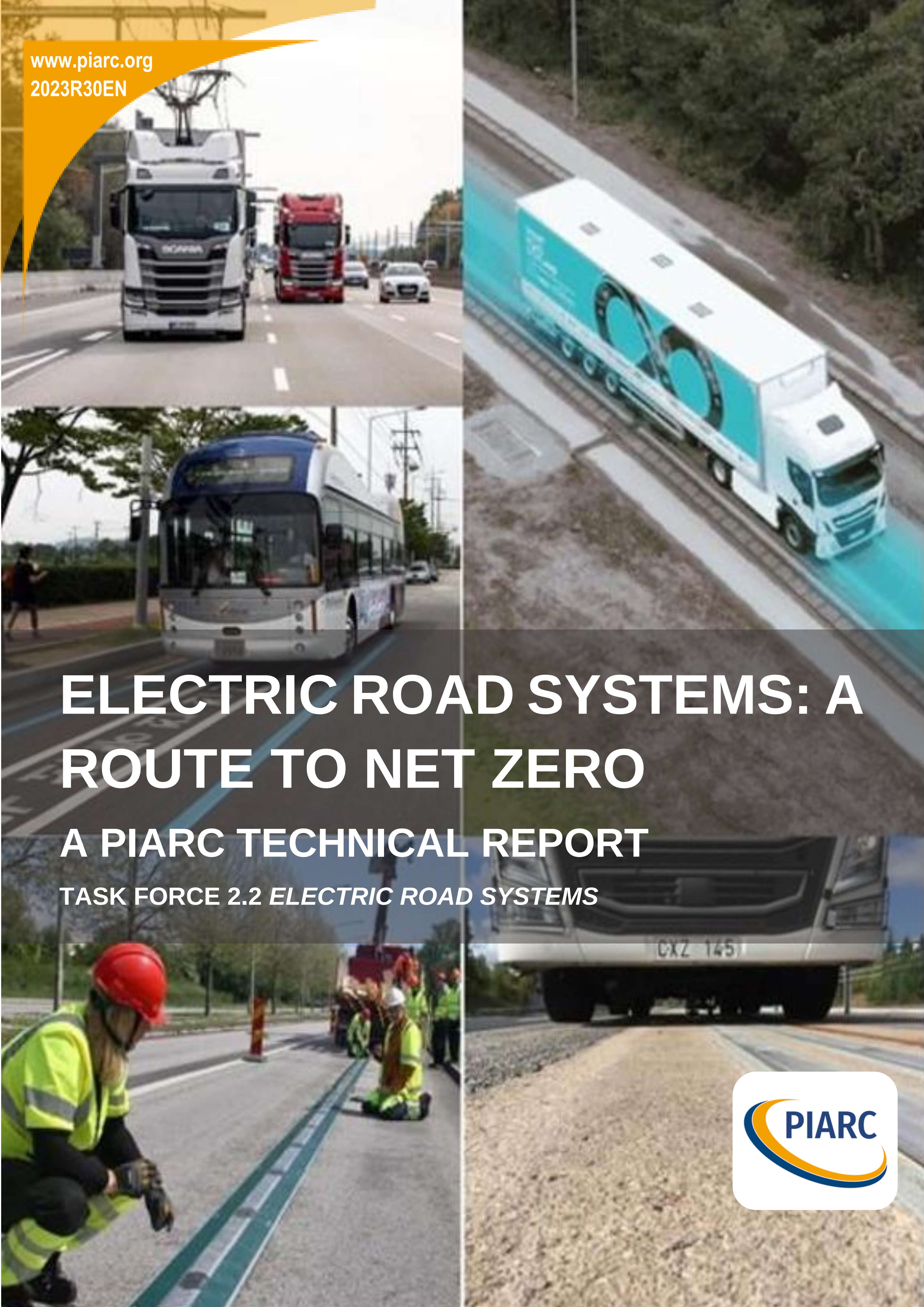


www.piarc.org
2023R30EN

ELECTRIC ROAD SYSTEMS: A ROUTE TO NET ZERO

A PIARC TECHNICAL REPORT

TASK FORCE 2.2 *ELECTRIC ROAD SYSTEMS*

PIARC

STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2020– 2023 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were appointed by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.

This report is available from the internet site of the World Road Association (PIARC): http://www.piarc.org

World Road Association (PIARC)
Arche Sud 5° niveau
92055 La Défense cedex, France

International Standard Book Number: 978-2-84060-807-3

Front cover © Authors

ELECTRIC ROAD SYSTEMS: A ROUTE TO NET ZERO

A PIARC TECHNICAL REPORT

TASK FORCE 2.2 *ELECTRIC ROAD SYSTEMS*

AUTHORS/ ACKNOWLEDGEMENTS

The Task Force 2.2 would like to acknowledge all the Task Force (TF) members who contributed to the gathering, analysis and discussion of the information for this report. In specific the TF would like to acknowledge the main contributors to the preparation of this report:

- Britta Sommers (Germany),
- Diane Turchetta (USA),
- Diego Ramirez Cardona (Canada),
- Henri Chua (Malaysia/United Kingdom),
- Jan Pettersson (Sweden),
- Kenneth Natanaelsson (Sweden),
- Lina Nordin (Sweden),
- Pascal Rossigny (France),
- Patrick Duprat (France), and
- Tonia Buell (USA).

The TF would also like to acknowledge the following additional contributors to the preparation of this document:

- Carlos Santillán Doherty (Mexico),
- Dario Zaninelli (Italy),
- Giuseppe Mastroviti (Italy),
- Jesús María Leal Bermejo (Spain), and
- Pierre Delaigue (France).

The original version was edited by Tonia Buell (USA) and Henri Chua (Malaysia/United Kingdom) for which the TF is grateful. In addition, the TF would like to acknowledge the work of Mats Alaküla of Lund Institute of Technology, Sweden, Matteo Craglia of International Transport Forum, France, Patrick Plötz of Fraunhofer Institute for Systems and Innovation Research ISI, Germany, and Tallis Blalack of ASPIRE NSF Research Center, USA, Lori Tavasszy of Delft University of Technology, Netherlands who peer reviewed this report. The translation into French/English and Spanish/English of the original version were respectively produced by Patrick Duprat (France) and Jesús María Leal Bermejo (Spain) for which the TF is grateful.

The Task Force was chaired by Jan Pettersson (Sweden). Doros Nicolaides (United Kingdom) then Henri Chua (Malaysia/United Kingdom), Jesús María Leal Bermejo (Spain) and Patrick Duprat (France) were respectively English, Spanish and French-speaking Secretaries. The Webmaster was Carlos Santillán Doherty (Mexico). The Working Group Leaders were: 1) Patrick Duprat (France) – Technology Assessment, 2) Henri Chua (Malaysia/United Kingdom) - Stakeholders, Business Cases and Business Models and 3) Kenneth Natanaelsson (Sweden) - Policy and Strategies.

EXECUTIVE SUMMARY

2023R30EN

ELECTRIC ROAD SYSTEMS – A ROUTE TO NET ZERO

A PIARC TECHNICAL REPORT

The international Paris Agreement about climate change calls for action in every aspect of the modern society. The world's road transport sector is responsible for a considerable amount of the total CO_2 emissions, so there is an urgent need for decarbonising the road transport sector.

To achieve the Paris Agreement, the road transport sector needs to work with many solutions. For example, battery electric solutions, biofuels, fuel cells/hydrogen and Electric Road Systems (ERS). ERS are systems which dynamically charge the electric vehicles (EVs) while they are in motion. There is also the important requirement to increase the efficiency in the road transport system and to interact with other transport modes, such as maritime, aviation and railway sectors.

The way forward for decarbonising the road transport sector in the long run includes electrification since that are most cost effective and energy efficient. There are a number of challenges regarding electrification that must be addressed and solved, viz.:

- Cruising range,
- Charging (waiting time, charging congestion, infrastructure installation, including grid demands, and land use),
- Increased use of batteries (securing resources, disposal, deterioration of roads due to greater vehicle weight and vehicle agility),
- EV load (battery weight and volume, and reduction of payload),
- Safety issues,
- Energy and cost efficiency, and
- Grid issues.

A comparison between different electrification technologies shows that ERS is a very efficient means of electrification. ERS vehicles can be a very efficient solution in parallel with battery electric vehicles. Hence, ERS have the potential to become the solution with the lowest total cost of ownership for the users and also socio-economic positive for road owners and/or operators to deploy.

- ERS can contribute to decarbonisation of the road transport sector by:
- Providing zero emissions while driving,
- Offering an unlimited cruising range,
- Abolishing charging congestion,
- Reducing the size of on-board batteries,
- Reducing the vehicle's weight and potentially increasing its payload,
- Lowering vehicle cost, and
- Benefitting other road users, buses and cars.

EXECUTIVE SUMMARY

To make ERS to happen in the world is a challenge that involves many stakeholders. Co-operation among the stakeholders, for example, energy providers, grid owners, road administrations/owners, ERS providers, vehicle industry and policy makers, is an absolute key for success. ERS deployment also requires a total system perspective for implementation and interaction between all possible solutions to decarbonise the road transport sector.

A number of countries and road administrations are considering introducing ERS and working intensively to remove uncertainties regarding the technologies. Some countries also have deployment plans ready for ERS but it is critical that countries and administrations work together to establish common roadmaps to avoid the risk of creating cross-border barriers.

ERS are being demonstrated today across the world using a number of different technologies and the results from these demonstrations are very promising. Many technologies are mature enough or close to deployment readiness. The vehicle industry is still not fully committed but there are a number of large original equipment manufacturers (OEMs) that are part of the tests which are conducted across the world.

The important steps for implementing and operating ERS are as follows:

- Set clear goals for ERS in national policies for decarbonising the road sector,
- Create national and international roadmaps for deployment,
- Establish frameworks of laws, rules and standards,
- Continue to demonstrate technologies and create pilot projects,
- Co-operate between road, energy and vehicle sectors, and
- Secure cross-border inter-operability through international co-operation.

ERS are ready and can be an important piece in the puzzle to decarbonise the road sector. ERS can contribute to making life better for the users by removing range anxiety, preventing waiting lines to charge or, due to lower costs enabled by smaller batteries, making electric vehicles affordable to all.

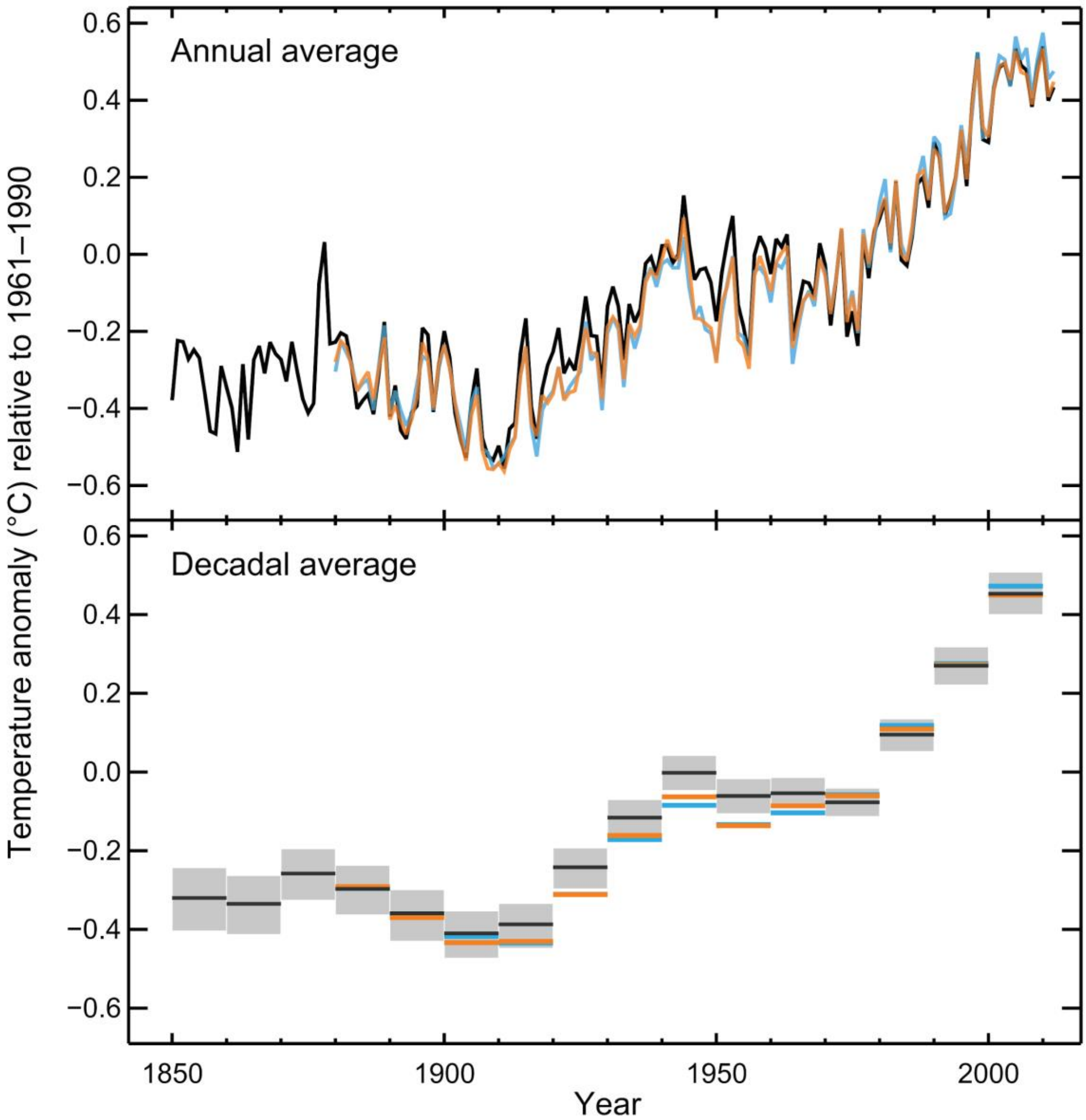
Contents

1. INTRODUCTION

1.1. BACKGROUND

In 2013, the Inter-governmental Panel on Climate Change (IPCC) presented clear and robust conclusions in a global assessment of climate change science that human activity is the dominant cause of observed warming since the mid-20th century. Its report, *Climate Change 2013: The Physical Science Basis* (IPCC, 2013), confirms that warming in the climate system of mother earth is unequivocal and highlights the role of greenhouse gas (GHG) emissions. Figure 1 presents the annual change in global temperature since 1850.

Figure 1: Observed Globally Averaged Combined Land and Ocean Surface Temperature Anomaly 1850-2012



Source: IPCC (2013).

Note: Anomalies are relative to the mean 1961-1990.

Fast forward two years, the Paris Agreement, a legally binding international treaty on climate change, was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12th December 2015. It entered into force on 4th November 2016. The Agreement's overarching goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" but to pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels." Since then, world leaders have stressed the need to limit global warming to 1.5°C by 2100.

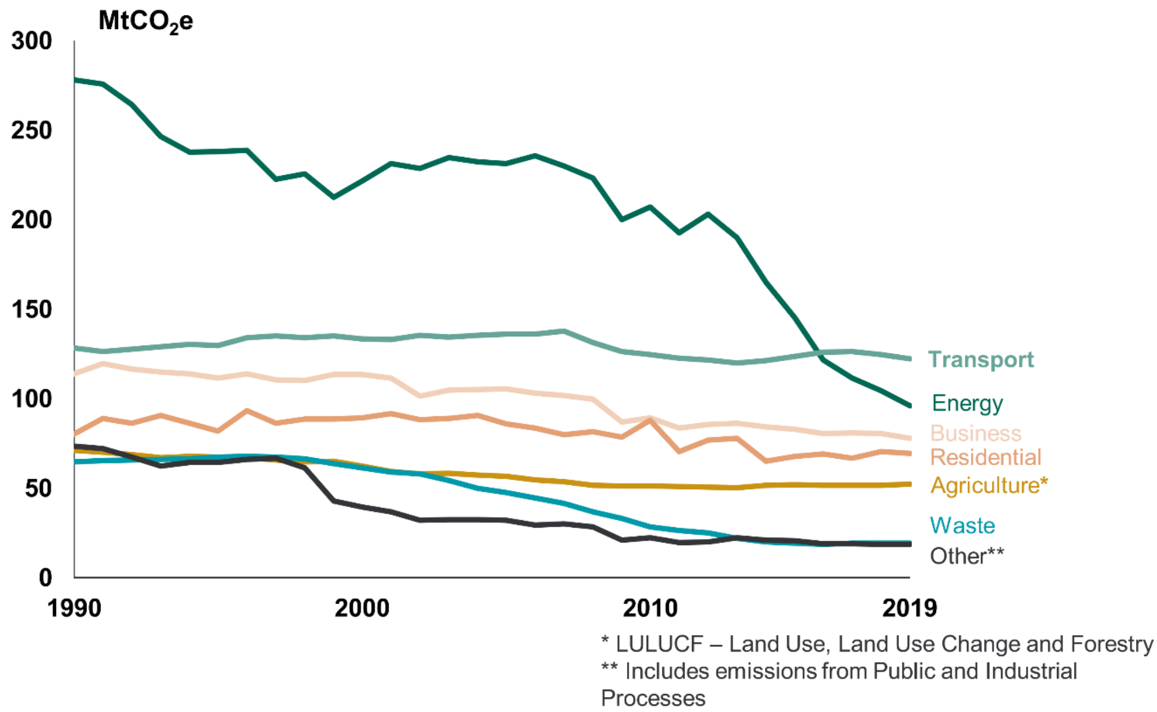
Transport is a vital means to everyday life and economic activities, such as going to school, visiting a hospital, travelling to holiday destinations, delivering produce from farm to market, importing and exporting of goods etc. Twentieth century mechanised transport systems, with some exceptions, are powered by fossil fuels. Unfortunately, a side effect of burning fossil fuels, such as diesel, kerosene and petrol, is the emission of CO_2, which is a key type of greenhouse gases. Thus the modern mechanised transport systems are major contributors of GHG emissions. According to the International Energy Agency (IEA) data, in 2018, the transport sector accounted for 21% of the global CO_2 emissions, of which road transport contributed 75% of the total transport emissions (Ritchie, 2020).

This challenging global transport GHG emissions statistics is reflected at the country level. For example, in the United Kingdom, a high-income country (HIC), in 2019, the transport sector's GHG emissions accounted 27% of the UK's total domestic emissions of 455 Mt CO_2-eq, of which road transport accounted for the lion's share at 89% (DfT, 2021). In Sweden, another HIC, in 2022, the transport sector's GHG emissions accounted for 30% of the total domestic emissions. In the case of Mexico, a medium income country, in 2018, the transport sector represented 25% of the total domestic GHG emissions (171 $MtCO_2$ of a total 683 $MtCO_2$), with road transport accounting the lion's share at 86% (Gutiérrez Gardos et al, 2020). In Canada, the transport section was responsible for 28% of the total emissions of the country, of which 69% is attributed to road transport (Environment and Climate Change Canada, 2022).

A more challenging aspect of the transport sector GHG emissions is that, while the emissions of other sectors, such as power and building, have abated, this trend is not matched by the transport sector. For example, Figure 2 shows the GHG emissions by sector in the United Kingdom between 1990 and 2019. It can be seen that since 1990 all sectors, bar the transport sector, have steadily reduced their GHG emissions. Whereas the transport sector's emissions have remained broadly steady, making it the largest emitter by sector since 2016. Even more challenging during this period (1990-2019) UK vans (light goods vehicles) GHG emissions have increased from 12 $MtCO_2$-eq to 19 $MtCO_2$-eq, an increase of nearly 60%.

Many countries have adopted a three-pronged ASI (Avoid, Shift and Improve) approach to decarbonise its road transport to meet its climate change commitment. The first involves avoiding the use of transport by way of changing land-use, e.g. 15-minute city, and employing technology, e.g. using teleconferencing technology to work from home. The second entails modal shift to zero to low emissions transport modes, such as Active Travel (walk and bicycle) and public transport (electric bus, tram and train). Given the dominance of road transport avoid and shift actions can be very helpful but insufficient by themselves. The third necessitates improving the road transport vehicles (and in some cases the road infrastructure too) to use carbon neutral fuels, such as biofuels, efuels, electricity and hydrogen.

