indirectly, were the second biggest challenge. The regulatory and business model was ranked third. Of least concern was reliability and availability of the road network, alongside ownership and political influence. This is unexpected as ownership and political influence (environment) are closely linked to the business model and regulatory framework that would govern ERS use.

Most Challenging

1. Installation & maintenance costs
2. Impact on road
3. Regulatory and business model
4. User acceptance and public opinion
5. Technical feasibility
6. Increased electricity demand
7. Safety and security
8. Ownership and political influence

Least Challenging	9.	Reliability and availability of road network

Illustration 15: ERS Implementation Challenges

Illustration 16 illustrates the above results by stakeholder group. This highlights the different concerns and priorities organisations have across the ERS industry. These challenges are not unique to any one type of ERS concept, they are all equally applicable. Stakeholder views were explored in more depth through interviews of representatives of the different depths.

During interviews stakeholders were asked what their main concerns/considerations were for implementing ERS in their respective countries. The concerns of road administrations were wide ranging, with some concerns being country specific. However most stated that the biggest issues/primary considerations they had regarding ERS relate to:

- *Technological feasibility* – are current systems capable of delivering high levels of power suitable for HGV use; how reliable current systems are (not only their power transfer capabilities but also communications and energy payment protocols)
- *Road user satisfaction/safety* – what level of disruption will installing and maintaining these systems have; which type of road users will they be suitable for; how available will the systems be; what level of coverage is required; and what are the risks for road users (regarding electrocution, vulnerable road users and so on)
- *Funding and investment strategies* – finance, ownership and maintenance of the systems, what is the payback time, what will the level of uptake be; will there be private sector investment or alternative financing.
- *Installation and maintenance* – what impact will routine winter maintenance have on systems; how will the presence of systems alter existing maintenance strategies;
- *Procurement and Supply* – Is industry capable of supplying the materials in the quantities that would be required for large scale installations; is industry able to produce enough ERS compatible vehicles within a short time frame to encourage uptake.

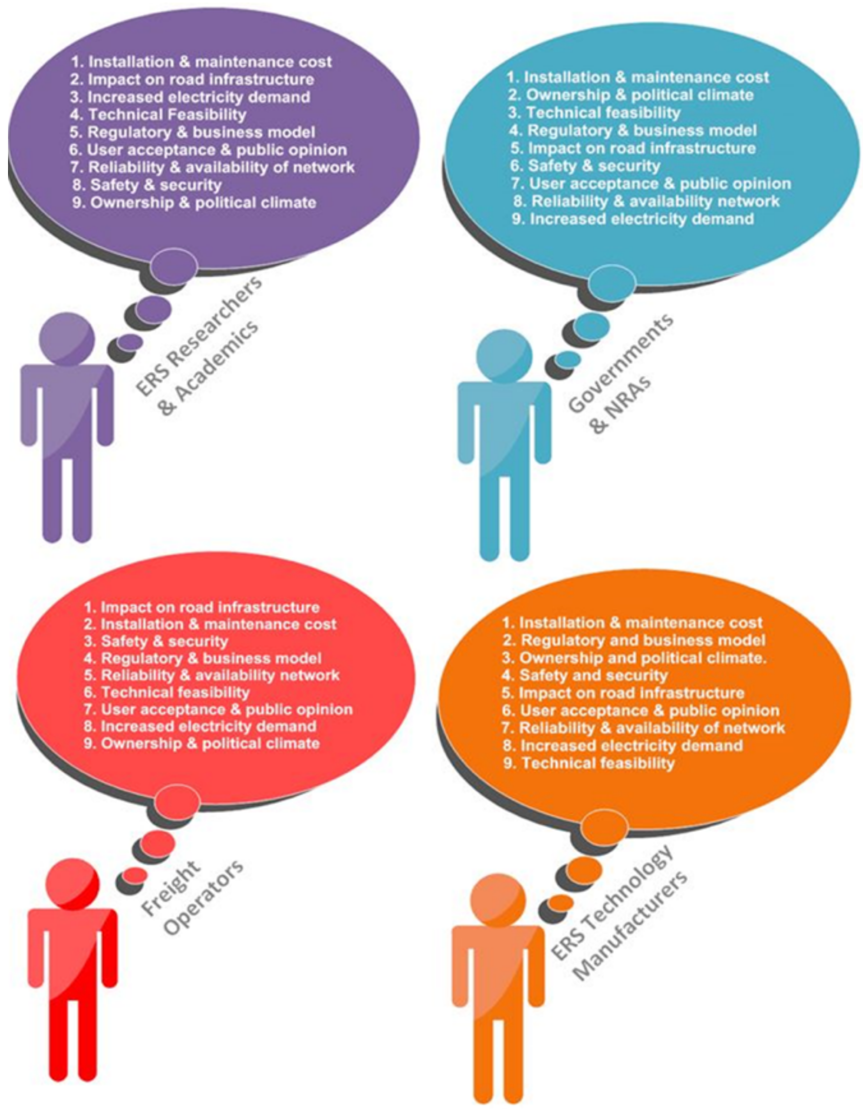

Illustration 17: ERS Challenges by Stakeholder

During interviews stakeholders were asked what their opinion of current ERS developments and solutions were. Most NRAs interviewed believed that ERS concepts were promising and were seen as a positive potential step towards improving low carbon road transport. Others indicated a limited understanding of ERS, given its relative novelty, and were not in a position to definitively state a position.

Whilst many were open to both conductive and inductive solutions, some administrations had a preference. For instance, one interviewee commented that a conductive overhead or rail solution would not be suitable due to safety concerns (regarding motorcycle users and electrocution in general), visual impact, and their impact on routine winter maintenance activities. Other administrations commented that future ERS uptake will include both inductive and conductive solutions. LMIC participants viewed the technologies as promising however any potential ERS uptake would be secondary to other issues such as health care, basic infrastructure, education etc. LMICs had concerns regarding the cost and security of ERS due to vulnerability to theft, vandalism and political instability.

NRAs also noted that concessions on their highways ranged between 5-16 years. Given the capital costs involved, coupled with initially low uptake of EVs and ERS compatible vehicles, some NRAs believed that longer concessions would need to be granted for in order for contractors to recoup their original investment. Some estimated that concessions would need to run for 25-30 years instead of the current standard. All European NRAs stated that they would, if not already, be happy to provide test sites (both off-road and on-road) for future demonstrations, alongside supporting further research and development activities. Regarding installation times NRAs all commented that systems should ideally take no longer than current resurfacing works take; this would be in the range of 4-8 day per km.

When interviewees were asked to identify the biggest challenges for implementing ERS (for their organisation and in general) a range of challenges were highlighted, including:

- ***Available electricity grid connections and grid capacity limits****.* Manufacturers often stated that in the case of highway applications having available grid connections and capacity would be a significant challenge that requires collaboration from all actors involved in ERS deployment (governments, utility companies, power suppliers, road administrations, manufactures and so on). However, in terms of urban applications (i.e. municipal bus schemes) it was less of a challenge as grid infrastructure in cities is far more developed than in rural settings. Interviewed NRAs had similar concerns, citing difficulties in implementing rapid static charging points at highway service stations. In these locations current businesses (hotels, shops, fuel stations, depots etc) have already used most of the grid capacity, with the cost of installing additional substations for charging infrastructure being extremely high (especially in the context of low EV uptake in most developed countries).
- ***Installation times****.* Meeting the demands of municipal and highway authorities' expectations for installation duration (i.e. quick leading to minimal disruption or complications) was also seen a big challenge by NRAs and manufacturers alike. With the exception of one manufacturer, many stated extensive on-road installation times (ranging from weeks to months per km). For instance a complete installation for an: OLEV system (dynamic inductive) is in the order of 3 weeks per 100m; a Siemens system (conductive overhead) is in the order of 1 month per km (based on current demonstrations); an Elways system (conductive rail) is in the order of 2 weeks per km (based on current demonstrations). Electreon state their solution is simpler (in terms of design and installation) than rival solutions as such they state they can install in-road equipment and carry out carriageway reinstatement at a rate of 1-2km every 2 days. NRAs all commented that ERS systems would need to cause minimal disruption to their network, ideally with installation coinciding with planned maintenance works at a comparable installation rate. In the case of asphalt resurfacing this would be approximately 4-6 weeks per 10-20km.
- ***Demand for dynamic charging****.* Interviewees, across all stakeholder groups, believed there was little short term demand for dynamic charging. Although they remained optimistic about future uptake, given a number of national commitments to GHG reductions and limited short term options to meet these targets. In cases where dynamic inductive bus demonstrations/operations are underway, although there is government support there is not a clear directive from government that it considers ERS as a future pathway. Manufacturers stated that initial uptake of ERS will be from Freight and Public Transit Operators. Without a

clear statement from Government as to the future of transport fuels and ERS infrastructure roadmaps, these initial users will be assuming more risk, as such have little demand for these products. Interviewees also stated that uptake of EVs in their countries was very low for passenger vehicles, let alone for medium-heavy duty vehicles. As such they did not foresee current demand changing until there has been significant uptake in EV ownership. Noting that unless there is sufficient ERS usage, the relative cost of infrastructure is much higher (per user), with a lower overall efficiency.

- ***Continuous and reliable operation.*** Manufacturers stated during interviews that a current challenge is having a system that can operate reliably under constant loading throughout the day. Given the limited number of test beds and demonstrations (which are subjected to constant loading) testing long term functionality (over weeks/months) is very difficult.
- ***Capital cost.*** Many manufacturers acknowledged that the costs of their systems per km were substantial, in the context of current low demand. For those that are in a position where they are able to undertake on-road trials minimising production costs is a high priority. However for those in the earlier stages of development minimising cost was not as much of a priority as developing a functional prototype and undertaking testing. All noted that while their systems are currently expensive increases in demand would lead better economies of scale for production, with further construction experience would lead to lower costs and quicker installations. One interviewee stated that they had reduced production costs by 20% over the last five years. Some stated that current demonstrations were bespoke and expensive components used would not be used if produced at mass scales.
- ***Further technological development.*** Many interviewees stated that with limited demand from final users, securing funding for further development and testing is difficult. For smaller organisations, such as a number of start-ups developing inductive and conductive rail solutions, this is a considerable challenge. One interviewee stated that this challenge is partly a consequence of the chosen technological branch. For instance, conductive overhead systems are fairly mature; there is little difference between rail and road infrastructure. If an organisation has to develop all ERS components (infrastructure, vehicle on-board equipment, connection devices, communication protocols etc) this is significantly more expensive than just developing on-board equipment and communications. Furthermore a system with all components under development is less attractive to investors as there are more uncertainties and risks. Researchers also commented that with the exception of private contracts with manufacturers and a few European/American research programmes there is a lack of available funding to address many unanswered questions regarding implementation.

All NRAs interviewed stated that currently there is little to no demand for this type of infrastructure. As discussed this is a result of a number of factors. For instance all ERS technologies are fairly novel and still under development, as such there are many stakeholders (especially freight and industry) who are not yet as informed as there is little national/international discussions taking place. Some commented that ERS discussions begin with national governments clearly setting out their position with regards to ERS. Many felt that if Governments provided clear directives or roadmaps towards implementation, this would enable freight operators or early adopters to uptake this technology. This highlights the “chicken and egg” situation were road users will not adopt if supporting infrastructure is not available and if there is low uptake of EVs or ERS compatible vehicles there will not be sufficient demand to match investment. All acknowledge that the uptake of EV's have been very low given the upfront capital costs and range limitations.

Interviewees had mixed responses regarding the question "what will an ERS future look like and how will rival (including non-ERS technologies) work together". Some manufacturers felt that in the context of long distance travel (i.e. freight corridors across multiple countries in Europe) there could only be one type of solution, as interoperability between vehicles and countries is essential (and having many types of solution all working together would be extremely complicated to implement). On the other hand, some manufacturers felt that all solutions would have to work together to decarbonisation transport, especially in the context of achieving GHG targets within Government set timeframes. Further to this many stated that in line with key challenges, discussed above, the goal for any ERS manufacturer was for their systems to encourage greater EV uptake (which requires involvement from all solutions). In this light, ERS would be a backbone solution covering only strategic locations of any road network, with rival technologies (fuel cells, battery swap etc) filling in the spaces in between.

While there were mixed views as to whether a single network should host multiple ERS solutions there was a clear consensus that some solutions were more suitable for certain purposes and geographies. For instance, in urban centres where there are many grid connection points and elevated concerns over public safety an inductive solution might be more suitable. In closed environments (such as ports, industrial estates, mines) where heavier loads are moved along short set routes, with less chance of human interaction, a conductive solution is more appropriate. Similarly, for mountainous or hilly terrain a conductive solution may be better placed as they are capable of delivering higher rates of power than current inductive solutions.

In general, NRAs interviewed had not yet identified a clear winner to back. In some cases, this was due to a lack of knowledge on ERS, and in others it stems from the recognition that climate change target deadline are fast approaching and they would need to utilise every resource they have at their disposal to meet them. When considering the possibility that rival technologies (i.e. improvements in battery performance, size, weight, cost and charging convenience/time) could render ERS redundant many, across all stakeholder groups were unsure what impact this could have for an ERS future. Many noted that at the current rate of development (i.e. for batteries, alternative fuels, etc) sufficient advances would not occur soon enough (or in the case of alternative and bio fuels production would not meet the demand of the transport industry alongside competing industries) to achieve current GHG reduction targets in a cost-effective way.

3.3.4. Technology Readiness Level and Time to Deployment

Given background and experience, stakeholders were asked to provide estimates of the technology readiness level (TRL) for each concept as a whole, regardless of manufacturer. Additionally, stakeholders were also asked to estimate the time to deployment (in years). Illustration 18 provides an overview of technology readiness levels that stakeholders used to guide their responses.

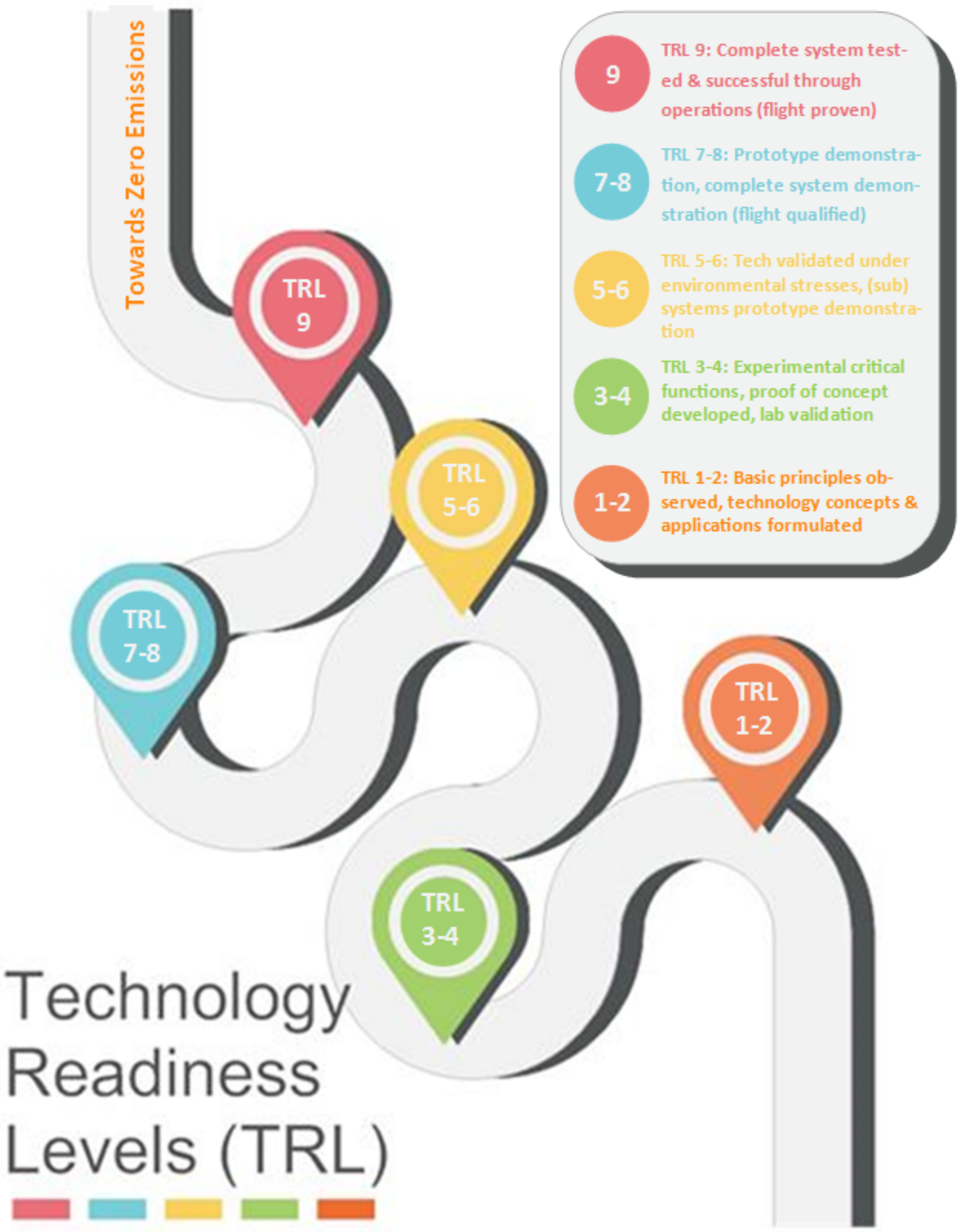

Illustration 18: Technology Readiness Level Description

Illustration 19 illustrates the estimated TRL and YTD as per stakeholder group. Freight estimates were excluded due to no responses to this question. In general it can be seen that for all ERS concepts, technology manufacturers and power suppliers provided the most optimistic estimates. This is followed by researchers and academics who also viewed ERS developments positively. Governments and NRAs, although relatively optimistic, generally believed the technology was not as developed as other stakeholders did.

Illustration 20 provides the averages of stakeholder estimates for TRL and years to deployment (YTD). It can be seen that on average, stakeholders believed that conductive overhead static charging and inductive static charging were the most mature concepts with average TRLs of 7 (2.3 YTD) and 7 (2.2 YTD) respectively. With regards to dynamic applications inductive and conductive in-road ERS were at a similar level of development, with TRL ratings of 5 (5.5 YTD) and 5 (5.5 YTD). On average, stakeholders believed that the most advanced ERS concept, in terms of development, was the conductive overhead solution, with a TRL rating of 6 (4.1 YTD). This estimate reflects the fact that the conductive overhead solution has a long standing history as it is essentially an evolution of overhead rail and trolley bus technologies, which have been in use for many decades. In light of recent developments, overhead conductive systems are subject to larger and longer demonstrations than alternative ERS concepts for highway use.

	Static Inductive (TRL / YTD)	Dynamic Inductive (TRL / YTD)	Static Conductive Overhead (TRL / YTD)	Static Conductive In-Road (TRL / YTD)	Dynamic Conductive Overhead (TRL / YTD)	Dynamic Conductive In-Road (TRL / YTD)
Technology Manufacturer	7 /1.7	5 / 6.4	8 / 1.9	6 / 3.8	7 / 4.2	5 / 6.8
Researchers & Academics	7 / 1.6	5 / 4.7	7 / 1.2	5 / 4.3	6 / 3.6	5 / 5.2
Governments & NRAs	6 / 3.2	5 / 6.5	7 / 2.8	6 / 3.6	6 / 3.3	5 / 4.6
Power Suppliers	8 / 1.5	7 / 2.5	9 / 0	9 / 0	9 / 0	9 / 0
Other	5 / 2	4 / 3	6 / 3.5	6 / 4.3	6 / 3.5	5 / 3.8

Illustration 19: Estimated TRL/YTD by Stakeholder Group

ERS technology	TRL Level	Years to Deployment
Inductive (Static)	7	2
Inductive (Dynamic)	5	6
Conductive (Dynamic Overhead)	6	4
Conductive (Dynamic In-road)	5	6
Conductive (Static Overhead)	7	2
Conductive (Static In-Road)	6	4

Illustration 20: Average Estimated TRL/YTD

3.4. Task 1 Summary

Three types of stakeholder engagement activities were undertaken: online questionnaire (available in four languages); interviews with key stakeholders; and a workshop to discuss ERS in LMICs. The questionnaire received 119 questionnaire responses from 39 countries (across low-high income countries): 40 NRAs/Governments, 46 Research/Academic Institutes, 17 ERS Technology Manufacturers, 6 Freight Operators, 2 Electricity Suppliers, and 8 Other.

Overall ERS concepts are viewed positively by all stakeholder groups; with the general understanding that ERS are capable of providing significant environmental and economic benefits (in terms of GHG emissions, local air quality, noise, and road user fuel costs). However a majority felt that installation and operation costs were a significant disadvantage of ERS. Large number of research projects (public and private) and majority of participants' organisations plan to continue ERS development activities. Freight Operators were the most pessimistic about the financial viability of moving to ERS, believing infrastructural and vehicle running costs to be a disadvantage. In general the biggest challenge for stakeholders are the installation and maintenance costs, the impact on existing infrastructure and the regulatory/business model surrounding their deployment. Technical feasibility, safety and security, ERS ownership and political climate were also seen as primary challenges by all stakeholders.

Benefits of ERS, as perceived by stakeholders, include: reduced EV range anxiety; increased energy efficiency of transport; less reliance on fossil fuels; reduction in EV battery costs (reducing the overall price of an EV); fuel savings; promotes uptake of sustainable power generation technologies; potential to increase cooperation and cross industry communication; increasing public awareness of air quality/pollution from transport; potential to create jobs and economic opportunities. Disadvantages of ERS, as perceived by stakeholders, include: large upfront capital costs for infrastructure; immature technologies as applied to transport; diffusion and interoperability of ERS systems; the number of actors involved requiring high level cooperation and communication; lack of large scale demonstrations; capital cost of ERS compatible vehicles; gaining public and political support; government uncertainty in new technologies and their pathways; loss of revenue from fossil fuel sales; availability of skilled workforce to implement and maintain infrastructure; difficulties producing low carbon electricity; and lack of funding and government support for ERS. Average estimates for TRL's and YTD are: dynamic inductive = TRL5 with 6 YTD; dynamic conductive rail = TRL5 with 6 YTD; and dynamic conductive overhead = TRL6 with 4 YTD.

Interviews carried out with 13 participants: 6 NRAs, 5 Technology Manufacturers/Consultants, 1 Research Institute, 1 Freight Vehicle Manufacturer. NRAs were unsure of inductive ERS suitability for HGVs, especially with regards to system reliability in power transfer, communications, and payment methods. NRAs stated that current ERS installation times (although these are for demonstration purposes) would cause unacceptable levels of disruption to their networks during construction, alongside the impact ERS will have on maintenance strategies. Any installation would have to be installed at a similar rate to existing works, optimally occurring at the same time as resurfacing/reconstruction works. NRAs were concerned about procurement and supply of materials, especially in the context of fair competition as there are limited ERS technology manufacturers. Some NRAs (from both low and high income countries had a limited understanding of ERS) NRAs had different preferences of which type of system was more suitable for their network (depending on their safety/environmental requirements) – no general favourite system but acknowledged that conductive overhead systems were the most mature and nearest to market.

NRAs believed ERS would be best suited on toll roads, but would have to extend concessions to allow for satisfactory payback. All commented that having available grid capacity and connections along the highway would require significant investment. In this context ERS is more suited to urban environments where these are more readily available. All interviewed stakeholders believed at present there was little to no demand for ERS, but that a main driver behind ERS developments was national commitments to reducing GHGs. Most stakeholders agreed that Freight and Public Transit organisations would be the first adopters of ERS. Interviewed stakeholders stated that Governments needed to provide clear statement of intent to invest in ERS and develop roadmaps for their implementation. Only then could demand increase. Many believed there was not a rivalry between different ERS solutions or competing technologies. The type of ERS implemented will depend on the application/environment it is intended to be used in. Rival low carbon technologies were typically seen are complementary to ERS, and in the context of climate change targets Governments would have to employ every solution at their disposal.

LMIC ERS workshop findings indicated that many LMICs have under developed networks, had pavement constructions that were not optimal for ERS (i.e shallow gravel pavements), or challenging topographies, limiting the suitability of ERS implementation. Conventional highways lacked proper maintenance increasing the risk any ERS would not be properly maintained due to lack of resources and availability of skilled workforces. Political and social stability across LMICs is a challenging aspect. Cooperation between government organisations and private enterprises inside and across national borders is typically difficult to achieve and can prevent collaboration. LMICs may not have the availability of a skilled workforce to install and operate ERS, meaning skills may have to be imported – increasing costs. However there is an opportunity to up-skill their workforces to provide better economic prospects. ERS costs may be increased compared to developed countries as materials might have to be transported larger distances and overcome issues with customs/border crossings which is a common challenge in LMICs. LMICs may be able to leap-frog ERS technologies one implementation has been achieved in high income countries, applying their best practice and taking advantage of economies of scale which lower production costs.