Figure 2: The UK Domestic CO2 Emissions by Sector 1990-2019



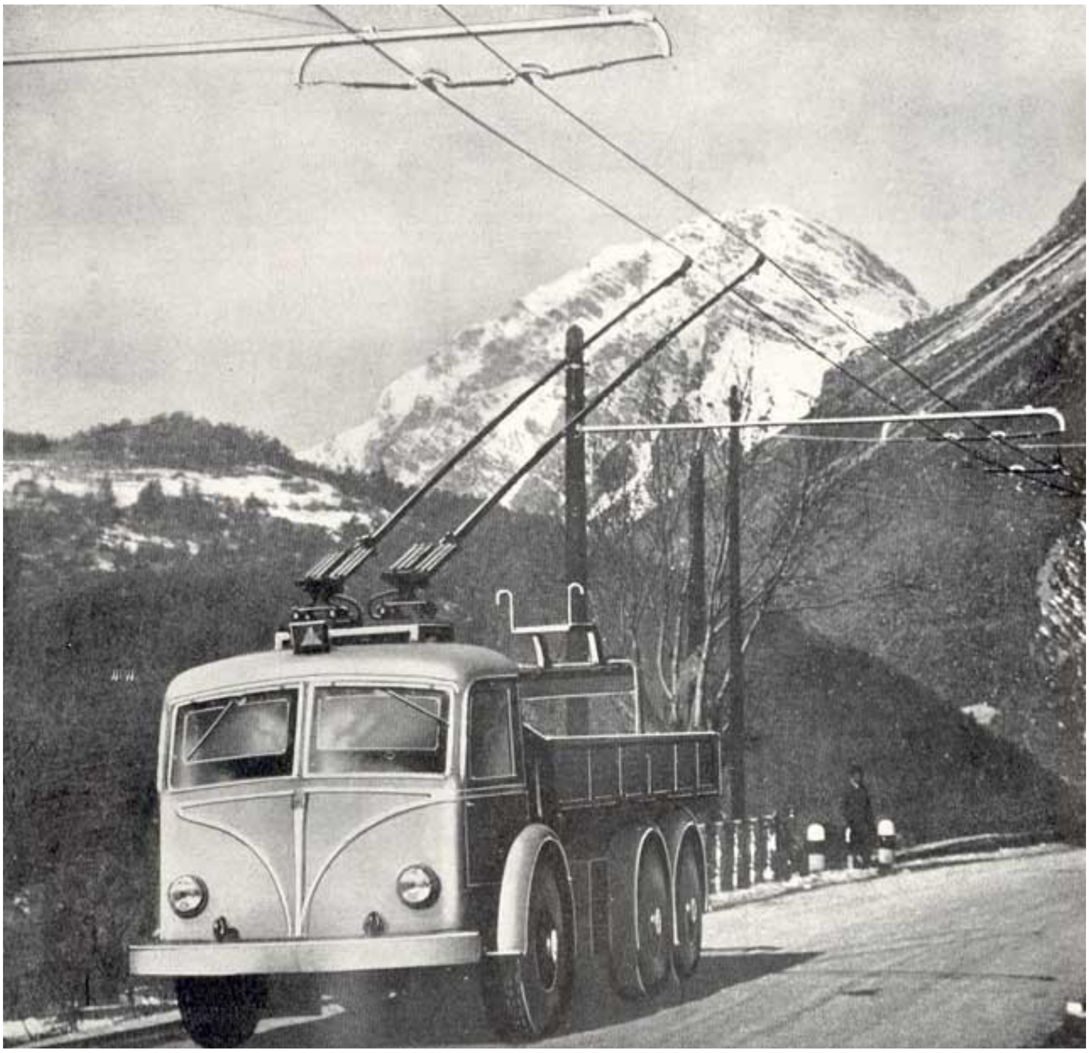
Source: DfT, 2021.

Biofuels, such as ethanol and biodiesel, can advantageously be used with existing fuelling infrastructure and internal combustion engine (ICE) vehicles; an advantage. However, their major drawback is their production denies the land used for the production of food for human consumption (ITF, 2021). Synthetic fuels, or efuels, can also be easily integrated with existing infrastructure and vehicles. Nevertheless, they are very expensive to produce and their use should be prioritised towards the very hard to decarbonise transport mode, i.e. aviation (Ueckerdt et al, 2021). Hydrogen is theoretically ideal to replace fossil fuels to power road transport vehicles. Its use produces no CO_2 and refuelling time is very short, i.e. in minutes, as with current fossil fuels. Also the existing road infrastructure requires no new investment by the road owner/operator – a plus not only from the investment perspective but can be advantageous from a legal perspective as at least one country has restriction on charging vehicles to use some of its principal highways. Furthermore, hydrogen powered vehicles can flexibly go anywhere and everywhere as like current ICE vehicles. However, there are two key drawbacks: 1) inefficient in energy terms and 2) currently very expensive. The former is because to produce (renewable) green hydrogen, one first has to generate electricity, which is then used to produce hydrogen and possibly to liquefy it for practical storage. In the course of the production and liquification process, a very considerable portion of the energy value of the input electricity is lost. Some have also argued that the use of hydrogen should be prioritised to difficult to decarbonise transport modes, such as aviation, and other industrial sectors, such as steel.

The use of electricity to power road transport vehicles is as old as motorised road transport. The world's first trolley bus, the *Elektromoke*, was introduced in Berlin, Germany, in 1882. Although ICE diesel buses have replaced many trolleybuses around the middle of the last century many cities across the globe still operate trolleybuses. For example, Athens, Beijing, Belgrade, Marrakech, Milan, Sao Paulo, Shanghai and Vancouver.

Italy also had trolley trucks. The Valtellina system was built in 1938 and operated until 1962 by AEM (Milano Power Company), the owner of hydro-electric power plants in Valtellina, Italy. A total of 20 trolley trucks were used to carry concrete, sand and equipment for the construction of the San Giacomo and Cancano II dams in the Valtellina valley. Figure 3 shows an Italian trolley truck.

Figure 3: A Trolley Truck near Bormio, Italy (1940)



Source: hutnyak.com

In the context of GHG emissions and climate change, the key advantage of using electricity to power road transport vehicles is that renewable electricity is a carbon free fuel. In this regard, in recent years battery electric vehicles (BEVs) have been introduced to replace ICE road vehicles. However, batteries are very heavy, mineral resource intensive, expensive and time consuming to recharge. Hence, BEVs are more suitable as light vehicles, i.e. cars and vans, as the payload of heavy vehicles (HVs) could be compromised by the size of the battery pack. Unless the BEV comes with a very large battery pack, which is expensive, cruising range could also be an issue. Further, because of the long recharging time, this could create congestion at the charging station and long dwell time. As such, BEVs may not be suitable as 24/7 intensively used vehicles, such as ambulances, unless the fleet size is increased.

One solution to overcome the various BEV limitations, such as cruising range and payload, is to dynamically charge the EVs while they are in motion. This way the battery size can be reduced, bringing many advantages, such as reducing resource used, lowering cost and increasing the payload for HVs while at the same time extending the cruising range. The systems for dynamic charging are collectively referred to as Electric Road Systems (ERS).

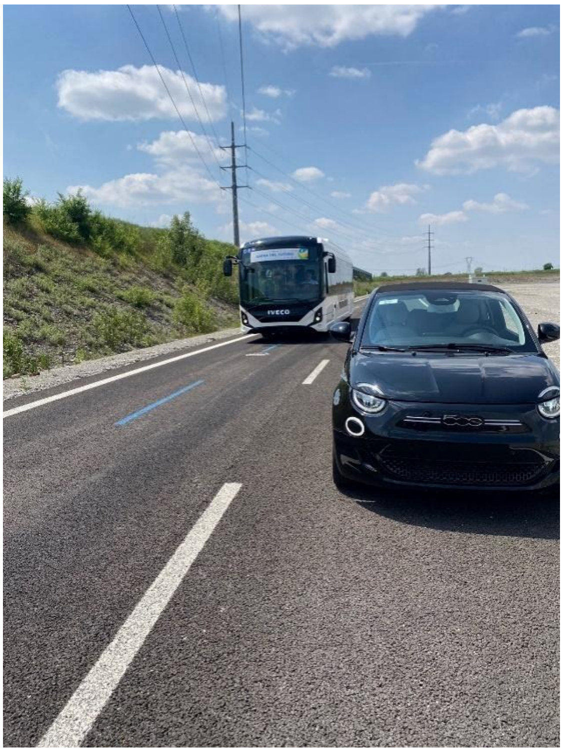
Broadly, the ERS can be categorised into three technological groups:

Inductive systems, which are in essence wireless charging by induction coils embedded into the road pavement. Figure 4 shows an inductive system,

Figure 4: An Example of an Inductive Electric Road System

Under Construction

In Operation



Source: Mastroviti, 2023.

Conductive rail systems, which are made up of three alternative power transfer configuration variants: 1) an electrified rail in the pavement, 2) an electrified rail on the pavement and 3) an electrified rail at the roadside. The first two rail systems are further referred to in this report as the “ground rail” systems, whereas the third technology is hereafter known as the “lateral rail” systems. Figure 5 presents three examples of the rail systems, and

Figure 5: Examples of Conductive Rail Electric Road Systems

Ground Rail In Pavement System

Source: Evias.

Ground Rail On Pavement System

Source: Elonroad.

Lateral Rail System

Source: Honda.

Conductive catenary or overhead systems, which have overhead electric cables, are hereafter referred to as the “catenary” systems. An example is displayed in Figure 6.

Figure 6: A Catenary Electric Road System

Source: Mastroviti, 2023.

1.2. Study Objectives

PIARC carried out a Special Project study of ERS in 2017-2018 (PIARC, 2018). That study was primarily focused on exploring the literature available on ERS.

The PIARC Strategic Plan for 2020–2023 identified the following topics as the basis for the consideration of the Task Force 2.2:

- Literature review of ERS technologies, covering their technical aspects, including Technology Readiness Level, inter-operability, life cycle analyses (LCA), costs and integration with other technologies as part of "smart road" infrastructure,
- Postulation of the pros and cons of different ERS technologies,
- Analysis of new experiences from test, demonstration and pilot projects to formulate learnings and best practices,
- Identification of the stakeholders of ERS,
- For road and transport administrations, establishment of potential business models, which address different vehicle types using ERS, potential subsidies to kick start ERS roll out, ERS costs and benefits, evolving competing and complementary technologies and evolutions of ERS technologies over the next several years,
- Review of existing and planned ERS implementations on public roads as well as research projects outside open roads,
- Identification and analysis of national policies promoting ERS,
- Development of recommendations on strategies that could accelerate ERS implementation, next steps for road and transport administration in different stages of ERS implementations and future roles of international cooperation and PIARC,
- Contribution to an international narrative for ERS, and
- Coordination and collaboration with other PIARC technical committees and task forces which have an interest in ERS.

1.3. SCOPE OF THIS REPORT

This *Final Report* is the accumulation of discussions, research and analyses over 2020-2023 by the Task Force 2.2 members. Following its inauguration meeting, which was held on-line because of the Covid pandemic, on 6th November 2020, the Task Force has had 16 additional meetings, of which all, but one, were held online. The exceptional meeting was held in Sweden at the end of August to the beginning of September 2022 and included technical visits to two ERS demonstration projects (in Lund and Visby).

Following this introductory chapter, Chapter 2 outlines the methodology employed by the TF to undertake the research on the ERS and summarises the work undertaken during the early months on the literature review, case study development, stakeholder survey and workshops. Chapter 3 discusses the technology assessment undertaken and ends with a brief description of the key learnings and best practices. Chapter 4 describes the analyses on stakeholders, business cases and business models. The penultimate Chapter 5 covers the issues explored on policy and strategies to implement ERS. Last, but not least, the conclusion and recommendations are presented in Chapter 6.

2. METHODOLOGY

2.1. APPROACH

The Task Force employed a classic research study approach to address the study objectives set by PIARC. The study approach can be summarised as follows:

- Collect and review ERS literature,
- Develop key case studies,
- Survey key stakeholders,
- Host workshops, and
- Carry out further analysis.

To efficiently and cohesively share the research workload the TF was organised into 3 working groups as follows:

- Working Group 1: Technology Assessment. This predominantly addressed the PIARC topics 1 to 3 in Section 1.2 above,
- Working Group 2: Stakeholders, Business Cases and Business Models. This working group focused on the PIARC topics 4 and 5 in Section 1.2 above. Following further deliberation PIARC topic 5 (Business Models) was addressed as two separate issues of Business Cases and Business Models, and
- Working Group 3: Policy and Strategies. This group covered the PIARC topics 6-8 in Section 1.2 above.

The PIARC topics 9 and 10 in Section 1.2 above were jointly addressed by all TF members.

2.2. LITERATURE REVIEW

PIARC carried out a preliminary study on ERS in 2018 (PIARC, 2018). That study included a literature review of the then available ERS information. Since then, interests and activities on ERS have increased significantly. Hence, it was determined that a fresh effort to review the available ERS literature was vital. The new literature review focused on reviewing the types of ERS technologies, their Technology Readiness Levels (TRL), demonstration projects, inter-operability, life cycle analysis, costs, and pros and cons.

The search for available literature involved the TF membership putting forward the ERS documents from the PIARC Members Countries and beyond. In total, 60 documents were received from PIARC Task Force's members in 2021 and reviewed. Appendix A below gives the list of the literature reviewed. These documents are from 3 international organisations and 13 different countries, namely: Belgium, China, Denmark, France, Germany, Italy, Japan, South Africa, South Korea, Spain, Sweden, UK and the USA. Full detail of the literature review was reported in the TF's report, *Collection of Case Studies* (PIARC, 2020).

2.3. CASE STUDIES

Information collected during the literature review was used to produce a list of case studies about the ERS trials and demonstrations around the world. In total eighteen case studies were identified. A standard template was used to present each of the case studies. The information about each case study was systematically presented under four main headings, namely:

- Technology assessment,

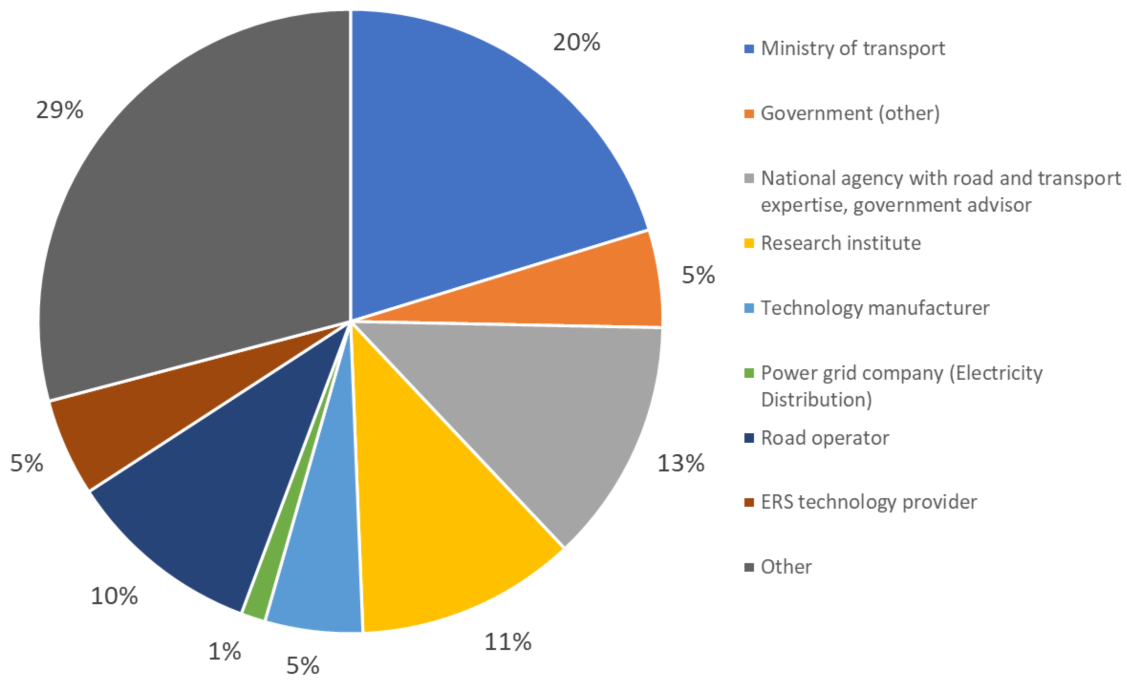
- Business models and stakeholders,
- Policy and strategies, and
- Key findings.

Eighteen case studies were described in the TF's report, *Collection of Case Studies* (PIARC, 2020). Since that report, ERS have continued to evolve with new data and new ERS demonstration projects are planned. Consequently, an updated list of 27 Case Studies is available in Appendix B below.

2.4. Survey

A survey was undertaken to obtain insights from various ERS stakeholders across the world. The survey questionnaire used is shown in Appendix D.1 below. In total, 79 responses were received from 38 different countries. The organisation representation is shown in Figure 7. The questionnaire consisted of questions that aim to understand stakeholders' perception of ERS technologies, their technological readiness levels, as well as the progress that had been made in terms of ERS activities and policy generation.

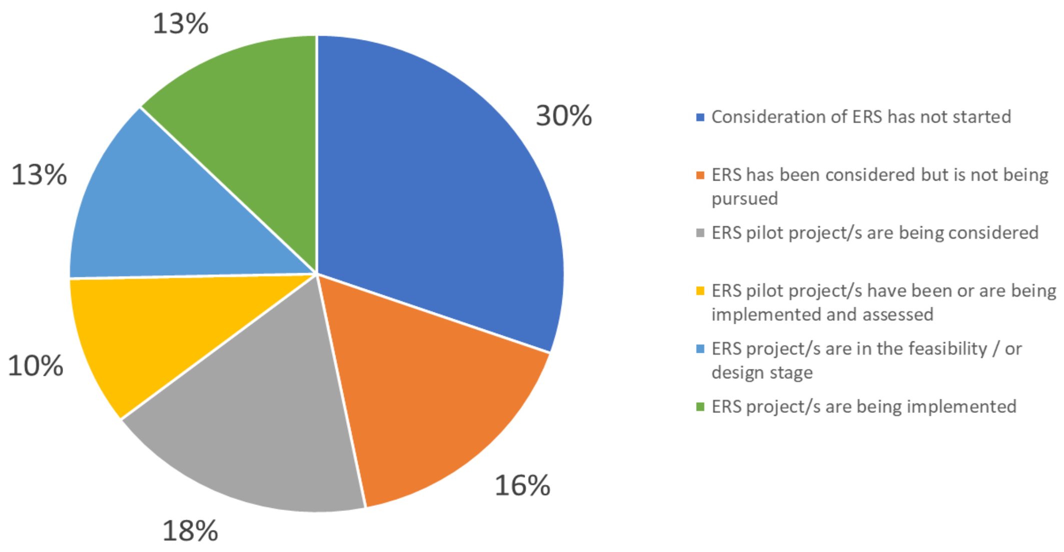
Figure 7: Stakeholder Organisation Representation



Source: TF2.2 ERS.

The state of ERS within various stakeholder organisations is shown in Figure 8. Notably 46% of responders are not currently undertaking any ERS related activities, while the remaining 54% are either considering ERS projects or implementing further investigations into the technology.

Figure 8: State of ERS within Various Stakeholder Organisations

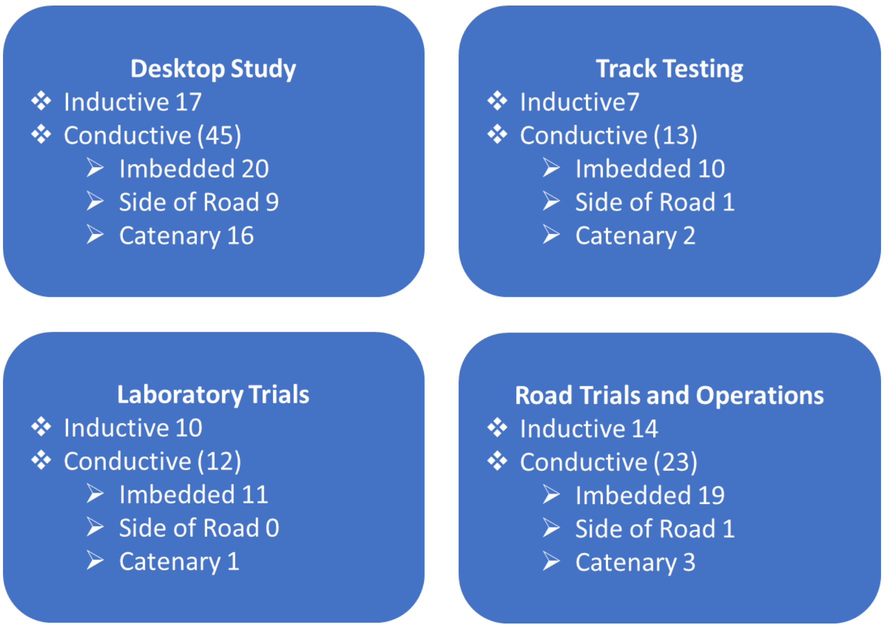


Source: TF2.2 ERS.

Those organisations that are involved with ERS related activities were asked to specify the type of activity, and the relevant ERS technology, that they are involved with. The results are summarised in Figure 9 below. Most stakeholders are conducting desktop studies, skewed to conductive systems. However, in terms of track tests, laboratory trials and road trials and operations, the gap between inductive and conductive systems is significantly smaller.

The questionnaire also contains questions that relate to the state of ERS policies in organisations, the expected timeliness for the commencement of various ERS related activities and the perceptions of stakeholder on the benefits, drawbacks, and challenges faced by the ERS. The responses to these and other questions are further analysed in this final report.

Figure 9: ERS Activities Undertaken by Survey Participants



Source: TF 2.2 ERS.

Note: The survey was undertaken in 2020.

2.5. WORKSHOPS

Three workshops with a broad range of relevant stakeholders were undertaken to support the activities of the TF and to disseminate knowledge about ERS.

The first workshop took place in February 2021 and was focused on ERS technologies. It involved the following key ERS technology providers: Alstom (France), Electreon (Israel), Elonroad (Sweden), Evias (Sweden), Honda (Japan) and Siemens & Engie (respectively, Germany and France).

The second workshop took place in May 2021 and focused on Business Models & Stakeholders. The workshop involved, in no specific order of importance: Scania and Renault (respectively, Swedish and French automotive OEMs), EON and Vattenfall (respectively, German and Swedish power suppliers), DB Schenker and Contargo (both German logistics service providers), Vinci Autoroutes (French road concessionaire), European Commission (European supra-national agency) and Meta Strategy Consulting (French consultancy company).