The level of disruption ERS construction would have in LMIC was seen as even greater than the impact it would have in more developed countries due to a lack of available alternative routes. LMICs would be more concerned with factors such as vandalism (from civil unrest) and theft (of valuable components/materials and illegal abstraction of electricity. This could then have safety implications for wider society, alongside increasing ERS operator costs. Reliability of energy is a primary concern for LMIC for ERS and in the wider context of populations not having equal access to electricity. This is especially relevant in rural geographies where key freight routes pass. The impact of rival or complementary low carbon technologies was minimal in LMIC, for instance EV uptake is very low outside of Europe, America, and China. ERS requires a high proportion of EVs/Hybrids which have a high cost of ownership. In LMIC the main mode of personal transport is two-wheelers, not suitable for ERS use. The price of ERS compatible vehicles ownership would have to be greatly reduced to see greater uptake. LMICs have limited resources which struggle to meet the basic demands of their populations (medical care, employment, education, access to energy & clean water etc.). LMICs may not be able to justify expenditure on any system that will benefit a fraction of the population when there are more primary challenges that addressing urgently. LMIC could suffer losses in revenue from fossil fuel duties, which may also increase unemployment in petrochemical related industries (such as service stations).

4. TASK 2: COMPARISON OF DIFFERENT ERS TECHNOLOGIES

This section provides an evaluation of the ERS technologies identified in Task 1, discussing both conductive and inductive systems. A high-level overview of the potential benefits, limitations and impacts of each system is provided, highlighting the elements relevant to road administrations and LMIC. A qualitative assessment of the risks associated with each ERS is also presented. It is important to highlight that the evaluation and discussion provided in this section is based on the information provided from published literature and referenced cited sources at the time of publication.

4.1. TECHNICAL FEASIBILITY AND CHALLENGES

4.1.1. Technical feasibility of inductive ERS

Task 1 gathered information on a number of ERS technologies being currently developed and trialled. Tables 7 and 8 provide a high-level overview of the reviewed ERS systems. A total of 17 systems were identified, 11 of which were classed as inductive ERS and these systems are highlighted in table 9 In this section, the technical feasibility of these inductive systems is discussed in terms of potential advantages and disadvantages. Detailed historical overviews of each system is provided by authors [4-5], [7], [11], [133-136], alongside individual case studies presented in Appendix B, and the technical details of each ERS and the potential benefits and limitations identified are provided in Appendix C.

The inductive systems shown in table 7 are at various stages of technological maturity, from laboratory development to public demonstrations, to commercialised products. Note that the TRL ratings for ERS in this study are estimated based on the criteria used for defining TRLs (shown in Section 3.3.4) and the information gathered from the stakeholder engagement and from the literature search.

Table 6: Overview of Dynamic Inductive ERS Systems

System	Organisation	Power & Efficiency	Vehicle Suitability	TRL
OLEV	Dongwon Inc. / KAIST	15-85kW, 71-91%[3, 4, 5,11,14,15]	Buses, Passenger vehicles, Light Duty Goods, Tram/Rail	9
CWD	Politecnico di Torino / CRF	20kW, 75-85%[5,114]	Passenger Vehicles, Light Duty Goods	3-4
IPV	Seat Emmedi Group	20kW, 70-80%[5,27]	Passenger Vehicles, Light/Heavy Duty Goods, Buses & Shuttles	3-4
PRIMOVE	Bombardier / Scania	Up to 200kW, 68.8-90%[5,32,45]	Passenger Vehicles, Light Duty Goods, Buses	5-6

HALO	Qualcomm	20kW, 80%[5]	Passenger Vehicles, Light Duty Goods	3-4
WPT	Oak Ridge National Laboratories / OEM's	2.5-20kW, 88-95%[5,48,49,51]	Passenger Vehicles	3-4
INTIS	Integrated Infrastructure Solutions	11-60kW, 88-93%[107,108,110]	Small Plant, Passenger Vehicles	3-4
Electreon	Electreon Inc.	5-20kW, 88-90%[166]	Passenger Cars & Buses	5-6
Victoria	CIRCE	Up to 50kW, 92%[167]	Buses & Shuttles	7-8
WPT	University of California	Up to 200kW, 60%[5]	Passenger Cars, Light/Heavy Duty Vehicles	2-3
Momentum Charger	Momentum Dynamics Corp.	50-75kW (upto 300kW), 95%[121]	Buses and Shuttles	3-4

Dongwon OLEV

The Dongwon OLEV system appears to be closest system to being market ready. In 2009/2010 the first demonstration of inductive ERS took place in South Korea. While a number of inductive ERS were in development at the same time as OLEV (for e.g. Oak Ridge National Laboratories WCEV system – refer to Appendix B.6) this was the first exhibit outside of laboratory settings to successfully demonstrate a dynamic system in an operational environment. The company currently has dynamic charging installations for bus schemes operating in the South Korean cities of Seoul, Daejeon, Gumi, and Saejong, and have recently developed a coreless power track for universal WPT modules for dynamic charging. The company offers a range of different systems that are suitable for small cars, buses and light duty vehicles, with continued development and expansion into new markets and applications. The potential limitations for the OLEV systems include the following:

- The power rating does not seem large enough to drive HGVs – cars to buses only (a 1MW system is under development but only for rail, not HGVs[14]);
- It has a relatively low efficiency (75-85% dynamic), when compared with conductive ERS efficiency (>95%);
- The systems have a low lateral misalignment tolerance, resulting in lower dynamic efficiencies;
- There is no evidence that any OLEV systems have been tested at highway speeds;
- The literature suggests that it has limited interoperability potential with other inductive systems.

As part of the recent CIRP project working towards SAE J2954[168] standard, the OLEV system has been tested with Qualcomm and Witricity systems for interoperability. Tests between different manufacturers resulted in overall operating efficiencies of approximately 70%, however it should be noted that these tests only examined the power transfer capabilities, and not the communications behind the systems. The company is looking towards new markets outside of vehicle charging (such as industrial applications e.g. crane, auto guided vehicles in factories), owing to a lack of demand, supporting infrastructure and political support for inductively charged vehicles.

Oak Ridge National Laboratories WPT

As mentioned above, the Oak Ridge National Laboratories WPT system was one of the first in the world to demonstrate dynamic charging, alongside Dongwon / KAIST. Although Oak Ridge Nat. Lab. have demonstrated the functionality of their system, it is only under laboratory conditions (6.6kW[46] and 20kW[48]), and have yet to demonstrate its capability on in-service roads. The system is only suitable for small-medium sized vehicles, with relatively high efficiencies achieved (up to 95%[5,48,49,51]). In addition to dynamic charging, Oak Ridge also has systems with static charging capability. Similarly to the OLEV system, it has a low lateral misalignment tolerance.

CIRCE Victoria

CIRCE's Victoria system is currently undergoing testing on a public road in Malaga, Spain, using a fully electric modified bus. The trial site is a 10km[166] test route on a public road and comprises of static inductive points (at the start-end of route and on-route) and a 100m dynamic inductive section. The study aims to use the test results as a platform for further refinement of the system and development. The current system has similar dynamic efficiency compared to conductive. However, it is restricted to charging buses and shuttles and possibly small cars and not HGVs, and has yet to show evidence of successfully charging vehicles at high speeds.

Electreon & PRIMOVE

Electreon and Bombardier (PRIMOVE) are still in the process of testing their dynamic systems and have yet to demonstrate their performance in an operational environment. Electreon are testing their system on a private 100m[167] test track which has been in place since early 2018, and are currently constructing a new 300m test track which is due to be completed by the end of 2018. In addition, a test site along an existing bus route in Tel Aviv has been secured and installation and testing is expected to start later in 2018. The literature suggests that the system efficiency is comparable to the OLEV and CIRCE systems, but is not compatible or interoperable with them or other systems. The current testing programme suggests that Electreon are targeting public transport vehicles only, most likely due to its low power rating (only up to 60kW) which is not suitable to drive HGVs.

Bombardier has a well-established static charging system but have yet to achieve the same level of success with their dynamic system. Bombardier's system has a high power transfer (up to 200kW[40]) and is currently trialling with HGVs in partnership with Scania. However, Bombardier has yet to demonstrate this potential in on-road conditions. Testing has been done at speeds up to 50km/h[45], with good efficiencies at large lateral misalignments (10-15cm[45]). An additional benefit of this system, that has yet to be seen on other inductive systems, is its incorporation of AV technology. PRIMOVE system and infrastructure is reported to be interoperable between all modes of transport i.e. trams, HGVs, passenger cars.

Other inductive ERS

The Polito, SAET, Qualcomm, INTIS, and Momentum Charger systems all appear to be at a similar level of advancement to the Oak Ridge system with estimated TRL rating of 3-4. Polito, in collaboration with Centro Ricerche Fiat (CRF) have developed and tested a dynamic inductive system, called Charge While Driving (CWD), and operates using the same principle as the KAIST/Dongwon OLEV system. The Polito system has been subject to rigorous testing and development with the support many expert consortium partners within the FABRIC project. The Polito system has also shown successful interoperability with other inductive systems, namely the SAET system.

Similar to Polito, the SAET Emmedi Group has developed their WPT system as part of the recently concluded FABRIC project. Both the Polito and SAET systems are being tested and developed on the Susa Test track in Italy, with Polito and SAET systems being tested up to 50km/h and 80km/h respectively[19,26]. Both systems are still in early stages of development, and have demonstrated limited capabilities to date, while there still remains issues of reliability and performance of communications, and relatively low efficiency (75% dynamic[5]) when compared with conductive ERS.

The Qualcomm HALO system has also benefited from the support many expert consortium partners within the FABRIC project. The HALO systems has shown to be capable of charging two cars on their 25m segment of test track[5], and has been successfully tested at speeds up to 100km/h[169]. The current system has limited power transfer (up to 20kW) which is only suitable for light vehicles.

The INTIS systems were developed for a range of small-medium vehicles with power transfer of between 30-60kW[107,110] with relatively high efficiencies (88-93%[107]), whilst the Momentum Charger appears to be a high power dynamic system capable of charging multiple heavy duty vehicles. Momentum Dynamics Corp. are currently demonstrating their systems on a number of commercial bus operations but information from these demonstrations has yet to be made available to the public.

Finally, the North Carolina State system and the University of California system appear to not be as well advanced as the other inductive systems. Researchers at North Carolina State University developed a system for dynamic charging called Multi-Resonant Inductive Power Transfer (WRIPT). This system has been tested under dynamic conditions on a small laboratory test track. However, there has been little development with this system over the last few years. The PATH testing programme at the University of California demonstrated their systems functionality, reliability and overall safety. However, the selection of a low frequency (for Electro Magnetic Field or EMF safety reasons) led to practical implications and a low overall efficiency of 60%. The PATH programme ended in the 1990's with no further developments for dynamic inductive charging recorded.

More details of all of the above systems can be found in Appendix B (case studies) and in Appendix C.

4.1.2. Summary of the challenges for inductive ERS

There are a number of technological barriers that need to be overcome for dynamic inductive charging to become feasible. The following issues have been identified as the most immediate issues for inductive ERS manufacturers:

- A number of systems (CWD and IPV) have issues synchronising primary coil segments with the vehicle pick-up. Synchronisation is affected by vehicle speed, lateral alignment, signal switching and communications speeds; all of which can impact the power transfer rate and overall efficiency.
- A number of inductive systems have low power ratings, typically around 20kW, which are only suitable to light duty vehicles. For powering larger vehicles, power levels, efficiencies and misalignments need to be improved. This is especially relevant given the findings of [149] which conclude the only feasible near term applications of ERS are for metropolitan bus schemes, and freight corridors (short-long-international haul).
- At current levels of development inductive systems are only capable of delivering power at vehicle speeds of approximately 80-100km/h, which is ideal for trucks which have a maximum

highway speed of 90km/h in most states. However this is not suitable for passenger vehicles which would typically travel much faster (up to 120-130km/h).

- Another important issue that needs addressing is the ability of multiple vehicles to charge on a single segment or coil section. This factor is related to the synchronisation of coils and their communication speeds.

One of the main challenges is interoperability, which is the ability of different ERS systems to power electric vehicles regardless of vehicle type. Currently, interoperability does not exist in ERS systems (inductive or conductive) in terms of providing efficient power transfer, from the grid to the ERS, and for multiple vehicle types. In addition, there are no standards or regulations available to provide a clear path for interoperability to occur. IEC 61980[177] aims to provide standardisation for inductive power transfer for EVs, but guidelines do not exist yet or are still in development.

For ERS interoperability to become functional, it requires communication protocols. In terms of existing standards, the ISO/IEC 15118[198] ("Road vehicles -- Vehicle to grid communication interface") standard governs the charging of electric vehicles (ISO/IEC15118[198], DIS, 2011), dealing specifically with the communication links between vehicles and charging equipment. This standard could be used as a starting point for ERS interoperability.

Other factors that limit efficiencies and power levels between systems include:

- IPR;
- installation depths (similar air gap);
- ERS geometry (coil size, dimensions);
- system architectures;
- electrical and electromagnetic requirements for conductive and inductive ERS respectively.

4.1.3. Technical feasibility of conductive ERS

Currently there are only five key organisations (supported by much larger consortiums across industry, government and academia) that are developing solutions for conductive ERS (rail and catenary) and these are highlighted in Table 8. Some of these systems are far more technologically mature than inductive systems, with many undergoing public road demonstrations today. The following section provides a brief overview of the technical feasibility of each system. For a more in-depth historical overview, system details, and discussion regarding installation and maintenance the reader is advised to refer to the individual case studies presented in Appendix B of this report. A number of static conductive charging systems (non-cabled) are also included in the case studies in Appendix B for reference but are not discussed in this section.

Table 7: Conductive Systems Overview

System	Organisation	Power & Efficiency	Vehicle Suitability	TRL
Elways	Elways AB	Up to 200kW, 82-95%[5,81]	All types	6-7
ElonRoad	ElonRoad AB	Up to240kW, 90-97%[112,113]	All types	4-5
Slide-in/APS for Roads	Alstom/Volvo AB	Up to 120kW, 97%[5,115] (400kW expected final system)	All types	4-5
HPDC	Honda R&D Ltd.	Upto 450kW, >95%[128,130]	All types (only tested to date on passenger/race cars)	4-5
eHighway	Siemens AG	Up to 500kW, 80-97%[5,68]	Medium-Heavy duty vehicles	7-8

Elways AB

Elways AB, founded in 2009, have developed a segmented conductive rail solution suitable for both passenger vehicles and HGVs. In the presence of an electrified rail an inverted pantograph extends from beneath the vehicle to connect to the conductive channels inside the rail. The system is fully autonomous, and does not require user interaction. If the road user performs an evasive/overtaking manoeuvre the pantograph immediately retracts. The most recent revision is capable of providing up to 200kW[5] per segment with an overall efficiency of 85-95%[5,81]. The system is currently in the pre-commercial procurement stage of development and is being tested as part of Trafikverket (Swedish NRA) eRoadArlanda project (involving a large consortium of 19 partners). The planned demonstration is a 24 month trial on a 2km stretch of road near Stockholm, Sweden, which began in late 2017[170]. This road (893) is not a major road, and will not be subject to the kind of loading expected on motorways, although the project has undertaken successful testing of up to 100km/h[82]. The limitations identified with this system include:

- The Elways system is only suitable for high speed roads with specific geometry requirements (cannot be installed on roads with sharp bends);
- Foreign object detection only informs driver of potential collisions warning, and does not automatically retract the pantograph;
- Cannot be used if road surface is submerged in water;
- Electrified rail sections are longer than the vehicle passing over, leaving lengths before and after the vehicle that are potentially hazardous.

ElonRoad

ElonRoad AB is another Swedish development, who together with Lund University has developed a unique system for conductive dynamic charging. It is an encased rail (domed 5cm apex/30cm base[125]), bolted on top of the pavement's surface. Three inverted pantographs fixed to the vehicles underside automatically extends to contact the rail once aligned. The system can deliver up to 240kW[112] of power at efficiencies of 90-97%[112,113]. Segments are made from 1m long modules separated by 15cm of isolation[125]; only the rails the vehicle is travelling over are electrified. Water drains freely beneath, and it can be easily removed for maintenance. The system being tested on a purpose built track in Lund, Sweden, undergoing development 2016. ElonRoad are currently constructing a 210m test track for testing a variety of cars and motorcycles at for speeds ranging from 50-90m/h, whilst also development of ploughing device for winter maintenance is underway. Participation in Electrivillage Mariestad (Sweden) also provides an opportunity for public road testing by 2021. The limitations of this system include;

- Currently the system is mounted above surface level, which is a risk to vehicles and motorcycles crossing lanes at speed;
- The system has only undergone testing on a test track, and is not considered suitable yet for public road demonstration;
- Short rail sections require a high frequency of switching controls units along the roadside, which increases roadside infrastructure that requires additional maintenance and safety (provision of VRS). This common to many different systems, and is not limited to the ElonRoad solution.

Alstom

Alstom is a French multinational organisation who has adapted a system original design for their rail and tram installations, in partnership with Volvo AB called APS (Aesthetic Power Supply) for Roads. The system contains a set of segmented rails that are embedded in a shallow installation (~8cm) in the pavement and sit approx. 2mm above the surface profile. An inverted pantograph extends from the vehicle rear to connect both rails via a carbon wearing shoe. Testing is currently being undertaken with an adapted Volvo truck on a purpose built 400m long track in Hallered, Sweden[84]. The Alstom system can deliver up to 126kW[115] of power at an efficiency of 97%[5], but has the potential to be scaled up to 1MW[115] as is used with Alstom tram. Track power limitations meant this system could only be tested up to 126kW, however it is designed up to 400kW.As suggested, the system is designed for HGVs, but is capable of supporting all vehicle types. APS for Roads has been tested at speeds of up to 90km/h. There is a planned 2km demonstration on public roads in Sweden and France in 2020-21, with a large scale pilot (30-60km) anticipated in 2030. Alstom have also conducting accelerated pavement testing and wheel tracking on sample road section under laboratory conditions. Some of the limitations identified with this system are similar to the ElonRoad system in that the system is mounted above surface level, and that it has only undergone testing on a test track. Other concerns include the friction of the rail surfacing and potential modifications needed to ensure that it meets the requirements of high speed motorway surfacing.

Honda R&D

In 2014 Honda R&D Ltd. began development of a dynamic conductive rail system called High Power Dynamic Charging (HPDC). Unlike other systems the rail is not embedded in the road but fixed to a VRS. A pantograph extends laterally from the side sill to connect a rolling head to the positive and negative channels of the rail. Since its development Honda has demonstrated four prototypes which have been subject to extensive track testing on a 300m purpose built test track, and extensive simulation modelling energy consumptions under different loads and conditions. The most current prototype is capable of delivering 450kW[130] (input) and 375kW[130] (vehicle output) at an efficiency of 90-95%, and has been tested at speeds of up to 150km/h[130]. The collection unit is capable of delivering power across a horizontal range of up to 1.3m[129] between the vehicle and the conductive rail. Information about the performance of this system is limited, however Honda is developing their fourth prototype. It should also be noted that while this rail system is far less intrusive than other rail solutions there are a number of safety implications involved with having a live rail installed on an asset which is potentially subject to vehicle impact.

Siemens AB

Siemens AB have developed dynamic catenary conductive systems called eHighway. Overhead cables are supported by roadside cantilever masts. Once the vehicle detects the presence of an installation its pantograph extends from the roof to connect to the electrified cables. It is capable of delivering 500kW of power at an efficiency of approximately 85%[68] at speeds up to 80km/h[80] (with 200kW tested with an efficiency of 90-97% at 90km/h). Unlike other systems (with the exception of Honda R&D and ElonRoad) the system has no direct impact on the pavement itself as all components are above or on the road side. The system can be switched of instantly, and vehicles are free to move in and out of the charging lane at will. The cables are suspended 5-6m above the pavement surface, meaning this system is only suitable for HGVs or buses. Of all the conductive ERS solutions discussed, eHighway is the most technologically mature, and have the most public demonstrations. It has been tested under Californian summers and Swedish winters for some time without fault. Also it has been tested with different vehicle manufacturers, axle numbers, and drive units. Since its initial development and trial on the 2.1km test track (since 2012) in Berlin, Germany, there have been a number of important developments. These include:

- A two year demonstration installed on 2km public road (E16 highway) Stockholm, Sweden[68] using Scania vehicles;
- Piloting a 10km eHighway commissioned[69] on A5 autobahn between Frankfurt Airport and Darmstadt/Weiterstadt interchange (5km in each direction testing 15 trucks at a time [127]);
- Part of FESH I & II consortium (2017-2021) constructing a 12km of eHighway in A1 Autobahn Holstein, Germany[75] (due to finish in 2018);
- Volkswagen announce supply of vehicles for field trials in Germany;
- Plans to commission a third pilot in Germany between Baden and Wurttemberg on the B462 federal highway (to be completed in late 2018).
- Development and presentation of 3rd generation pantograph for Scania long-haul hybrid truck

4.1.4. Summary of the challenges for conductive ERS

On review of the technical feasibility of conductive ERS, there are a number of technological barriers that need to be overcome for some systems. The following issues have been identified as the most immediate issues for conductive ERS manufacturers:

- For conductive rail (in-road) ERS, a number of systems have issues with the system creating a raised surface profile in the carriageway. Changes in the surface profile is a major risk to divers and motorcyclists;
- A number of conductive rail systems use electrified rails which have a very different friction level to the adjacent road surfacing. To ensure the safety of road users, the skid resistance of the rails must meet the requirements of the road surfacing for different types of roads (primary and secondary routes).
- For conductive overhead ERS, the systems are restricted to HGVs and buses. The challenge for conductive overhead ERS is to make their systems suitable for all types of vehicles.
- Conductive overhead systems are also limited to open roads and motorways; tunnels, bridges and roads with any overhead infrastructure would not be suitable for these systems;

- The Honda system is limited to roads with VRS; therefore roads with no VRS, and any roads with hard shoulders or emergency stop lanes (all motorways) would not be deemed suitable for this system.

4.2. Impact on infrastructure and maintenance

Road pavements are designed and constructed to carry a certain volume of traffic over a given design period, which is typically >40 years for major highways with remedial surfacing treatments expected every 10-15 years. The responsibility of maintaining the pavement condition to a high level of safety and comfort is overseen by the highways authority or road administration, with design and maintenance procedures carried out under specifications set forth by the administration. Whilst on-road ERS currently exist, to date, installations in public roads are rare with no data available on the effects on pavement condition from these sites. As installation procedures are expected to be ERS specific, special dispensation would be required to allow ERS installations on any given road network, based on evidence provided from laboratory testing and off-road trials. Furthermore, the extent of the potential impact on the maintenance and operation of the road network will be largely unknown, except for conductive catenary ERS which should have no impact on road condition and expected maintenance operations. Therefore, in this section we are only considering the impact of inductive and conductive rail ERS on infrastructure and maintenance.

4.2.1. Roads with inductive and conductive rail ERS

Roads and highways with inductive and conductive rail ERS will be expected to have similar service lives to conventional pavements for NRAs to consider integrating this technology on their road networks. Although maintenance intervals may be more frequent initially, the presence of the ERS in the carriageway should not take away from the long-term performance of the road and therefore induce no increase to maintenance costs. The key areas associated with ERS that will impact on road infrastructure and could to lead to additional road maintenance are highlighted below:

- ERS installation method;
- Materials used in the installation;
- Performance monitoring and maintenance operations of the ERS and pavement.

A brief discussion on these factors is presented below.

ERS Installation method

Although the inductive ERS is radically different from conductive rail ERS, it is expected that the installation procedures will be similar with a trench based approach most likely. Trench based installations are typically used by utility companies in existing road pavements. The main benefits of this approach are that it is relatively quick and cost effective to implement (only one lane closure required to complete the works) and ideally should have minimal impact on the structural integrity of the pavement (lower long-term maintenance costs). However, durability can sometimes be an issue for routine utility reinstatements. Due to the complex nature of ERS, the installations are expected to be a major undertaking, which could lead to extensive delays for road users. However, these procedures will be refined and optimised as engineers become more experienced, which should improve the quality control/assurance of the installations, which in turn should improve the long term durability of the reinstatements and reduce future maintenance interventions.

ERS technologies reviewed in this study that could be installed in narrow trenches include the Alstom, ElonRoad, Elways, POLITO, INTIS and Electreon systems. However, within shallow installations the ERS is more susceptible to greater stresses and strains from traffic loading, thus increasing potential maintenance of the system itself. The presence of any longitudinal joints in the carriageway may also affect long-term maintenance operations and costs. Note that most of these systems have yet to be trialled in in-service roads; hence the durability of these installations under medium-heavy traffic conditions is still unknown.

ERS installations that require major works (full-depth excavations and/or full lane-width reconstruction) are hugely invasive to the existing carriageway and will most likely require a high volume of new road materials, which increases the number of workers and equipment on-site, additional lane closures, and increased traffic management and health and safety. All of which leads to greater disruption to road users and significant costs to the client.

Any procedure for installation must guarantee the following for a road administration:

- Roadworks meet country specific legal requirements (in terms of health and safety and the factors discussed above).
- Installation and subsequent operation does not damage the surrounding pavement or compromise overall performance.
- Traffic flows can be managed safely and effectively to minimise disruption
- Existing roadside assets (utilities, drainage, communications) and existing structures (bridges, tunnels, gantries) are not damaged during installation
- It can be installed during periods of low flow, ideally during the nigh time (between 22:00-05:00), although it is likely that this window would be too short for ERS installations.