Last, but not least, the third workshop took place in November 2021 and focused on National Policies & Strategies. Representatives from ministries, transport administrations and research institutes joined from Austria, China, France, Germany, Sweden, the UK, and the USA.

The workshops had many participants and nearly 500 people registered their interest for the first workshop and almost 300 attended. All workshops provided many insights and proved great interest for ERS. The first workshop gave a very clear picture that the ERS technologies exist and continue to improve and, most importantly, many can already be deployed. The second workshop focused on the importance that a number of stakeholders need to come together to overcome the “chicken and egg” problem of innovations to make ERS happen. Participants of the third and last workshop took away the knowledge that some countries have already started to make plans to roll out ERS but there are still many countries, not just LMIC ones, who are just starting to learn about the ERS technologies.

Due to the Covid-19 pandemic all three workshops were carried out virtually and recorded. The recordings are available as below:

- Workshop 1 - International Webinar, "Electric Road Systems". Available on: https://www.piarc.org/en/activities/PIARC-International-Seminars-Proceedings/International-Seminars-2021-World-Road-Association/International-Webinar-Electric-Road-Systems-February-2021,
- Workshop 2 - Virtual International Workshop, "Electric Road Systems - Business Models". Available on: https://www.piarc.org/en/activities/PIARC-International-Seminars-Proceedings/International-Seminars-2021-World-Road-Association/International-Workshop-Electric-Road-Systems-Business-Models-June-2021, and
- Workshop 3 - Virtual International Workshop, "Electric Road Systems - National policies and strategies". Available on: https://www.piarc.org/en/activities/PIARC-International-Seminars-Proceedings/International-Seminars-2021-World-Road-Association/International-Workshop-Electric-Road-Systems-National-Policies-Strategies-November-2021.

2.6. Further Analyses

Following from the publication of the TF's literature review and case studies (PIARC, 2020), the TF produced an internal briefing note. This outlines the knowledge gap and further analyses to be carried out. The further analyses by the three working groups are reported in the next three chapters as follows:

- Technology assessment,
- Stakeholders, business cases and business models, and
- Policy and strategies.

3. TECHNOLOGIY ASSESSMENT

3.1. Technology Analysis

The aim of this task is to collect information about new experiences from demonstration projects around the world, strengthening the (i) practical, (ii) engineering, (iii) operational, (iv) traffic management, (v) road safety, (vi) cybersecurity and (vii) maintenance perspectives of deploying ERS. The work builds upon the findings of the case studies presented in the previous deliverable – *Collection of Case Studies* (PIARC, 2021). It combines literature review with knowledge and expertise available by WG1 members, who are worldwide leaders in the area of ERS. This includes contributions from academia, technology providers, road and highway authorities, street operations, etc.

3.1.1. Practical

Key practical concerns for road and highway authorities regarding implementation of ERS include the type of roads to be electrified and the use or not of a dedicated lane for ERS. There are pros and cons for installing ERS on dedicated lanes and measures against accidents and traffic congestion need to be considered.

With a number of ERS technologies demonstrated around the world, road authorities do not always have a comprehensive understanding about the benefits and drawbacks of each technology. Also despite the fact that the core ERS technology has been substantially developed, extra technologies and standards need to be developed for integrating the technology into the road system in a safe and effective manner. This includes, for example, definition of procedures for preparing the road to accommodate ERS (e.g. scarring the asphalt pavement), geometric configuration of the equipment installed under or above the pavement, and procedures to install the system with the least possible impact on road traffic.

Once the system is deployed, road and highway authorities need to ensure the safe operation and maintenance of the network. Ownership and liability of the ERS equipment will also be important and this depends on the operational model of ERS. There are primarily two basic scenarios: 1) the ERS is owned and operated by the road/highway authority and 2) the ERS system is owned by another party (e.g. electricity infrastructure provider, technology provider, etc). In the first case, road/highway authorities will be concerned about increased liabilities and additional maintenance demands. In the second scenario, road/highway authorities need to involve additional parties into their operational plans to minimise disruptions to road users. Needless to say, in both cases new operational plans will be required.

3.1.2. Engineering

Implementing ERS, particularly retrofitting them to existing roads, may come with a number of challenges involving electrical, mechanical, civil, and environmental aspects. It is important to develop an effective system in terms of electrical power which is safe and meets national guidance and regulations. ERS providers and vehicle manufacturers need to identify the necessary vehicle modifications to enable ERS, whereas road and highway authorities need to work on materials and pavement restoration without affecting road durability and performance.

Some countries, e.g. the UK, have extremely narrow verges, i.e. 1.5m in the UK, which are already used for kerbs and drainage, vehicle restraint systems, signs and markers, gantries, technology and communications cabling and power supplies. The practicalities of fitting power cables (for whatever system is used), cabinets, poles, and collision protection to the poles (in the case of catenary systems) will need to be carefully considered if significant widening (and the planning requirements for additional land acquisition) is to be avoided.

The added infrastructure must not introduce additional safety risks to road users and needs to guard against issues arising from weather or other conditions.

3.1.3. Operational

Road and highway authorities are not set up to maintain power systems of this type and therefore, if they are to maintain them, will need to develop new skills and purchase new equipment to do so. The authorities would also need to decide how power consumption is measured and paid by users of the ERS, but an approach consistent with static chargers (fee paid by kwh consumed) could probably make the most sense.

It is also key to understand what additional notice will be needed to inform drivers and operators about maintenance activities, so they are not reliant on those disconnected sections for charging.

3.1.4. Traffic Management

Road and highway authorities would need to manage live traffic when the network is being upgraded with ERS in the same manner as they currently manage traffic during roadworks. Installation or maintenance work of ERS may not create any new traffic management challenges to road operators.

3.1.5. Road Safety

Road safety is an important element for the successful introduction of ERS at a national scale. Users may perceive ERS as an additional hazard due to the power and voltages required. Catenary poles, power cabinets and other added infrastructure elements need to be assessed as new potential hazards and appropriate measures could be needed to mitigate risks. Of particular importance is for the ERS system to be fail safe in all circumstances so that there is no chance of exposure to a live cable or rail.

Also, vehicles will be equipped with extra equipment (wireless pads, pantographs, arm collectors, etc.) which can impose a risk to other vehicles and road users.

3.1.6. Cybersecurity

The introduction of ERS needs to be assessed against cyber security measures to ensure that ERS does not present additional risk/liability to the highway authority, drivers, power suppliers, etc.

3.1.7. Road Maintenance

Routine and periodic maintenance of the road network would likely need to be adapted to suit the ERS. However, the cost that this could impose in new practices and/or new plants and equipment should be considered as part of the whole life cost. For example, does a catenary system have sufficient height to allow a standard planer, paver and wagon with an uplifted load bay to operate below it for a standard resurfacing exercise? Does a Ground Rail system allow the rail to be lifted out to allow standard planers to be used for resurfacing or would narrow planers and pavers have to be used to avoid this?

It appears that ERS could add complication to maintenance activities. Key considerations include extra time to add to current procedures, work rate and what can be achieved overnight, additional skills / training for maintenance crews, set up of different crews, etc.

3.2. Inter-operability Analysis

For a large-scale deployment of an ERS system in several countries or continents, inter-operability is a key factor. But inter-operability can have many facets and can be broken down into different levels. In this section, we will examine the different aspects and levels of inter-operability for electric road systems.

For ERS, we can distinguish different categories of inter-operability:

- Inter-operability between countries for a given electric road solution,
- Inter-operability of one vehicle with different ERS solutions,
- Inter-operability of one ERS solution with different types of vehicles, and
- Inter-operability between ERS solution of the same technology family.

3.2.1. Inter-operability Between Countries

To be inter-operable in different countries, that is to say allowing vehicles to cross borders without operating problems, a technical solution must comply with the regulations of each country. This constraint applies to different fields and phases: design/performance, construction and operation.

Many local constraints and regulations can be an obstacle to achieving this level of inter-operability, among them we can identify:

- Climate differences that can impact the design of the technical solution (performances of the system and of its components),
- Road construction rules that can impact the design of the technical solution in terms of integration in and alongside the road,
- Differences in terms of energy supply impacting the interface the ERS,
- Differences in terms of toll system impacting the billing system to put in place,
- Differences in terms of road regulation and road operation (including rescue) that impact the design and the functionalities of the ERS at the infrastructure and on-board levels, and
- Communication regulation differences impacting communication rules between the infrastructure and the on-boards ERS sub-system and potentially with the billing system.

All the above aspects could be dealt with via the standardisation of ERS. For instance in Europe, a fully standardised solution by CEN/CENELEC, where all the National Committees are represented, would probably solve the problem of the inter-operability between EU countries.

However, this cross-border inter-operability should not be seen as an absolute condition to the deployment at scale of ERS networks since ERS along shorter highway corridors within each country operating with compatible captive fleets can bring significant decarbonisation and reduced air pollution benefits.

3.2.2. Inter-operability of One Vehicle with Different ERS Solutions

Such an inter-operability would mean that a vehicle will be able to collect power on different ERS infrastructures, in which case road operators will be free to select which ERS to install on their network. But this would imply that any vehicle can be powered and charged on several ERS infrastructures.

None of the ERS solutions have the same interface between the infrastructure and the vehicle. Although some ERS solutions use the same principles for the power transfer, this is the reason why they have been differentiated as three families of ERS as in Section 1.1 above.

The way for collecting the power is different for each ERS family: a pantograph for catenary systems, a pick-up rail under the vehicle or at the side of the vehicle for conductive ground and lateral rail infrastructure, respectively, and receiver(s) under the vehicle for inductive solutions. Once collected, the electric current needs to be converted for powering the engine and/or recharging the batteries. This step is also linked to the type of ERS infrastructure adopted: an inductive system needs the conversion of AC to DC and a conductive system (be it catenary or rail) needs to manage the DC to DC conversion with different levels of input voltage.

To be inter-operable between several families of ERS, a vehicle must hence be equipped with different power collectors and possibly with different current conversion equipment. The technical feasibility needs to be checked in terms of volume and added weight for each vehicle type.

It is unlikely that all vehicle types can be compatible with all types of ERS. For example, light vehicles (LVs), i.e. cars and vans, cannot be compatible with catenary systems because of the height of their power cables, which are geared to serving HGVs and buses and coaches.

Having different types of energy collectors on a vehicle is possible and already the case today in hybrid vehicles and even in fully electric vehicles, which are equipped with AC and DC ports and an associated DC/DC converter and an AC/DC on-board charger.

3.2.3. ERS Solutions Compatibility with Different Types of Vehicles

Another important aspect of inter-operability is the possibility for a given ERS infrastructure to be used by as many different categories of vehicles as possible. It is desirable that the infrastructure built can benefit the largest number of road users, in order to facilitate the amortisation of the heavy investments and to maximise the decarbonisation potential.

The main interest of the ERS is to decarbonise long-distance road freight transport as short-distance goods deliveries can be managed with full electric vehicles. This obviously concerns heavy-duty trucks where the battery size can be significantly reduced with ERS. But highways are also used for long-distance trips by other categories of vehicles: smaller trucks, coaches, light vehicles and even cars. The importance of this type of inter-operability between vehicle types has been studied in France (DGITM, 2021a) and in Sweden (Chalmers University of Technology, 2019) and by Márquez-Fernández et al, 2017.

With their present design and performances, not all ERS solutions would be able to be used efficiently by all categories of vehicles:

- Catenary systems: semi-trailers above 26 tonnes and buses and coaches,
- Ground Rail solutions: all vehicle types, and
- Inductive systems: potentially all categories of vehicles but inductive systems will need to demonstrate their ability to deliver the high levels of power required by HGVs.

3.2.4. Inter-operability Between ERS Solutions of the Same Technology Family

Each ERS technical solution has been designed with different interfaces between the infrastructure and the power collectors. To achieve inter-operability between the conductive solutions (catenary and rail) or between the Ground Rail systems could lead to the duplication of the on-board ERS equipment and drive up the vehicle costs.

3.3. STANDARDISATION

Electric road systems are new and still under development with some demonstrations and first pilot projects for the most advanced technologies. For this reason, ERS are not yet standardised, but this step will become essential for large-scale deployment.

Standardisation will be necessary, as for any system, to contribute to product safety and reliability, environmental performance and to facilitate public procurement. It will also be essential for inter-operability and compatibility with other surrounding systems. Standardisation will also contribute to the competitiveness of technologies and the development of components by different suppliers.

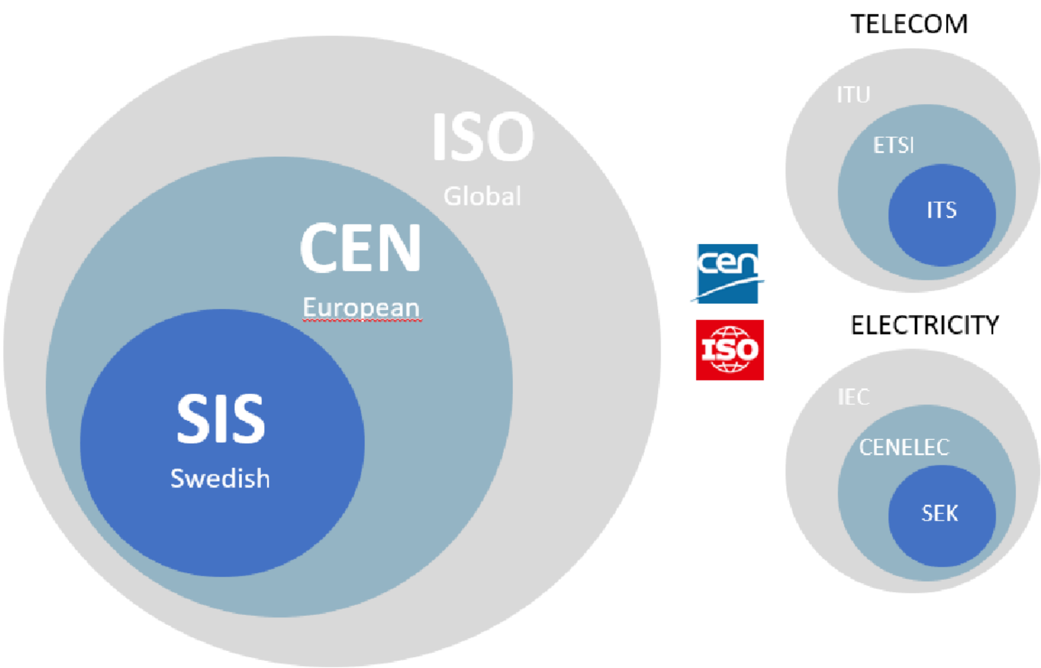
A difficulty for this ERS work is that it mixes different domains with different standardisation references: power supply system, civil works, road construction, road operation, vehicles, billing system, etc.

3.3.1. Standard Organisation and Standards Application

Standards can be developed at different levels, country, region/continent or global. Global standards are developed within ISO (International Organisation for Standardisation), IEC (International Electrotechnical Commission) for the electrotechnical area or ITU (International Telecommunication Union) for the telecommunications area. A corresponding organisation can be found at low level, and using the example of Sweden, the relationship between standards is shown in the following Figure 10 below.

Global standards are by definition voluntary to apply. For the European countries, the European standards (EN) have a preference over the global standards, and once adopted, it is mandatory to implement in the national standard in each EU country.

Figure 10: Global, European and Swedish Standard Organisations



Source: RISE, 2021.

3.3.2. ERS Standardisation Status

ERS standardisation is still at an early phase, but some draft standards are under way. The standardisation strategy is different according to the ERS solutions.

3.3.2.1. Inductive solutions

On inductive solutions, the on-going works at IEC level with dynamic transfer are:

- IEC 63243 - Dynamic electric vehicle wireless power transfer systems,
- ISO/AWI 5474-6 - Electrically propelled road vehicles — Inter-operability and safety of dynamic wireless power transfer (DWPT) for electric vehicles,
- SAE J2954-3 Dynamic Wireless Power Transfer (DWPT) for Electric Vehicles,
- IEC 61980-1 Edition 2.0 2020-11: Electric vehicle wireless power transfer (WPT) systems - Part 1: General requirements,
- IEC 61980-3 Edition 1.0 2022-11: Electric vehicle wireless power transfer (WPT) systems - Part 3: Specific requirements for magnetic field wireless power transfer systems,
- IEC 61980-4 (under development): Electric vehicle wireless power transfer (WPT) systems - Part 4: Interoperability and safety of high-power power transfer (H-WPT) for electric vehicles,
- SAE J2954 AUG2022 : Wireless Power Transfer for Light-Duty Plug-in/Electric Vehicles and Alignment Methodology,
- ISO 5474-4 (Light-Duty EV, under development): Electrically propelled road vehicles — Functional requirements and safety requirements for power transfer — Part 4: Magnetic field wireless power transfer — Safety and interoperability requirements
- ISO 5474-6 (Heavy-Duty EV, under development) : Electrically propelled road vehicles — Interoperability and safety of dynamic wireless power transfer (D-WPT) for electric vehicles,

- IEC 61980-5 (under development) : Electric vehicle wireless power transfer (WPT) systems - Part 5: Interoperability and safety of dynamic wireless power transfer (D-WPT) for electric vehicles,
- ISO 5474-4 (Will be changed to Light-Duty EV static+dynamic, under development) : Electrically propelled road vehicles — Functional requirements and safety requirements for power transfer — Part 4: Magnetic field wireless power transfer — Safety and interoperability requirements,
- ISO 5474-6 (Will be changed to Heavy-Duty EV static+dynamic, under development) : Electrically propelled road vehicles — Interoperability and safety of dynamic wireless power transfer (D-WPT) for electric vehicles,
- ISO 19363 2020-04 : Electrically propelled road vehicles — Magnetic field wireless power transfer — Safety and interoperability requirements,
- ISO 5474-4 (Will be changed to Light-Duty EV static+dynamic, under development) : Electrically propelled road vehicles — Functional requirements and safety requirements for power transfer — Part 4: Magnetic field wireless power transfer — Safety and interoperability requirements, and
- ISO 5474-6 (Will be changed to Heavy-Duty EV static+dynamic, under development) : Electrically propelled road vehicles — Interoperability and safety of dynamic wireless power transfer (D-WPT) for electric vehicles.

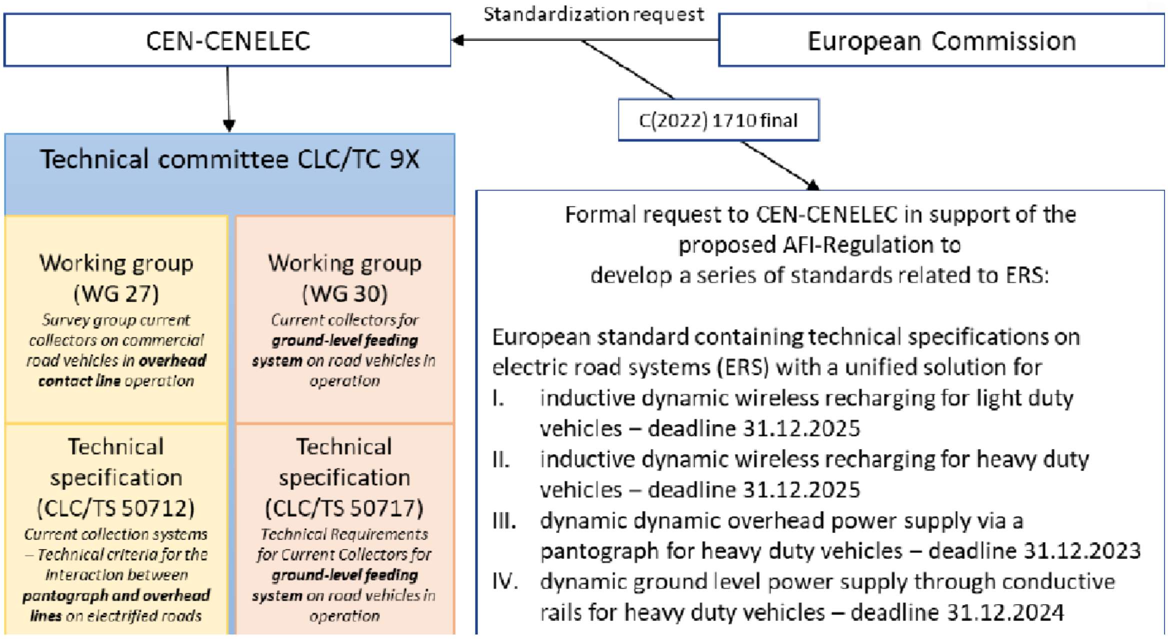
3.3.2.2. Catenary and Ground Rail solutions

The standardisation of the conductive solutions, excluding the Lateral Rail systems, is mainly under way in Europe where European standards (EN) have a preference over the global standards. Since 2020, in CEN/CENELEC (CLC), the Technical Committee 9X (TC9X) has been working on ERS standardisation in two working groups:

- CLC/TC 9X/WG 27 – Current collection systems – Technical criteria for the interaction between pantograph and overhead contact lines on electrified roads, and
- CLC/TC 9X/WG 30 – Current collectors for ground-level feeding system on road vehicles in operation.

The following schematic illustration as shown in Figure 11 summarises the on-going and future works .

Figure 11: Schematic Illustration of Activities on Standardisation of ERS at CEN-CENELEC



Source: CollERS, 2022.

A first technical specification, CLC/TS 50717, has been fully approved in September 2022.

3.3.2.3. Lateral Rail solutions

For the ERS concept developed by Honda with a roadside feeding system, a new work item has been submitted in ISO/TC 268/SC 2/WG 2.

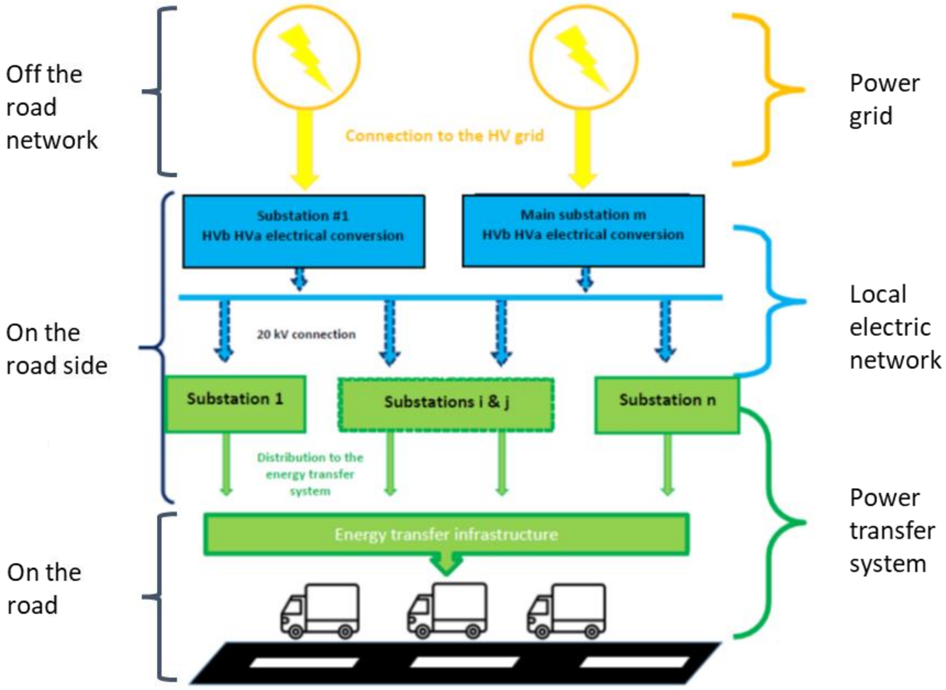
3.4. Cost Analysis

In the literature reviewed, some data about ERS costs were identified, but they were found to vary enormously depending on the documents, the scope covered and their date of distribution. This means a simple cost presentation summarising the ERS capital costs by technology could be very misleading and could lead to inappropriate decision making.

To be able to compare costs between different technical solutions, the first step is to define the scope of application: equipment and activities covered, the number of vehicles per kilometre to be powered and the total power required per kilometre.

Figure 12 shows a schematic diagram for an ERS infrastructure.

Figure 12: Schematic Diagram of an ERS Infrastructure



Source: TF2.2 ERS.

Independent of the ERS technical solutions, to cost this infrastructure means costing both the supply and the installation of the following equipment:

- High voltage poles and cables (from the grid or the electricity generation plants),
- High voltage – Medium voltage power substations,
- Medium voltage poles and cables from High voltage - Medium voltage power substations,
- Medium voltage power substations,
- Medium voltage cables between Medium voltage power substations,
- All ERS equipment, from medium-voltage electrical substations to those enabling energy to be transferred to vehicles (at road level), and
- An ERS Control Centre.

To determine ERS cost for a motorway network, there is a need to establish the key drivers that have a major impact on costs. These are:

- The number of ERS vehicles to be taken into account per km, which impacts the cost of medium-voltage electrical substations: a 5MW substation required for a configuration catering to 14 trucks per km is more than one million euros more expensive than a 0.8MW substation required for a configuration for only 2 lorries per km,
- The distances between grid connections or the electricity generation plants to the electric road, and
- The energy transfer capacity of the ERS technology chosen, which has an impact on the percentage of the road network to be equipped - this can vary the cost for the entire road network by at least a factor of 1 to 2.

The French Study (DGITM, 2021a) attempted to do this in 2021. It reported a total cost of between 30 and 35 billion euros to equip a network of 9,000 km of motorways in France. It is understood that due to the lack of time and data, the study did not consider all the factors that need to be taken into account to produce a robust set of cost estimates. Nevertheless, these cost figures give a rough idea of the ERS costs for France and should be used with care.

In conclusion, it can be said that there is no single cost for each ERS technology. It depends on a large number of related factors, such as the configuration of the electricity network, traffic flows and the performance of the technical solutions. There is significant uncertainty with respect to ERS costing. The level of maturity and stability of the technical solutions as well as the knowledge of their mass production costs will also be important factors for better cost estimate for a large-scale ERS deployment.

3.5. Impact Analysis

3.5.1. Environmental impact

3.5.1.1. Landscape

The landscape can be described in terms of landforms, topography, reliefs, geological direction, rock types, soil types and hydrology. The openness of the landscape is an important part of the description as well as the type and density of the vegetation. When discussing what impact a certain change to or an additional infrastructure might have on the landscape it is also important to consider general movement patterns of people and animals, significant landmarks or cultural memories or the history of the area. A catenary system would cause a fragmentation of the landscape, especially in open areas.

When discussing ERS and their impact on the surrounding landscape it is important to include all parts of the electric road, hence all roadside equipment needed. The impact that electric roads would have on the landscape would depend on the type of technologies as well as on the number and the appearance of substations. The catenary technology would obviously affect the skyline of a landscape while the ground based technologies would be barely visible a short distance from the road.

3.5.1.2. Visual/aesthetic impact

The densely spaced poles that hold the catenary cables will cause a visual impact of the landscape. The rail solutions on the road will also be visual. Since any aesthetic impact lies in the eye of the beholder, some people might like the ERS road to light up, where green lights indicate that the road is ready to charge, while others would rather prefer an inductive system which is not visual at all. For countries, which currently do not have continuous roadside safety barriers, the catenary and lateral rail systems' new roadside barriers along the verge of the road might cause a confined feeling when driving. Safety guardrails are not needed for the ground rail and inductive ERS since there are no obstacles at the roadside area as long as switching boxes and transformer stations (sub stations) are placed outside of the 10 m safety zone, or adequately protected.

3.5.1.3. Potential nuisances such as noise

It is often mentioned that noise from an electric vehicle is much less than noise from a combustion engine. However, at speeds above 30 km/h the rolling noise from tyres will be louder than the noise from the combustion engine for cars and at 50 km/h for trucks. With ERS there could potentially arise other kinds of noise, such as during arcing or when current collectors are sliding along the rail. This aspect does not concern an inductive ERS. Transmitting stations might have a specific sound as well. However, except at very low speeds, any noise from catenary or rail ERS will likely be drowned out by noise from the rolling tyres and/or subsystems on board, such as compressors, fans etc.

3.5.1.4. Electromagnetic

It is difficult to understand which electromagnetic impact ERS might have on people, technical devices, radio communications, animals and plants. Several studies indicate that electromagnetic fields (EMF)might affect animals in different ways, but which kind of electromagnetic fields that can be expected from ERS has been difficult to measure. There are various parts of the system that might emit electromagnetic radiation at different times. One component to consider is the EMF produced while the vehicle is charging from the road, others are connected to different components in the vehicles and furthermore other spectra of EMF are produced in the case of arcing from the system. To be able to measure various spectra of the EMF at a distance from a road, which could impact people and/or animals in the surroundings of an electric road, will be difficult since the devices for measuring the EMF are often placed at a fixed spot at a certain distance from the object. To be able to register the emitted EMF at exactly the right interval both in terms of where the arcing will appear as well as within the correct EMF interval is tricky to accomplish. Measurements should preferably be performed attached to the vehicle or riding alongside at the same speed.

It should be noted that all conductive ERS, i.e. catenary and rail systems, have very much in common with the supply to railways and trolleybuses, all of which has been in use for up to a century.

3.5.1.5. Particles

Airborne particles are often mentioned in terms of their size, where the most common are denoted as PM (particulate matter), such as PM 10 is 10 µm and PM 2.5 is 2.5 µm. As a result of the introduction of particulate filters in diesel cars the exhaust emissions have been much reduced. Instead non-exhaust related particles represent 90% of all emissions from the road and traffic related emissions. Such non-exhaust particles can for instance be dust from wear of studded tyres, train and rail bound traffic, dust from maintenance operations and construction etc.

With catenary and rail ERS, particles might come from the contact between current collector and ERS. To date there have been too few studies on the impact of particles, but it will very much depend on materials used and their wear characteristics. Again, the inductive technology will not produce any particle pollution unlike the other technologies since there is no physical contact between the moving parts. Further studies are needed to fully comprehend the amount and types of particles to expect.

3.5.1.6. Use of materials

The amount of materials used varies by type of ERS. It is possible to say that all technologies will need the same amount of cabling to get to the substations from the grid, but from there and to a fully deployed ERS there are large differences. In the case of the catenary systems there are substantial wiring and cables running between the poles. Moreover, the poles are huge and include robust foundations beneath the surface. In addition, the safety rails will be another issue that will vary from other ERS technologies. It should be recognised that inductive systems will use significantly more copper (for the embedded coils) than the other types of ERS.

It is common to use life cycle assessment (LCA) methods to assess the environmental impact of a product or technology. Such methods are usually very comprehensive and predicated upon the evaluation of the product/technology from production to its end of life. There are several LCA studies that attempt to compare the material use of the catenary system with those of railways and even trolleybuses. But the catenary technology from Siemens seems to be more robust than those of railways and trolleybuses. The current Siemens' catenary system is predicated upon a more robust construction method, involving bigger and materially denser poles as well as more sturdy safety barriers around the poles to mitigate against vehicles driving into such poles in case of an accident. As a result of ERS being so new to the market there are very few LCAs made on ERS and those that are done have used existing information regarding railways and trams (Nordin, 2020). Before any conclusions can be drawn regarding the lifecycle impact that ERS might have, further studies are needed on material use, maintenance and operations as well as the impact that various ERS will have on road and road construction.

3.5.2. ERS Impacts on the Road

The analysis conducted here focuses on the installation, operation and maintenance aspects of pavements equipped with ERS devices.

3.5.2.1. Inductive solutions

Inductive solutions employ transmitting coils placed in the pavement at a shallow depth (about 10 cm). Although inductive technology demonstration tests to date have been satisfactory, it should be noted they are predicated upon low traffic flow and low power transmission level, which is insufficient to drive fully loaded HGVs and definitely unable to simultaneously charge their reserve batteries. In real life applications, daily traffic flow levels can be expected to be many quanta of the traffic flows tested. For example, in 2019 (pre-Covid), a typical stretch of the English motorways carried an AADT (annual average daily traffic) of 89,200 vehicles per day and HGV traffic typically accounted for about 15% of total traffic (DfT, 2020). Also, for inductive systems to drive and charge HGVs in motion, the power transmission level will need to increase by several times of those tested to date. Hence, until high traffic and high-power transmission data are available, it would be prudent to bear in mind the following three points as highlighted below:

Impact of the heating of the coils during their operation at high power to supply the vehicles: there is a need to measure the rise in temperature and evaluate its impact on the bituminous layers of the pavement. It will be necessary to determine the impact on both the characteristics of the bitumen and the deformations of the asphalt rutting, particularly in summer period,

Impact of the presence of shallow embedded emitting coils on the integrity of the pavement and therefore its durability: a pavement is, in fact, a multi-layer complex, which finds its resistance in the perfect bonding of all the elements. As soon as two layers are poorly bonded together, the mechanical resistance is strongly altered. This is also true in the event of the presence of "foreign bodies" in the pavement, thus interrupting its continuity. By way of illustration, we can mention a device sometimes inserted in pavements to improve their mechanical performance, which, in the end, can weaken them when it alters the overall cohesion. There are anti-cracking devices: to prevent pavement cracking, it has been considered to place geosynthetics or geogrids between the pavement layers. While the idea seems theoretically relevant, it has been found to be difficult to get the top layer of pavement to hold above this device, and

Another point of vigilance is the construction and backfilling of the trenches for feeding the coils from the trackside. The choice of materials and the geometry of the trenches must be made in such a way as not to create a mechanical weakness or to encourage the appearance of disorders during the life of the pavement.

In summary, recent inductive tests with low traffic flows and low power transmission levels have been satisfactory. Nevertheless, until further tests, with real life traffic levels that vary significantly more than tested flows and with considerably higher power transmission levels capable of driving and charging HGVs in motion, are carried out and their outcomes known, it would be prudent to bear in mind that the mechanical strength of the pavement could be greatly affected by the insertion of the inductive coils, power boxes and cables. This point must be checked with bituminous pavements and with hydraulic concrete pavements and a choice of materials and structure must be made. Further tests with traffic resembling real life situations will be particularly helpful to validate or otherwise the above concerns.

3.5.2.2. Ground Rail solutions

Although the potential impact can be expected to be lower than that of the inductive system, the same questions are relevant for the ground rail in pavement ERS. This is because the trenches for the power rail are shallow and the top side of the rail is exposed to the elements, which allows any heat generated to dissipate. Nevertheless, this expected lower impact will also need to be verified.

In addition to these issues, there are other concerns:

The impact of the presence of a central rail in terms of discontinuity of the pavement surface and therefore of skid resistance. This characteristic will be a major verification point to validate or not the technology. The subject of skid resistance is essential to ensure the safety of users, in particular, that of two-wheelers,

The impact of the sealing of the central rail and the necessary consideration of the effectiveness of the sealing products. The penetration of water at the rail would have a disastrous impact on the mechanical durability and therefore the durability of the pavement. This function must be assured over time,

The subject of maintenance of the wearing course with a central rail must be carefully considered. Should the rail be removed to repair the surface course? What will be the impact in terms of maintenance costs? Or should the rail be maintained and the pavement work be carried out on both sides of the rail? One point of vigilance will be to respect the rules of the art in terms of laying the asphalt, particularly with regard to compaction, and

The presence of the longitudinal discontinuity of the pavement due to the insertion of the electrified element could modify the drainage capacity of the pavement, especially creating possible and dangerous water stagnation. In addition, the presence of the longitudinal rail can create a discontinuity step on the pavement surface for different thermal expansion resulting in danger. In some nations, such as Italy, the insertion of longitudinal elements into the road surface is prohibited.

3.5.2.3. Catenary and Lateral Rail solutions

As for the catenary and lateral rail solutions, it is considered that they do not affect the integrity of the pavement and therefore present an advantage from the point of view of pavement construction and maintenance. They are therefore easier to install. This is indeed also the case for lateral rail solutions with a roadside feeder rail and catenary solutions with overhead cables. However, in the presence of overhead cables, the renovation of the pavement could need specialised equipment, as the conventional equipment requires a significant clearance height, particularly for the evolution of trucks with lifted skips. It is claimed that conventional maintenance equipment continues to be used for catenary systems in Germany.

3.5.3. Mutual Impacts between ERS and Other Technologies

3.5.3.1. How other technologies could impact ERS

Battery evolutions

The limits of today's large embedded batteries for long haul road transport (i.e. large environmental footprint from their production, reduction of payload, increase of standstill charging times, limited range) create an opportunity to seek better solutions like ERS. But the battery industry is moving fast with active research and development investments. Disruptive evolutions in battery materials and architecture, energy densities, charging times, or costs are potentially underway and could provide new solutions to the current limitations of large batteries. For example:

Nickel and cobalt free batteries (e.g. Lithium Iron Phosphate batteries) could alleviate the need for these critical materials, and hence limit the negative environmental impacts of large batteries, and

Lithium-sulphur, lithium-air or solid-state batteries could provide higher energy densities and better charging rates, hence improving payload and charging times, the two main operational downsides of large battery trucks.

However, the improvements in battery performance have not reduced the potential of ERS to provide the energy required for electric mobility on the infrastructure and limit the size of battery embedded in the vehicles. To limit the footprint of electric trucks, both of the approaches should actually be combined: reduction of battery size and improvement of battery performance.

Green hydrogen

Green hydrogen, used either in combustion engines or through fuel cells to power electric motors, could provide another carbon neutral solution for long-haul trucks. However, we need to keep in mind that fuel-cell trucks are electric vehicles, thus they could be compatible with ERS infrastructure and hence both approaches should not be opposed as they could complement each other.

Combustion engines using green hydrogen have clear environmental benefits - no particulate matter (PM) or CO_2 emissions. Presently green hydrogen is unavailable in significant quantities and therefore expensive. However, should their availability increase and prices fall significantly hydrogen could theoretically challenge ERS. Experts agree, however, that chances for this are slim, due to the inherent inefficiency of hydrogen production, the high cost of its distribution system towards refuelling stations, and the high demand of green hydrogen to replace current grey hydrogen uses. Hence, hydrogen should be considered as a long-term net zero road transport solution.

Electric charging network

The deployment of static chargers for light-duty or heavy-duty vehicles requires bringing power connections along the highway network. This energy backbone could be leveraged to connect an ERS infrastructure distributed along the highways. Associated investments could be used by both charging approaches.

3.5.3.2. How ERS could impact other technologies

Implementing an ERS system in a roadway could lead to 3 types of benefits for other applications:

Data required by ERS systems could be used by other systems. For example, the lateral position of the vehicle, measured and controlled in ERS systems because it affects the energy transfer efficiency, could also be used for vehicle guidance and trajectory assessment systems of autonomous vehicles,

The connection between the vehicles and the road infrastructure within an ERS could be leveraged to transmit other types of data required by other applications. For example, this connection, whether a physical or wireless one, has the potential to be leveraged to transmit safety related data and traffic information as an alternative to C-ITS V2X communication protocols, and

Roadwork required by the installation of ERS could represent an opportunity to install other equipment. During the installation of the ERS, whether involving the “opening up” of the pavement with a continuous longitudinal trench and lateral trenches connecting the ERS to roadside electric management units or building the catenary system along the roadside, temporary highway lane closure will be required. This could be a unique opportunity to simultaneously install other sensors or roadway equipment (e.g. power and data network cables and traffic sensors).

3.5.4. Potential Evolutions of the ERS Technologies

3.5.4.1. Evolutions of ERS technologies

Like any systems in their early development stages, ERS will evolve over time based on feedback collected from the first implemented sites. The first ERS systems deployed have been focusing on improving their respective shortcomings, for example:

- Inductive systems have been continuously working on improving their charging powers per coil unit,
- Conductive rail systems have been working on improving adherence challenges, and
- Catenary systems have been working on improving contact strip wearing properties and pantograph architecture.

Evolutions of ERS based on other constraints, such as the costs of some raw materials used (e.g. copper for inductive systems) could also be expected, even if they are hard to predict.

Overall, ERS costs per vehicle and per km of road equipped can be expected to fall as deployments of ERS scale up massively.

3.6. Engineering Performance Quantification

To identify if ERS are the most beneficial solutions for the road transportation to reduce the GHG emissions and to select among the different solutions, the following questions need to be answered:

What is the GHG emissions reduction provided by the ERS compared to the current situation for road freight vehicles?

What are the savings in terms of on-board batteries compared to BEVs?

What are the value-added effects if light commercial vehicles and passenger cars also use the ERS network?

What are the parameters which affect the road network proportion to be equipped with ERS system?

3.6.1. CO_2 and Other GHG Emissions Reduction for ERS Trucks

The French Study Report (DGITM, 2021a) shows that combined with the total electrification of intra-regional transport, an ERS network of 9,000km of the French highways (less than 1% of the national road network) would save 33 $MtCO_2eq$/year for HGVs, i.e. 87% of the emissions of a "diesel as usual" scenario, and 60 $MtCO_2eq$/year (-86%) if including LCVs, thus leading to an almost total electrification of road transport.

Another report provided by the Research & Innovation Platform for Electric Road Systems in Sweden (RISE, 2021) shows that a steep reduction in CO_2 emissions could be gained by implementing ERS on between 20% and 40% of the E-road and N-road network in Sweden. The higher 40% ERS coverage could yield CO_2 emissions savings of 40% and 70% of the total emissions from light vehicles and heavy vehicles in Sweden, respectively.

In Germany in June 2020, the National Platform for Mobility of the Future, the main policy advisory body of the transport ministry, recommended 4,000km (less than 2% of the national road network) of highways be equipped with ERS by 2030, in order to secure reaching 40% reduction in transport CO_2.

3.6.2. Battery and Cost Saving on ERS Trucks Compared to BEV

In order to compare also the ERS system to the “full-battery” electric trucks (BETs), it is important to note that, as per the French ERS WG1 report (DGITM, 2021a), the required autonomy for heavy goods vehicles with the ERS is reduced to 250km compared with long-haul BETs of 750km. The associated battery capacity would then be reduced from 1,200kWh for a BET to around 350kWh for an ERS truck. With a future battery cost estimated 100€/kWh, the on-board battery saving would be 80,000€/truck. Even taking into account the price of the ERS infrastructure, the total saving in France would be 4,250M€/year.

With regard to battery CO_2 footprint, considering a value of 70kg CO_2eq/kWh for the lifetime of the battery (conservative value for 2030), the associated saving is 17$MtCO_2eq$/year.

3.6.3. Impacts of Light Duty and Intermediate Vehicles on GHG Emissions Reduction, Battery Saving, Business Case

In the previous sections, only the road freight vehicles were considered to define the savings associated to the ERS system, but if passenger cars and Light Duty Vehicles could also be compatible with the ERS system:

- the additional savings in terms of greenhouse gas emissions in France would be at least 4$MtCO_2eq$/year (DGTIM, 2021a),
- Dominguez (2018) has shown that a reduction of 80% (cars) and 70% (trucks) of the ESS size when introducing ERS could lead to a reduction of the combined cost of on-board batteries

and fast charging stations by 50%. In Sweden, that corresponds to a reduction of the CO_2 emissions[1] from battery manufacturing of about 25 $MtCO_2$ to be distributed over an estimated battery lifetime, and

- Similar results for Denmark have also been presented by Dominguez (2017).