The allowable time for an installation is also an important consideration, given the high associated direct and indirect economic cost of road closures. Installation times will vary by ERS type and manufacturer. However it is difficult to estimate installation/lane closure times as there is little or no evidence of these in practice. As such best practice for any type of installation is yet to be defined.

ERS Materials

The materials specified for the installation of ERS will play a significant part in the long-term performance of the road. For example, ERS that requires concrete embedment (in-situ build or pre-fabricated) such as the OLEV and PRIMOVE systems will be preferred in “rigid’ concrete pavement construction. However, if ERS systems encased in concrete are installed in “fully flexible” asphalt pavements, and assuming they are overlaid with an asphalt surfacing, this will almost certainly lead to reflective cracking at the surface, as well as cracking of the transverse joints where the power supply is taken in from roadside cabinets.

Reflective cracking is the propagation of cracking through upper bound layers due to movement, from concrete shrinkage (thermal movement) or at longitudinal joints, of the lower bound layers. Once cracking extends full-depth, it will allow moisture ingress which can then lead to more severe problems in the pavement foundation which could require extensive maintenance.

Alternatively, installing the ERS flush with the surrounding road surface should mitigate the risk of reflective cracking. However, a change of road surfacing (asphalt-concrete-asphalt, asphalt-rail-asphalt) may increase skid resistance concerns, and joint maintenance programmes. A more suitable solution for road owners would be to specify the use of bituminous-like materials in fully flexible pavements which have similar properties (stiffness, flexibility, durability) to asphalt materials that are self-compacting materials and can be laid at cold temperatures i.e. cold-mixtures. For conductive rail ERS, the surface of the rail may have to be modified (texture or grooves) to improve its skid resistance properties.

Note that the installation of any ERS in heavily trafficked motorways has yet to be undertaken. Therefore, the performance of the systems and the surrounding pavement in this environment is unknown.

Performance monitoring and maintenance of ERS and pavement

Future maintenance of roads containing ERS is highly dependent on the type of construction required for each system and the design life of the in-road components of the ERS. Manufacturers are expected to demonstrate to NRAs that the ERS will require limited maintenance during its service life, and that it is durable enough to withstand the conditions similar to heavily trafficked motorways. Performance-monitoring will likely be carried out by engineers representing the manufacturers, with maintenance interventions kept to a minimum so as to avoid unnecessary road works and road user delays. Expected ERS maintenance is varied depending on system type; The Dongwon OLEV in-road components is expected to require maintenance every 10 years[12] while the PRIMOVE and Electreon in-road components are expected to be maintenance free over their lifetime. The ElonRoad and Elways systems have an estimated life of 10 years[113] and 20 years[5] respectively, depending on the wear and tear from vehicle pick-ups and traffic loads. While the in-road components of the Alstom system are expected to be maintenance free for their design life (20-30 years[87]).

Where ERS installations require an asphalt overlay, the expected maintenance will depend on the performance of the asphalt overlay and the subsequent effect of the ERS underneath. Electreon installed a 20m coil segment in a public road in 2015 to understand long term durability under real traffic loading. Current results indicate that the section and surround pavement has not shown any signs of defects, and the passive components remain undamaged. However, for the ElonRoad system, initial results from a public road trial highlighted a number of issues including reflective cracking around the rails and skid resistance issues. The Dongwon OLEV system is pre-fabricated and assembled off-site so there is a high degree of quality control/assurance under these conditions. There are also no reports about its impact on the pavement, and it has experienced hot summers in California and cold winters in South Korea; however, due to the nature of the construction (concrete installation under an asphalt overlay) it would be remiss to expect that these sites would remain defect free. Illustration 21 presents examples of pavement deterioration where inductive ERS has been installed.

Illustration 21: Examples of pavement deterioration for inductive ERS: (top left) longitudinal reflective cracking coming through asphalt surfacing; (top right and bottom) cracking from bus stop installations. © Google Maps, 2018

With concrete construction, thermal movement due to curing will inevitably introduce reflective cracking in any asphalt overlays, usually above the concrete joint locations. Previous experience with overlays to jointed concrete pavements suggest the use of a Stress Absorbance Membrane Interlayer (SAMI) or geo-grid layer between the ERS and the asphalt layer(s) to help mitigate potential cracking. Alternatively, the use of a saw cut and seal in the asphalt surface above the joints in the concrete layer below has been shown to control reflective cracking and should also be considered.

Where an asphalt overlay is not applied, the expected maintenance of ERS in concrete would replicate that which is normally associated with jointed concrete pavements, with visual inspections undertaken to identify defective joints and assessment of the skid resistance of the surfacing.

In terms of routine asphalt surfacing maintenance operations, and assuming that the ERS equipment does not hamper the performance of the pavement, a radically different maintenance operation is required to take into account the presence of the ERS in the roads, and enable the highways authorities to carry out maintenance as and when needed. This will require careful planning and close collaboration between the road authorities and the ERS manufacturers and possible introduction of bespoke maintenance equipment. The maintenance operations are likely to be very different for inductive and conductive rail ERS due to the nature of the equipment and how they are installed in the road. At the time of publication, there was no public information available that describes road maintenance operations for electric roads, the additional costs that they might entail, and what radical changes, if any, are required i.e. winter maintenance operations may need to be reviewed (salting of roads, snow removal, pothole repairs).

The installation of roadside equipment may require increased safety measures such as VRS installation, particularly along high speed roads, which will also require additional maintenance. More discussion on safety and security is presented in the next section.

4.3. Safety and security

The greatest concern to road owners is safety. Concerns over road worker and user safety, particularly during maintenance operations, and skid resistance are likely to rank highly in future implementation plans. To help understand the safety and security issues associated with ERS, this section discusses some of the major risks identified in this study. Electrical safety standards are covered in Section 4.5.4.3 and a separate risk assessment is presented in Section 4.6.

4.3.1. Skid resistance

One factor that is highly correlated with accident risk on roads is skid resistance. Whilst the skid resistance requirements may vary with country, the effects of ERS implementation may be similar. It is generally accepted that the installation of materials with lower skid resistance properties than the adjacent road surfacing should be avoided. For e.g. where concrete (with inductive ERS embedded within) is introduced into an asphalt road, the change in surfacing can greatly affect the skid resistance properties across the lane and increase the risks of accidents. In this case it would be preferable to have inductive ERS buried below the road surfacing to mitigate this risk.

Where conductive rail ERS is introduced into a pavement, the change in the skid resistance is even greater due to the reduced friction of the metallic rails. If the skid resistance of the rails and the road surface is significantly different, there is a risk that vehicles will tend to slew under braking. In order to minimise this risk, the skid resistance of the rails should ideally be similar to that of the road surface.

4.3.2. Road surface profile

For inductive and conductive rail ERS, the main safety concern is the height of the ERS above the road surface. An uneven road surface can lead to driver safety concerns and uncomfortable driving experience for road users especially at high traffic speeds. Designated lanes which have ERS equipment installed on the road surface between the wheel paths may be a viable solution but there are still major concerns over safety for road users especially motorcyclists, the effects on changing lanes, and the potential impact on vehicles that breakdown (e.g. tyre blowouts on HGVs). Therefore, the installation of such devices would have to be agreed by the road authority and a limit on the height of protrusion would be likely. This type of surface irregularity is not expected to be found on major motorways where traffic speed is in excess of 80km/h and is therefore a safety concern particularly for motorcyclists.

4.3.3. Road maintenance and resurfacing

In terms of future road maintenance and resurfacing operations, there is no information available in the public domain where this has been fully addressed. When the road surfacing has reached the end of its service life, which can vary between 8-15 years depending on the effects of traffic, weather etc., it will need to be resurfaced. For ERS installed along the centre of the road, it may be possible to plane off the asphalt surfacing on either side of the system, depending on the location and depth of transverse power cables. However, assuming that it is safe to undertake such maintenance, the potential effects of this operation on the performance of ERS is unknown. The development of a bespoke road planning equipment for roads equipped with ERS may be required although comments from key stakeholders suggest that this may not be necessary. Alternatively it may be more practical to remove the ERS during road maintenance operations.

In summary, there is a need to identify and outline safe operating procedures for future maintenance and resurfacing operations.

4.3.4. Roadside equipment

Roadside equipment should be installed behind the roadside barrier particularly on motorways. The safety distance between the edge of the road and the roadside unit often depends on the road category (e.g. in France this is 10m for motorways, 7m for other new roads, 4m for all other roads).

4.3.4.1. Access chambers

Access chambers may be required for underground roadside equipment. It is likely that these access chambers will be located on the roadside verge or footpath. If located on a footpath, the covers should be flush and level with the surrounding surface, so as to not present a trip hazard to pedestrians. Although sub-surface roadside equipment may be a safer option in regards to road users than above-surface roadside equipment, health and safety regulations for working in enclosed spaces would have to be strictly adhered to.

4.3.4.2. Public access

The equipment should not be easily accessible by members of the public e.g. any housing covering the roadside equipment should be securely closed, to prevent accidental or deliberate contact with potentially large electric currents.

4.3.5. Cybersecurity

All ERS will require IT systems for control and billing purposes, and as such will be susceptible to breaches of cybersecurity.

4.3.5.1. Inductive systems

Most if not all inductive system will require a wireless connection between the vehicle and the charging infrastructure. This is required to inform the charging system that a vehicle needing power is approaching, and that the vehicle in question has the right to draw the power (e.g. an account exists for the user). Furthermore, various systems require a negotiation to establish the required and safe power levels available for power transfer. Typically this communications link needs to be high-speed and low latency, so is normally implemented using WiFi or some similar system.

In addition, the infrastructure equipment will require a communications link to a back-office control system for system status, updates and logging. This will normally use standard Internet protocols.

In both cases, the communications system will require protection against cyber-attack. As existing systems have moved little beyond prototype stages, little information is available on cybersecurity measure implemented.

4.3.5.2. Conductive systems

The cybersecurity requirements for conductive systems are expected to be similar to those for inductive systems, though the latency requirements for the vehicle to infrastructure communications are unlikely to be as onerous, and could probably be achieved using mobile phone technology.

4.3.6. Summary

ERS technologies are currently in early stages of testing and demonstration with safety aspects being evaluated. The major factors for evaluation, from a road administrations perspective, are safety for road workers and users alike, particularly during maintenance operations. Other factors identified for further evaluation includes skid resistance, change in surface profiles, cyber security, and ease of access to ERS equipment (in-road and at the roadside) for maintenance workers and the public.

4.4. Environmental and social impacts

4.4.1. Environmental impacts

A key driver for ERS development is the environmental concerns surrounding global transport systems. In light of these concerns many governments have introduced national and international reduction targets for GHGs; For instance the Climate Change Act 2008 in the UK[171], the Climate Act 2018 in Sweden[172], and the international Paris Agreement 2015[173]. The environmental benefits of ERS are well known especially if sustainable resources (wind, solar PV, hydro) are used to generate electricity to power ERS and EVs. Even if electricity is not generated via sustainable means ERS has the potential to minimise local GHGs and air quality emissions (such as NO_x, PM_{10}, SO_3).

In addition to providing a solution to charging HGVs, a potential benefit of ERS compared to statically charged vehicles is a reduction in battery size/weight. However, at this stage of ERS development there are few publicly available peer reviewed life cycle analysis studies that indicate this to be the case, especially for inductive systems.

ERS compared to diesel

A recent study [145] compared the life cycle impacts of diesel HGV operations to the conductive overhead ERS (based on the Siemens eHighway solution) for HGVs based on Swedish traffic flows. The study examined four baseline scenarios for energy consumption: (i) European mix, (ii) Nordic mix, (iii) wind generated electricity, and (iv) coal generated electricity. Traffic volumes and loadings were also core parameters of the study. It should be noted that the study used the ReCiPe mid/end point characterisation method to compare impacts across 18 environmental categories. Results indicated that wind-generated electricity had the lowest impact (31g/tkm), followed by Nordic mix, EU mix, diesel, and coal-generated electricity mix (41g/tkm, 117g/tkm, 165g/tkm and 229g/tkm respectively). On the assumption of 1000 trucks per day, compared to diesel the conductive overhead system had a GHG break-even time of 3-4 years when using the Nordic electricity mix. Similarly for EU mix electricity, the GHG break-even point compared to diesel is approximately 10 years. Given the impacts of the current EU mix electricity a GHG break-even time of 5 years is only achievable with higher utilisation, approximately 1400 trucks per day. Normalised end-point results indicate that purely coal generated electricity is more environmentally damaging, across the majority of impact categories, than diesel. Lower impacts, compared to diesel can be achieved with all other electricity mixes. This indicates that if electricity is sustainably generated, then the embodied impacts of the ERS infrastructure itself are more concerning than the in-use impacts. The overhead conductive system uses substantial quantities of copper (a common material for most ERS concepts) and steel; however these impacts could be minimised through closed loop recycling techniques. For conductive overhead systems there are negative life cycle impacts associated with the use of large amounts of copper (a scarce material), and diffuse emissions from copper cable friction wear (estimated at 10kg loss per km annually, as is the case in overhead rail electrification).

While many of the power electronic components have shorter lifecycle horizons the majority of passive components (copper cables, steel masts, vehicle restrain systems) have relatively service lives i.e. 10+ years. Note copper cables will wear and could reuire replacement, and masts bases are susepatble to corrosion if not properly maintained. Copper wear could lead to higher levels of metals present in the surrounding ground. Considerations must be given to the lock-in effect of constructed ERS infrastructure. High capital costs in combination with a long system lifetime mean any ERS has to be utilised efficiently for many years to make economic and environmental returns. This is heavily dependent on the business model chosen when financing ERS infrastructure. However, in terms of the environmental payback the above study illustrates the possibilities of relatively fast returns when sustainably generated electricity is used to power ERS.

The potential impact of ERS on energy use and GHG was evaluated in this study along with its possible contribution to the decarbonisation of road transport.

Plug-in and semi-dynamic ERS infrastructure

A recent study [146] compared the life cycle energy and GHG emissions of plug-in charging and semi-dynamic inductive ERS for an electric bus scheme (semi-dynamic uses short inductive segments combined with static charging at stops). The study concluded a number of interesting findings.

- Firstly it found that if the battery size was reduced for inductive ERS this weight reduction would only result in a minor GHG saving compared to plug-in charging. While electricity consumption is relatively similar in both systems, any saving for inductive ERS is offset by the efficiency differences – the study assumed a power transfer efficiency of 85% (compared to 90% for conductive plug-in).
- If the overall efficiency of the inductive ERS is raised to 90% then environmental gains increase, resulting in a 6% GHG saving. Further GHG savings, up to 19%, can be made if the following conditions are met:
  - an power efficiency of 93.5%;
  - daytime electricity carbon intensity is 10% lower than night time electricity carbon intensity;
  - higher power levels (up to 66kW);
  - if vehicles spend 10% longer charging;
  - if a 5% fuel saving can be realised if a 10% vehicle mass reduction is achieved.

The study also assumes a 24 year techno-economic lifetime for an inductive ERS, with a 20 year lifetime for plug-in chargers. It found that if both systems are retired after 17 years of service, due to innovations and newer models entering the market, then there is no difference in global warming impact between the two options.

While the above study [146] does not examine full dynamic inductive ERS nor does it compare the findings to the life cycle impacts of conventional fuels, it does provide a useful indication as to how sustainable inductive ERS is.

In summary, after reviewing all of the publicly available literature it is clear that there is a gap in current research regarding life cycle assessment and environmental impact assessments of ERS concepts. This is partly due to novelty of these systems, with many solutions still at the prototype stage of development.

4.4.2. Social impacts

Similar to environmental impacts there is a lack of publicly available research regarding the social implications of ERS concepts. In 2014 Torkington et al. [148] conducted extensive stakeholder engagement with industry groups and private vehicle users. Furthermore it conducted a socio-economic assessment which modelled the impacts of replacing a proportion of the vehicle fleet with EVs and inductively charged EVs. The first part of the report concludes that surveyed private vehicle users viewed inductive charging positively, and would be willing to pay more for this capability. However a large proportion of respondents indicated that they would not be willing to pay for public inductive charging infrastructure. Those who stated that they would contribute to inductive charging infrastructure would only do so if inductive EVs made up approximately 20% of the transport fleet [148].

Improved practicality of EVs and simplified charging (which would be common for all types of ERS) were seen by private users as a very important factor for uptake. Similarly GHG reductions and improved local air quality were also key factors for viewing the technologies positively. The socio-economic element of the report concluded that financial gains were accrued by wider society rather than individual drivers.

The modelling was performed for private cars, taxis, vans, buses using case studies in London, Barcelona, and Florence over a seven year period.

- For a bus fleet with 20% EV or ERS compatible EVs, the societal savings were estimated to be between €4m-€10m.
- For cars, taxis, and vans the societal saving over 7 years for 20% uptake ranged between €6m-€168m, €1m-€22m, and €26m-€916m respectively.

These savings were accumulated through operational savings which outweigh the higher capital costs of inductive EVs compared to diesel vehicles.

For this PIARC study, a summary table was designed to highlight a number of potential positive and negative impacts from each ERS concept. These are not definitive impacts, owing to a lack of data given the novelty of ERS concepts. Each technology has been assessed in comparison to the current road transport system as a baseline. Fifteen social impact categories were assessed. A tick (✓) indicates a potential positive social impact from ERS, a cross (✕) indicates a potential negative social impact from ERS, and a dash (-) indicates neither a positive or negative social impact. It should also be noted that these impacts occur only where maximum ERS compatible EVs and ERS infrastructural uptake has been achieved.

Table 8: Potential social Impacts of ERS

Type of Possible Social Impact	Conductive Overhead	Conductive Rail	Inductive
Fuel/Operational savings (lower running costs)	✓	✓	✓
Improving local air quality (reducing roadside NO_2 and PM_{10})	✓	✓	✓
Reducing GHG emissions (reducing CO_2, NOx CH_4, O_3, CFCs)	✓	✓	✓
Visual and landscape impact	✕	✕	-
Noise nuisance	✕	✕	✓
Convenience of charging	✓	✓	✓
Suitable for private vehicle users	✕	✓	✓

Public access to charging infrastructure	✗	✓	✓
Affordability of ERS compatible EV	✓	✓	✓
Health impacts	✓	✓	✓
Use of space	-	-	-
Traffic congestion (during installation)	✗	✗	✗
Traffic congestion (during maintenance)	✓	✗	✗
Journey quality	-	✗	-
Public safety	-	✗	-

As can be seen from table 8, ERS concepts share many similarities in the positive and negative social impacts that they might offer, both directly to users and wider society in general. There are a few differences:

- Both conductive rail and inductive solutions offer the possibility that any type of vehicle can make use of them. However the conductive overhead system is only suitable for HGVs, limiting access to private vehicle users.
- Whilst noise generated from tyre and pavement interactions cannot be completely minimised with any ERS system, all systems have the potential to minimise engine noise as internal combustion is no longer taking place. However, improvements may be offset to some degree by the noise generated from the friction between the sliding of the pantograph over the rails/cables. Furthermore, noticeable reductions will only be realised if there is a sufficient proportion of ERS compatible vehicles compared to ICE driven vehicles operating in the same space.
- In terms of maintenance related traffic congestion, conductive solutions have the advantage that most, if not all, components are easily accessible, allowing for less impact on road users. However for conductive rail and inductive systems the future maintenance operations of these roads are less clear and may require extensive roadworks and therefore increase traffic congestion. Inductive systems are also prone to failure although this should be minimal as only weatherproof passive components are placed beneath the carriageway. Moreover some inductive systems are buried well below the surface level (up to 8cm), allowing for future maintenance works. As such inductive systems should cause minimal disruptions during maintenance.
- Journey quality and public safety should not be impacted by the presence of conductive overhead and inductive systems. However, the presence of conductive rails could impact on these two factors due to the change in surface profile, skid resistance properties, and the possible risk of electrocution.

The potential negative social impacts could include:

- The aesthetics of the conductive ERS, with the overhead concept being more visually unappealing of the two conductive solutions. It should be noted that in the context of motorways, large visually unappealing infrastructure already exists in the form of overhead gantries.
- In terms of traffic congestion caused by construction works all systems have limitations due to their installation times which would require extensive road closures.

In summary, in the absence of publicly available social impact assessments, this study has provided an assessment based on consultation with relevant ERS and social science experts. However, the results from this assessment are subjective and require evidence from further research to properly quantify the potential social impacts of ERS.

4.5. Regulatory framework and standards

4.5.1. Introduction

The regulatory framework for road transport consists of legislative instruments (acts of parliament, EU Directives, government licences, regulations, rules), international and national standards, the regulatory bodies which set and enforce these and regulatory processes. The aim of the regulatory framework is to protect the public interest and regulate the market, but with minimum administrative burden and without inhibiting innovation. The regulatory framework normally addresses issues such as safety, consumer interest, environmental impacts and competition. Regulations need to be regularly updated so as not to become barriers to new technology or contribute to inefficiencies, and to ensure they continue to protect the public in the face of technological or societal changes. Regulations, and acts of parliament in particular, can be difficult and time consuming to put in place or modify often requiring extensive consultation.

The regulations relevant to ERS relate not just to transport, but also to consumer rights, procurement and competition, energy provision, health and safety, environmental protection and land-use. These can vary significantly between countries, as can the governance of the road administrations themselves. Whereas the majority of road networks are owned by the public sector, some roads and structures may also be part of a design build finance and operate (DBFO) organisation or private public partnership. In these cases there may be some type of concession contract transferring operating rights and obligations to the private company.

Regulations may be enforced through the courts e.g. through penalties for organisations or individuals. Compliance of road administrations with regulations may also be overseen by the appropriate government ministry or a separate government body. For example Highways England operates through a licence agreement which is monitored by the Office of Rail and Road (Infrastructure Act 2015[174]). In Bosnia and Herzegovina the road company is subject to the jurisdiction of the police who may fine them if they judge they have not properly fulfilled their duties. In Australia the National Transport Commission develops regulatory reform. In the case of ERS, energy regulators e.g. OFGEM in the UK, would also play a role.

4.5.2. Potential areas of concern for ERS

Introducing a disruptive technology such as ERS to road networks will inevitably raise a number of regulatory challenges. Regulatory frameworks vary significantly between countries therefore it is not possible to do a full review, however potential areas where regulations may present challenges are discussed below.

Public procurement

Public procurement rules exist to promote fair competition. If a technology is only produced by one manufacturer these regulations may present a problem, as it will effectively create a monopoly. This also relates to intellectual property rights (IPR)/patents and interoperability; as it depends on whether similar technologies can be produced and integrated on the same network. Currently (see Section 4.1.2) ERS are propriety and there is no interoperability between systems. If there is a monopoly, economic regulation would be required to ensure customers are treated fairly. This could be integrated into the role of existing transport regulators or require a new organisation to be established.

Ownership and liability

The delivery mechanisms of ERS is still being debated, but might well include some form of PPP where the technology is installed on a public road network, but owned and maintained by a private company. This raises a number of potential issues:

- In some countries e.g. Sweden there are regulations about the installation of equipment on public roads which is not owned by a public organisation.
- If there are no domestic suppliers of ERS, then any laws that restrict foreign investment in national infrastructure may cause difficulties.
- If there is an accident involving the ERS system, there may be uncertainty as to who would be liable for damages.
- It is also unknown who is responsible for securely processing the personal data which needs to be collected for payment, and data sharing between the various organisations involved would be carried out securely.

Land-use and planning

The legal rights of a road administration in regard to land ownership can be complicated. For example in the UK, road administrations do not necessary own the land itself (i.e. the sub-soil and the air space above it), but uphold the right of the public to travel over the land without obstruction with specified powers and duties related to this set out in the Highways Act 1980. Unless purchased by the road administration for construction the land belongs to the original landowner (most likely the owner of the adjacent land). It is unclear as to how the installation and operation of ERS relates to this legal position as it is outside the normal duties and powers of a road administration to provide safe travel and maintain the road infrastructure. In Sweden if a new function is added to the existing infrastructure a new road plan is required and it is expected that the installation of ERS would be viewed as a new function.

All the ERS technologies require the installation of electrical equipment (and VRS) adjacent to the road and the overhead systems also require the installation of roadside masts at regular intervals. Assuming that this land is available, road administrations would not necessarily own the land, so would require access. In Sweden, the road administration has right of way for installing road equipment, but it is unclear if electrical transformers would be covered by this. In the UK road administrations have the power to carry out specific tasks requiring access such as construct and maintain drains, protect the highway against natural hazards or install barriers. Other types of equipment are not mentioned, so may not be covered. Obtaining access could require purchasing land or providing landowners with compensation, it may even involve compulsory purchase.

Electricity provision and safety

The energy industry is highly regulated. Independent regulators are responsible for the regulation of the energy sector including safety, ensuring demand is met, protecting consumers in regard to quality and pricing, and promoting competition. Usually a licence or permit is required to carry out activities such as electricity generation, transmission, distribution and supply. These licences include certain conditions or standards, and in the EU the relationships between the different licence holders are strictly governed. For example, it is not possible to both distribute and supply electricity so if the road administration or PPP organisation that operates the ERS own the transformer and grid connections it may be the case that it cannot then sell electricity to vehicle owners. Exemptions for internal grids are possible, but there may be limits on voltage, extent and ownership by a private company.

The procurement of electricity in the EC is open to competition; if only one electricity supplier provides the charging service this could require amendment to current laws.

Vehicles

New and retro-fitted electric vehicles (manufacturer supported only) need to comply with regulations set forth by the national transport sectors and roads administrations, ensuring safe operation for the road user and no impact to the road infrastructure. For example, the installation of the ERS equipment is likely to affect the EC Type Approval, and will almost certainly impact on roadworthiness testing due to potential safety and environmental implications. However, it is unknown if hauliers operating licences (national and international) and any payment made by foreign freight operators to use the network would be affected.

4.5.3. Introducing new regulations

The regulatory framework for ERS is complex and bespoke to individual countries, and even individual regions within countries. In LMIC, regulations may also be less transparent and more vulnerable to political influence and corruption.

These challenges are not unsurmountable, but it is likely to require several years to put in place or amend relevant legislation. For example in the UK the Autonomous and Electric Vehicles Act 2018[175] provides new powers for the government to ensure motorway service stations have sufficient electric charging points and to address insurance concerns in relation to autonomous vehicles. The new laws include:

- Making sure that public charge points are compatible with all vehicles;
- Standardising for the payment schemes;
- Introduction of standards for reliability and quality assurance.

It could be envisaged that a similar act would be required for ERS.

4.5.4. Technical standards

The design and construction of roads are governed by the design specifications set out by the respective road administrations in any given country. While design standards and construction methodologies will vary from country to country, the impact of the ERS installation will be similar. ERS installation is likely to be somewhat different to conventional road construction, with different and innovative methods likely to be adopted to satisfy the requirements of the technology. However, it is also important that the materials and design used for ERS installation complies with existing road specifications to allow safe operation of the roads and to maintain the structural integrity of the pavement structure. As yet, there are no design and construction guidelines specific for ERS. The following sections provide examples of various technical standards that ERS installations may have to satisfy where available.

4.5.4.1. Physical Performance

The physical characteristics (size, weight, materials, strength, and robustness) of ERS will be a key consideration for road administrations. For systems to be installed on, beneath or above the road they will have to meet existing regulatory standards, or require standards to be adapted to allow for the implementation of these novel technologies. For example regarding the physical size of components buried under the road (such as inductive coils, casings, and cabling) the UK's Specification for the Reinstatement of Openings in Highways[176] (SROH) section 1.8.1 mandates that equipment with an external diameter greater than 20mm is not permissible unless special circumstances exist[144]. The standard states that the size of the system shall not weaken the structural strength of the pavement or its wearing course. Similar regulations exist across Europe for buried component's physical size. The only size limitation for overhead conductive systems would relate to its clearance from the ground. In this case it must comply with standards for bridges and tunnels, allowing safe passage of extra-large vehicles. Additionally this clearance should also comply with electrical safety standard. For instance in the UK the minimum clearance of overhead electric cables, in a publicly accessible area, is 5.2m.

In Europe there are no specific requirements regarding the weight, materials, or strength of a power transfer system. However regulations are clear that any device that is placed in or beneath the road shall not accelerate pavement deterioration. An ERS in-road system must be strong enough to withstand typical and exceptional highway loads, pressures and vibrations (such as the continual traffic loadings of 40 tonne HGVs). The robustness of a system should be at least equivalent to, if not greater than that of the current standards regarding: humidity, rain, heat and fire resistance, snow and frost, UVA and UVB. For example a system reinstated with asphalt should withstand:

- Laying temperatures (120-200^{o}C) – rubber components and casings may be susceptible to damage at higher temperatures
- The impact of de-icing salts – a potential issue for conductive rail systems where salts can cause corrosion or act as a conductor in the case of parallel rails
- Spillage events of hazardous materials – such as fuels, oil, bio-waste, etc.
- Direct exposure to fire

A typical wearing course is approximately 4-6cm thick, inductive systems should perform efficiently through this medium in addition to the air gap between the vehicle and pavement surface. For porous asphalt, the ERS performance must not be reduced when the wearing course is soaked with water.

4.5.4.2. Operational Performance

There are a number of requirements any type of system must comply with regarding consequences under operation. The pavements mechanical characteristics can be impacted by changes in strength, skid resistance, waterproofing, and surface profile consequently leading to accelerated deterioration and potential safety issues. Under operation, a system should not exceed the ambient temperature of the pavement, remaining below 40^{o}C. Beyond electromagnetic compatibility (EMC), no specific requirements have been identified regarding EMF emissions from buried or roadside equipment. However, EMF emissions should not interfere with existing equipment (variable message signs, optical and magnetic sensors, traffic lights, ITS transceivers). Furthermore EMF should not interfere with communications equipment used by emergency services, road workers, or health devices (such as pacemakers) for drivers/passengers/pedestrians. Legislation only exists for EMF regarding public or worker safety; there are currently no regulations that cover EMF emissions within a pavement structure.

In terms of network performance and reliability, ERS should not alter traffic conditions (for example from free-flow to a stop-start state). Any type of system must perform so that the following requirements are at least maintained:

- A critical performance factor is vehicle speed. The system must be capable of functioning efficiently for vehicles travelling at highway speeds (90-130km/h). If systems are not capable of power transfer at these speeds it could result in road users slowing down, leading to a breakdown of free-flow; alongside associated safety implications of slow moving vehicles in a high speed environment.
    - The system should be easily switched off to allow for routine maintenance works, and the presence of easily accessible emergency cut-off switches (located at the roadside) may need to be considered. Any type of system must be able to detect abnormal operating conditions and automatically switch-off.
- A system must be able to be remotely switched off, in case of emergency, without impacting the speed of vehicles that were previously charging.
- It should cope with gradient of speeds from different road users, allowing HGVs to charge at maximum speed limits (90km/h) and also accommodate faster moving vehicles.

Whilst the potential uptake of ERS compatible vehicles in the short term is anticipated to be low, long-term provisions should be made to accommodate higher levels of demand. Any installation should satisfy maximum demand in a way that does not lead to congestion in the charging lane or cause a breakdown of free-flowing traffic. To this end technological provisions should be made so that a vehicle, under charging conditions, can freely exit the lane in the case of overtaking or evasive manoeuvres. Similarly ERS technology must satisfy typical driving behaviours in that it should allow charging when the vehicle is misaligned from the system/lane centres.

The majority of available ERS systems are segmented into variable lengths for safety. Ideally individual segments should support the charging of multiple vehicles at once. For instance a typical headway between two vehicles travelling at 80km/h is 1.1 seconds (equivalent to 24m spacing's). Under peak conditions and congested states this can reduce to 2-4m vehicle spacing's. As such any system should support charging under this scenario.

4.5.4.3. Electrical safety considerations

The IEC Technical Committee 69 (IEC-TC69) is responsible for the standardisation of EVs including charging infrastructure. Requirements for off-board equipment (such as power electronics and switching boxes) are specified in *IEC 61980: Electric Vehicle Wireless Power Transfer Systems*[177]*.* This standard governs: the characteristics and operating conditions of the off-board supply equipment; specifies the off-board electrical safety requirements; communications (for safety and system processes); requirements for equipment positioning (for efficiency and processes); requirements for multiple vehicles using a system and specific EMC requirements (those not covered in IEC 61851-21-2[178]). However the standard does not relate to safety aspects related to periodical maintenance; off-road conductive systems (trolley buses, rail vehicles); and power circuit supply (covered in ISO 6469[179]). Overhead requirements for catenary based solutions for electric vehicles likely to use current rail standards.

SAE J2954[168] Wireless Charging of Electric and Plug-in Hybrid Vehicle outline the guidelines for inductive power transfer for light duty Plug-in and electric vehicles and alignment methodology. The practice covers electromagnetic compatibility, EMF, minimum performance, safety and testing.

There are a number of general requirements for all systems:

- Hazardous live parts shall not be accessible. Use IEC TS 60479-1 2005 Effects of current on human beings and livestock[180].
- Protection measures against electric shock under single faults conditions shall be implemented (BS EN 61149).
- IEC 60364[181] is an international standard for installations for buildings (BS7671[182] in the UK or NFPA 70[183] in the US). The standards cover protection for safety, selection and installation of equipment, requirements for special installations including electric vehicles and verification.
- Accessible parts of the WPT system from exceeding certain temperatures to prevent skin burns when touched accidentally or intentionally IEC Guide 117[184] and IEC 60364-4-42:210-05. The metal parts with bare metallic surface should not exceed 80 °C. and the parts with non-metallic surface should not exceed 90 °C
- Degrees of protection against access to hazardous parts: The minimum IP degrees in public road installation: IP 69K (ISO20653[185]) as installed.

Human exposure to electromagnetic waves is one of the standout points for the inductive power transfer, governed by the Institute of Electrical and Electronic Engineers (IEEE) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Reviews by both organisations have found there is no evidence that radio frequency EMF cause cancer, however they may increase body temperature, stimulating nerves and muscle tissue. The main standards related to ERS are as follows:

- Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1 Hz - 100 kHz). Health Physics 99(6):818-836; 2010186.
- IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz", IEEE Std. C95.1-2005187.
- IEC62311: Assessment of electronic and electrical equipment related to human exposure restriction for electromagnetic fields (0Hz to 300 GHz)188.
- IEC62233: Measurement methods for electromagnetic fields of household appliances and similar apparatus with regard to human exposure189.
- 1999/519/EC, "Council Recommendation of 12th July 1999 on the limitation of exposure of the general public to electromagnetic fields (0hz to 300Ghz), Official Journal if the European Communities No. L 199, 30th July 1999, pp. 59–70190.

In summary, there are standards, regulations and guidelines that road operator should consider for conductive and inductive power transfer solutions. The main concern for wireless power transfer is the impact of electromagnetic exposure on humans due to inductive power transfer through the air gap. The ICNIRP or IEEE standards provide similar guidelines to comply with EM exposure. The main concern for conductive solutions, especially for rail systems is the exposure of live wires/rails, the IEC standard states that hazardous live parts should not be accessible, this means that the solutions should only active when there is an compliant vehicle using it and there is no possibility for a human to be in contact with rails/wires during power transfer. In terms of conductive overhead cables, the cable should be out of reach of humans with sufficient clearance; the rail industry standards can be adopted and modified where necessary for vehicles on road.

4.6. RISK ASSESSMENT

A risk evaluation in terms of operational and maintenance safety was carried out as described in Section 2.3.4. The risk assessment considers the full lifecycle of the technologies and includes the risks to all affected parties. The aim is to understand the safety risks resulting from each technology and whether these can feasibly be managed: high level mitigations are considered.

Levels of concern have been selected by risk specialists at TRL, informed by previous research carried out for electric vehicle and road system projects as well as relevant standards and guidance. Within the risk assessment, five different types of system were considered:

- Inductive power transfer (Dynamic)
- Conduction charging (Overhead equipment)
- Conduction charging (In-road-rail)
- Plug-in charging technology
- Inductive Power Transfer (Static)

The outcomes of the risk assessment are provided in Appendix E and summarised here.

Table 9: Summary of risks identified

ERS and power transfer type	Installation					Use					Maintenance					Renewal/ Decommissioning				
	Level of concern					*Level of concern*					*Level of concern*					*Level of concern*				
	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH	VL	L	M	H	VH
Inductive	4	1					11	2				8	1			2	1			
Conductive rail	2	1	2			1	11	8	1	3	1	11	3	1		2	1			
Conductive overhead	4	1				1	16	3				8				2	1			
Inductive static	4	1				2	11	3				10				2	1			
Plug-in	2	1				2	6					5				1	2			

Note: VL=Very Low, L=Low, M=Medium, H=High, and VH=Very High. Values within the table refer to the number of risks under each categories.

4.6.1. Inductive ERS

In total, 29 hazards were identified for this type of technology.

- It can be seen that the majority of hazards identified in this risk assessment fall into the very low or low category, with three hazards being determined to fall within the medium region.
    - Risks of medium concern include the increased exposure for operatives to live traffic when maintaining the system and carrying out repairs.
- There were no hazards identified as being in the high to very high region.
- The presence of this technology overall fits within the very low to low level of concern but there are areas that should be looked at further.
    - For example, having inductive ERS equipment near roads and live traffic, over a lifetime may increase the exposure period an operative experiences having to work next to live traffic. This could increase if the systems that are laid underground are found to be inefficient and impacted by severe weather (ice, snow, flood) which

precipitates further maintenance work. Further research and testing would need to occur to investigate this.

4.6.2. Conductive rail ERS

In total, 48 hazards were identified for conductive rail ERS. The most of all the technologies considered.

- It can be seen that although the majority of hazards identified in this risk assessment fall into the low category, there are key risks that have been categorised as presenting high or very high level of concern.
    - Key risks include debris and the requirement to remove debris to ensure the safe operation of the system, poor drainage, corrosion/defects, and the embedded/mounted rail destabilising motorcyclists, the possibility of electrocution (under worst case scenarios, such as a vehicle strike with mounted solutions), objects being jammed in the rail causing a vehicle strike if not detect and prevented,
    - Hazards deemed to have high risk levels should undergo further testing and investigation to provide evidence that the level of risk is tolerable or identify appropriate mitigations to reduce the risk to a tolerable level.
    - There are many safety feautures that can be adapted from the tram/rail industry. Operations across the world involving power being transferred at the street level function without issue or breaches of safety.However while rail systems are operationala in urban settings, highways are completely different, untested environments.

4.6.3. Conductive overhead ERS

In total, 34 hazards were identified for this system.

- It can be seen that the majority of hazards identified in this risk assessment fall into the low category but some hazards are within the medium category, which may require further investigation and mitigation.
- unique risks include emergency helicopter landings being complicated/prohibitive due to cables and working at height during parts of the installation process. However establishing alternative landing patterns, automatic shutdown of power, and safe working mitigation measures can be used to minimize risks.
- Although this technology has been in use for over a century in the rail industry, it is important to understand that the control of overhead line equipment within the railway occurs in a controlled environment where infrastructure is not widely accessible to the general public. Should this ERS be deployed within the public domain, the ability to control the movement of vehicles and driver competencies is reduced.

4.6.4. Inductive static charging solution

In total, 34 hazards were identified for inductive static charging solution.

- It can be seen that the majority of hazards identified in this risk assessment fall into the very low or low category for concern.
- However, there were three hazards identified as presenting a medium level of concern.

- These risks are substandard road surface/reduced skid resistance, damage to infrastructure and collision with equipment. However, with appropriate design and consideration to the location of equipment, it is likely that the risks can be mitigated.

4.6.5. Plug-in charging solution

For this system 19 hazards were identified in total.

- It can be seen that all of the hazards identified in this risk assessment fall into the very low or low category.
  - Risks of very low or low concern include collision with charging system and operative sustaining a burn.

The hazards and risks associated with plug-in charging systems are already well known as this technology has been in use for over a decade. It presents a very low level of concern provided the system is installed by competent operatives, installed in an appropriate and safe location, used correctly and maintained throughout its life.

4.6.6. Summary of risk assessment

ERS technologies are currently in early stages of testing and demonstration with safety aspects being evaluated. This risk assessment provides only an indication of the safety and associated levels of concern of each system. It can be seen that plug in charging systems are likely to present the lowest level of risk but this is largely due to the fact the risks are known and understood. Risk assessments should be conducted for individual technologies and designs to ensure all risks are reduced as low as reasonably practicable through appropriate design and mitigation. Once risks are considered to be tolerable, the system should be tested and trialled both off and on road to validate identified risks and tolerability of risk decisions.

4.7. Rival and complementary technologies

As a measure of the value that ERS can bring to NRAs and road users a comparison with other technology developments that could inhibit or benefit the development and uptake of ERS is presented and discussed in this section.

4.7.1. Static / fixed charging

There are a number of different forms of EV charging, ultimately the present and future optimised charging network will feature an array of these different chargers that best suit location, charging demand, charging time, electricity supply and cost considerations. It is vital not to underestimate the importance of home charging; the ability to slowly charge the vehicle overnight at the EV owner's residence is both convenient and a cost effective means to refuel the vehicle. Scaling the current levels of home charging to a scenario with the high penetration of EVs may change the feasibility of home charging; population growth, technology capabilities, energy and power availability, attitudes to energy consumption, market structures as well as potential changes in mobility are all factors that could influence charging behaviour.

Static Charging technologies can be divided into two main groups, conductive and inductive. The former can further be divided into two sub groups such as automatic and manual, automatic being movable arm and manual being plug in. Though automatic conductive charging is used by some buses as opportunistic charging; it is not commonly used on cars and vans etc. Meanwhile inductive chargers are those that transmit electrical energy inductively using an electromagnetic coupling.

Conductive charging is the most established and widespread technology currently available for charging battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), hereafter referred to as electric vehicles (EVs). Widespread implementation of publicly available EV charging stations began in 2010 with the introduction of 3,200 units across Europe[191]. In 2016 it was estimated that the European stock of publicly accessible plug-in charging units was approximately 131,293[191]. In 2017, it is estimated that China had installed approximately 214,000 public charging units[192], and the U.S.A. had a stock of approximately 43,000 public charging units[193].

In general there are two types of conductive static EV chargers, On-Board and Off-Board. These are classified by their ability to transfer power. SAE International classifies current systems into three levels, highlighted in the table below. On-Board refers to alternating current (AC) chargers; Off-Board refers to direct current (DC) chargers. On-Board chargers generally transfer power at a lower rate and are operated by a pilot signal SAE J1772. These systems are less susceptible to battery heating concerns however add weight to the vehicle. On-Board systems have a battery management system managed by an on-board rectifier. As such, On-Board chargers work by delivery power to the vehicles on-board battery charger. Off-board charging systems are capable of transferring power at a higher rate and have a more sophisticated battery management system.

They operate by directly charging the vehicles battery; this removes weight from the vehicle compared to On-Board chargers. Off-Board chargers are more susceptible to battery heating.

Table 10: Static Cable Charging Overview

Level	Power Rating	Estimated Charge Time
AC Level 1	120 Volts AC, 1.4kW, 12 Amps	PHEV: 7 hours (0% to full)
	120 Volts AC, 1.9kW, 16 Amps	BEV: 17 hours (20% to full)
DC Level 1	200-450 Volts DC, up to 36kW, 80 Amps	PHEV: 22 mins (0% to 80%)
		BEV: 72 mins (20% to full)
AC Level 2	240 Volts, up to 19.2kW, 80 Amps	3.3kW PEV: 3 hours (0% to full)
		3.3kW BEV: 7 hours (20% to full)
		7kW PEV: 1.5 hours (0% to full)
		7kW BEV: 3.5 hours (20% to full)
		20kW PEV: 22 mins (0% to full)
		20kW BEV: 72 mins (20% to full)

DC Level 2	200-450 Volts, up to 90kW, 200 Amps	45kW PHEV: 10 mins (0% to 80%) 45kW BEV: 20 mins (20% to 80%)
***AC Level 3**	>20kW single phase and 3 phase	*To be determined, not yet finalised
***DC Level 3**	200-600 Volts, up to 240kW, 400 Amps	BEV: <10 mins (0% to 80%)

There are a number of regional variances for EV charging units around the world. This is a consequence of different countries having different electrical systems and grid infrastructure, but also differences in charging needs depending on vehicle type and charging location.

In the U.S.A. conductive chargers typically operate within the 100-127 volt range at a frequency of 60Hz; mainly using AC single phase, but also have infrastructure for DC fast systems. American systems use AC/DC J1772 connectors, with AC connectors available for Level 1 and 2. In Europe it is more common to find 220-240 volt systems, operating at a frequency of 50Hz. European systems offer single or three phase AC power. Charging systems in the EU use a variety of connectors including; IEC 62196-2 Type 1 (J1772 compatible) for single phase, IEC 62196-2 Type 2 for singe and three phase; and IEC 62196-2 Type 3 for single and three phase power. In China most systems operate at 220-240 volts at a frequency of 50Hz. AC single phase and DC fast systems are more widely available in China. China has a exclusive version of AC and DC connectors. Japans systems operate at 100-127 volts at a frequency of 50-60Hz depending on the area of the country. Northern Japan operates at a frequency of 50Hz, while the south operates its grid at a frequency of 60Hz. In Japan charging systems are typically AC single phase for low to moderate charging times, but also have stock of DC fast charging systems. The Japanese connector for AC systems is SAE J1772. DC fast system connectors adopt the CHaDeMo system and coupler.

4.7.2. Battery technology

The current electric cars are mainly equipped with battery capacity 20-40 kWh, this battery capacity generally provides range up to 150 km, which covers approximately 95% of all journeys (Krems, 2013). However, users expect their vehicle to drive for approximately 330 km before refuelling; therefore the majority of the electric vehicles currently available in the market are unable to provide such range. This is mainly due to the current cost and size of the batteries.

The battery energy density determines energy per kg. The weight of the battery is important as in some case it can account for 25% of the total weight of the vehicle. In 2012 battery density was 100Wh/kg, whereas the energy density of modern electric vehicles (in 2017-18) is approximately 150 Wh/kg. The target for electric vehicle manufacturers is to reach 250kWh/kg by 2020[194] meaning that a vehicle that could provide 330km range could weight in par with ICE cars[199, 200].

Battery price is also expected to reduce significantly. History has shown as rapid decrease in the last 10 years; 1000$/kWh in 2010, 350 $/kWh in 2015 and $227 per kWh in 2018. The price is expected to reduce to even further in the next 10 years; 200 $/kWh by 2020, 120 $/kWh by 2025 and 75$/kWh by 2030[199, 200]. This cost reduction means that the cost of battery will reduce total vehicle costs from 48% (in 2016) to 18% by 2030, making electric cars cheaper than ICE cars by 2025[195]. This suggests that by 2025 it may be more affordable to purchase an electric car than an ICE car.

However, for HGVs this may not be the case. A HGV can drive up to 4.5 hours before taking a break (approx. 400km). The battery required to provide such range would be significant, with current estimates of 5 tonnes (in 2017), which might be reduced to 3.2 tonnes by 2020. Batteries of this size are major constraint for freight operators who wish to electrify their fleets, and a unless there is a breakthrough that sees electric battery ranges for HGVs improve to 400km or more, HGV may not be feasible in the near future[196]. The battery electric trucks could be suitable for urban or short range driving; but the battery electric trucks are not a solution for long haul trucks under current forecasts.

4.7.3. Alternative fuels

Although electric powered vehicles are seen by many as the most viable alternative to fossil fuels, other fuels types may also be used. Use of fuel cell powered HGVs can be seen as an alternative to battery electric HGVs or ERS powered HGVs. A fuel cell HGV can achieve up to 400km range without adding on significant weight and detracting from the payload. Energy density of hydrogen is 33kWh/kg while diesel is approximately 11kWh/kg (Energy Density of Hydrogen, 2018). Thus it could contain more energy per kg but it needs a larger volume to store the greater space to contain/store the fuel cell i.e. hydrogen gas. Currently hydrogen fuel-cell HGVs are in their infancy in terms of development, mainly due to high costs of the vehicle, lack of refuelling infrastructure, and the potential for greater CO_{2e} emissions depending on how the hydrogen is produced. However, where capital costs, infrastructure needs, and renewable sources are available, fuel cell technology is capable of providing sufficient range for long haul freight and clean energy emissions.

Biogas and LNG (Liquid Natural Gas) could also play a role in potential fuel cell technology. Biogas such as bio-methane is produced by organic matter and can be captured from waste from landfill sites, farms, the food industry, and energy crops. The gas is normally stored in compressed cylinders on-board the vehicle and refuelled at the filling station just like ICE vehicles. The bio-methane is a renewable gas and it offers significant reduction in CO_2, NO_x and PM emissions. The biogas also requires widely available refuelling infrastructure. Though it provides significant emission savings biogas is not carbon neutral and has concerns over its long-term sustainability. LNG is liquefied version of natural gas; the gas is cooled down to very low temperatures to compress the volume. LNG provides improvements in NO_x and PM but the CO_2 savings are not significant when compared with diesel. LNG needs to be stored at low temperatures in cryogenic tanks. LNG also requires refuelling infrastructure to be considered a viable option.

The economic case for biogas and LNG varies from case to case. Biogas and LNG can be considered as alternative fuels now in order to reduce the emissions and still be economically viable to diesel and petrol. However, these fuels and no zero emission and countries are targeting zero emissions from road transport, therefore biogas and LNG may not be a suitable solution in future.

4.7.4. Impacts of rival technologies on ERS

Due to the current developments and uptakes of static charging solutions, battery technology, and alternative fuel developments, these advancements could be viewed as rivals which could inhibit ERS uptake and implementation. However, these 'rival' solutions could be considered complementary to ERS, and in the context of climate change targets Governments would benefit from having every solution at their disposal.