However, to make passenger cars as well as Light Duty Vehicles compatible with the ERS system, the catenary solution needs to be disregarded as this solution is only compatible with heavy goods vehicles and buses and coaches.

3.6.4. Proportion of Road Network to Electrify

Establishing an optimal proportion of the road network to be equipped with ERS is a very complex exercise. The calculation for a given ERS corridor must be done taking into account a lot of factors, such as:

the use case of the corridor and the size of the batteries,

the power transfer performances of the selected ERS solution, and

the requirements or needs in terms of batteries recharging while driving.

3.6.4.1. Impact of the corridor use case

For a corridor used by a captive fleet of ERS trucks only driving back and forth on it, the percentage of road to be equipped can be optimised. For example, limited to 33%, if using an ERS solution capable of delivering 400kW by vehicle based on an average consumption of 129kW for a fully loaded truck driving at 90kph. This percentage could be reduced if we accept to discharge the batteries during the day and are recharged during the night. In this last case it will be linked to the battery capacity embarked.

3.6.4.2. Impact of the power transfer performances of the selected ERS solution

In the previous case, we have seen that the percentage of roads to be electrified can be limited to 33% when using an ERS solution delivering 400kW. However, with an ERS solution which is unable to transfer power of more than 100kW, i.e. less than the average consumption of a fully loaded truck, the batteries will be discharging while driving, even if the entire length of the road is electrified. As such, the vehicle will need to be recharged at a static charging station to top up the batteries.

3.6.4.3. Impact of the requirements or needs in terms of batteries recharging while driving

Even if the freight transport is done primarily on the main roads that can be electrified, the start or the end of the trip can be far away from the ERS network. For this reason, the trucks will still need a battery to manage the distances driven beyond the ERS network. One advantage of the electric roads is the ability to recharge the batteries while driving, i.e. without the need to stop for battery recharging. Thus, we would need a sufficiently high linear percentage of electrified roads to be sure that the batteries will be full when leaving the ERS network. The French ERS Study (DGITM, 2021a) assumed that that the ERS trucks would need to have reserve power to allow the vehicles to drive up to 250 km outside the ERS network. With this assumption trucks will be able to reach any point within France. It examined two levels of ERS network coverage (percentage of electrified kilometres

[1] Assuming 440 million kWh battery capacity in a full EV fleet of cars and trucks.

in relation to the total length of the road): 1) 50% and 2) 80%. For the 50% network coverage the ERS power transfer capability will need to be 510kW. Whereas with 80% network coverage the power transfer capability can be reduced to 350kW. Since the publication of the study report these network coverage and power transfer assumptions have been debated by the French ERS stakeholders. A Dutch study (Decisio, 2022) assumed ERS vehicles only need reserve power of as little as 60 km as the Netherlands is so much smaller than France in terms of area.

Other parameters may also impact the proportion of road network to be electrified, such as the number of vehicles that can use the ERS system simultaneously at full power transfer.

3.7. Safety Aspects Analysis

The safety aspects analysis of ERS technical solutions is based on the identification of safety hazards caused by integration of ERS solution on road infrastructure and its environment, including road users, maintenance workers, and emergency rescuers.

The deployment of electric road systems will only be allowed if it does not create new risks for road users. For safety, as for other items, every ERS technical solution has some drawbacks.

Therefore, ERS providers will have to find mitigation solutions to address the potential risks listed in Table 1 below and they will have to validate them with the competent authorities.

Table 1: Safety Concerns of ERS Technologies

Safety Aspects	Technical Solutions/ERS Suppliers					
	Catenary	Inductive	Rail			
	Siemens	All	Alstom	Elonroad	Evias	Honda
Electrocution risk inside the vehicle	X		X	X	X	X
Electrocution risk on or from the road	X		X	X	X	X
Increased risk exposure for motorcyclists due to additional safety side barriers	X					X
Increased risk exposure for road users due to grip variations with the ERS infrastructure surface			X	X	X	
Risks due to electromagnetic fields for road users or nearby residents		X				
Road accident risk due to ERS elements falling or loosening (from the vehicle)	X	X	X	X	X	X
Road accident risk of transit of over-sized vehicles	X					
Emergency access limitation (evacuation) due to additional safety side barriers	X					X

Source: TF2.2 ERS.

3.8. Maintenance Aspects

Issues related to the impact of ERS on the maintenance of existing road infrastructure and new electric road infrastructure were considered, with the views of operators taken using a limited survey. Consideration was given to catenary, rail and inductive systems. The following observations were made:

All electric road systems will in their own way impact on the currently established maintenance activities of the existing highway assets. Nevertheless, the infrastructure adjacent to and/or on the central reservation / median is most unlikely to be affected,

Broadly, inductive systems, being embedded under the pavement, when functioning, will likely have the least implication on the business as usual (BAU) routine and winter maintenance activities. However, they will likely have their system specific implication on periodic maintenance and critically were an embedded coil to fail prematurely, pavement digging would need to be involved to reach the failed part. Catenary systems will pose their specific challenges to routine and periodic maintenance whereas rail systems will cause their system-related impacts to winter and periodic maintenance,

On routine maintenance the poles and, for countries where continuous roadside safety barriers are currently not used, new continuous safety barriers of catenary systems may act as an impediment to the current established maintenance practice. Unlike Germany which has continuous safety barriers, a modified routine maintenance procedure could be required and this could be more time consuming and costly to execute,

The established routine maintenance procedure for the existing highway assets can be expected to continue for the rail and inductive systems,

On periodic maintenance the different ERS systems will likely bring different challenges. The overhead cables of catenary systems could be a height impediment to the maintenance of the road surface of the ERS lane(s), i.e. lane 1 and possibly lane 2, and the shoulder. This could mean that existing plant, such as pavers and raised tipper trucks, could not be used and new alternatives would need to be purchased. It is claimed that this is not an issue in Germany,

Ground rail and inductive systems are likely to have a similar level of impact on the periodic maintenance of the pavement. For both systems it is unclear whether it would be possible to retain the embedded inductive and ground rail systems when planing out the ERS lane(s) during resurfacing activities. To retain the rail or the embedded coil will likely require more exacting and time consuming resurfacing actions, possibly leading to higher cost. Should the rail or coil system need to be replaced as part of replacing the road surface that will be very costly,

Electric road systems are likely to have an impact on winter maintenance activities. Where snow clearance is an issue, catenary and lateral rail systems may be an impediment to removing snow to the verge. In the case of the ground rail systems, which include a slot rail, grit and salt may gather in the slot and, as is common practice, a rubber nosed plough would be required to clear snow. However, for ground rail on pavement systems, a different and possibly more time consuming and costly snow clearing process may be required. Inductive systems are unlikely to impede typical winter maintenance activities, It should also be highlighted for ground rail systems with a slot rail and retrospectively installed inductive systems, water damage to road pavement could be an additional challenge, leading to additional maintenance.

Electric road systems introduce additional hazards (particularly a high voltage system to the road) that are likely to change the manner in which roads are maintained or add additional steps into the maintenance of existing highway infrastructure to ensure the safety of operatives, and

Incident support would need to contend with additional hazards on highways with ERS when attending incidents, particularly the potential for energised high voltage systems with rail and catenary systems. This may impede responses where those systems are present, while it is confirmed the system is not live. New emergency response procedure will need to be developed. Inductive systems are likely to have the least impact on these issues.

In addition to impacting the maintenance of existing highway elements, electric road systems will also introduce new infrastructure that will require maintenance. The key issues are as follows:

- Electric road systems will introduce high voltage systems that road authorities currently do not have the expertise to maintain. This will require bringing in new skills and upskilling the current workforce to deal with these additional features. It will also require additional maintenance budget,
- If the electric road system is owned / maintained by a separate entity, conflicts may arise between the maintenance of the electric road systems and maintenance of the rest of the highways asset, with the ERS likely to take precedence,
- The ERS may affect performance indicators on which operators are measured, such as lane availability,
- All systems would need similar power distribution networks along the roadside,
- Catenary systems will introduce additional infrastructure, including the possibility of a continuous safety barrier along the entire length of the verge where ERS is present, poles at approximately every 50m and the associated arms and supports. This introduces additional maintenance liability,
- Apart from the power rails, rail systems may introduce other maintenance activities. Some rail systems are embedded on the surface, whereas others are housed in a slot which is drained from the bottom. This slot and drainage will need to be maintained and kept clear of debris,
- Inductive systems are likely to introduce the least additional maintenance, but their replacement cycle may have to coincide with the cycle for resurfacing the road for embedded systems, introducing additional costs and activities to the pavement resurfacing cycle,
- ERS may introduce additional winter maintenance activities, for example, the de-icing of wires or rails. The use of salt may also cause accelerated corrosion to elements of the ERS,
- Due to their nature it is likely that ERS are likely to require close monitoring and rapid response to issues that cause a loss of service, and
- Key to good asset management is high quality surveys. ERS will introduce additional infrastructure and hence bring additional survey requirements to understand the condition of the new ERS assets and plan for their maintenance. The different systems will have different survey requirements.

Currently, conclusions based on real life experience are hard to find due to limited experience of ERS and this experience is only being derived from pilot schemes. It is not clear at this stage whether new techniques will come forward as part of the development of ERS that will reduce some of the additional maintenance activities that will be required. Conclusions drawn are based on current maintenance techniques.

The consideration of the issues and the survey indicate that there are likely to be significant maintenance challenges to consider if introducing ERS, both to maintain the current highway, to undertake routine activities such and the management of incidents, and due to the new infrastructure the ERS system will introduce. This is likely to cause additional costs for the maintenance of the highways network in general and to maintain the ERS. These issues are likely to be more considerable for catenary systems due to the amount of new roadside infrastructure that would be introduced and, for countries where continuous roadside safety barriers are currently not used, their introduction could impede the maintenance of other assets along the verge. A lower impact for rail and even lower for inductive systems could be expected. Although water damage to road pavement could be a real concern for both the ground rail with slot rail systems and retrospectively installed inductive systems.

During the development of ERS careful consideration will need to be given to these issues to limit as much as possible the introduction of additional infrastructure and to ensure the maintenance of existing infrastructure can be undertaken as efficiently as possible.

3.9. Learnings and Best Practices

Until recently ERS were considered a black box or a new technology with underappreciated potential and contribution to achieving climate protection targets. This has changed by the year 2023. This positive transformation is due to various developments. The USA and South Korea started early ERS tests in the 2010s. More recently, Germany and Sweden have stepped up with demonstration projects, including on public roads. In parallel, different technological approaches have emerged that make it possible to charge vehicles while driving.

In particular, the ongoing tests with overhead cables in Germany, inductive approaches and conductive rail solutions in Sweden provide useful “lessons learned” and “best practices” due to the length of the test routes and the duration of the projects of up to four years. They form the basic framework for this section and are part of the use cases described in this report.

In addition to the information collected for the use cases, interviews have been conducted with almost all manufacturers of ERS technologies. In addition to general questions about the projects, such as the focus, the location or the technology used, the questions were divided into clusters: Road; Infrastructure; Energy, Consumption, Measurement and Payment; and Acceptance.

Furthermore, a questionnaire on technical details of the technologies and projects was sent to the interviewees to be able to query the technical specifications. The questionnaire can be found in Appendix D.2. The questions included descriptions of the technology and vehicles used, information on the power supply, electrical specifications and infrastructure. Interviews have been conducted with selected organisations as shown in Table 2 below.

The focus is on manufacturers of ERS technologies actively involved in tests, as well as a manufacturer that will soon start with a pilot line. Unfortunately, an interview with a supplier of inductive technology did not materialise at the time of the interviews, which were conducted in the summer of 2022. In this case, the exercise mainly draws on the findings from a test conducted in Sweden and the answers from the questionnaires.

The information from the questionnaires and the interviewees was recorded in Excel tables and was evaluated for further processing based on the requirements for lessons learned and best practices. Detailed information on the questions and on the different ERS technologies can be found in the Appendix C of this publication.

Table 2: Selected ERS Stakeholder Profiles

Institution	ERS Technology	Focus of work (institution)	Country
Alstom	Ground rail	French rolling stock manufacturer	France
Die Autobahn GmbH des Bundes	Catenary (eHighway) and Inductive trialled	Infrastructure operator	Germany
e-Netz Südhessen	Accompanying research	Grid operator	Germany
Electreon	Inductive	ERS technology provider	Israel
Elonroad	Ground rail	ERS technology provider	Sweden
EVIAS AB	Ground rail	ERS technology provider	Sweden
GDDKiA (General Directorate for National Roads and Motorways)	Undetermined	Polish national road authority	Poland
Honda	Lateral rail	Japanese vehicle manufacturer	Japan
Scania AB	Catenary (eHighway)	Swedish vehicle manufacturer	Sweden
Siemens Mobility GmbH	Catenary (eHighway)	German sustainable mobility manufacturer	Germany
Trafikverket	Three ERS technologies trialled	Swedish Transport Administration	Sweden
University of Applied Sciences Erfurt	Accompanying research	Traffic and transportation	Germany

Source: TF2.2 ERS.

3.9.1. Lessons Learned and Best Practices

The lessons learned and best practices for the different ERS technologies are explained below. At the time of writing (spring 2023) the technologies are still at different levels of maturity and are being tested on roads that range from non-public roads to busy highways. The vehicle types involved also vary between test sites and range from passenger cars and light commercial vehicles to heavy trucks and buses. The findings must therefore always be considered in the context of these aspects without calling into question their operational capability and contribution to achieving climate protection targets in the future.

3.9.1.1. Emission-free operation

ERS technologies can enable zero-emission vehicle operation when electricity from renewable sources is used.

The technical feasibility and suitability for everyday use are being investigated on various test roads. Several tests of a catenary system in Germany are currently underway. Hitherto, they are the most extensive, due to their route length (a total of 35 km both directions on three test routes), the number of vehicles (in 2023, 22 heavy trucks of different vintages and technical designs are being used) and their use in real operations by transport companies. The inductive system is being tested in Israel, the USA and various European countries, such as Germany, Italy and Sweden. Currently, the focus is on passenger cars, light commercial vehicles and public transport buses. It is claimed that this inductive system could power heavy trucks while driving. The ground rail systems (both in and on pavement technologies) are currently being tested primarily in Sweden. Aspects, such as the possible effects of cold, heat and wet weather conditions and the exclusion of danger to two-wheelers are being studied.

It has been shown that extensive tests on public roads are necessary to prove the suitability for everyday use. Involving the future users of such a technology can contribute to a higher acceptance. However, informing local residents and people driving on the test track also increases interest in the technology on the one hand and understanding of any restrictions that may occur on the other.

3.9.1.2. Infrastructure deployment

Currently the various tests on non-public and public roads have varying lengths, between 20 m (inductive) and 17 km (catenary). This is linked to different Technology Readiness Levels (TRLs) and the degrees of experience with rolling out the technologies, but also with the necessary preparatory and preliminary work.

Depending on the type of ERS to be deployed, shorter or longer lane closures are necessary. Due to the differences in the technologies and their currently diverging degrees of technological maturity, information on the duration of the roll-out and therefore the possible time extents of lane closures are not really comparable. In addition, preparatory work must also be included, for example, for the grid connection and the installation of substations, in order to obtain realistic estimates of the organisational and time expenditure. The current tests with the different technologies used do not allow for a comparison in principle, as the track lengths, the energy required and the number and type of vehicles used vary significantly.

Particular challenges along the routes, such as bridges, tunnels, tight curves, motorway junctions and more must also be taken into account during planning and construction. Initial experiences and solutions can be derived from the projects in Germany. France, among others, has announced that it wants to investigate some of the challenges for conductive technology on a test track in the Alps in 2024.

3.9.1.3. Road

Inductive and ground rail systems impact the road surface and the pavement. Some of the pavement damages that occurred during the tests could be reduced significantly in the future on the basis of the findings and further analysis. In some cases, further tests are necessary, e.g. to investigate the behaviour of the road surface and the pavement in very hot or extremely cold conditions. The catenary and lateral rail systems have no direct influence on the road surface and road the pavement.

3.9.1.4. Maintenance and repair

For all technologies, it can be concluded that there could be considerable influences on regular maintenance and repair work on the routes. In Germany, the segmentation of longer catenary sections into several subsections, which can be switched on and off independently of each other, allows selective maintenance and repair. Due to the embedded power transmitters under the road, inductive systems have no influence on maintenance and repair work. Occasional cleaning work may be required for rail solutions with slots. Usually, these solutions also include the possibility of switching off individual segments in order to enable maintenance and repair work on the road, if necessary. Actually, road accidents have not had any impacts on the different ERS technologies deployed on public roads. This confirms that all technologies can handle the traffic requirements.

On longer routes equipped with ERS, consideration should be given to informing users of planned work on the ERS infrastructure well in advance.

3.9.1.5. Safety

For the catenary systems, road owners can decide if additional protection is needed for the infrastructure in the area of the masts/poles. For the other ERS technologies, it was indicated that no additional safety measures are necessary. Rescue operations are possible but require adjustments to existing rescue concepts for the catenary system. The hazard prevention authorities must be involved in the planning on an ERS corridor at an early stage. The three tests in Germany have shown that a good information policy and training for emergency services can allay reservations and increase understanding of the technology.

3.9.1.6. Vehicle types

While inductive and rail systems could cover all vehicle types in the long term, catenary technology focuses on heavy trucks and buses. Currently, the TRL levels of the individual ERS technologies still vary, although significant leaps in development are expected in the next few years. Solutions should be discussed that may not immediately include all vehicle types but can make a timely and significant contribution to achieving climate protection goals in transport.

3.9.1.7. Battery sizes and resources

If ERS technologies are deployed at an appropriately widespread level, they can contribute to vehicles requiring smaller batteries and thus help conserve resources.

3.9.1.8. Measurement and payment

The ERS technologies offer different ways of identifying vehicles, using the ERS route and measuring energy consumption. In some cases, further business models are also being considered, which include the processing of billing.

Due to the existing toll system for trucks in Germany, consideration is being given to using the existing tolling on-board unit (OBU) system to measure energy consumption and possibly also to pay for the energy consumed. This means that users would not need to purchase and install additional devices. In addition, other European countries also have toll systems, which could well be part of the solution with a view to rolling out ERS in Europe. However, unless the existing OBU system is modified, it is not likely that the existing tolling OBU system can exactly measure the actual amount of electricity consumed but only to provide an estimate of the power used. In addition, however, it must also be noted that there are countries in Europe that have other operator models. For a European solution, approaches must be found in terms of simplification for users that enable inter-operability. For the use of ERS beyond Europe, the respective circumstances and requirements, such as toll collection or not, the structure of the road operators and the structure of the energy market input on site must also be taken into account for a customised solution.

3.9.2. Summary

ERS technologies are efficient and have the potential to contribute to the decarbonisation of the transport sector. Through the direct use of (green) electricity, ERS can reduce noise pollution and reduce greenhouse gas emissions, especially road freight transport.

Each of the ERS technologies has its merits and advantages. “Variations in TRL have been found for different subsystems within a single ERS-technology as well as comparing a single subsystem for several ERS-technologies” (Widegren et al, 2022). The lessons learned and best practices offer starting points for the different stakeholders to delve deeper into the respective fields of action. They point out the differences in the technologies, but also their specific advantages. It is also clear that there is still a need for further developments and finding solutions, such as measuring energy requirements and billing.

The results from this and other working groups on technical requirements make it clear that ERS can meet the requirements of road operators, users, OEMs as well as energy network operators.

4. STAKEHOLDERS, BUSINESS CASES AND BUSINESS MODELS

4.1. INTRODUCTION

This chapter reports on the analyses undertaken on ERS stakeholders, business cases and business models. ERS involves many stakeholders, from the road owner and OEMs to the users and non-users. The non-users are indirectly ERS stakeholders too because ERS, some systems more than others, generate externalities affecting non-users. The Task Force draws a clear distinction between business cases and business models. The former asks 'Why?' and relates to addressing the investment decision – why a community or a country should carry out a new initiative or project, in this particular case an ERS. Whereas the latter is to do with 'How?' - how to implement, operate and charge for the ERS services in an efficient and sustainable manner.

Following from this introductory section the next section describes the different ERS stakeholders and their relationships with each other. Section 4.3 explores the different types of business cases, the cost and benefit metrics and how these metrics are arranged into a business case accounting framework as well as offers guidance on the quantification and valuation of selected key metrics. The final section 4.4 highlights the range of business models and their potential applications.

4.2. STAKEHOLDERS

ERS technologies can contribute to the decarbonisation of transport. It should not be forgotten that numerous stakeholders are involved and need to be involved in the process of their development, testing and implementation. The individual stakeholders do not stand alone but are involved in a network of very different relationships with one another. In the following, an overview of the stakeholders, their relationships and their global distribution will provide an insight into the complex interrelationships that play an important role in the successful implementation of ERS.

4.2.1. Identification of Stakeholders

Stakeholders have a greater or lesser importance in the development and implementation of ERS. Furthermore, for the most part they are not involved in all process steps, but often play a temporary role. For example, users such as transport companies are usually not directly involved in the development of the necessary equipment for the vehicles. Or the owners of the roads are not involved in the development of the different ERS technologies. However, each of these stakeholders has a function so that the goal can be achieved in the end: to reduce greenhouse gas emissions in the transport sector in the long term.