Most of the ERS systems presented in this study started out as static charging solutions and this was the first step in their development process. Therefore, technological advancements in static charging technologies is beneficial to ERS where some of new capabilities are transferrable to dynamic ERS solutions. In addition, having static charging solutions which are more available and more technically advance, reduces concerns for road users and promotes the use of EVs, thereby increasing support for dynamic ERS solutions where circumstances allow. Uptake of static charging solutions may only be suitable for light vehicles and commercial buses rather than HGVs due to battery size and charging time constraints. Furthermore, the greater power transfer efficiencies associated with conductive static charging solutions may reduce the potential implementation of ERS particularly for buses and light vehicles.

With electric battery technology, rapid advancement in this area is beneficial to ERS in that increases in the range of batteries reduces the concerns of users, and therefore should see a greater uptake of EVs. Greater uptakes in EVs could help promote ERS development as ERS is viable solution for EVs, particularly where circumstances arise and it's economically beneficial to meet the user demand (EV market approaching saturation). Furthermore, improvements in EV battery technology that leads to increased battery density, means that for ERS batteries, which use smaller size batteries, similar increases are expected. For example if EV battery density improves power from 50kW to 100kW, a similar increase in ERS battery is should be similar i.e. from 10kW to 20kW. Alternatively, if EV uptake is not high, this may reduce the potential implementation of ERS.

Biofuels are only an intermediate step in decarbonisation as they are not zero carbon. The lack of refuelling infrastructure also means biofuels and alternative fuel options such as hydrogen fuel cells may struggle to generate growth in their respective areas. Therefore, alternative fuels may not affect the appeal or demand for ERS implementation. However, in situations where biofuel options are favourable, lower implementation and running costs may reduce the appeal of ERS.

4.8. Implementation in LMIC

Challenges and opportunities specific to LMIC were discussed during a workshop held at TRL, and in interviews with LMIC stakeholders. The discussions are summarised below and notes from the workshop include in Appendix D.

4.8.1. Installation and maintenance of ERS systems

Road networks in many LMIC are still under development, which presents both challenges and opportunities. There is usually a greater variety of pavement types than in high income countries ranging from asphalt/concrete motorways to gravel/earth rural roads. Often the majority of the network is unpaved and in poor condition. The conductive rail and inductive systems are designed to be installed in an asphalt or concrete road, so this would restrict the routes where it could be installed. The in-road technologies also require a minimum pavement depth which may not be found in LMIC. For example in South Africa the pavement depth is normally 100 to 150 mm and the KAIST and Bombardier system requires a depth of around 300mm. The undeveloped nature of the network does provide opportunities to include ERS when constructing new roads. This would be more cost-effective than retrofitting as is necessary in high income countries where the network is established and few new roads are constructed. LMIC often have challenging climates and topographies which may further restrict where it can be installed.

Planning regulations are often less strict or not enforced in LMIC. In some countries housing construction (often illegal) alongside the road edges would make it difficult to install roadside equipment, for example the gantries for the overhead systems and electricity sub-stations.

There is a lack of maintenance of conventional roads, and a high risk that ERS would also not be properly maintained potentially leading to technology becoming abandoned. There are examples of other technologies being installed using aid funding and then the LMIC being unable to maintain them through lack of resources or skills. Also ownership/responsibility of an infrastructure asset may be shared between a ministry of transport, local authority or private company which can lead to disputes over who should pay for maintenance. Conversely if the ERS is maintained it might be combined with other types of maintenance improving the condition of the network.

Strategic freight corridors run across countries, so installation of ERS along these routes would require cooperation between neighbouring countries. Cooperation between countries or even different regions within countries is often a challenge in LMIC as political issues and feelings of competition prevent collaboration.

Some positive views were that the different types of ERS available provide flexibility in selecting the most appropriate technology. Also that concerns over aesthetics and NIMBYism are less prevalent in LMIC, so obtaining planning permission may be more straightforward.

4.8.2. Expertise and equipment requirements

Another consideration is the availability of skilled labour to install and maintain the system. Trained workers may need to be imported from other countries increasing the cost of installation and maintenance. However this is also an opportunity to create employment and upskill the local population with skilled jobs installing, operating and maintaining the ERS. Another issue is retention of staff, as often once trained people move to areas where there are better economic prospects therefore leaving the LMIC without the skilled labour required to install the ERS.

There can be high transport costs for importing materials and plant from other countries, and risks in exchange rates. If items are not on a government approved list key equipment goods can be held by customs authorities affecting project schedules. However, if ERS components could be manufactured locally this would circumvent these issues and provide additional employment.

There could be an opportunity for technological leap-frogging i.e. an LMIC adopting the latest technology rather than following the development steps high income countries have been through. It was highlighted that people in LMIC are often very adaptable and are used to using their own ingenuity to develop simpler/cheaper components without having to rely on foreign imports.

4.8.3. Impact on road infrastructure and maintenance

There were concerns on the impact of the on-road systems on the durability of the pavement, skid resistance and winter service activities. Although these concerns are not limited to LMIC, they are less likely to have the resources to absorb or adapt to these types of impacts.

There were concerns that in-road systems would make it difficult to achieve design standards, e.g. relating to construction depths, texture etc. In particular the ERS rails which are above the road, but those flush to the road would also change skid resistance. It could also make future maintenance difficult to carry out without damaging the embedding ERS equipment. If ERS sections are overlaid too many times, the air gap between the coils and vehicle would increase reducing the power transfer efficiency.

The disruption to traffic whilst the road is closed for the installation of the ERS technology was also of concern. This would be minimal for the overhead systems, as the majority of enabling works and installation can take place at the side of the road, but would be significant for the in-road systems. LMIC are likely to have fewer viable alternative routes if a main road is closed, as often the network is less dense and local roads are likely to be in poor condition and unable to cope with the main road traffic levels.

An additional concern was the vulnerability of the technology to theft and vandalism, and its potential to be a target during periods of civil unrest. Whilst theft and vandalism are a concern in high income countries, when the population is poorer activities such as stealing electricity or expensive metal components are more prevalent.

The requirement to install vehicle restraint systems to mitigate the risks of vehicle collision with power units, overhead masts etc. means there are additional assets which have to be maintained by the NRA. The installation of roadside equipment could also hamper future road development such as widening the road.

It was suggested that if ERS lanes were over or underutilised this could modify the maintenance requirements of a particular lane compared to adjacent lanes. Overloading of vehicles is often a problem in LMIC and there is little research on how in-road ERS performs under greater loads.

4.8.4. Energy supply and reliability

In some LMIC a large proportion of the population do not have access to electricity, and production is insufficient to meet demand. For example in Nigeria 60% of the country's population have no access to grid electricity and often those that do have access experience an extremely unreliable supply. Therefore the additional demand exerted by ERS is likely to cause significant challenges. However, at a local level this may stimulate investment in areas where current demand is not sufficient to attract investors.

In rural areas, which strategic routes are likely to cross, connecting to the grid is likely to be difficult and expensive with long connection distances. One possibility suggested was connecting to local micro-grids. This may present an opportunity for a community to sell electricity to the ERS operator. Alternatively if a project provided electricity to both a local community and to the ERS, it would be of greater interest to funders. There may be opportunities to link to renewable energy sources, for example there is a large interest in expanding solar power in many African countries.

4.8.5. Social and environmental impacts

There were a number of concerns raised in relation to safety including the impact of the electromagnetic field on pacemakers for inductive systems, skid resistance of in-road systems, electrocution from live rails and the need to educate road users about ERS and how to safely interact with them. These are similar to concerns in high income countries, although protection from vandalism and theft is more important in LMIC.

A major topic of discussion at the LMIC workshop was social justice considerations, for example is it acceptable to install a system only the rich can afford to use, whilst much of the population has no access to conventional roads in good condition. It was suggested that there are so many other urgent priorities in terms of providing conventional transport, and also addressing issues such as healthcare, access to electricity, education etc. that spending a large amount of money on ERS could not be justified. The traffic in LMIC is much more mixed with a large proportion of two-wheeled vehicles that would not be compatible with ERS. Also traffic is less controlled and does not always align with lanes.

Land-use requirements for roadside equipment is an issue, as it may not be clear who owns land and there may be illegal buildings (often constructed by more vulnerable people) adjacent to the road. There were also concerns that ERS installation could become a Politian's "vanity project" and there was potential for ERS to become entwined in political agendas and corruption.

It was thought that ERS could help to improve local air quality, and if renewable energy sources were used it could reduce carbon emissions. It was noted that if component parts were manufactured locally these may have associated environmental pollutants. ERS could also reduce noise. If ERS brought additional investment to an area it could improve the quality of life for local communities.

The impact of extreme weather events on ERS was unknown and it was suggested that local wildlife may be affecting by the technology, for example large animals such as elephants may have trouble cross roads with overhead equipment.

4.8.6. Impact of competing technologies

Introducing battery EVs were felt to be more of a priority than ERS, as a large issue in many LMIC cities is air pollution and this more established technology could help to address this. As the battery range of EV improves it erodes one of the key benefits of ERS, namely removing range anxiety.

It was felt that trams, rail and waterborne are more established modes of transport and could provide the improved public transport which LMIC require. Also mopeds, bikes and rickshaws are cheap and prevalent means of private transport and use of these is forecast to grow.

4.8.7. Business case and operational costs

Stakeholders stated that the high capital cost required for installation of ERS is even more of a challenge than for high income countries and felt it may also be difficult to justify when there are so many other priorities and the system would only benefit a small percentage of the population. Hauliers in LMIC are also likely to have older vehicles and are unlikely to be able to afford to purchase new vehicles or retro-fit charging equipment. There is normally limited finance options for fleet upgrades and freight companies tend to be smaller.

It is more difficult to make the business case for installation of expensive technology in LMIC as normally a higher return and a shorter payback period is required to justify large capital investments. The investment risks are also higher with local currency risks, more unstable economies and greater volatility in electricity prices. It may be more difficult to integrate business models with local regulations, standards and laws.

The large populations in many LMIC may translate into higher uptake of the technology than in less populated areas. Although there is less of an incentive to drive uptake as carbon policies are less advanced. The more rapid development in regulations, standards etc. however may provide opportunities to integrate necessary changes together with other revisions.

The government would suffer from a loss of revenue from fossil fuel taxes, and there may be job losses in the petroleum industry and service stations if fossil fuel use declined as a result of installing ERS.

4.8.8. Concluding remarks

All stakeholders felt that LMIC have other priorities and ERS is unlikely to feature in investment plans at this time. Instead the focus is on constructing and maintaining conventional roads in good condition and establishing energy supply to all the population. In cities where pollution and congestion are an issue, static charging points for cars and buses are more likely to be of interest than ERS.

That being said there are some situations where stakeholders could see value in installing ERS, e.g. on specific trans-national freight routes or closed systems. There are some opportunities within LMIC that are not present in high income countries and if outside funding could be obtained it could be feasible. However the system would have to be established in developed countries before it is likely to be considered in LMIC.

4.9. SUMMARY SHEETS

A description of the types of technologies and a summary of the results of the evaluation is presented in the summary sheets in Appendix F. This evaluation is based on the information available at the time of submission, and highlights case studies where work is on-going to address identified issues.

5. TASK 3: BUSINESS MODEL FROM A ROAD ADMINISTRATION PERSPECTIVE

In this section potential business models for ERS are considered from a road administration perspective. This includes a discussion on the costs associated ERS including the capital costs involved in installing the system and also its on-going operation and maintenance costs. Also the stakeholders involved including road owners and operators, technology manufacturers, electricity distributors, freight operators and planning authorities; different options for delivery models that could be considered, such as PFI contracts for operation and maintenance of the technology; and road user payment options. Task 3 also involved using a cost-benefit model developed for a previous UK project to explore the economics of implementing different ERS technologies.

5.1. Developing a business model

The development of a coherent business model in conjunction with demonstrations of the whole systems including charging technology is needed in order to commercialise ERS. A business model requires identification of the value proposition, customers, revenue source and how it will be obtained, expenses and the actors involved in delivery.

5.1.1. Understanding the market and competition

For all ERS concepts it is expected that the main customers will be freight operators using HGVs, although the in-road systems could also be used by LVs on longer journeys providing them with a larger customer base than overhead systems. Passenger cars are likely to charge at home if possible, as this is likely to be cheaper and more convenient than public charging facilities. However, on longer journey drivers may choose to top-up on route in which case ERS could be used and some drivers may not have the off-street parking required for installation of charging equipment so would need to use public charging facilities. Intercity buses and coaches could also use ERS if static charging at depots and stops are not sufficient for longer journeys. Static charging facilities are therefore a significant competitor technology for LVs, but are currently less relevant to HGVs.

For LVs to take advantage of ERS, they would need to have the appropriate equipment installed, which would add weight and additional cost to vehicles. This may mean that although it technically feasible for them to use ERS it is not practical or economic when there are alternative static systems. Also the majority of LVs are used mainly for short journeys, whereas HGVs travel long distances. Understanding the potential market for ERS is important as a system designed solely for HGVs may look very different to a system aimed a more mixed user group both technically and in terms of the business model. User behaviour, convenience and cost (initial and operating) will all play a role in determining the potential market and if this will include both freight operators and private cars.

Some stakeholders have suggested that freight operators may only require 25km per day of charging to achieve satisfactory payback compared to diesel operations. Research from [9] suggests that for a KAIST/Dongwon bus, operating along a specific route, would consume €12.5k/year of electricity, equivalent to €50 per km of route per year. Estimates from [114] suggest that for passenger cars travelling 65km per day would cost €325/year; resulting in a saving of €1500/year compared to equivalent journeys using diesel. Estimates from [63] suggest an annual saving of €15k-18k per bus using an ERS system. [65] Estimate that commercial freight operators can save 57-82% of their diesel fuel costs using ERS. [68] Indicate that commercial freight operators can save €20k per 40-tonne truck travelling 100,000km on fuel expenses using overhead conductive ERS. [78] states that 1km of conductive rail ERS can provide €157k of fuel savings per year (when all user savings are aggregated). Furthermore [78] concludes that 20,000km of conductive rail ERS could provide €3.1bn annual savings compared to diesel use.

A further consideration is the potential for disruptive technologies around connected and autonomous vehicles, mobility as a service (MaaS) and the sharing economy to radically alter the current business model of privately owned vehicles. Future scenarios could see people pay for mobility as required, which could for example be based on public transport and shared pods in cities, and specific vehicles for longer journeys. A potential future where private vehicle ownership is drastically reduced in favour of shared EVs could drastically reduce the vehicles in urban environments in place of highly utilised electric vehicles that might require some form of dynamic charging.

Another aspect which could determine the market for a particular ERS system is interoperability. Currently a variety of technologies have been developed and demonstrated with no interoperability between or within concept types (see Section 4.1.2). The various conductive solutions proposed are all inherently non-interoperable, and some (e.g. the Siemens E-road) are limited to limited classes of vehicles. The interoperability considerations for inductive power transfer systems are more advanced. It is recognised that installing multiple non-interoperable systems is not viable, and efforts have been started in standards bodies to standardise the key parameters which will affect interoperability. For example ISO 19363 standardises the magnetic field requirements for inductive power transfer, while ISO 15118 addresses the communications interfaces between the vehicle and the infrastructure.

5.1.2. Identifying revenue source and how this will be obtained

Revenue is expected to be generated by charging a fee to customers who choose to charge their vehicles using the technology, most likely this will be through an on-board charging system which calculates the cost based on the amount of electricity consumed.

A yearly fee or EV vehicle only toll road (e.g. to a port or mine) are also possibilities. The options for fleets and private individuals might be different, and there could be different prices and / or taxes on this basis. Other options for private customers could be to have a private EV allowance as part of a MaaS contract. Different charges could also be applied during peak times or busy routes in order to moderate demand.

In order to be financially viable the electricity mark-up and uptake of the technology need to be sufficient to fund the operation and maintenance of the system and payback the initial investment over a reasonable timeframe. It should be noted that the private sector normally expects a higher rate of return on transport infrastructure investments than the public sector e.g. up to 20% to 30%. Another point to consider is the loss of government revenue from fuel tax as VAT on electricity is currently less than diesel in most countries. Although most governments are viewing investment in ERS as a solution to meeting carbon reduction targets, some governments may wish to recoup some of these losses.

Whereas the mark-up needs to be high enough to make the ERS economically viable, it also needs to be low enough that users of the system have reduced costs compared to conventional fuels. This includes recouping their investment in vehicle equipment within a reasonable time period. Electric vehicles are more efficient than diesel and electricity is less expensive, so this should be possible. Governments may also wish to subsidise the cost at least initially to encourage take-up.

5.1.3. Estimating initial and long-term costs

The costs involved in installing and to a lesser extent operating ERS are large. A non-exhaustive list of some of the main expenses is given below.

Installation costs:

- Materials and components including transport
- Plant and labour
- Electrical equipment and grid connections
- Safety barriers for roadside equipment
- In some cases costs associated with land-use
- Payment system
- Retro fitting equipment to vehicles or new vehicles
- Traffic delay during installation

Operation and maintenance costs:

- Electricity consumed
- Maintenance and inspection of ERS technology
- Vehicle deprecation and maintenance
- Any additional maintenance to pavement
- Delays associated with maintenance
- Administrative costs

An estimate of the installation and operational costs for each ERS type are provided in the case studies in Appendix B. These are preliminary estimates made by researchers and manufacturers, and so their accuracy is unknown. It can also be expected that costs will reduce over time as processes get refined and from economy of scale.

5.1.4. Actors and their drivers

The commercial delivery of ERS involves complex interactions between several actors, all of which need to benefit from the enterprise. Although reductions in carbon and air pollution are important government policies, these external costs are unlikely to drive customer and investor behaviour to the extent economic costs do.

For example:

- The customer benefits by obtaining an affordable, convenient, reliable source of power with minimal cost to upgrade their vehicle and little maintenance.
- The government meets its low carbon policy objectives and supports national industry.
- The road administration has a new revenue stream (or at least no additional costs) and meets customer needs and government requirements.
- The electricity supplier sells more electricity and experiences a more balanced electricity demand.

When considering costs, it should be noted that it is not proposed to install ERS on the entire network. For instance, interviews with NRAs (who are heavily involved in ERS developments) have suggested that by electrifying only 5% of their road network they could achieve approximately a 50% GHG reduction (compared to current levels). This is also seen in the KAIST/Dongwon installations where only a small proportion of the buses route is electrified.

5.2. Types of business models

Key questions to be answered in developing the business model are:

- Who funds the installation of the equipment
- Who funds the operation and maintenance of the system
- How much will users pay to use the system
- How much are vehicle owners willing to pay to install and maintain the equipment
- Who receives payment by the users
- How long will it take to repay the initial investment

Like EVs there is a chicken and egg situation, with hauliers only likely to purchase ERS equipment for their fleet if there are sufficient routes to use it and funders only willing to invest in installing the technology if there are sufficient vehicles with the equipment installed for them to recoup their investment within a reasonable time period. In order to ERS to be introduced it is likely that government support is required for funding/part funding the initial investment and through policies and financial incentives to promote up-take. For example 70% of the costs of the Swedish e-highway trial are publically funded.

It is possible that ERS could be fully funded by the government; i.e. they would fund installation, operation and maintenance; and charge users to recoup the public investment. However, most business models currently being discussed for ERS generally envisage some type of private-public partnership between the government and private stakeholders. The exact form this would take and the actors involved depends on the system type, e.g. if it is suitable for both LVs and HGVs or the route particular benefits a particular industry or region. This could be some form of concession, similar to a DBFO road or structure which transfers the risk of poor uptake to the private sector. It is also affected by the size of the required capital investment, appetite for risk by the government and private sector and strength of the carbon reduction policies and drivers from government. The business model also needs to align with the regulatory framework (see Section 4.6), which may need some modification to accommodate private ownership and investment in public roads.

It may be worth looking at business models from other types of large infrastructure projects and the lessons that can be learnt. For example Eurotunnel which due to higher construction costs and lower initial take-up took longer than envisaged to become profitable.

5.3. Business models for LMIC

The most obvious difference is that LMIC governments have limited capital to invest in the installation of ERS, so any investment would need to be by the private sector or aid providers such as the World Bank or international green funding. Other differences include higher discount rates than in high income countries, favouring technologies where the payback is likely to be sooner rather than long-term.

Electricity and diesel may be subsidised by the government, either for all or for particular sectors and may be government owned. Electricity prices are also likely to be more volatile, with the increasing demand as the country develops and limited capacity affecting prices. There may also be a greater number of mini-grids, so multiple potential providers of power for a single route.

Lower labour costs could reduce installation costs, but this may be offset by the need to use foreign trained staff at least initially. Obtaining specialised installation equipment may also be expensive if this needs to be imported and foreign exchange rates are high.

Vehicles are usually kept running for longer, and therefore new vehicle technology will take longer to penetrate the market. Governance and administration is often less efficient as the organisational structures are not in place and co-operation between agencies can be more difficult. The economy may suffer from high inflation costs.

5.4. COST-BENEFIT ANALYSIS

As part of a previous UK project CBA of some types of ERS was carried out. As part of Task 3 the model developed was modified and used to provide some insight into the likely costs and benefits of ERS over its lifetime and the payback time on the investment made. As the model was developed for the UK the costs are in GBP and the original inputs to the model were set to reflect a case study motorway within the UK, with electricity prices, traffic levels, speed limits etc. all based on UK data. This analysis provides indicative results and some general findings, but each country will have different costs, traffic levels, discount rates etc. so would require its own bespoke model to fully explore this.

5.4.1. Description of the model

The Excel-based model was based on a model previously developed by TRL for the UK Highways Agency (now Highways England) for the evaluation of the costs and benefits of implementing and running an electric recharging system along an illustrative one kilometre section (one lane) of motorway over a 20 year period. The UK Department for Transport guidance on transport appraisal WebTAG[151] approach to cost-benefit analysis was followed as a guide.

The outputs of the model are:

- The annual system operational costs, i.e. the maintenance and administration costs, plus the cost of the electricity used by the users.
- The annual benefits accrued from selling electricity to the users.
- Annual societal benefits (both in terms of absolute and monetary values); namely reduction in the CO_2 emissions, and reduction of the PM and NO_x emissions at the tailpipe.
- Cumulative balance and payback time.

The following impacts are not assessed:

- Accident rates
- Changes in journey time and reliability
- Noise impacts; since the main source of noise at speeds higher than 50km/h is the tyres rather than engines
- User benefits; these would arise from cost savings from using electricity rather than diesel or petrol.

More details on the model parameters are provided in Appendix G.

5.4.2. Scenarios

The following scenarios were explored:

Electricity mark-up:

The electricity mark-up is a margin charged by the road operator to vehicle users on top of their electricity supply tariff (assumed to be equivalent to a rail or industrial tariff). This dictates what the users pay for charging their vehicles and the revenue obtained by the system operator to cover the costs of installing and maintaining the infrastructure. In the Task 3 analysis:

- Mark-up is constant for all the 20 year appraisal period
- Two values are compared - 10% and 65%. This was chosen as representing a range between minimal mark-up that would cover running costs to a level that, on top of an industrial tariff, would make the price to the user comparable to a domestic tariff used when charging at home.

Technology penetration

The number of vehicles using the ERS system, and how this evolves over the appraisal period were assumed to be as follows for the inductive and rail systems:

- Annual take-up rate for both LVs and HGVs: 5%
- Initial percentage of equipped LVs and HGVs: 5%
- Limit to the technology penetration in the LVs fleet: 30%
- Limit to the technology penetration in the HGVs fleet: 75%

These assumptions were taken from the previous work undertaken for Highways England and were chosen, in the absence of any definitive evidence, to represent an uptake rate that could realistically be achieved given typical vehicle replacement cycles. The maximum penetrations achieved were chosen to reflect the likelihood that a much lower proportion of light vehicles would need regular on-route re-charging, given typical trip distances and battery ranges, than is the case for heavy vehicles.

The same HGVs percentages have been used for the overhead system (while the model uses 0% for all the parameters in the case of LVs, since the technology is for HGVs only). It is assumed that both HGVs and LVs can use rail and inductive ERS as there are there are systems able to accommodate both vehicle types being tested, even if these are developed to different rates. The take-up rate is shown in illustration 22.