Around 200 stakeholders have been identified from the use cases and the questionnaire, including ERS technology developers, OEMs, energy system stakeholders, road construction and operation experts, government institutions, users, residents along ERS routes and the press.

The ERS use cases and the institutions identified from the questionnaire are a good basis for obtaining an overview of the diverse stakeholders.

4.2.2. Stakeholder Types and Clusters

In a further step, the approximately 200 identified stakeholders were categorised into 38 types of stakeholders as presented in Table 3 below.

Table 3: Stakeholder Types

OEM	Energy supplier	Energy systems, technology solution provider	Energy operator	Charging, electrification equipment manufacturer
Electricity construction company	Telecommunication operator	Charging provider	ERS expert	Technology supplier / provider
Manufacturer wireless charging / electrification	Infrastructure constructor	Research institute	Research & Development	Public institution Funding source
Government	Federal administration	Public administration	Road manager	Highway / road operator
Road pavement contractor	Aviation, train manufacturer	Railway solution manufacturer	Public transport operator	Software solution provider
Consulting company	Engineering / construction company	Sustainability consultant	Race and test track operator	Concrete and bitumen supplier
Innovation agency	Clean tech company	Construction group	Shipping company	Transport company
Science / technology company	Small-medium enterprise	Other		

Source: TF2.2 ERS.

The stakeholder types were then grouped into six stakeholder clusters as displayed in Table 4 below.

It is clear that stakeholders directly involved in development, testing and implementation play an important role. In addition, governmental institutions as well as standardisation institutions should not be forgotten. In addition to the six clusters in Table 4 above, another group should be added: the stakeholders who are not direct users of ERS, i.e. non users. They are affected by the electrification of the road in many different ways. They include residents, employees of road maintenance depots, police and fire brigades, and the general public.

Table 4: Stakeholder Clusters

Cluster	Types of Stakeholders
OEM	OEM
Power supplier	Energy supplier, Energy systems and technology solution provider, Energy operator, Charging and electrification equipment manufacturer, Electricity construction company
ERS system supplier	Telecommunication operator, Charging provider, ERS expert, Technology supplier/provider, Manufacturer of wireless charging and electrification solutions, Infrastructure constructor, Research institute/R&D, Aviation-, train- and railway solution manufacturers, Software solution provider, Consulting company, Engineering and construction company, Sustainability consultant, Race and test track operator, Concrete and bitumen supplier, Clean tech company, Construction group, Small-medium enterprise
Government	Public institution Funding source, Government, Federal and public administrations, Innovation agency
Road operator, road owner	Road manager, Highway/road operator, Road pavement contractor, Construction group
User / freight operators	Public transport operator, Shipping and transport companies, Science and technology company

Source: TF2.2 ERS.

These stakeholder clusters, like the stakeholders themselves, are closely or less closely connected - thematically, temporally, and also as competitors. The next step is to clarify these connections and describe the stakeholder relationships that are particularly relevant for successful implementation.

4.2.3. Stakeholder Geography

Interest in ERS technologies has continued to grow in the years since the last PIARC report on ERS. This is shown not only by the number of use cases that could be investigated for this report, but also by the stakeholders reached by the questionnaire, which indicates that there is great interest in this form of road electrification.

In 2022, stakeholders were identified in the following countries:

- **Africa:** Nigeria,
- **Asia:** India, Japan, Malaysia and South Korea,
- **Europe:** Austria, Belgium, Finland, France, Germany, Great Britain, Greece, Italy, Netherlands, Spain and Sweden,
- **Middle East:** Dubai and Israel,
- **North America:** Canada and USA, and
- **Oceania:** New Zealand

The development stages range from an initial interest in the technology, through feasibility studies and initial test routes, to concrete involvement and planning of pilot routes. In Europe in particular, further development steps can be expected in the near future.

4.3. Business Cases

PIARC conducted an earlier investigation of ERS in 2018. This earlier investigation was principally focused on the technological options with ad hoc information on capital costs for the roadside infrastructure. It also included a rudimentary “business case” predicated upon an untypical but extremely busy section of motorway with annual average daily traffic (AADT) of 130,000 vehicles per day) in central England.

The literature review undertaken at the start of this Task Force’s work programme did not uncover any systematically presented ERS business cases. The review found ad hoc capital costs for various ERS technologies and some operating cost figures. However, a fully working ERS system is not just about the construction and operation of the ERS roadside infrastructure. There are many other ERS jigsaw pieces. There is the associated “back-office” system for billing users and supply-chain revenue allocation. Also the acquisition, ownership and use of the ERS compatible vehicles. Further it is accepted that ERS can impact the existing highway operation and maintenance costs, depending on the ERS technology.

4.3.1. Types of business cases

Broadly there are two types of business cases: 1) socio-economic and 2) financial.

A socio-economic business case examines an investment proposal from the societal perspective. In other words whether an investment would be beneficial for society as a whole. Thus, a socio-economic business case would include not just the financial costs, e.g. construction cost, and benefits, e.g. vehicle operating cost saving, but also the resulting externalities, such as reductions in greenhouse gas emissions. It would also exclude transfer payments, such as value added tax and tariff, as they are intra-payments between stakeholders without scarce resources being consumed.

A financial business case assesses the investment proposal from the investor perspective, i.e. whether the investment would and by how much pay back the investment cost. Thus it includes only the costs and benefits of the investor and users.

4.3.2. Business Case Metrics

Costs, e.g. construction and operating costs, form one side of the business case coin. The other side consists of a range of benefits. For example, the reduction in GHG emissions, assuming that the electricity to power the ERS will be from renewable sources. ERS vehicles have lower operating costs than ICE vehicles and, with smaller batteries than BEVs', they are cheaper to acquire than BEVs. Further some ERS technologies are more visually intrusive than others. Let us not forget ERS could reduce premature deaths due to lower air pollution, particularly NOX and particulates.

Section 4.2 highlights the many ERS stakeholders. This can be combined with the various likely ERS costs and benefits as shown in Table 5 below.

Table 5: ERS Costs and Benefits by Stakeholder

Item	Stakeholder	Cost	Benefit
1	OEM	Capital	
2	Power Supplier	Capital and Fuel – Electricity	
3	ERS Supplier	Capital	
4	Government	Tax ICE (1)	Tax ERS (1)
5	Road Owner	Capital, Financing (2) and Road Operation & Maintenance (O&M)	
6	Road Operator	ERS O&M	Incremental Road Toll (3, 4)
7	User	ERS Charge, Vehicle Operating Cost (VOC), Power Tax (1) and Incremental Road Toll (3, 4)	No ICE VOC, Fuel Tax (1) and Incremental Time Saving (3, 5).
8	Non User	Visual Intrusion	Lower Air Pollution, Better Health, Lower Global Warming and Incremental Road Safety (3)

Notes:

Tax is not an economic resource cost but a transfer payment between stakeholders.

Financing cost is also not an economic resource cost but a transfer payment.

Resulting from change in route choice.

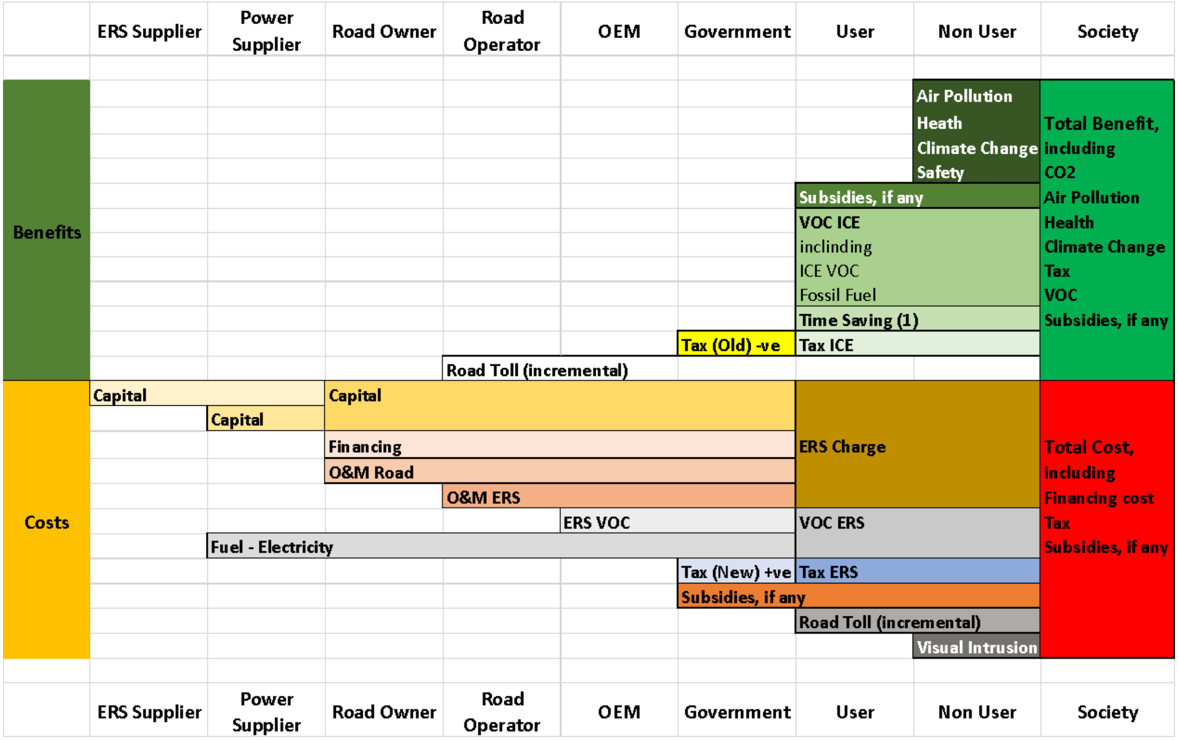
Road Toll is also not an economic resource cost but a transfer payment.

Additional time saving with charging on the move instead stationary static charging, if BEVs.

4.3.3. Types of Business Cases

Table 5 above can be re-arranged to demonstrate how the ERS costs are passed from one stakeholder to another and how the different benefits accrue to the Society as shown in Figure 13. In essence the table is an accounting framework for developing ERS business cases. This accounting framework includes subsidies received, if any, for completeness. However, it should be noted for socio-economic business cases, subsidies are transfer payments as demonstrated by their presence as both a benefit and a cost in the final column of the table ('Society').

Figure 13: ERS Costs and Benefit Supply Chain



Source: TF2.2 ERS.

Note: 1. Time saving from change in route choice and, if compared with BEVs, from charging on the move instead of stationery static charging.

4.3.4. Some Business Case Quantification Fundamentals and Challenges

4.3.4.1. Appraisal period

One fundamental consideration of any business case developments is the length of the appraisal period adopted to judge the proposal. In the transport sector the appraisal period typically varies between 25 and 40 years but longer periods are not unknown, e.g. up to 60 years in the UK. On the other hand, ITS (intelligent transport system) projects are often appraised on the basis of significantly shorter appraisal period, i.e. 10-15 years. The appropriate choice will depend on a multitude of factors, including the national custom, Reference Case (more below), speed of alternative technological development and obsolescence, and technical factors, such as discount rate. A sensible approach would be to employ a shorter rather than longer appraisal period given the high level of uncertainty.

4.3.4.2. Reference Case

Another business case fundamental is the 'Do-Nothing/Minimum Scenario' or alternatively the 'Reference Case'. In other words, what is the 'business as usual (BAU) scenario' for comparing against the proposed ERS?'

An ERS is most practical and beneficial if it allows regional and cross-border inter-operability. Except for very specific applications, ad hoc sections of ERS here and there may not make sense as they are likely to be impractical, costly and wasteful. As such ERS should be very much an "all-or-nothing" implementation, i.e. for a country or continent. The reference case for long-distance ERS should reflect this by employing national or harmonised continental parameters.

A key element of defining the reference case will be to define the principal road network which will allow the ERS to reach all or most centres of population and economic activities. For example, as carried out in the French ERS Study (DGITM, 2021a). Another will be to establish the fuel(s) used by vehicles in the without ERS scenario, these may not be just diesel and petrol. One particular consideration for the LMICs is the import and use of second-hand reconditioned vehicles from high-income countries (HICs). As the HICs switch away from conventional fossil fuel vehicles there will be fewer of them to cascade to the LMICs in the future.

4.3.4.3. Metric valuation

Quantifying the myriad of ERS cost and benefit metrics for a business case is no small challenge. To make it even more complicated the valuations of the different metrics vary widely between countries and/or even between regions within a country. Importing metric valuations from elsewhere due to the lack of local values should be done with extreme caution. In the EU countries HEATCO (2006) provides guidance on harmonised metric valuations. Besides locality variation there are two other key valuation considerations. Firstly, ERS are a novelty with hitherto lowish, albeit increasing, TRLs. This means their construction and operating costs are still unproven and can vary widely (see Section 3.4 above). Coupled with the uncertain costs the economies of scale of ERS are also not well established. Secondly, the “greenness” of the electricity used by the proposed ERS operation is critical for valuing the GHG savings benefit. In many countries, not all additional electricity coming on stream will be carbon free. In some LMICs new coal power stations are still being built. Further due to the war in Ukraine some HICs have recommissioned their previously mothballed coal power stations and/or delayed the planned shutdown of existing fossil fuel power stations.

Given the valuation challenges business case analysts would be wise to sensitise a range of metric valuations and/or apply risk analysis. However the latter is difficult to apply to unknown unknowns.

4.3.5. Business Case Examples

PIARC (2018) study outlined a business case predicated upon a single section of English motorway. That analysis was far from robust and as indicated in section 4.3.1 far from an average highway for ERS implementation.

A far more comprehensive business case analysis was reported in the French ERS Study (2021a). However it was a financial business case through the eyes of potential investors and users. While the potential GHG savings were quantified as very substantial and helpful to Net Zero they were not monetised in the analysis. Nevertheless the French Study demonstrated that a nationwide ERS will be positive for France.

4.4. Business Models

The implementation of ERS contributes and accelerates the “energy transition” in the road transport sector: from conventional internal combustion engines to electrical ones. This shift implies the involvement of new stakeholders and the subsequent surge of new relationships between them: road users, road owners, charging technology suppliers, vehicle manufacturers and renewable energy distributors. The organisation of such relationships, in innovative business models, needs to be addressed simultaneously with the development of the ERS technologies, in order to ensure a healthy socio-economical environment for their implementation (Tongur and Engwall, 2014).

ERS business models are conceptual frameworks that help to demonstrate the viability of the ERS implementation and explain how the system operates, makes money, and how it achieves its goals. They also serve as a description of how the ERS offers value to the customers.

ERS business models need then to be tailored to the different characteristics of the environment where the system is implemented, as the stakeholders' possible relationships, needs and constraints depend on the economical, legal and sociocultural context of the project.

This section presents a compilation of the main components of the different business models being developed around the world in order to commercialise and introduce ERS in a sustainable way. The addressed aspects include the definition of the customers, the vision of the added value of ERS, the income and cost structure, and the processes and policies adopted to allow the introduction of ERS.

4.4.1. General elements on the development of ERS business models

Road transportation is a system that comprises multiple elements and subsystems. In the current system, the OEM fabricates and sells or leases the vehicles to the road users, who then buy fuel from fossil fuel suppliers in order to circulate on the roads, which are designed, built, financed, operated and maintained by an infrastructure owner or concessionaire. These, though complimentary, operate rather autonomously and independently from each other (Tongur and Engwall, 2014).

In contrast, ERS requires the development of numerous strong interfaces between the different stakeholders, as each element or subsystem is dependent on the others. For example, the vehicle's powertrain needs to be tightly compatible with the ERS technology, which needs to be compatible with the road infrastructure design and maintenance, which has to be linked to the electricity transmission network. Additionally, billing and electricity metering need to be compatible with the road infrastructure operation, which needs to be linked with the energy distributor (Tongur and Engwall, 2014). For simplification purposes, ERS environment can be described in four main subsystems (Hasselgren, 2020):

- Power grid infrastructure: power grids, connection points, power transfer points,
- ERS infrastructure: road, power transfer technology, electricity metering system,
- ERS-related services: billing, access control, information management, and
- ERS-related responsibilities: maintenance, operation, financing and ownership.

4.4.2. ERS Business Model Elements from Regions Around the World

4.4.2.1. The European Union

The European Union is a region where international road transportation of goods and people is extremely developed and common. A standard and inter-operable European ERS solution would work similarly to the European Electronic Toll Services (EETS): mobility providers acting as Single Point of Contact (SPoC) would manage the access (contracts and invoicing) of road users to ERS charging facilities, which would be installed in the road infrastructures by the infrastructure managers or operators. Such access would consist in the sale of electrical power to ERS users, using a single metering and billing system for the whole region. This would enable the development of a competitive market across the continent for ERS access. Transport companies (users) would thus be able to choose the most favourable electricity prices, the best service and the tariff models that best suit them on the market (Hartwig et al, 2020).

4.4.2.2. Sweden

In the Swedish vision, in a scenario where ERS is already deployed, the typical ERS interaction is started by a transport buyer who hires a carrier. The carrier then requires a vehicle compatible with ERS, which is provided by the vehicle manufacturer. The carrier also needs access to an ERS-equipped road infrastructure, which is provided by the ERS operator, whose role is to supply electricity by acting as the interface between the carrier and the electricity distributor (Hasselgren, 2020).

The Swedish ERS business model is proposed to be based around 4 building blocks, with each addressing a cost category: power grid expansion, ERS infrastructure deployment, vehicles adaptation to ERS, usage recording and payment systems development. These blocks are seen as easily combinable and adaptable in order to meet implementation needs.

It is the understanding that Trafikverket, the Swedish transport administrator, will build and operate the ERS and be responsible for their operation and maintenance. The Swedish road regulator will charge the users of ERS for the electricity used plus a fee that will cover the costs of maintaining the ERS and for the billing system. In essence the Swedes will be employing a conventional public sector business model.

4.4.2.3. France

An exhaustive study to determine the economic pertinence of ERS was carried out by a French work group formed by multiple and diverse stakeholders (DGITM, 2021a and 2021b). Using a socio-economic approach, ERS viability was assessed for three different types of stakeholders: public authorities, carriers and highway operators. The sum of them all is considered to be the viability for the whole community.

In the ERS economic model considered, highway operators (concessionaires) would be granted the concession of a highway or highway section through a tendering process launched by the government. Operators would be in charge of implementing the ERS technology on their granted infrastructure and then offering the service to the road users. The access to the ERS service could be managed directly by the highway operator or through an associated service provider.

In this model, the main gains for highway operators come from the sale of electricity to road users. Carriers' main gains are based on the lower transportation costs, including battery cost saving, with an ERS fleet compared to a conventional (fossil fuel-based) one. The public authorities' gains are based on the CO_2 emissions savings by the implementation of ERS. The socio-economic approach revealed a positive balance for all considered stakeholders, when ERS is compared with diesel, as well as with other alternative energy sources (all-battery and biodiesel). Nonetheless, low electricity costs were deemed crucial for the positive balance for highway operators.

HGVs were depicted as the main customer segment for ERS in France, as is the case in many other European countries. It was also highlighted that allowing different types of vehicles (HGVs, light commercial vehicles (LCVs), etc.) to access the ERS infrastructure would increase its financial viability.

The low regional (Europe) production capacity of power supply infrastructure (substations) was identified as the main risk for the rapid deployment of ERS.

4.4.2.4. Germany

Germany's efforts on ERS mainly target heavy goods traffic, as it is considered, perhaps optimistically, that battery technologies with public and private static charging stations will allow the decarbonisation of passenger cars. The proposed stakeholder model for Germany considers the ERS infrastructure as part of the road, and its construction and operation fall within the responsibility of a single entity (Hartwig, 2020). In the German context, this responsibility would fall on the federal highway administrator. ERS infrastructure construction would be paid for with the federal budget as it is presently done with regular highways (Hartwig, 2020).

Concerning financing of the highways' investment and operations, the toll already charged to all highway users would co-finance the ERS-related costs (Hartwig, 2020). In this model, users would access the ERS service though a mobility service provider company acting as a SPoC. Such a company would handle the legal relationships associated with toll and electricity billing in order to issue a single summarised invoice to the user. It is important to highlight the fact that the aforementioned toll fees exclude the mobility service, meaning the delivery of electricity. For the benefit of the users, the surge of multiple ERS service providers would be promoted, in order to develop a competitive market for electricity with different tariffs and tariffs models (Hartwig, 2020).

4.4.2.5. United Kingdom

The University of Leeds explored the business model opportunities for electric vehicles that could satisfy the needs of the vehicle manufacturing industry, infrastructure managers and energy providers (Hall et al, 2017). The study highlights the potential of shifting the transportation sector core competence towards the provision of mobility services, rather than the provision of vehicles and fuel. Mobility as a Service (MaaS) is portrayed as a viable way to integrate new forms of vehicle use (such as ERS) with wider mobility packages, thus addressing transportation sector stakeholders' needs in an integrated way. This model proposes the existence MaaS provider which would act as a single point of contact for different mobility services, including the access to a pool of ERS-compatible vehicles. Since the road user would not own the vehicle, but rather pay for a mobility service, the MaaS provider would assure the interface between road users, vehicles manufacturers, electricity providers and infrastructure managers (Hall et al, 2017).

4.4.2.6. USA

According to the ASPIRE Engineering Research Center, ERS business models that target a diverse type of vehicles (cars, vans, trucks, buses) increase the infrastructure utilisation rate, thus lowering the cost per mile driven to users and increasing the return rate to investors.