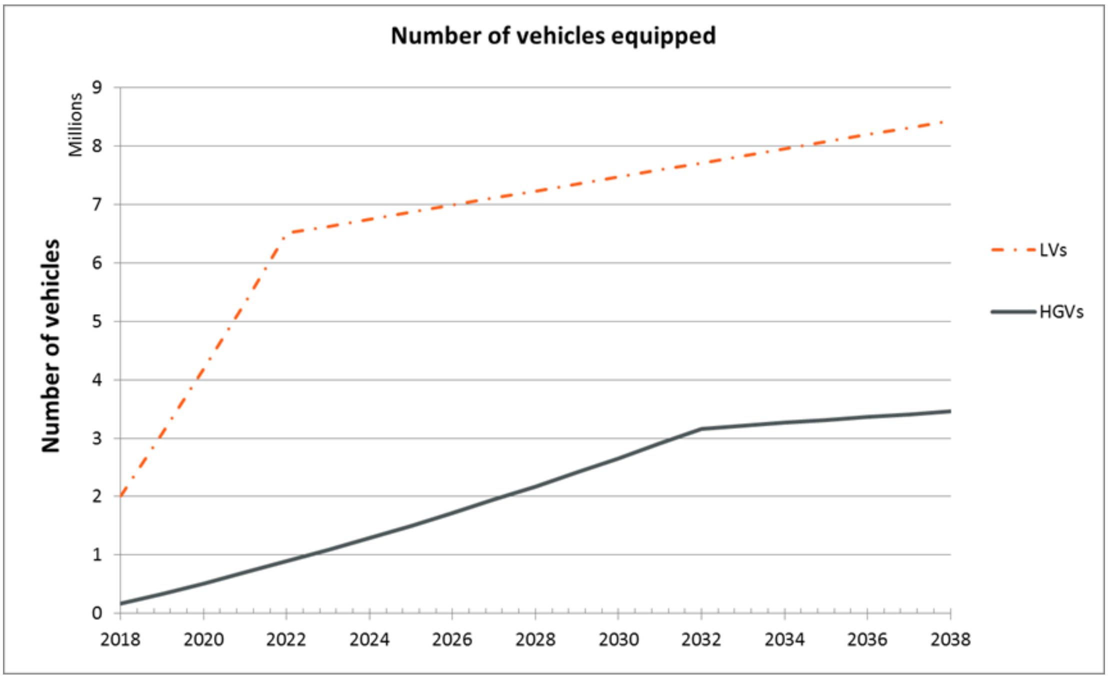

Illustration 22: Penetration rate scenario used for the analysis

5.4.2.1. Assumptions specific to the type of charging system

Infrastructure cost

- For the inductive system installation costs from two sources were used, OLEV and Primove. While the former, as fully commercialised system, gives a single value (500 k€ per lane per km), the latter has a range of possible costs (3.62M€ - 6.15 M€ per lane per km). The OLEV cost and Primove costs significantly differ in magnitude. Therefore the following two values have been considered for the analysis:
  - The single value from OLEV, 500 k€ per lane per km (Imin).
  - The average cost calculated using the Primove range, Imax, that is, 4,885 k€ per lane per km (Imax).
- For the Overhead system the selected values are the minimum and maximum figures of the range found in the literature review, that is, 2.2 M€ and 2.6M€ per lane per km (Omin and Omax).
- For the rail system there are three sources, which provide two ranges of values (from 450 k€ to 1 M€ per lane per km, and from 600 k€ to 1.5 M€ per lane per km) and a punctual value of 1 M€ per lane per km. Since the two ranges overlap, and the punctual value is included in both ranges, the following two figures have been considered for the analysis:
  - The smallest value found in the literature review, that is the minimum value of the first of the two range of costs, i.e. 450k€ per lane per km (Rmin)
  - The highest value found in the literature review, that is, the maximum cost of the second one of the two ranges, i.e. 1.5M€ per lane per km (Rmax)

The costs selected for the analysis are summarised, both in sterling pounds and in euros, in Table 11:.

Table 11: Infrastructure cost per lane per kilometre used in the analysis (exchange rate of 27th July 2018, 0.89)

Systems	Selection criteria	Abbreviation used	Cost €	Cost £
Inductive	OLEV cost	I_{min}	500,000 €	445,000 £
	Average of Primove cost range	I_{max}	4,885,000 €	4,347,650 £
Overhead	Minimum value of the range	O_{min}	2,200,000 €	1,958,000 £
	Maximum value of the range	O_{max}	2,600,000 €	2,314,000 £
Rail	Minimum value of the range	R_{min}	450,000 €	400,500 £
	Maximum value of the range	R_{max}	1,500,000 €	1,335,000 £

System efficiency and power demand

As part of Task 1 ERS efficiencies were collected. Table 13 shows the efficiencies used in the CBA.

Table 12: ERS efficiencies used in the CBA analysis

System	Efficiency range	Average efficiency	LV consumption at 68mph constant speed (kWh/km)	HGV consumption at 56 mph constant speed (kWh/km)
Inductive	60% -- 91%	73%	0.22	1.95
Overhead	80% -- 97%	87%	0.18	1.66
Rail	82% -- 97%	87%	0.18	1.66

Based on these efficiencies and on the assumptions on the technology penetration in the LVs and HGVs fleet the energy demands shown in Illustration 6 are calculated.

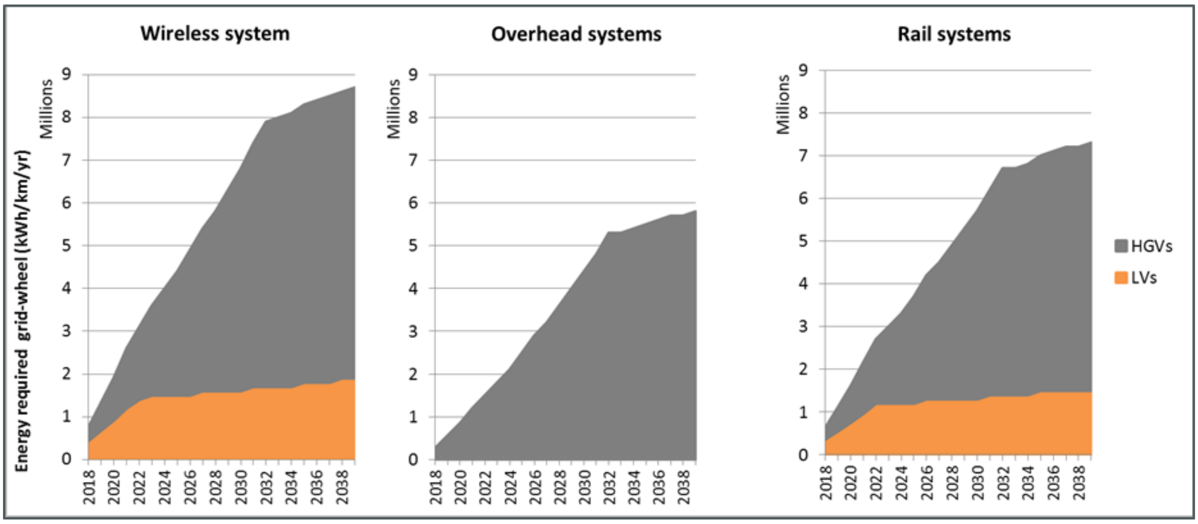

Illustration 6: Energy required per kilometre per year for inductive and conductive ERS.

5.4.3. Outputs

The outputs of the analysis are summarised below.

5.4.3.1. Cumulative balance

The cumulative balance is shown in

Illustration 7 and Illustration 8 for an electricity mark-up of 10% and 65%, respectively. The pay-back year and the balance after 20 years are summarised in Table 1314.

Highlights:

- With a mark-up of 10% on the electricity price none of the scenarios analysed reaches the break-even year by the 20 years of the assessment.
- A inductive system whose cost is around £4.3 million (€4.9 million), does not reach the break-even year in a 20 years period with an electricity mark-up of 65%.
- A inductive system which costs as much as the OLEV system, Imin, has a similar outcome to the cheapest rail system Rmin in terms of paid back year, which is the sixth year of operation. They both reach high savings after 20 years; the inductive system in particular allows larger savings (about £1 million higher than the cheapest rail system, Rmin).
- A rail system on the high side of the cost range can reach the break-even year before 20 years for high mark-ups on the electricity. The highest mark-up considered (65%) needs 13 years of operations before starting receiving a profit, which can be as high as £2.7 million after 20 years of operations.
- The overhead system analysed does not reach the break-even year in 20 years in any of the scenarios analysed.

Table 13: Break-even year and balance after 20 years

	Mark-up 10%		Mark-up 65%	
System	**Break-even year**	**Savings after 20 years**	**Break-even year**	**Savings after 20 years**
I_{min}	>20 years	- 0.4 M£	6	5.7 M£
I_{max}	>20 years	-9.0 M£	>20 years	-2.9 M£
O_{min}	>20 years	-4.0 M£	>20 years	-0.2 M£
O_{max}	>20 years	-4.7 M£	>20 years	-1.0 M£
R_{min}	>20 years	-0.4 M£	6	4.7 M£
R_{max}	>20 years	-2.5 M£	13	2.7 M£

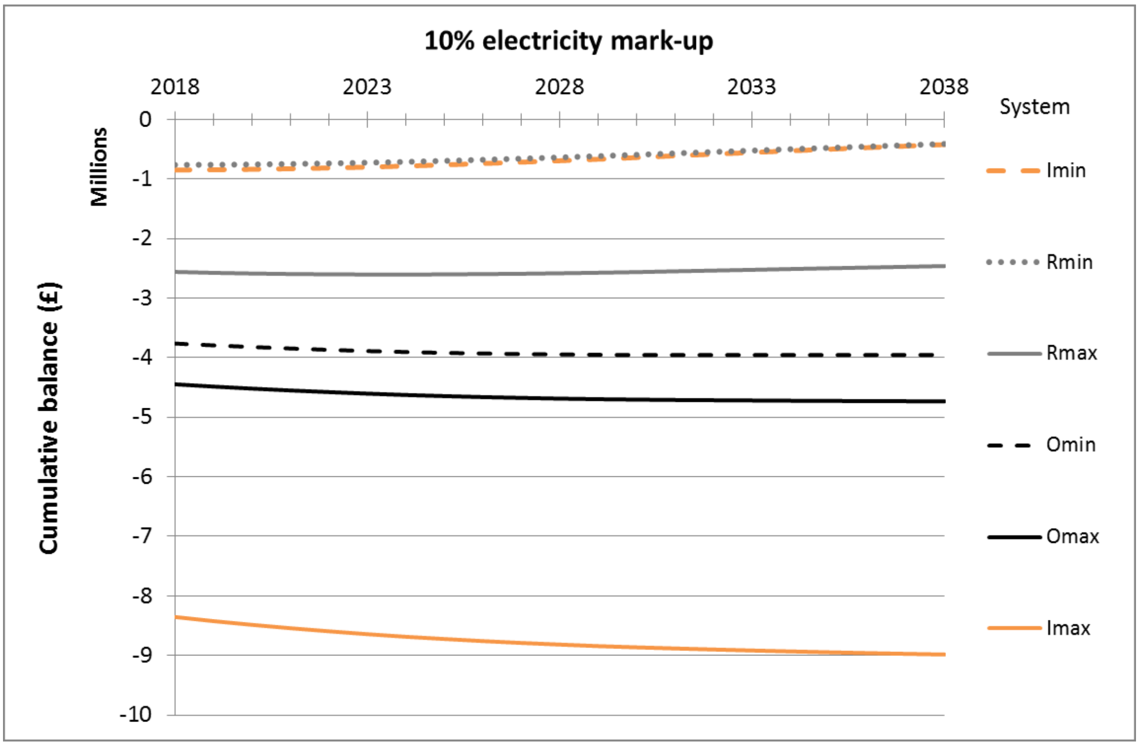

Illustration 7: Cumulative balance and different charging systems with 10% mark-up on the electricity

Table 15 shows the Net Present Value divided by the initial investment in the system, which is the capital cost (NPV/k). The results presented above can be explained in the light of this parameter.

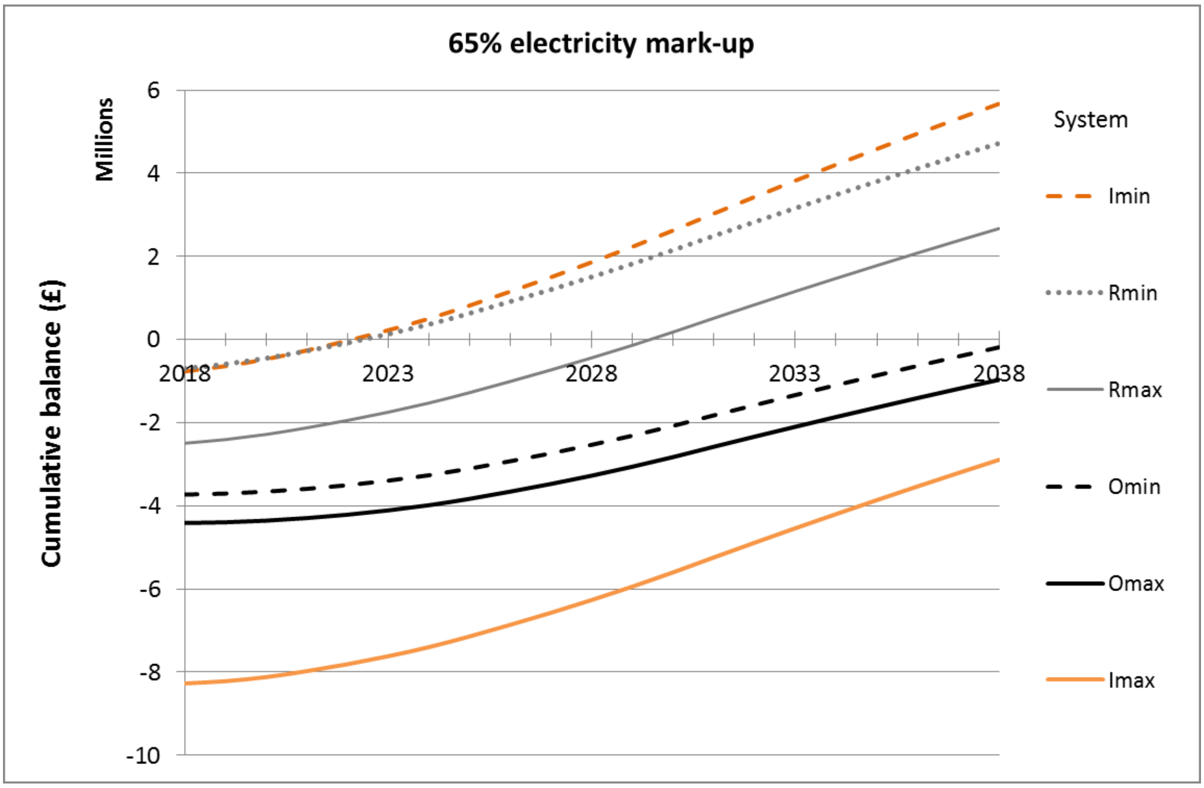

Illustration 8: Cumulative balance and different charging systems with 65% mark-up on the electricity

Table 14: NPV divided by the capital cost for two electricity mark-up

PR1	NPV/k	
System type	**Mark-up 10%**	**Mark-up 65%**
$\mathbf{I_{min}}$	-0.59	7.87
$\mathbf{I_{max}}$	-1.29	-0.42
$\mathbf{O_{min}}$	-1.26	-0.06
$\mathbf{O_{max}}$	-1.28	-0.26
$\mathbf{R_{min}}$	-0.64	7.36
$\mathbf{R_{max}}$	-1.15	1.25

5.4.4. Annual balance

The following three illustrations (Illustration 9, 27 and 28) show the annual costs, broken-down in to administrative, maintenance and electricity costs. The first chart on each illustration is a reminder of the capital cost, which is a one-off cost in the first year. Note that the y-axis is different between the capital cost charts and the annual costs.

Notes:

- The maintenance cost has been assumed to be 1% of the capital cost, therefore these figures are different in the six scenarios reported in the illustrations[44, 45, 82, 150].
- The electricity cost depends on the system efficiency (for a given technology take-up rate); therefore, this cost for the rail system is equal to the electricity cost for the overhead system (which is due to the electric HGVs only), plus the electricity cost due to the electric LVs.
- The administration cost has been set to be 5% of the total electricity cost (as an indicator of the number of users); therefore, it is the same value for a same system type (that is, regardless of the capital cost).

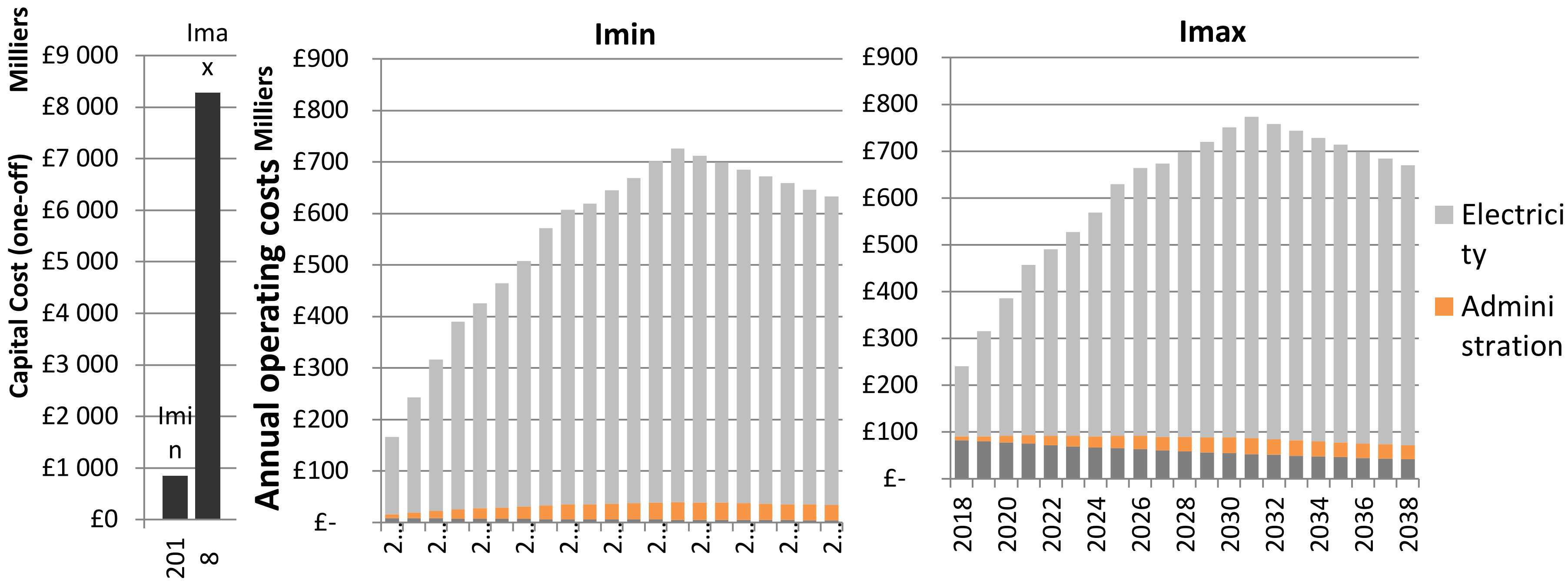

Illustration 9: Annual costs (administrative, maintenance and electricity) for Inductive ERS

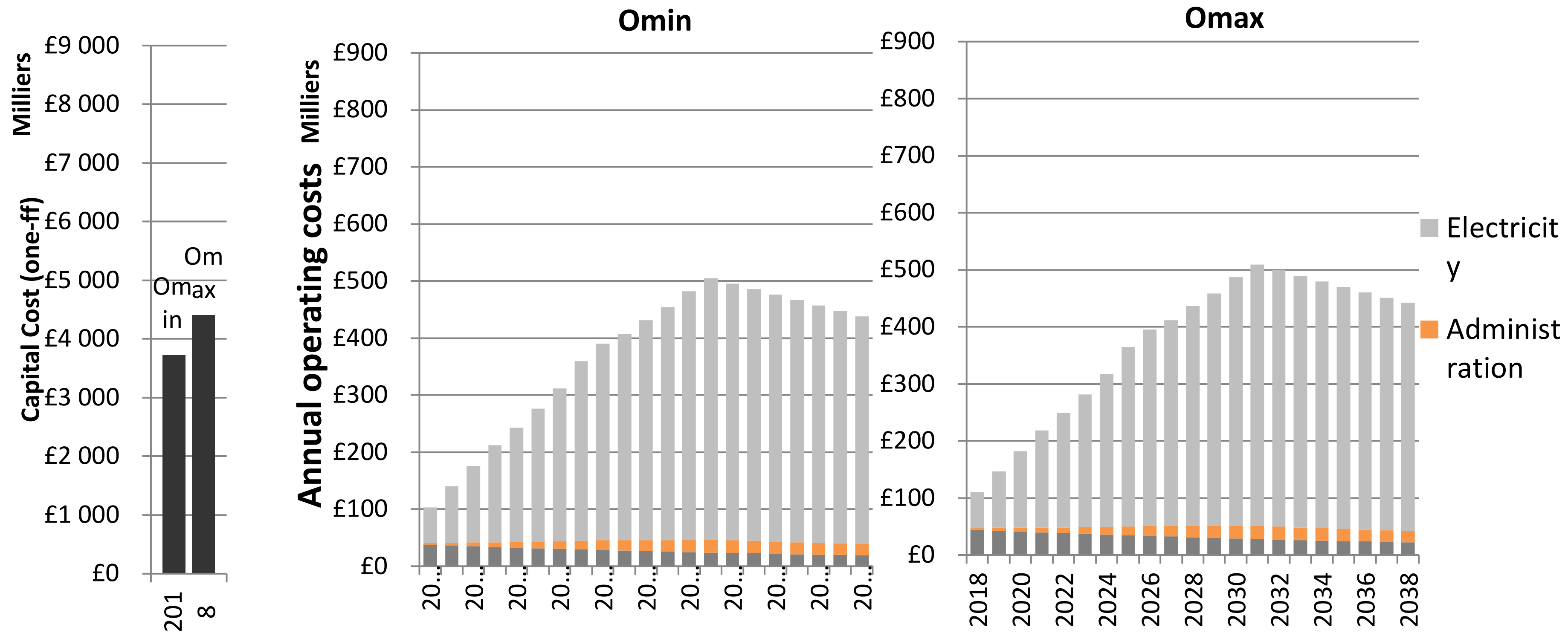

Illustration 27: Annual costs (administrative, maintenance and electricity) for Overhead system

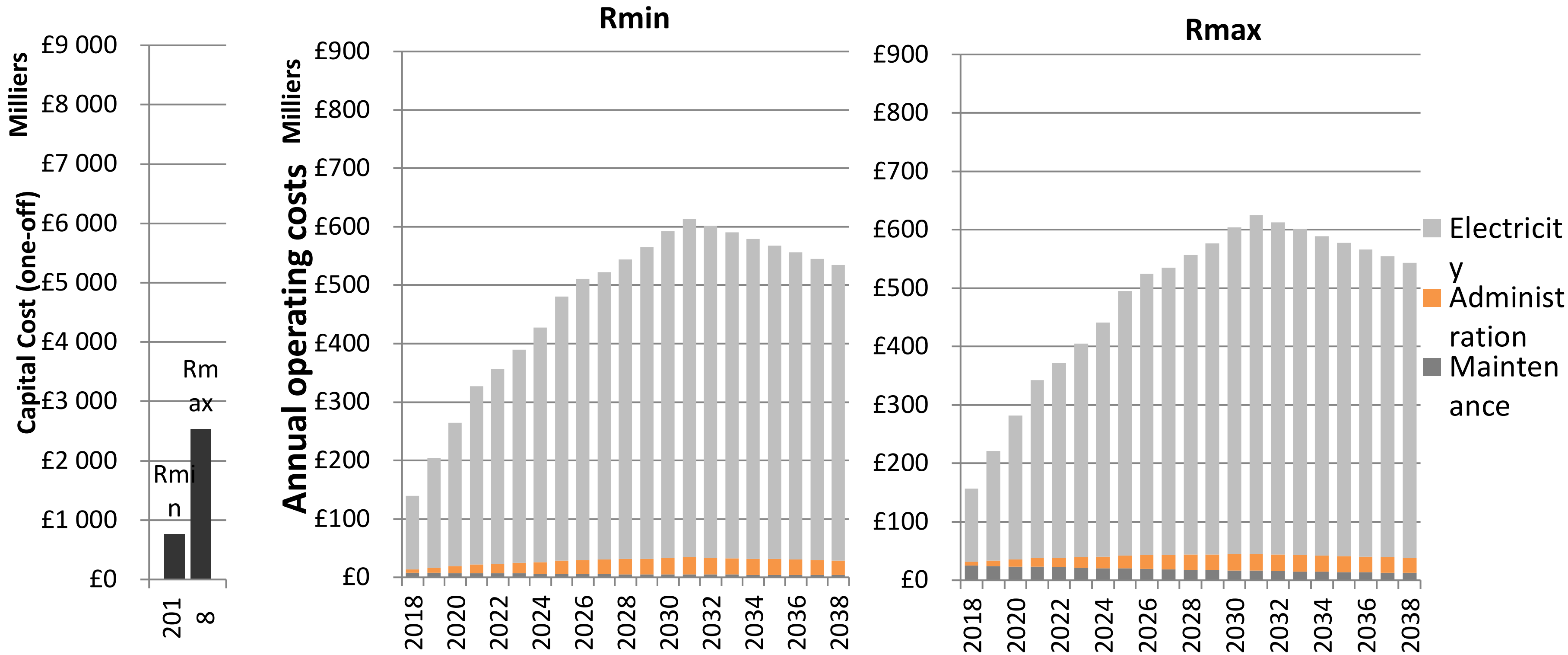

Illustration 28: Annual costs (administrative, maintenance and electricity) for Rail system

5.4.5. Balance sensitivity to capital cost and electricity mark-up

The balance sensitivity to capital cost and electricity mark-up is provided in Illustration 12. Note that the overhead charging systems is used by HGVs only, which reduces the amount of user payments.

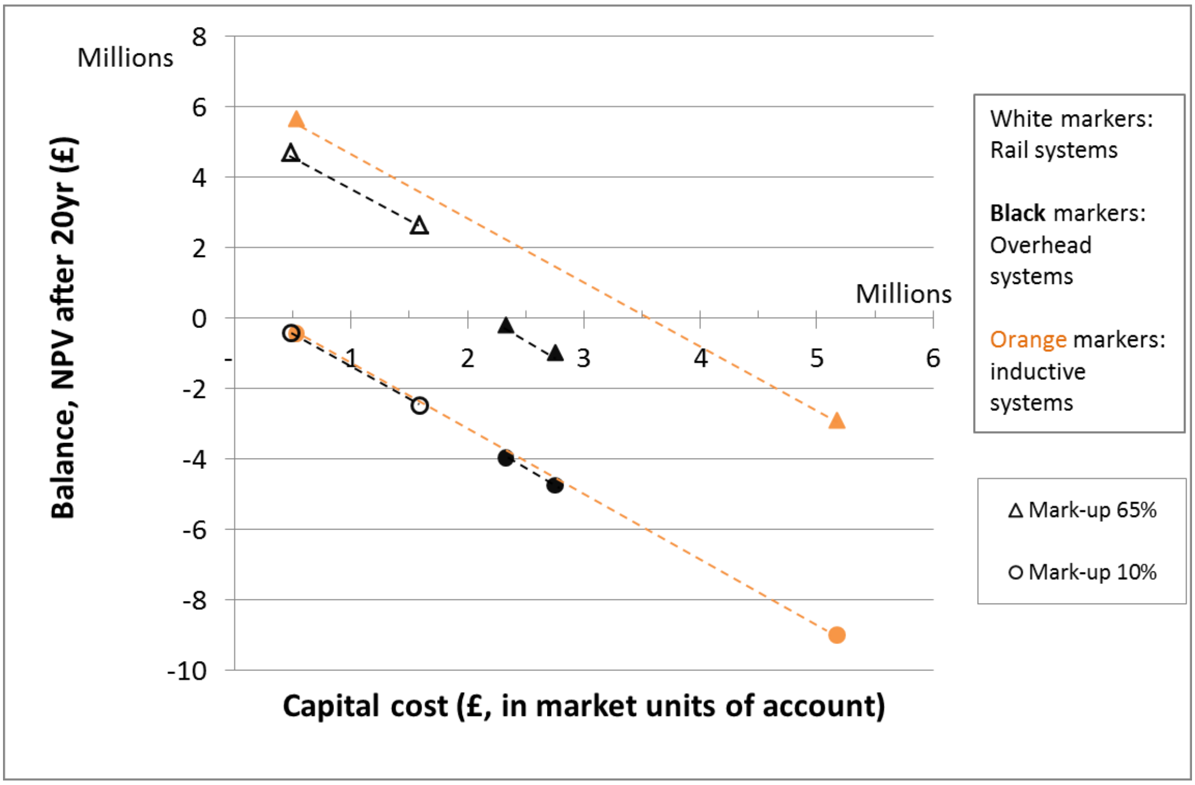

Illustration 12: Variation of the cumulative balance after 20 years (NPV in market units of account) with the capital cost of the system and the electricity mark-up.

5.4.5.1. Emissions

The CO_2 emission variation is calculated from the difference between reduction in emissions caused by the shift of some vehicles from ICE to electricity, and the increased emission from the power plant for the production of the electricity for the EVs. Therefore, CO_2 emission savings, for a given technology up-take scenario, are the same for the HGV fleet of the two contact power transfer systems (i.e. the overhead and rail systems), since a same value for their efficiency has been used. Overall however, the CO_2 savings of the two contact power transfer systems differ due to the fact that rail systems can also be used by LVs (and therefore the total emission savings are higher.

The calculation of the NOx and PM emissions at the tailpipe takes into account the decreased number of ICE vehicles only; therefore, the reduction in the emissions due to HGVs shifting to electricity is the same for the three power transfer systems for a give technology penetration rate. The overall emission of the overhead system is lower compared to the rail and inductive charging systems because these also include savings due to the LVs fleet.

Table 15: Saved emissions per kilometre over 20 years

<table>
<tr><th>System type</th><th>Total CO_2 savings per km</th><th>Total NO_x savings per km</th><th>Total PM savings per km</th></tr>
<tr><td>Inductive</td><td>39,500 tonnes</td><td rowspan="2">49 tonnes</td><td rowspan="2">3 tonnes</td></tr>
<tr><td>Rail</td><td>42,100 tonnes</td></tr>
<tr><td>Overhead</td><td>25,000 tonnes</td><td>8.7 tonnes</td><td>0.7 tonnes</td></tr>
</table>

Table 16 summarises the corresponding total (i.e. over 20 years period) monetary savings per kilometre.

Table 16: Savings from emission reductions per kilometre over 20 years

<table>
<tr><th>System type</th><th>Total CO_2 damage cost saved per km</th><th>Total NO_x per km</th><th>PM per km per year</th></tr>
<tr><td>Inductive</td><td>3.8 m£</td><td rowspan="2">£49 k (damage cost, central value)

£1 m (abatement cost, central value</td><td rowspan="2">£0.16 m (damage cost, central value)

£0.38 m (inner conurbation)</td></tr>
<tr><td>Rail</td><td>3.9 m£</td></tr>
<tr><td>Overhead</td><td>2.4 m£</td><td>£8.5 k (damage cost, central value)

£0.17 m (abatement cost, central value</td><td>£0.04 m (damage cost, central value)

£0.09 m (abatement cost, central value</td></tr>
</table>

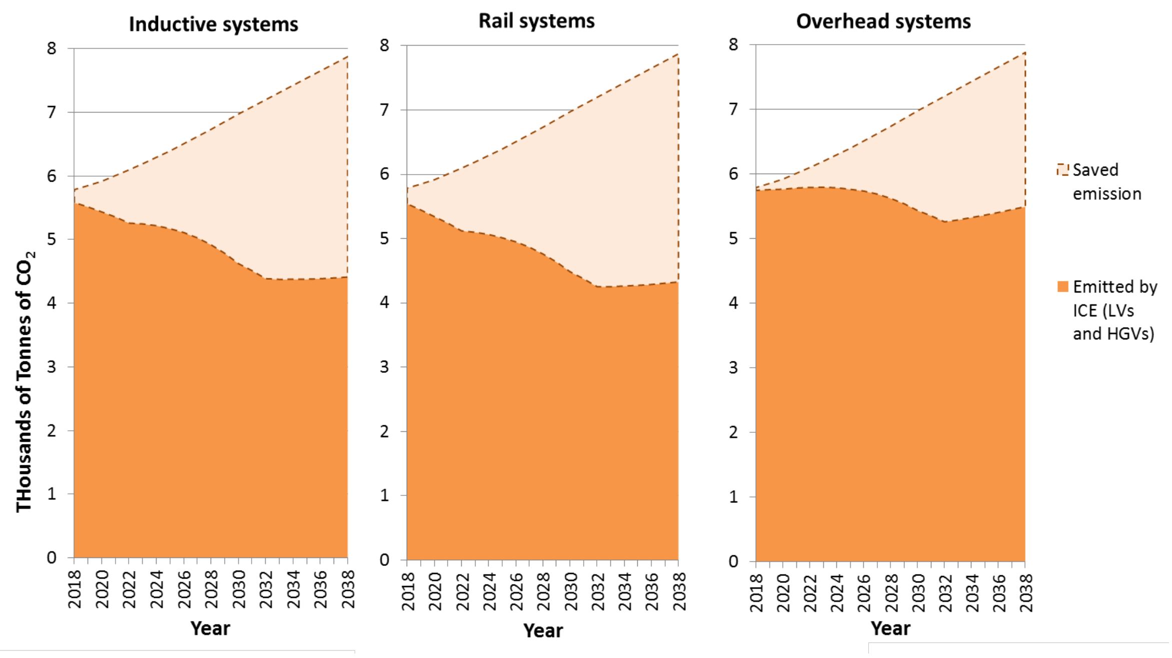

Illustration 13: Annual CO_2 emissions forecast for the ICE fleet and CO_2 savings achievable using the inductive and conductive rail charging system for LVs and HGVs and the overhead charging system for HGVs

5.4.6. Differences between countries

The CBA model developed by TRL is based upon the methodology set out in the UK Department for Transport (DfT) Transport Assessment Guidance (TAG)[151]. It is therefore UK-specific, both in scope and in individual values used for putting a monetary value to costs and benefits. Applying the model to another country would therefore require a number of changes to be made to ensure that country-specific differences are properly taken into account. The following discussion identifies model parameters that would have to be reviewed and potentially revised. Particular attention is paid to LMIC, as there are greater differences for these countries than for other high income countries.

Although the CBA was developed in the framework of high income economies; nonetheless it is acknowledged as meaningful guidance tool also in Low and Medium Income Countries (LMICs)[152]. The core principles of such analysis can be applied in both contexts; however, country-specific economic characteristics need to be taken into consideration[155].

5.4.6.1. Discount rate

In transport appraisal future costs and benefits are discounted so that they are expressed as Net Present Value (NPV). Whilst European discounts are generally similar to the UK (3.5%), the discount rate recommended for lower income countries (e.g. 12% for India[160]) is usually significantly higher. This would make a very significant difference to benefit cost ratios because ERS requires a lot of capital investment to install but the main benefits take several years to develop.

5.4.6.2. CO_2 emission intensity for electricity generation

The TRL model calculates CO_2 emissions from the amount of electricity taken from the power supply grid. However, the amount of CO_2 per kWh of electricity used, the carbon intensity, varies very widely between countries depending upon the sources of electricity generation used. Table 17 shows some examples of the ratio of carbon intensity to the UK; showing that the same amount of electrical energy used in those countries would result in significantly larger amounts of CO_2 emitted than in the UK.

Region	CO_2 emitted in the region for the generation of electricity (kgCO2/kWh)	Compared to the UK
UK	0.51	1.00
Africa	0.73	1.45
Central/Eastern Europe	0.82	1.62
Asia (excluding China)	0.93	1.83
China	0.97	1.91
India	1.33	2.62

Table 18: Comparison with the UK of the CO2 emitted for the production of electricity in different regions[153]

5.4.6.3. NO_x and PM emissions

Vehicle emissions in the model are calculated using UK-specific emission factors. These are lower for new vehicles. Equivalent emission factors are not readily available for all countries, but would vary significantly with the age and composition of their vehicle fleet, as well as other factors such as maintenance and enforcement of emission standards. The emission savings from using electric power would be expected to be very high in developing countries; however the uptake of EVs would usually be lower because of their greater cost.

5.4.6.4. Monetary values associated with the emissions

Transport appraisal attaches monetary values to kilograms or tonnes of avoided emissions, both of local pollutants like NO_x and PM, and global emissions such as carbon. However, the values are country specific. In the UK the value is based on calculations of the damage caused by the pollutant and 'willingness to pay' to reduce that damage. While it would be logical for CO_2 savings to have the same value across the world, because its impacts are global, different values are still used in practice, as shown in Illustration 13 and Illustration 14.

Table 19: Comparison with the UK of the carbon values used in different regions for CBAs of investment projects162

Region	Carbon value, 2014 USD	Comparison of the carbon value
UK	95.3	1.00
Estonia	37.8	0.40
Hungary	45.2	0.47
Israel	30.5	0.32
New Zealand	31.7	0.33
EU Commission	42.5	0.45

Table 20: Comparison of the carbon price for industry, power and buildings of different regions[156]

Region	Effective CO2 price (average across industry, buildings and the power sector; €/tone)	Carbon price for industry, power and buildings, compared to the UK
UK	14.28	1.00
Estonia	9.46	0.66
Hungary	4.95	0.35
Israel	20.41	1.43
New Zealand	1.15	0.08
Czech Republic	6.72	0.47
Poland	10.61	0.74
Russia	0.00	0.00
Indonesia	0.00	0.00
China	1.55	0.11
India	0.96	0.07
South Africa	2.95	0.21

5.4.6.5. Labour cost/back office cost

The model uses UK-based costs for installation and makes assumptions about ongoing maintenance and back office costs. These will vary widely between countries. While labour costs would in general be lower in LMIC, which would reduce some of the installation costs, a LMIC might need to develop the skills of local workers first, or even have to bring in suitable workers from outside the country.

5.4.6.6. Technology cost

It is likely that a LMIC would have to import some of the technology needed, which could make it more expensive. The installation costs would therefore have to be estimated on a country specific basis.

5.4.6.7. Electricity costs

The model uses UK industrial electricity prices in 2017, which is around average for Europe. However electricity prices vary significantly between countries and over time, as it does for diesel. Ovo energy[163] reviewed energy prices from a range of countries and found in 2011 they varied from 8 US cents per KWh in India to 41 US cents per KWh in Denmark. Denmark, Germany and Spain have high electricity costs and India and China relatively cheap. In some countries such as South Africa and Nigeria there have been large changes in electricity prices over the past decade making it difficult to forecast costs. Examples are shown in tables 21, 22 and 23.

Furthermore, energy costs are often subsidised in developing countries, as shown in illustration 31, which makes it harder to understand the true economic case.

Table 21: Electricity prices for household consumers (taxes included), second half 2017[154]

Region	Households (€/kwh)	Non-households (€/kwh)
UK	0.19	0.12
EU-28	0.20	0.11
Estonia	0.13	0.08
Hungary	0.11	0.08
Albania	0.09	..
Serbia	0.07	0.07
Czech Republic	0.15	0.07
Poland	0.15	0.09

Table 22: Residential electricity prices in 2016 (purchase power parity (PPP) adjusted exchange rates)[159]

Region	€/MWh	Ratio
UK	180	1.00
Russia	126	0.70
Indonesia	175	0.97
China	120	0.67
India	209	1.16
South Africa	197	1.10

Table 23: Diesel price (13th August 2018)[157]

Region	€/litre	Ratio
UK	1.44	1.00
Estonia	1.27	0.88
Hungary	1.21	0.84
Albania	1.39	0.96
Serbia	1.35	0.93
Israel	1.47	1.02
New Zealand	0.93	0.64
Czech Republic	1.24	0.86
Poland	1.14	0.79
Russia	0.57	0.39
Indonesia	0.65	0.45
China	0.84	0.58
India	0.88	0.61
South Africa	0.95	0.65

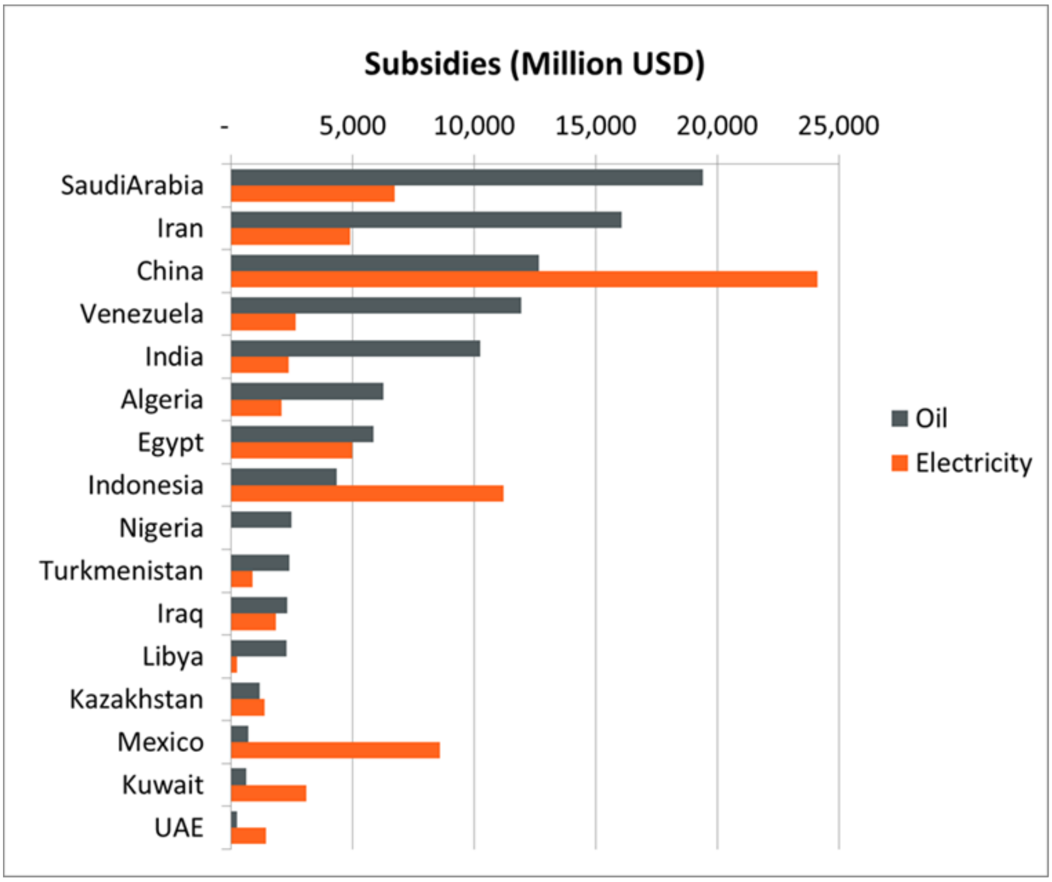

Illustration 14: Total energy subsidies compared, oil and electricity[158]

5.4.6.8. On-board technology uptake rate

The model makes assumptions about the rate of uptake of the ERS technology. Uptake depends on a multiple range of factors such as if it is possible to retrofit the system to vehicles, the cost of installing the technology in vehicles, the operating costs, availability of the system and its reliability. Customer perceptions which are not always based on fact and any government incentives put in place to encourage update of the technology also influence up-take. Uptake is difficult to predict and likely to differ widely between countries. As an example plug-in EVs have been commercially available for some time, but there has been a much more rapid adoption rate in some countries than others e.g. in 2017 39% of new cars sold in Norway were plug-in EVs compared to 1% in the USA[164]. Although it is hard to predict for any country, it would be expected for uptake to be lower and slower for LMICs, which typically have older vehicles and longer replacement cycles.

5.4.6.9. Higher increase in traffic

Whilst traffic growth in many high come countries is plateauing traffic growth in many LMICs it is a lot higher than in the UK. These countries are still at an earlier stage in the adoption of private motor vehicles, and also often have a higher economic growth rate. Appropriate values and forecasts would be needed to apply the model to a different country.

5.5. Task 3 conclusions

5.5.1. The economic feasibility of ERS

As discussed in the previous section the economic feasibility for ERS will vary by country as the electricity price, discount rate, take-up, traffic increases and installation costs and so on will all be bespoke to a particular country. As part of Task 3 cost-benefit analysis was carried out on a case study motorway in the UK, this was based on UK values for parameters such as electricity prices, discount rate etc. and the traffic levels and mix of the case study section. Where possible real data or information from literature was used, however significant assumptions still needed to be made in terms of take-up, electricity mark-up and operational costs etc. as these are currently unknown. Based on the analysis carried out the following conclusions can be made, however readers should be aware that these are only applicable in the scenarios described and with the assumptions stated.

5.5.1.1. Installation costs

The information collected in Task 1 suggests that the overhead system is the least costly ERS technology to install, and some types of inductive technologies the most. However the inductive technology had the most variation in installation costs, and the lower estimates for installing inductive ERS are lower than both the high and low rail ERS estimates.

5.5.1.2. Operational costs

The main operating costs are purchasing electricity; maintenance and administrative costs are a much smaller percentage of the overall operational costs. The overhead scenarios had the lowest operational costs and the inductive the largest, this relates to the reported lower energy efficiency rating of the inductive systems.

5.5.1.3. Emissions reductions

The savings in GHG emissions depends on the energy efficiency of the technology and the level of take-up. The greatest reduction in GHG emissions is seen with rail ERS as it is both high in energy efficiency and able to be used by LVs as well as HGVs. The lowest GHG emission reductions is seen with the overhead, as it is less energy efficient and cannot be used by LVs. The reductions in NOx and PM emissions take into account only the reduction of ICE vehicles, so are the same for both inductive and rail technologies and less for overhead due to the restriction in use by LVs.

5.5.1.4. Overall economic case

Over the 20 year CBA appraisal period, none of the ERS technologies recouped the investment with an electricity mark-up of 10%. When the electricity mark-up was increased to 65% both rail technologies and the lowest cost inductive technology showed cost savings. The overhead scenarios are affected by the reduced market (HGV use only) and so neither made a saving. The technology with the most savings was the lower cost inductive technology, but the higher cost inductive technology made a loss. Both the rail ERS technologies made a saving.

The shortest payback time was 6 years for the lowest cost inductive technology and the lowest cost rail technology, the higher cost rail technology had a payback time of 13 years.

5.5.1.5. Summary

In summary, the CBA analysis shows that it is possible to make a return on investment in ERS, but that a sufficient mark-up needs to be made on the electric price. It is unknown how willing users of the system would be to pay this amount but comparing the prices with current systems, it is likely for LDs that charging from home would be cheaper than using ERS, but the ERS charging price is comparable with public static charging systems. Users may also be willing to pay for the convenience of charging on route. For HGVs the cost with a 65% mark-up is still cheaper than diesel, so there would be an incentive to use the system and move away from fossil fuels.

In terms of which system to invest in, the capital cost of the overhead system is likely to be lower, but there would be a long payback time given that only HGVs can use the system. Therefore although rail and inductive are more expensive to install and maintain, if LDs as well as HGVs use the system the payback on the investment is higher.

5.5.2. Potential business models

From discussions in the literature it seems the most likely business model is some form of public-private partnership. The most advanced thinking in this area comes from Sweden and suggests that the capital cost and investment risk is too high for most private organisations to be the sole investors, and that Government (national and/or regional) funding is required. Government is likely to accept longer payback times than private investors, and are more likely to pay to reduce carbon and local air pollutants. It is acknowledged (from Section 4.5) that in most countries the PPP is likely to require some amendments to the regulatory framework.

6. CONCLUSIONS OF THE STUDY

This report was written as part of the *Electric Road Systems – a solution for the future study* commissioned by the World Roads Association PIARC. The study had three main tasks:

1. To describe ERS with regard to their its Technology Readiness Level (TRL) and the key players involved in its development
2. To compare different ERS technologies and their perceived advantages and disadvantages
3. To consider the business model from a Road Administration perspective

A summary of each of these areas and conclusions are included below:

6.1. DESCRIPTION OF ERS, ITS TECHNICAL FEASIBILITY AND MARKET READINESS

Information from literature and stakeholders was used to provide a description of ERS and current levels of development. In this study ERS is defined as a system that provides electric vehicle charging through either conductive or inductive (wireless) means for various types of vehicles as they travel. ERS is generally classified into three groups: inductive, conductive (catenary/overhead) and conductive (in-road rail).

6.1.1. Technical feasibility

The project identified 17 different ERS technologies currently in development, 12 of which were classed as inductive, and 5 classed as conductive (rail and overhead combined). Information was collected on each system on parameters such as: power output and efficiency, operational speed, suitability for different vehicle types and evidence of performance levels (laboratory testing, off-road trials, on-road trials). Based on the information collected the technology readiness level (TRL) was assessed.

Conclusions:

An assessment of technology readiness and market readiness was carried out and showed a wide range varying from TRL 2-9. The majority of the inductive ERS systems (50%) scored between TRL 3 and 4, whilst only two systems had a TRL greater than 6. The majority of the conductive ERS systems (60%) scored between TRL 4 and 5, whilst the remaining two systems had a TRL between 6 and 8. The KAIST/Dongwon OLEV (from South Korea) and the SIEMENS (from Sweden) systems appear to be the most advanced inductive and conductive ERS technology respectively and those closest to market readiness. The majority of the remaining ERS technologies are still at demonstrator stage and require or are in the process of undertaking on-road trials to determine their technical feasibility.

Power outputs were generally greater for conductive ERS which showed greater capability for charging HGVs, whilst inductive ERS appears to be more suited to powering lighter vehicles and buses, with the exception of the Bombardier system which is currently conducting testing with HGVs. The majority of the conductive ERS systems were capable of achieving efficiencies greater than 90%, whilst the inductive ERS efficiency levels had greater variation between 70-95%. The main challenge for inductive ERS functionality is to improve power transfer efficiency and maintaining it for different vehicle types. Currently, interoperability is practically non-existent for all ERS systems.

6.1.2. Stakeholder perspectives

The results from this study suggest that many stakeholders believed that ERS has the potential to act as a key pathway for rapidly decarbonising road transport, offering a range of environmental benefits for wider society. Around half of the stakeholders that completed the online survey were actively engaged in ERS developments (although this may not be a representative sample), with plans to continue ERS research over the next 24 months. In general, there was a consensus that overhead conductive ERS was the most technologically mature and closest to market, with conductive rail and inductive ERS further behind.