An ERS deployment project (about 1.6km in length) was planned in Los Angeles, California, for the commercial application of the overhead system along the 30km long corridor linking near two major ports (I-710 project). For this project, market demand for ERS would be originated by policy makers, who, by choosing and promoting the ERS technology as a solution to the environmental problem of the transport infrastructure in the region, would push transport companies to purchase ERS-compatible vehicles. This surge in demand for ERS technology, would in turn encourage subsystem suppliers, such as truck manufacturers and fleet managers, to invest and commercialise ERS-related goods and services (Tongur, 2018).

4.4.3. Discussion

At present, there is no established and proven business model for ERS in the world. So far, efforts to develop ERS have mostly been focused on validating the technical interfaces (technical feasibility) of the technology through several demonstrator projects around the world. Such demonstrators have not enabled the observation of the expected economic and externalities gains of ERS, impeding the experimentation with commercial exploitation of ERS.

However, technology demonstrators have exposed and helped define the nature and extent of the new interfaces between the different ERS subsystems, which constitute a major difference with respect to the present transportation system organisation, where different business models exist simultaneously but mostly independently: vehicles and fuel are sold to customers by private companies, and the right-of-way (the road) is a service either managed entirely by a public entity (as in Sweden), or by a mix of public and private companies through public-private partnerships (PPP) (as in Germany or the USA).

Fuel provision represents the major transformation brought by ERS, with a big potential for innovation. For example, the French model suggests that the road owner or operator buys and resells the fuel (electricity), acting as a SPoC. However, the German model suggests allowing ERS users to directly buy the electricity from the power supplier of their choice, dissociating the road use toll from the electricity consumption fee, which is not dissimilar to the current fossil fuel model.

ERS requires innovative business models that provide a sustainable framework to the new interfaces between incumbent and new transportation stakeholders (Hall et al, 2017). However, further development of the ERS technology faces then a chicken-or-egg dilemma, since the long-term deployment projects which would enable innovation in business models appear to be currently blocked by the lack of a clear economic model for ERS. This may explain the reluctance of some major OEMs to be less than enthusiastic towards ERS.

Strong governmental decisions to support ERS deployment projects, fuelled by the societal need to decarbonise transportation, would be a possible solution to overcome this blockage. Public policies must incite and reduce the risk for private investors interested in developing the needed deployment projects where ERS business model innovation can happen.

5. POLICY AND STRATEGIES

5.1. Introduction

The climate target for transport is a binding directive for action, and strategic planning for all modes of transport must be guided by it. Carbon emissions from transport must be reduced close to zero to achieve climate neutrality. This adjusted reduction pathway should be laid out in new climate protection laws in each state.

A climate-neutral transport sector will succeed in attaining a "traffic transition" (avoiding and shifting traffic) and an "energy transition" in transport (making improvements by phasing out fossil fuels and transitioning to 100 percent renewable energy in the transport sector). Together, these two transitions make up the "mobility transition" that is needed to achieve climate neutrality for the transport sector.

In passenger transport, the target will be reached by increasing the expansion of publicly accessible transport for all settlement areas compared with current plans, greatly expanding and rededicating traffic space for bicycle and foot traffic, and making the ambitious switch to zero-emission vehicle technologies (electrification of cars).

In freight transport, the target will be reached by increasing cost transparency for the different modes (to enable road and rail to truly be compared, for example), which would in turn increase efficiency in transport chains, and by strengthening the focus on regionalism. Taxes on petroleum products have to be taken into account. Legislators should communicate legal frameworks and visions for roles, responsibilities and freight transport's share of total mobility transport early on and transparently.

5.2. Current National Policies

The electrification of the transport system has already started in the segment of light vehicles and more local and regional transport for the segments of heavy duty vehicles. The first step in the transition is through a battery solution with stationary charging ports. However, in order for deep decarbonisation to occur in the global transportation sector there is a need to implement various types of electrified vehicles. Hydrogen and/or ERS solutions are probably more suitable for heavier vehicles with transport over longer distance with a higher need for energy. These solutions have the potential to decrease the need for big batteries and increase potential payload. They might also increase the operational time for the vehicles as they don't need to spend time for static charging as often as pure BETs. ERS also have potential to be used by light duty vehicles and could be a good way to reduce the size of batteries and limit the dependency on scarce resources. These last two solutions aren´t in full production yet, hydrogen fuel cells are expected to be implemented in the later part of this decade (2020) and ERS will probably be built in full scale in some countries in the beginning of the next decade (2030) or sooner, i.e. towards the end of the 2020s.

Results from the ITF report, *Decarbonising Europe's Trucks - How to Minimise Cost Uncertainty* (ITF, 2022), indicate that BEVs and ERS have the greatest promise to be cost competitive with conventional diesel in the European vehicle segments explored in this analysis. This is predominantly due to their higher energy efficiencies, which keep operational costs low and offset the higher upfront purchase costs. ERS has the potential to be one of the most effective solutions to decarbonise trucks and the following section presents the status of the ERS activities.

5.3. Status of ERS

ERS is a relatively new technology that is under development and different technologies have reached different levels of maturity. There is a great interest over the world for ERS because the solution has great potential to reduce the emissions in an effective way. However, the development and concrete activities in the process to implement ERS differs over the world.

The process and plans to implement ERS often follow these steps:

- Research and development,
- Field test in restricted area,
- Demonstration on public roads (shorter stretches and few users),
- Pilots (longer stretches and more users), and
- Full scale roll outs.

The aim of the first steps in the implementation process are more or less to build up knowledge and the later steps are both to get more knowledge in real conditions and to prepare for a future roll out of an electric road system. Some parts of the process might be the same regardless of where you are building the ERS system and some parts might be country specific depending on how the transport system is designed and used.

The plans for implementing ERS often follow the process above but might vary depending on different circumstances over the world. Most nations over the world have goals related to the reduction of CO_2 emissions that they are working towards, where ERS is one tool to reduce emissions from transport.

In Europe there are several nations that have some activities related to ERS and are somewhere in the process between research to planning of the first routes for the road network. In the USA there are ongoing and planned research projects to gain more knowledge, but also projects which aim to demonstrate the technologies on public roads. In Asia there are ongoing research projects and some field tests, for example, in Japan where Honda has a test area. In south America and Oceania ERS are mainly in the research phases and use smaller field test areas to conduct the research. The activities in Africa are less advanced but ERS are a topic of interests for researchers in some more advanced countries, for example South Africa.

5.4. Examples of Demonstration and/or Pilot Projects

In this section, we are going to describe some examples of ERS test activities conducted in some PIARC member countries. It is a description of some of the activities in the member state, and some conclusions what we can learn from them. For example, demonstration projects in Italy, Germany, the UK, the USA, Israel, France and Sweden.

5.4.1. Germany

Germany aims to become climate-neutral by 2045. To achieve this goal, there must also be innovative solutions in the transport sector. After all, transportation accounts for a significant share of greenhouse gas emissions in Germany and worldwide.

While many passenger battery-electric vehicles are already on the road, this drive system is also increasingly being used in light commercial vehicles, but there are still a number of hurdles in terms of sustainable climate-friendly solutions in heavy road freight transport. However, these solutions are urgently needed in order to be able to cope with the continuing increase in transport volumes in the future in the most climate-friendly way possible. Even rail freight transport can only handle a limited share of freight traffic despite significant expansion.

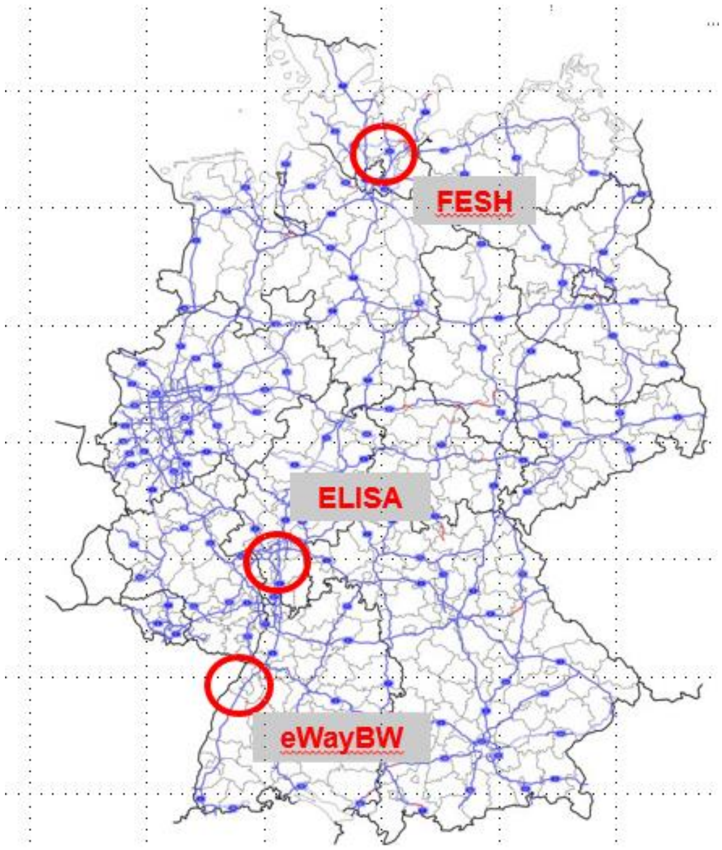
5.4.1.1. eHighway

For some years now, the German government has been funding research into catenary trucks as an alternative to the dominant diesel drive. This technology, familiar to the rail sector but also from trolleybuses and streetcars, makes it possible to power trucks electrically while they are on the move. In addition, batteries on board the vehicles can also be directly and efficiently supplied with electricity from renewable sources while the vehicle is in motion. This means that electric propulsion is also possible outside of catenary lines.

Currently, prototypes for catenary trucks and the infrastructure of logistics companies are being put through their paces in everyday operation on three test routes (ELISA in Hesse, FESH in Schleswig-Holstein and eWayBW in Baden-Württemberg) in Germany as displayed in Figure 14 below.

Even though tests with new vehicle configurations, including battery electric HGVs, are still underway, the technology has proven its worth. ERS can be implemented quickly and make a relevant contribution to the decarbonisation of heavy goods transport.

Figure 14: German ERS Test Locations



Source: Sommer, 2023.

5.4.1.2. ELISA

Scope: Dynamic (currently 10 km, in 2023 17 km) and overhead line system,

Status: In operation since 2019,

Location: On the A5 close to Frankfurt,

Number of vehicles: Since 2019, 5 trucks have been successively included in the tests. By April 2023, a total of 11 trucks will be used in real operations by the transport companies. One will be pure BEVs with pantographs. 10 trucks will be hybrid vehicles with different vehicle configurations and pantographs, and

Partners: Autobahn GmbH des Bundes, Technical University Darmstadt, e-Netz Südhessen AG and Siemens Mobility.

5.4.1.3. FESH

Scope: Dynamic (10 km) and overhead line system,

Status: In operation since 2019,

Location: On the A1 between Hamburg and Lübeck,

Number of vehicles: Since 2019, 5 trucks have been successively included in the tests and will be used by an etransport company in real operation. In 2023 a battery electric HGV will also be part of the test fleet, and

Partners: Ministry for Energy Transition, Agriculture, Environment, Nature and Digitalization of the State of Schleswig-Holstein.

5.4.1.4. 5eWayBW

Scope: Dynamic (8 km) and overhead line system,

Status: In operation since 2021,

Location: On the federal road B 462 between Kuppenheim and Gernsbach-Obertsrot,

Number of vehicles: Since 2019, 5 trucks have been successively included in the tests and will be used by three transport companies in real operation, and

Partners: Ministry of Transportation of the State of Baden-Württemberg.

Initial results show that:

- The eHighway system enables the realisation of zero-emission road freight transport while saving the energy storage systems used in terms of size and weight, thanks to dynamic charging. Future catenary trucks may also be operational without an internal combustion engine,
- The general technical feasibility as well as the suitability of the operational processes for everyday use have been confirmed in the pilot operation, which has been running successfully for several years so far,
- The technical maturity level allows a roll-out of the catenary infrastructure,
- The catenary trucks currently in use appear to meet the requirements of the transport companies and have been successfully integrated into logistics processes, and
- The eHighway system is robust, reliable and can be integrated into flowing traffic and the road surface without any significant intervention.

5.4.2. Sweden

Sweden has a goal to become climate-neutral by 2045 and to reduce GHG emissions by 70 percent from domestic transports in 2030[2]. Sweden is working with all possible solutions to achieve this goal. In the short run biofuels and stationary charging are the most important ones, and in the medium and long run fuel cells and ERS have the possibility to work as complements to stationary charging for heavy road freight transport.

There are still several challenges in terms of sustainable climate-friendly solutions in heavy road freight transport. Sweden considers that ERS has potential to be one of the solutions to electrify this transport sector. Therefore, Sweden was early to test and demonstrate technical solutions on public roads. The first tests of ERS with overhead line started in 2016 in Sweden just outside a town called Sandviken, and another test with conductive rail started in 2018 just outside Arlanda airport. These two test projects have now been completed and have been dismantled. There are now two on-going research projects that aim to demonstrate their technical solutions on public roads in Sweden, one with a conductive rail solution in Lund and one with an inductive solution between Visby City and its airport. Sweden is also planning to build a 21 km long permanent road with ERS

[2] Compared to the emissions in 2010, and domestic flight are not included.

between Örebro and Hallsberg. The experiences from these projects are presented here with more focus on the three on-going projects.

5.4.2.1. Evolution Road Test & Demonstration Site in Lund

EVolution Road is a pre-commercial test- and demonstration project in Lund, southern Sweden, which runs between 2019 and 2024. The purpose is to increase knowledge about ERS as part of a fossil-free transport system. The assignment comes from the Swedish Transport Administration.

A one-kilometre ERS is implemented on a public road in the city of Lund. The ERS consists of a thin rail immersed in or placed on top of the asphalt. Electric vehicles are equipped with a special pick-up mounted underneath the vehicle that charges both the battery and the drive line. The conductive ground-based solution ensures efficient transfer of power and opens up the charging infrastructure for all sizes of vehicles. In addition to power supply, the ERS includes technology that controls access, safety, real-time interaction with traffic, smart billing, balancing towards the grid and more. Two versions of the ERS are installed in the project. The first version consists of a rail placed on top of the asphalt. The second version is level with the asphalt, placed in a shallow milled trench which results in a seamless level road structure. The main focus has been on testing and evaluating the embedded version, suitable for higher speeds on highways.

The ERS site is located near the city centre of Lund and safety has been of utmost importance. The ERS has one-metre short rail segments that are separately powered just below the vehicle that guarantees high safety even in urban environments. The shorter segments enable charging of vehicles both while standing still and driving, which is a common driving pattern in cities. It is easy to install the electrical road on existing infrastructure. An outer box, held by sealant, keeps water from intrusion. An inner box that consists of all electronics and can easily be lifted out for quick replacement, and service can be done ‘off road’. Several installations have been done during the project lifetime as well as weekly switches of rails for testing and upgrading.

The result from the first installation is that the ERS was fast and easy to install, only had a small impact on the asphalt, and the traffic disturbance is minimal. The first stretch of 360 meters of the first ERS, i.e. mounted on top of the pavement system, in Lund, was installed in a couple of days. The first installation of the submerged version within the pavement, in Lund, a stretch of 600 metres, took a total of three days to install. The installation involved road preparation, such as milling a slot, lifting the ERS rails into the slot, sealing it with sealant and connecting it both electrically and mechanically.

So far, three vehicles (a city bus, cargo van and car) have been driving and charging at the same time on the road. The bus charges 40kW at 60A when standing still before accelerating, and both vehicles simultaneously charge 218kW at 315A, when accelerating or driving. The Van is tested at 90km/h with good results for the power and no detected sparks. 200kW has been transferred to the city bus at a speed of 40km/h. A trailer is being built that can reach higher speeds and power. It will be able pull 300 kW from the road at 90 km/h. Tests and development continue and the next generation of electric road from Elonroad is expected to deliver 400 kW per vehicle at peak power. The rail can still control each vehicle individually, and if the grid reaches its power limit the ERS will be able to control the amount of power each vehicle is allowed to consume.

Friction test has been performed in south of Sweden and passed, still more development and evaluation are ongoing. Very low noise results from sliding contacts. Noise is hardly noticeable over

30 km/h. The first evaluation of the installation in winter conditions has been done with approved measures related to friction and the road condition. No impacts on the road, such as rutting, cracks and settlements, have been observed so far in the project during the winter tests. More tests will be conducted during the winter. Two winter tests are under evaluation (Nov 2021 and Oct 2022) to ensure that the electric road's properties and durability are not affected by traffic in snow and ice or road maintenance in a cold climate. No major impact has been observed so far in the winter tests.

5.4.2.2. Smartroad Gotland

In April 2019, the Swedish Transport Administration announced that the Smartroad Gotland consortium, led by Electreon AB, a wholly owned subsidiary of Electreon Wireless, won a tender to demonstrate a wireless Electric Road System in Sweden. The road, based on Electreon's dynamic wireless charging technology, is the first in the world to charge both an electric truck and bus simultaneously while they drive.

Construction on the 1.65 km wireless Electric Road began in November 2019. The road, which is part of a total route of 4.1 km between the town of Visby and Visby airport on the Gotland Island, has been fully operational since early 2021. The e-bus has been used in commercial operation between the airport and the town, and the electric truck is being driven by a professional driver to ensure that the system will be ready for large-scale projects on highways.

As the first inductive ERS on a public road in Sweden, it was unclear what rules and regulations would apply to such an installation. An important lesson is that it takes considerable time to get permits for new infrastructure and new installations at public areas. It requires a rather complicated process to get approval for anything new that is visible. Grid connection, installation of energy storage and installation of receivers at vehicles are the most time consuming activities.

The construction was done in several steps to make it possible to improve the road construction process. Thereby each deployment has become faster and more reliable. To make these improvements possible and effective it has been important to work with the same people on site. Very few steps of the ERS construction process were unique, but as this was the first implementation many workers tended to think that the steps were more complicated than they really were. For example, electricians have connected grid cables thousands of times, but when asked to connect a grid cable to the electric road it takes three times as long, since they have never done this before. It has therefore been important to guide them on site and explain that it is in fact exactly the same activity although the functionality is different.

5.4.2.3. Pilot

The Swedish Transport Administration is carrying out the procurement of a permanent 21km long, two-way electric road, between Hallsberg and Örebro. The Swedish Transport Administration has decided that the procurement should be carried out in a technology-neutral manner. This means that, through the requirements, all electric road suppliers were given the opportunity to respond to the request.

The work of designing the tender documents required many different skills and thus tremendous organisation and co-operation from both the administration and the consultant for the preparation of the technical description. The human resource need ranges from people with knowledge of electric power and the administration’s systems for traffic management to operation and maintenance.

At the beginning of the work, a process was created for how "Functions and Requirements" would be developed. In this, a number of technical areas were formed that were judged to be relevant in order to be able to formulate in a coherent and structured way the new requirements required in the construction of electric roads.

The technology areas that were formed are as follows:

- Electricity supply and the technology of the electric road,
- Operation and maintenance of electric road system and road system,
- Access control electric road, energy measurement and billing,
- Overall system architecture,
- Community safety,
- Environment,
- Work environment and traffic safety, design requirements and design,
- Control and monitor electrical installation, and
- Control, monitor, information/traffic management.

A major challenge in the work was to handle the large number of requirements that were created and bring them into a newly established structure in the technical description for the electric road pilot, as well as formulating the requirements so that they are not contradictory or overlap each other in a way that becomes unclear for the bidders.

Since there were no internal control documents for electric roads, a number of control documents that supplement the technical description were prepared in parallel with the preparation of the technical description.

An overall system description was needed that, with the help of both texts and images, gave tenderers a clear picture of the total systems required for a functioning electric road, including where the interface is between the electric road contract and surrounding systems and contracts. Examples of areas bordering on the contracting are Electricity and ITS, Traffic management systems, Electrical management, Access and payment systems, etc.

It's also the first time that a road plan for ERS has been developed in Sweden and an early challenge has been to explain to the public how ERS is intended to work. What does it mean when a conductive technology is installed in the air or as part of the asphalt and how does it work when electricity is transmitted inductively? During the roadshow, curious questions have also arisen about how it should be implemented in practice and will there be any difference for traffic that does not use the electric road. Some, mainly based on different interests, have also asked about the risks involved in installing an electric road system, such as what happens in the event of a traffic accident on the road and how will the surroundings be affected. The land access for the infrastructure needed for the ERS is, of course, an issue that has touched those closest to them.

So far in the work with the road plan, these questions have been addressed and answered from a technology-neutral perspective as far as possible regardless of ERS. When the technology selection is in place for the pilot E20 Hallsberg-Örebro, it will be exciting to resume work on the road plan and submit it for determination testing that provides the right to carry out the project.

Experiences from demonstration projects and the work with the pilot project:

- The technical solutions for ERS that have been tested show they work and are practical solutions to electrify road transport in the future,
- To ensure the functionality (availability, robustness, safety) there are needs for additional road equipment of different magnitudes for different technologies,
- Friction tests indicate that there are solutions to adjust the friction on the ground-based conductive system to more closely match the friction of the road,
- Winter tests in Sweden show that operations of the ERS system and maintenance are working during the winter,
- There are tests of how the technologies from current demonstration projects are affected by ground frost in the northern part of Sweden,
- There are new considerations that infrastructure managers have to consider when building a permanent construction,
- It is important to communicate relevant facts to the public when working with the road plan, for example within the area of electromagnetic interference, and
- There are a lot of new functions that have to be defined within technical documents for the construction of an ERS system.