Apart from environmental benefits, stakeholders agreed that ERS could offer gains in fuel savings, minimise EV range concerns, and reducing the cost of EV ownership through minimising battery requirements. Interviews with NRAs and ERS manufacturers revealed that they believe different concepts should not be seen as rivals to each other rather as solutions built for different scenarios but having the same overall purpose. However, any mass adoption of highway ERS would have to be harmonised across networks and countries. This is especially relevant in the context of international freight routes; as such there may only be one dominant solution. Some NRAs felt that ERS would first have to be trialled on toll roads (as the operator has a high degree of control over the system); however this may require an extension of their concessions to allow for payback (especially in the early stages of ERS implementation where demand would be low).

Conclusions:

NRAs and ERS manufacturers believed that the first adopters would be freight industry and public transit operators. The biggest challenges stakeholders foresaw regarding ERS implementation is the high capital costs of all types of ERS and the legal/regulatory framework and business model that governs their deployment. Stakeholders felt that the main disadvantages of ERS aside from the high capital costs of equipment included the risk associated with relatively immature technologies (with limited public demonstrations illustrating viability), lack of interoperability between vehicle types and across systems, and the uncertainty of the impact that installations may have on the long-term performance of road infrastructure.

Another important limiting factor is the development of a clear strategy or statement of intent from governments on whether or not they consider ERS as a viable solution. Without clear guidance and support, ERS manufacturers and early adopters assume higher levels of risk in adapting this technology.

6.2. Main advantages, disadvantages and challenges for different ERS technologies

6.2.1. Safety

ERS technologies are currently in the early stages of testing and demonstration with safety aspects still being evaluated. The major factors for evaluation, from a road administrations perspective, are safety for road workers and users, particularly during maintenance operations. Other factors identified for further evaluation include skid resistance, change in surface profiles, cyber security, and ease of access to ERS equipment (in-road and at the roadside) for maintenance workers and the public.

Conclusions:

The risk assessment presented in this report provides only an indication of the safety and associated levels of concern of each system. Of the ERS technologies reviewed (including static charging and plug-in charging solutions), the plug-in charging systems were identified as the system to present the lowest level of risk, largely due to the fact the risks are well known and understood. Of the three ERS technologies, the inductive and conductive overhead ERS presented similar levels of risk (very low-medium), with the conductive rail ERS showing higher levels of risk overall.

Risk assessments should be conducted for individual technologies and designs to ensure all risks are reduced as low as reasonably practicable through appropriate design and mitigation. Once risks are considered to be tolerable, the system should be tested and trialled both off and on road to validate identified risks and tolerability of risk decisions.

6.2.2. Impact on infrastructure and maintenance

Whilst on-road ERS currently exist, to date, installations in public roads are rare with no data available on the effects on pavement condition from these sites. As installation procedures are expected to be technology specific, special dispensation would be required to allow ERS installations on any given road network, based on evidence provided from laboratory testing and off-road trials. Furthermore, the extent of the potential impact on the maintenance and operation of the road network will be largely unknown, except for conductive catenary ERS which should have no impact on road condition and expected maintenance operations.

Due to the complex nature of ERS, the installations are expected to be a major undertaking, which could lead to extensive delays for road users. However, these procedures will be refined and optimised as engineers become more experienced, which should improve the quality control/assurance of the installations, which in turn should improve the long term durability of the reinstatements and reduce future maintenance interventions.

Conclusions:

Future maintenance of roads containing ERS is highly dependent on the type of construction required for each system and the design life of the in-road components of the ERS. Conductive overhead ERS should have no impact on road condition and expected maintenance operations. For conductive rail and inductive ERS, collaborative studies between technology manufacturers and NRAs should demonstrate that the ERS is durable enough to withstand the conditions experienced on heavily trafficked motorways and will require limited maintenance during its service life. Expected ERS maintenance is varies depending on system type; ERS technologies reviewed in this report indicate that maintenance may be required every 10-30 years while others are expected to be maintenance free over their lifetime. Due to the novelty of these installations it would be remiss to expect that these sites will meet the original design life of the pavement or remain defect free for these durations.

6.2.3. Impacts of competing technologies

Due to the current developments and uptakes of static charging solutions, battery technology, and alternative fuel developments, these advancements could be viewed as rivals which could inhibit ERS uptake and implementation. However, these ‘rival’ solutions could be considered complementary to ERS, and in the context of climate change targets Governments would benefit from having every solution at their disposal.

Conclusions:

In this study, static charging solutions and electric battery technology are seen to be complimentary to ERS development and implementation. Advancements in these areas should see an increased uptake of EVs which reduces concerns for road users and promotes the use of EVs, thereby increasing support for dynamic ERS solutions where circumstances allow. Uptake of EVs using these battery solutions may only be suitable for light vehicles and commercial buses rather than HGVs due to battery size and charging time constraints. However,, the greater power transfer efficiencies associated with conductive static charging solutions may reduce the potential implementation of ERS particularly for buses and light vehicles.

Biofuels are only an intermediate step in decarbonisation as they are not zero carbon. The lack of refuelling infrastructure also means biofuels and alternative fuel options such as hydrogen fuel cells may struggle to generate growth in their respective areas.

6.2.4. Environmental and social impacts

Results from the literature review show that there is a gap in current research regarding life cycle assessment, and environmental and social impact assessments of ERS concepts. This is partly due to novelty of such these systems, with many solutions still at the prototype stage of development. Findings from research studies on the environmental impacts were limited although some studies suggest that reduction in battery sizes for ERS compatible vehicles would reduce GHGs, with power transfer efficiency identified as a major factor in GHG saving, along with higher power outputs from the ERS system.

The potential impact of ERS on energy use and GHG was evaluated and presented in this report. This report also provided an assessment on the potential social impacts based on consultation with relevant ERS and social science experts. However, the results from this assessment are subjective and require evidence from further research to properly quantify the potential social impacts of ERS.

Conclusions:

Results from the CBA showed that emission savings (CO_2, NO_2 and PM) were similar for conductive rail and inductive ERS as these systems were analysed for both light vehicles and HGVs. Only HGVs were included in the analysis for conductive overhead systems, so the reductions were not as great.

Vehicle emissions in the model were calculated using UK-specific emission factors. These are lower for new vehicles. Equivalent emission factors are not readily available for all countries, but would vary significantly with the age and composition of their vehicle fleet, as well as other factors such as maintenance and enforcement of emission standards. The emission savings from using electric power would be expected to be very high in developing countries; however the uptake of EVs is likely to be lower because of the high initial cost and longer fleet renewal time.

6.3. Financial viability and business model

For ERS to be adopted it has to be financially viable as well as technically feasible. This study used a previously developed cost-benefit analysis (CBA) model to better understand the economics of ERS. Although the CBA analysis carried out was for one country under specified scenarios, it showed that it is possible to make a return on investment in ERS if sufficient mark-up is applied to the electric price and there is a large enough uptake by users. Systems which have a more limited market i.e. only HGVs, will need lower installation costs to be comparable to those that can also be used by LVs. The analysis also showed that systems with higher initial costs may still be more economically favourable in the long term if there is sufficient technology penetration. In terms of comparing the three ERS concepts, the capital cost of the overhead system is likely to be lower, but there would be a long payback time given that only HGVs can use the system. Therefore although rail and inductive are more expensive to install and maintain, if LVs as well as HGVs use the system the payback on the investment is higher. Payback times as low as 6 years were seen for some technology types.

In order to be commercially viable, there also needs to be an appropriate business model. As the CBA analysis showed the level of take-up is key and therefore it is vital to understanding the market and customer requirements. The high capital costs, long payback time and the number of actors required to deploy ERS mean the most likely form of business model is some form of private public partnership (PPP). Government involvement also provides the market with more confidence that the technology will be rolled out. Currently most research efforts are focused on the technology itself, and so information on the exact form the PPP will take is limited. It seems likely that it will require modifications to current regulatory frameworks and technical standards in most countries.

Conclusions:

The CBA shows that some types of ERS are financially viable if sufficient capital investment can be made, as long as the electricity mark-up and uptake is sufficient. Systems able to accommodate LVs as well as HGVs are more likely to recoup the initial investment, even if uptake in LVs is much lower than HGVs. There is a need to better understand the market for ERS, in particular if LVs will use the system and the role of alternative technologies and other future social and technological changes. Further work is also required to better understand which types of routes different ERS technologies would be suitable for. The most likely business model is a PPP which will probably require modifications to the regulatory framework in most countries.

6.4. Implementation in LMIC

The consensus from the stakeholders and experts consulted in this study is that it is unlikely that ERS will be implemented in LMIC in the near future. All those consulted believed that the technology should first be fully established in high income countries before it is considered in LMIC, where there are other priorities such as provision of healthcare, schools etc. There are some opportunities for ERS in LMIC that are not available in high income countries, for example being able to include ERS when constructing new transport and electricity infrastructure rather than having to retrofit to existing roads. However, there are also additional challenges in deploying ERS in LMIC such as roads are often unsuitable (e.g. unpaved or with shallow pavements), there is a lack of resources and technical skills for installation, insufficient and unreliable electricity infrastructure etc. that in addition to the lack of capital would make implementation difficult to achieve. In the long-term ERS could be beneficial for transnational freight routes, but in the short-term more established low carbon technologies such as statically charged electric cars would be suitable.

Conclusions:

The high capital cost and technical challenges in installation mean that ERS is not likely to be deployed in LMIC in the short to medium term. The technology would need to be first established in high income countries before it could be considered by LMIC. In the longer term ERS could be deployed on transnational freight routes, but would require external funding.

6.5. The future of ERS

This study has drawn on literature, stakeholder views, cost-benefit analysis and expert opinion in order to review ERS and its potential. There are still many unknowns with regard to these systems, but based on the information currently available the response to the question the study set out to answer "*Is ERS a potential solution for the future?*" – is in the long term, yes. This study has shown that all three ERS concepts are technically feasible and potentially financially viable and therefore could contribute to decarbonising transport systems. However, in the short term, wide spread implementation of ERS is not likely as there are still many unknowns with regard to its implementation. There are specific safety and maintenance concerns which still need to be addressed, uncertainty around policy and regulations and the business model is not fully developed. ERS may be a viable solution in the shorter term, in certain locations where circumstances prove financially viable i.e. there is likely to be a high uptake such as along bus routes in urban areas or along freight routes between ports and distribution areas.

It is unlikely ERS will be universally rolled-out across road networks, but if the identified issues are resolved over the next 5 – 10 years early adopter NRAs could start to be installed on certain routes with high HGV use. For LMIC the installation of ERS is likely to be more long-term. It could be installed on certain international freight routes, if externally funded.

7. RECOMMENDATIONS

This section provides a series of recommendations based on the project findings. This is divided into recommendations for road administrations, LMIC and PIARC.

7.1. ROAD ADMINISTRATIONS

Some road administrations will be early adopters and will have already carried out some of the suggested actions, while others will prefer to take a 'wait and see' approach, gaining a better understanding of the potential risks and opportunities from the experiences of other road administrations. It is to be expected that road administrations will select the recommendations they feel is most appropriate for them. In order to aid this, the recommendations are divided into suggested:

- First steps – early actions to understand ERS and its feasibility.
- Interim steps – to become ready for ERS.
- Advanced steps – for road administrations who want to be early adopters.

It is to be expected that most road administrations will focus on the early steps over the next 5 years, with a smaller number of early adopters carrying out interim and advanced steps.

7.1.1. First steps

The first step is to better understanding ERS and its potential impact on road network. Examples of initial actions are:

- **Participation in international conferences** - Attend international conferences and workshops on ERS to learn more about the technology and the latest developments. This includes technology events not traditionally attended by NRAs.
- **Join PIARC and other international technical committees** - Participation in the activities of international organisations such as PIARC and FEHRL related to ERS, e.g. technical committees, tours/visits, workshops etc.

  Learn from other road administrations - Monitor progress of ERS development and trials carried out by other NRAs. Speak to those involved in trials about their findings.
- **Prepare a feasibility study** - Identify and evaluate different ERS technologies (including static charging, electric batteries capacities, and other alternative sources of power for vehicles), based on;
  - Safety;
  - Technical feasibility and market-readiness - systems that are most likely to meet the requirements of operating in an urban or highway environment, and could be used in future on-road trials;
  - Specifications for the installation of ERS equipment onto vehicles; and
  - Specifications for road installations.
- **Promote the use of low carbon vehicles** - Actions to encourage the uptake of low carbon vehicles on the road network, e.g. introducing charging points at service

stations would help to demonstrate commitment to reducing carbon and encourage greater use of EVs .

7.1.2. Interim steps

Deployment of ERS will require a long lead-in time. In addition to technical preparations, planning regulations, technical standards and working practices etc. will need to be modified. It is recommended that road administrations that are considering ERS start taking some no-regrets low cost actions in preparation for the deployment. In doing this road administrations should not become fixed-in to one type of technology, as currently there is no front runner type of ERS and it is most likely a combination of technologies including static and ERS will contribute to the de-carbonisation of the road transport system. Instead, it may be better to identify key decision points whilst keeping an open mind on the various ERS options. Example actions are:

- **Assess the potential impacts of ERS** - Assess the implications of ERS on infrastructure durability, winter service activities, resurfacing etc. and identify what could be done to help mitigate them. Consider the infrastructure lock-in effect of each technology; for example does it limit future capacity expansion works? Assess public and contractor health and safety risks and the requirements of additional protective measures, such as vehicle restraint systems and crash testing to verify the equipment required.
- **Identify suitable routes for ERS** - Identify locations where ERS installation would be most practical and economical. Then evaluate these routes in more detail; for example identify locations for electricity connections, how much extra capacity is required and at what cost. Also engage with users of that route to understand the potential uptake.
- **Develop guidelines for ERS systems** - Work with technology manufacturers and stakeholders to produce guidance on construction and installation procedures suitable for your network and acceptable time limits for these to occur within. Provide information and advice on your technical standards and maintenance procedures in order to work with them to identify solutions which are safe, practical, minimise travel disruption but also enable the ERS to function as efficiently as possible.
- **Identify specifications and standards that will require modifications** - Consider the requirements for installing each technology type, particularly planning laws and the relationship to the National Infrastructure Plan and other statutory instruments. Identify the requirements for installing each technology type and consider the modifications that would need to be made to in order to accommodate ERS installation, along with the estimated time it would take to incorporate these changes. If there are planned reviews/modifications of standards already in line perhaps these modifications could be incorporated at the same time.
- **Commission research** - Commission research into different aspects of ERS including impact on the road infrastructure, methods of safe and rapid installation minimising disruption to road users, the business model, life cycle assessments and environmental impact studies, impact on road users etc. There are still many

unknowns relating to the implementation and impacts of ERS and additional research can help address these knowledge gaps.

Deployment of ERS requires many actors to work together. It is recommended that road administrations play a key role in discussions on ERS and its implementation. Suggested actions include:

- **Discuss the possibility of installing ERS with government and policy levers to encourage uptake -** Government support is needed in order deploy ERS. A joint public statement with the Government would demonstrate the level of support ERS has. Government can also put in place policy instruments such as tax incentives to encourage ERS uptake.
- **Create a cross-industry forum** - Create a forum for cross-industry discussion on implementing ERS in your country (i.e. between NRAs, Electricity Suppliers, Technology Manufacturers, Freight and Logistics Operators, Vehicle Manufacturers, Materials Supply Chains, Environment and Transport Government departments, Communications and IT Providers, and Academia). This could discuss any specifically national issues regard implementation.
- **International standards and guidelines** - Whilst some issues will be specific to each country, issues with interoperability in particular will need to be addressed at an international level. It is recommended getting involved in international technical committees and working groups related to ERS standards and guidelines.

If a road administration is interested in being an early adopter of ERS it is suggested that it makes its position clearly to industry, national government and the wider public. For example by:

- **Including ERS as part of their low carbon vision** - Many NRAs have carbon reduction strategies and action plans. Incorporating ERS as part of a wider long term low carbon vision for the road network would make the NRAs position on the technology clear and encourage suppliers and researchers to present ideas in support of this.
- **Gain public support** - Engage with the public through social media and online forums, informing them of the potential benefits of ERS and getting their support for adoption.

7.1.3. Advanced steps

It is suggested that road administrations which wish to be early adopters of ERS support trials of the most promising technology and work with industry to ensure infrastructure requirements are taken into account. Example actions include:

- **Participation in trials** - Provide controlled testing environments for off-road trials, road space for on-road trials and feasibility demonstrations, and provide input into testing protocols to help understand the safety and other implications of ERS. Build-on/learn from the trials and research carried out by others focusing on different aspects in internal research, rather than duplicating work. A comprehensive set of off-road trials are recommended to:

- Identify the best candidate from a selection of ERS systems that are tailored to meet the objectives set out by the NRA, based on the methods investigated and evaluated during the Feasibility Study;
- Validate manufacturer claims and verify ERS system safety and functionality;
- Validate electromagnetic and electric safety of the systems;
- Validate performance and tolerance characteristics set out by manufacturers;
- Compare different ERS installation methods and grid connections with different ERS system manufacturers;
- Provide a better understanding of the potential long term impacts on road deterioration;
- Validate and if necessary amend cost estimates for road installation and grid connection of ERS systems;
- Provide road space for ERS feasibility demonstrations and provide input into testing protocols to help understand the safety and other implications of ERS

- **Work with government** - Work with national (and if relevant European) government to ensure the regulatory framework is flexible enough to adapt to new transport technologies and business models. Government also needs to send out a strong message to industry if ERS is to be deployed.

It is recommended that road administrations share the knowledge gained and lessons learnt from their trials and research. Potential actions include:

- **Participate in joint trials** – Collaborate with other road administrations or invite them to attend internal trials and demonstrators to share knowledge and potentially share testing facilities and trial vehicles, maximising lessons learned with other studies/trials across the world.

- **Publish results of trials** - Where possible (not commercially sensitive) publish results of trials and research (preferably in English).

7.2. LMIC

Whilst all the recommendations listed above may not be appropriate for road administrations in LMIC, as the deployment of ERS in the short - medium term is unlikely, it is still recommended that LMICs:

7.2.1. Keep abreast of advancements in ERS and contribute to international discussions

For example by:

- **Monitoring developments in ERS** - Review information on ERS and the results of recent trials, evaluate the requirements and implications in terms of your own national road network.

- **Provide feedback** - Identify any country specific challenges or barriers and highlight these at international forums and discussions e.g. through PIARC.
- **Participate in international and online discussions** - Where possible attend international events and online discussions on ERS.

7.2.2. Keep options open

It is also recommended that when constructing new transport and energy infrastructure that the potential for installing ERS is not ruled out in the future; in particular for trans-national freight routes. For example by:

- **Future proofing energy and transport infrastructure** - When constructing energy and transport infrastructure ensure there is sufficient space, energy connections etc. to enable the installation of ERS technology in the future.
- **Developing flexible standards and processes** - When developing or revising road standards and processes for planning, maintenance, procurement etc. consider how ERS could be included and if possible make sure these aren't a barrier to introducing ERS in the future.

7.2.3. Engage with potential funders

International funders are committed to reducing carbon and there are specific funds for green development. It is recommended that NRAs engage with these and discuss their position on ERS. For example by:

- **Discuss ERS with funders** - Discuss low carbon transport and the potential of ERS with funding organisations such as the World Bank. Find out their position on ERS and put forward your own position.
- **Multi-purpose projects** - Consider if combining ERS with other projects providing electricity and transport infrastructure would make it more economically viable. Or if enabling work could be included which might make it more viable in the future.
- **Green funding schemes** - Investigate the potential for funding ERS via green funding schemes. Understand if it is the type of project that would qualify for funding or would be required for it to qualify.

7.3. PIARC

The following actions are recommended for PIARC:

7.3.1. Provide information on ERS for members

It is recommended that PIARC build on this special project and continue to keep its members updated on developments in ERS and the potential implications of ERS for road administrations. For example by:

- **Involvement in international conferences on ERS** - At the PIARC World Congress 2019 there will be a three hour session on ERS. It is recommended that PIARC builds on this by getting involved in other international conferences which focus on the implementation of ERS and the impact on NRAs rather than the technology itself. For example by holding joint events with other organisations such as ERTRAC

(European Road Transport Research Advisory Council) or the Swedish Electro-mobility Centre which have organised previous conferences on ERS. Speakers should include NRAs, energy suppliers, technology producers, haulage companies etc. and the details disseminated to PIARC members to encourage their participation

- **Establishing an alternative fuel task force** - In the next work programme there could be a task force to consider the implications of alternatively powered vehicles such as electric vehicles (ERS and static), hydrogen etc. for road administrations. The task force could carry out horizon scanning on low carbon vehicles and potential impacts on the road network and summarise the current activities of different countries in this area. Depending on the state of development on ERS, a technical committee for alternative fuels could then be included in the following work cycle. Topics to be addressed could include
    - Review of ERS and alternative fuel technologies that are close to market.
    - To understand the activities of NRAs and Research Organisations.
    - To understand policy and instruments used by different Governments to promote low carbon vehicle technologies.
    - Produce a guidance document outlining potential actions to prepare for low carbon vehicle technology uptake.

7.3.2. Facilitate discussion with other stakeholders

It is recommended that PIARC encourage collaboration between road administrations and technology manufacturers, energy providers etc. It could act as facilitator of the conversations that need to happen, for example by:

- **Holding cross-industry workshops** - PIARC could hold a series of cross-industry workshops on different aspects of ERS, including impact on infrastructure, safety etc.
- **Liaising with of industry organisations** - PIARC could engage with its counter parts for other industries such as energy and vehicle manufacturers.

A. Represent its members in ERS discussions

PIARC could represent the views of its members in ERS discussions for example by:

- **Stating the position of its members** - PIARC could make a statement of the position on ERS and its role in decarbonisation.
- **Providing a road owner perspective in discussions** - Participation in setting standards and guidance on ERS from road owner perspective. Setting out concerns of NRAs to government and technology manufacturers.

8. GLOSSARY

Term	Definition
AADF	Average Annual Daily Flow
AC	Alternating Current
APS	Aesthetic Power Supply
B	Magnetic Field
BM	Business Model
BMS	Battery Management System
CAN	Controller Area Network
CBA	Cost Benefit Analysis
CO_2	Carbon Dioxide
CRF	Centro Ricerche Fiat
CWD	Charge While Driving
DBFO	Design Build Finance Operate
DC	Direct current
DEFRA	Department for Environment, Food and Rural Affairs
DWPT	Dynamic Wireless Power Transfer
eBus	Electric Bus
EC	European Commission
ECU	Electronic Control Unit
EFC	Emissions Forecasting Tool
EM	Electromagnetic
EMC	Electromagnetic Compatibility
EMF	Electromagnetic Field
EMI	Electromagnetic Interference
ERS	Electric Road System

EU	European Union
EV	Electric Vehicle
FOD	Foreign Object Detection
FP7	EU Seventh Framework Programme
G	Generation
GHG	Greenhouse Gas
GBP	Great British Pound
GVW	Gross Vehicle Weight
HEV	Hybrid Electric Vehicle
HF	High Frequency
HGV	Heavy Goods Vehicles
HPDC	High Power Dynamic Charge
ICE	Internal Combustion Engine
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEC	International Energy Commission
IEEE	Institute of Electrical and Electronics Engineers
Imin	Inductive Minimum Capital Cost
Imax	Inductive Maximum Capital Cost
IPR	Intellectual Property Rights
IPT	Inductive Power Transfer
IPV	Induction Powered Vehicle
KAIST	Korean Advanced Institute of Science and Technology
kHz	Kilo Hertz
KPH	Kilometres Per Hour
kW	Kilo Watt
LDV	Light Duty Vehicle

LKM	Lane Kilometres
LMIC	Low and Middle Income Countries
LV	Light Vehicles
LWH	Length Width Height
Maas	Mobility as a Service
MPH	Miles Per Hour
N2N	Node to Node
NAEI	National Atmospheric Emissions Inventory
NIMBY	Not In My Back Yard
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
NPV	Net Present Value
NRA	Network Road Administration
OBU	On-Board Unit
OCC	Operations and Control Centre
OEM	Original Equipment Manufacturer
OLEV	Online Electric Vehicle
Omin	Conductive Overhead Minimum Capital Cost
Omax	Conductive Overhead Maximum Capital Cost
ORNL	Oak Ridge National Laboratory
ORU	Other Road Users
PATH	Partners for Advanced Transportation Technology
PF	Power Factor
PHEV	Plug-In Hybrid Electric Vehicle
PM	Particulate Matter
POT	(PIARC) Project Oversight Team

PV	Photo Voltaic
QF	Quality Factor
R&D	Research and Development
RO	Road Operator
Rmin	Conductive Rail Minimum Capital Cost
Rmax	Conductive Rail Maximum Capital Cost
SMFIR	Shaped Magnetic Field in Resonance
SPSE	Specific Power Specific Energy Ratio
SRS	Static Recharging Solution
SV	System Voltage
T	Teslas
TAG	Transport Analysis Guidance
THD	Total Harmonic Distortion
TM	Traffic Management
TRL	Technology Readiness Level
V2G	Vehicle to Grid
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VAT	Value Added Tax
VRS	Vehicle Restraint System
WB	World Bank
WPT	Wireless Power Transfer
YTD	Years to Deployment

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International Standard Book Number: 978-2-84060-496-9