5.4.3. USA

Efforts to decarbonise the transportation sector in the USA have been outlined in the recently released *U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation*. The Blueprint was developed to meet the goal of net-zero GHG emissions economy-wide by 2050. Legislation has been passed to help decarbonise the transportation sector including:

The Bipartisan Infrastructure Law (BIL) was signed into law on November 15, 2021, enacted as the Infrastructure Investment and Jobs Act (IIJA), (Pub. L. 117-58). The BIL makes the most transformative investment in EV charging and alternative fuelling in US history, and includes $7.5 billion in dedicated funding for EV charging and alternative fuelling infrastructure to be installed across the country, and

The Inflation Reduction Act was signed into law on August 16, 2022, which builds on the foundational climate and clean energy actions secured by BIL by providing funding to advance and deploy clean energy fuels and technologies.

5.4.3.1. INDOT Demonstration in West Lafayette, Indiana

The Indiana Department of Transportation (INDOT) has been looking for zero-emission solutions for the high-volume of heavy-duty freight traffic across Indiana. INDOT worked with the Purdue University ASPIRE team to create a report on the economic viability of an Electrified Road System. The report showed that an electrified roadway had a positive ROI (Return on Investment) and could reduce the cost of transportation for heavy-duty vehicles if there was sufficient adoption. INDOT then contracted with the Purdue team to construct and test sample designs of a dynamic wireless charging solution that will meet the needs of heavy-duty trucks. The testing is being performed at the INDOT Accelerated Pavement Test (APT) facility in West Lafayette, Indiana. Included in the testing is a design that utilises a ferrite/concrete mix, which is commercially referred to as Magment.

The Purdue team has built a 230 kW, three-phase, dynamic-charging solution. This power level is designed to provide sufficient energy to drive a fully-loaded semitruck at highway speeds and charge a depleted battery. The transmitter coil design has been embedded in both concrete (with

Magment) and asphalt pavements (without Magment) and is currently under test in INDOT's Accelerated Pavement Testing facility to check for any long-term reliability issues in the pavements. Presently, testing is progressing as expected and the technology is being prepared to transition to a roadway installation.

In terms of the next step (i.e. roadway installation), INDOT has selected a section of State Highway 231 in West Lafayette, Indiana, near Purdue University, for a demonstration and to create a working testbed to explore performance in a roadway. Approximately 400 meters of 230 kW dynamic charging will be installed, likely by milling an existing concrete roadway to a depth of 3.5 inches (about 9 cm), placing the coils on the milled surface, and using a traditional pouring technique to place concrete over the coils. Cummins, an OEM, has verbally committed to provide a heavy-duty, battery-electric truck as the test vehicle. The project design is being finalised and will be placed out for construction bid in Q3 of 2023. The construction is expected to begin in spring 2024.

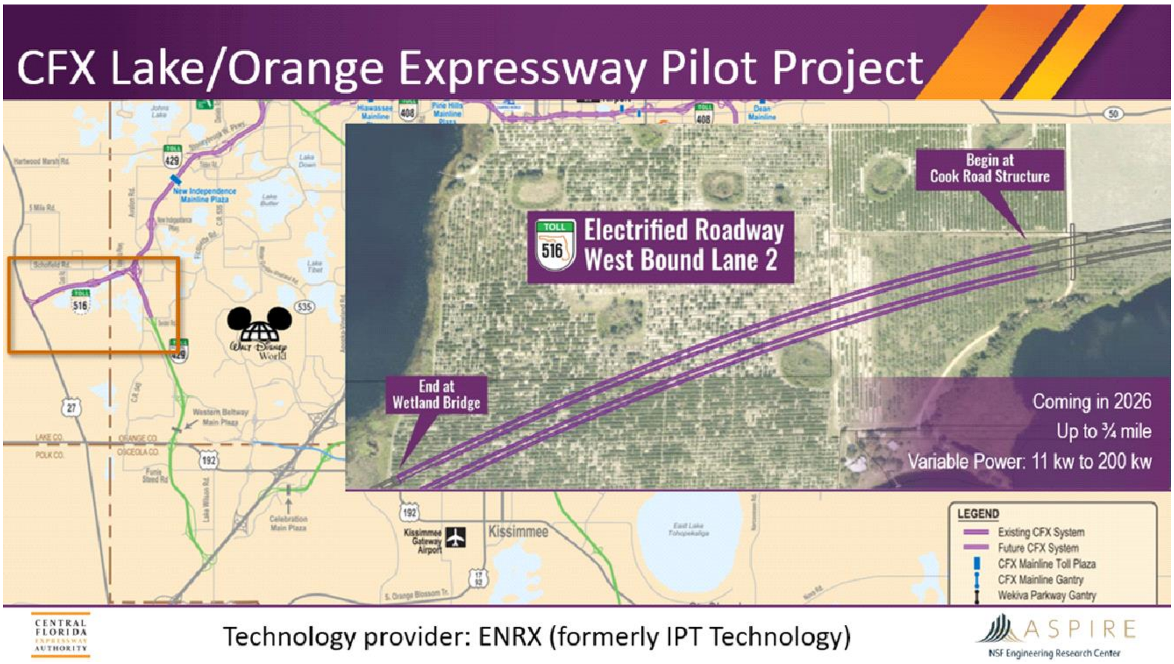
5.4.3.2. Central Florida Expressway Authority (CFX) Demonstration

Central Florida Expressway has a visionary leader who is willing to support the early adoption of important new technologies. After several years of working with the ASPIRE NSF Research Center, CFX included an electrified roadway demonstration on a new five mile stretch of roadway that they are building. The CFX Board has approved $10M for the dynamic charging demonstration. ASPIRE is serving as an advisor on the project. This project will move the industry forward by helping to define the information needed to include dynamic charging in a new construction bid, share lessons learned from the actual construction, and provide data from a climate very different than that of Indiana or Utah.

CFX has chosen ENRX (formerly IPT Technologies) to provide the dynamic charging system. The system will be a variable 11 kW to 200 kW, three-phase system embedded in concrete. A pre-cast concrete form will be used for the receiver with cast-in-place concrete being poured over the receiver. The ENRX system will be installed in the ASPIRE test track at Utah State University in the summer/fall of 2023 in order to test the installation process and the charging system.

CFX will be building the new 5-mile SR516 highway between Highway 27 and SR429 just west of Disney World in Orlando, Florida. The electrified roadway will be a 1200 metre section on the west end of the project between the bridge over Cook Road and the yet-to-be-installed Wetland Bridge as shown in Figure 15 below. Final design of the full roadway will be complete soon with a formal bidding process starting in late 2023. The roadway construction is planned to take two and a half years with the pavement installation taking place in 2026. The roadway is expected to open in autumn 2026. Demonstration vehicle providers have not yet been identified and are one of the significant hurdles remaining.

Figure 15: Central Florida Expressway Authority (CFX) Demonstration Project



Source: Blalack, 2023.

5.4.3.3. Utah Inland Port Authority Freight Electrification Demonstration Project

The Salt Lake City region has an air quality problem that threatens future business investment and relocation of new employees to the area. The Utah state legislature appropriated $15M to demonstrate the potential of electrified movement of freight in the region to improve air quality. ASPIRE, with its headquarters at Utah State University (USU), was chosen to lead the project. While USU has separately enabled a Phase 0 at the Electric Vehicle and Roadway (EVR) facility in Logan, Utah to demonstrate pre-pilot, non-commercial technology demonstrations, this project is intended to be a first phase of a regional electrification effort that will include battery-electric passenger trains.

While some of the technology providers have not yet been selected. The intent is to include multiple technology providers that can demonstrate high-power stationary wireless charging, a high-power Megawatt Charging System (MCS), dynamic wireless charging, and smart energy management. The 1 MW stationary wireless charger is intended to provide a Direct Current Fast Charging (DCFC) option for heavy-duty vehicles. The smart energy management system will mitigate grid loading by intelligently shifting power to where it is needed and reduce demand charges. Pre-pilot work will be done at Utah State University.

The project has not yet been fully defined, but it will focus on the movement of cargo containers from the Union Pacific railyard in Salt Lake City to local distribution warehouses. Drayage operators moving the cargo containers will also share this charging infrastructure and have agreed to be part of the pilot. Data loggers have been installed on the existing diesel drayage trucks to determine which routes can be supported by a battery-electric truck. Kenworth, an OEM, has agreed to provide battery-electric vehicles for the demonstration.

5.4.3.4. Utah State University demonstration track

USU has a quarter-mile (400 m) test track in Logan, Utah that has been used to test different iterations of USU-developed ERS charging technologies since 2015. Utah State University became the headquarters of the multi-university ASPIRE National Science Foundation Engineering Research Center in September of 2020. A 22-passenger bus was outfitted with receiving coils and has been used as a demonstration vehicle to give rides to thousands of visitors. The test track is used by industry partners to test their inductive charging solutions. Details of the most recent test-track demonstration project, with Electreon, are provided below. The USU test track will be used in conjunction with other ASPIRE-related ERS demonstration projects in the US.

The Electreon demonstration project has the follow characteristics:

- Scope: Dynamic wireless charging (164 feet) and integration on a class 8 hybrid truck,
- Status: In operation since October 2022, and
- Partners: Electreon, ASPIRE (USU), Kiewit, and Kenworth.

This type of technology is new for contractors. Therefore, it was critical to go into the details with the contractor and the construction crew in advance with regard to planning, designing, and constructing as well as to be onsite to oversee the different processes. It was learned that it is critical for an Electreon Project Manager to be present at all stages for knowledge transfer to ensure smooth implementation of the project.

The construction phase was relatively quick and straightforward. Installation did not take long, avoiding the necessity to close the road for an extended period. Roadway and grid work was done ahead of time and much could be accomplished through communication with the local construction team in advance to reduce implementation time and risk of delays.

Experiences from the Utah deployment were as follows:

- Installation of the demo track was done in one day,
- Results include 100 kW transfer in peak power, with three receivers, and
- Established a dashboard and API integration to monitor and display power transfer in real time.

5.4.3.5. Michigan DOT Project

The aim of the pilot is to host several use cases and analyse what the benefit is for users and what relevant pilot data can be generated. This requires coordination between many different entities, to successfully plan what technology to deploy and where. The pilot includes planning and integrating both static and dynamic charging for the use cases. The plan is to install on roads with different jurisdictions: on state and city owned roads as well as on a private road and property.

Scope: 1-mile dynamic electric charging roadway in Detroit and static opportunity charging for a variety of vehicles (van, bus and cargo). Subsequently, on 9/22/2022 Electreon signed a five-year agreement with MDOT to develop and work toward implementing a scalable wireless public in-road charging network beyond the 1-mile project,

Status: Expected phase 1 deployment Q3 2023 and phase 2 deployment Q3 2024, and

Partners: Michigan DOT, Electreon, Jacobs Engineering and Next Energy, Ford, Michigan Central, DTE, City of Detroit, Kiewit and others.

There is no precedence for building a public electric road in the USA, which creates certain challenges in planning and coordinating implementation of the project. The pilot requires a series of education and coordination meetings on how the system operates and how it may impact different stakeholders. These meetings help ensure that the stakeholders are comfortable with the technology, the process and how it impacts them, allowing for a smoother and more efficient path forward.

5.4.4. France

France has been active in studying ERS and the activities have consisted of a lot of research and some field tests over the last decade. The study results show that ERS might have an important role to play in the decarbonisation of the road transports, both for light- and heavy-duty transport. Some of the tests and also upcoming demonstration projects in France are presented below.

5.4.4.1. Alstom's ground-based conductive power supply system

Alstom France developed the infrastructure elements of the 300m long test track for ERS built in 2012 for the experiment at Volvo's test centre near Borås in Sweden. This proof of concept, which lasted until 2017, validated the feasibility of the solution's road application and its effectiveness in terms of the energy transfer system.

Following the success of its proof of concept, Alstom decided in 2017 to develop an infrastructure fully adapted to a road application in terms of safety, robustness and maintainability. After numerous laboratory tests carried out by IFSTTAR on gluing, rutting, thermal, skid resistance and mechanical resistance, two test tracks have been built for testing the infrastructure in real use cases. A first test track, 50m long, was built in 2019 on the IFSTTAR site near Nantes. The objective was to validate the skid resistance with a dedicated test machine (called SCRIM) and real vehicles (motorcycle and car).

A second test track was built in 2019 in the Vosges mountains to test the compatibility of the new feeding track with road winter maintenance. Compatibility with winter maintenance operations such as salting and snow removal was demonstrated during two successive winters. This demonstrator was also useful to show that the road infrastructure is not impacted, even after several years with negative temperature, and that the very low level of leakage current measured will not impact on the operation of ERS during the winter period.

5.4.4.2. European FABRIC project (2014-2018)

FABRIC (**F**e**A**si**B**ility analysis and development of on-**R**oad charg**I**ng solutions for future electric vehi**C**les) was a project funded by the EU Commission. The main objective was to evaluate the performance of on-road wireless prototypes in real driving conditions. FABRIC has developed three prototype wireless charging solutions and support ICT tools which have been demonstrated in its test sites in France and Italy. The French test site was in Versailles–Satory, where an inductive solution based on the Qualcomm Halo system has been experimented on a 100m long test track with a Renault Kangoo car.

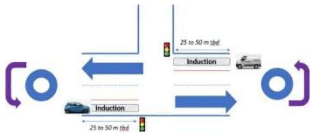
5.4.4.3. European INCIT-EV project

INCIT-EV is an EU project coordinated by CIRCE with 33 partners, which aims to demonstrate, at five demonstration environments including TENT-T corridors, an innovative set of charging infrastructures (7 use cases), technologies and its associated business models, ready to improve the

EV users experience (INCIT-EV, 2020). Two use cases will be covered with demonstrations in France implementing a technical solution by inductive charging provided by CIRCE for the ground part and by Vedecom for the on-board part:

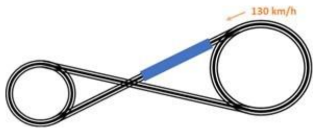
Use Case 2 - Wireless dynamic charging for a city bus line (in Paris) :

A dynamic inductive charging lane will be implemented in the city of Paris so that urban transport vehicles, such as buses, can be charged while waiting at the city's traffic lights. With a power of 120kW over a length of 25 meters.



Use Case 3 -Wireless dynamic charging for long distance routes (in Versailles) :

A dynamic inductive charging lane will be implemented in a test circuit to study the potential use of high-speed wireless charging on highways. With a power of 90kW along 80 meters, it is expected to be able to charge vehicles circulating up to 120km/h.



5.4.4.4. Projects under preparation (2023-2027)

Two consortia have responded to the call for projects for the demonstration of ERS launched by Bpifrance in October 2021. Led by road operators, their objective is to carry out demonstrations on test tracks and an open motorway. The technical solutions selected for these demonstrators are, for one consortium, an inductive and a ground rail solutions, and, for the other, only a ground-based conductive ERS solution. A third consortium submitted a proposal in early 2023 with a catenary system.

5.4.5. Italy

In Italy they are testing a loop of 1 kilometre electric charging via dynamic inductive charging that can be used by both light and heavy vehicles. A total of 6 vehicles are participating in the test: 2 cars, 2 buses and 2 trucks provided by Stellantis and Iveco, both OEMs. The test site is just beside the Motorway A35 between Brescia and Milano and closed to traffic. The project is supervised by the Milan Polytechnic and the Universities of Parma and Rome 3. There are also other partners in the projects from the regional road administration, power supply and distributions industry, vehicle industry, road construction and maintenance companies, blue light authorities and more.

The project has been running since 2018 and it will be finished in 2023 according to plan. The purpose of the test is to study the performance of the power transfer with the inductive technology and to optimise the performance in relation to both vehicles and the road construction and especially the asphalt mix. For example, the interaction between vehicles and infrastructure, electromagnetic fields, system efficiency, LCA studies and the impact of ERS vehicles on a public road are being analysed.

5.5. Summary and Conclusion

A number of countries and road administrations are planning for electric road systems and working intensively to remove uncertainties regarding the technologies. The countries are at different levels regarding the tests, some are doing field tests and some are planning for permanent installations in the infrastructure. However, all countries have a common challenge to address climate change and there seems to be a culture of sharing knowledge about ERS among the countries to decarbonise road transport.

There are countries which have more general plans for the electrification of their road transport, and especially their heavy transport, where ERS is a part of their electrification strategies. The first phase of these strategies usually consists of building infrastructure for static charging and the next steps usually consist of working with fuel cells and/or dynamic charging with electrical roads. For example, Sweden, Germany and France have published proposals for deployment plans for ERS within their strategies, although not decided yet by the politicians.

ERS might play different roles in different countries in the future. In some countries it will probably be more of a complement to static charging and in other cases it might be a backbone of the electrified road transport system. However, the common features of these plans are that they go through the following steps. Demonstrate technologies – Larger system Demonstrators/Pilots – and finally deployment of ERS. There are countries that currently are working or are in the process to start, with larger Demonstrations/Pilots in their implementation plans for ERS. In the near future there will probably be evidence from these projects that electrical road systems are working not just in a technical sense but also in larger system demonstrators within the transport system. The next step for these countries is a full scale deployment of ERS, and to make it happen decisions have to be taken by the politicians.

The most critical important steps for making electric road systems happen are as follows:

- Set clear goals for electric road systems in national policies for decarbonising the road sectors,
- Continue to demonstrate technologies and create pilots,
- Cooperate internationally for proof of concept,
- Create national and international roadmaps for deployment, and
- Secure inter-operability within ERS systems and in the vehicles to handle both dynamic and static charging.

6. CONCLUSION AND RECOMMENDATIONS

Following on the PIARC special project on Electric Road Systems (PIARC, 2018), the Task Force 2.2 has carried out further investigation into and analyses of ERS between 2020 and 2023. The analyses and findings are reported in this Final Report.

The following concluding remarks can be drawn:

- Electric Road Systems have been developed, tested and evolved since around 2010. Thus far about ten technical solutions exist and these can be grouped into three families of ERS:
- Catenary systems,
- Ground and Lateral Rail systems, and
- Inductive systems;

Following a literature search a total of 60 publications on ERS were reviewed;

- Twenty-seven ERS case studies were then compiled;
- A further five ERS experimental projects profiles were summarised;
- The numerous experiments (on and off road trials and public road pilots) carried out, nearly thirty to date, have enabled the technical solutions to be assessed and to evolve rapidly;

Hitherto, these developments and experiments only have been and/or are being conducted in high-income countries, i.e. Japan, South Korea, France, Germany, Italy, Sweden, the UK and the USA;

- The lessons learned and best practices from these experiments are especially useful for further progress. Nevertheless, experimental outcomes have their limitations;
- The creation of first permanent ERS projects, such as the one being procured in Sweden, is key to the comprehensive evaluation of an ERS system, but this requires large investments and potentially involves a high level of subsidies in the introductory phase;
- The technical solutions must continue to evolve in order to reduce the impact on the environment, road carriageways and operation, vehicles and road safety;
- Inter-operability across borders is a key factor for the attractiveness of any ERS technologies;
- Compatibility with other surface transport decarbonisation initiatives could enhance the attractiveness of ERS as a net zero transport solution;
- In many countries, particularly European ones, unlike the oil and gas industry, the electricity industry, from production to distribution, is not vertically integrated. Thus to deploy ERS many more stakeholders will likely to be involved. Hence engaging with ERS stakeholders, including non users, early in the consideration and planning process will help to smooth ERS deployment;
- As can be expected different ERS technologies have their advantages and disadvantages but all are a pathway to decarbonise some or almost all road transport;
- Like other road investments, investing in ERS involves costs and brings benefits. For sound governance and stewardship the responsible public authority should conduct the necessary cost-benefit analysis (i.e. business case assessment);

However, unlike typical road maintenance, road rehabilitation and new road construction, ERS capital and operation and maintenance costs are currently rather uncertain. This challenge is due to the infancy and limited applications of the technologies but this should improve as ERS become progressively adopted;

The quantification of benefits could also be tricky. Attention to what constitutes the Reference Case, i.e. do-nothing or do-minimum scenario, is critical as road transport continues to evolve and at different speeds in different countries;

For inter-operable cross-border ERS investments, like other cross-border road investments, employing harmonised benefit metric valuations will likely smooth decision making;

While developing the business case for investing in ERS is not as straight forward as appraising a new road investment, nevertheless, nascent analyses suggest that ERS investments can be economically efficient for the society as a whole and can also be an effective solution for decarbonising long distance road transport;

ERS are likely to be principally targeted at HGVs and buses and coaches. However, some ERS which are capable of serving all vehicle types can bring greater reduction in GHG emissions as well as saving in critical minerals to make batteries. On the other hand battery electric light vehicles (cars and vans) with static charging are increasingly well established and their performance will likely improve further. Hence, should static charging rollout keep pace with BEV adoption, the additional reduction in GHG emissions by light vehicles using ERS could be quite small. However, should universal static charging fail to adequately happen the case for ERS can be expected to grow significantly;

As ERS have yet to be deployed as operational systems there are no established business models. Three potential business models, i.e. purely public, predominantly private and, in between, some combination of public-private partnership, are currently being touted. It is noteworthy that the private orientated business model has two potential variants depending on who the users pay to for the electricity used, i.e. whether the road operator as in the case of toll roads or an electricity distributor of choice as by domestic electricity users in many European countries;

On policy development it is vital public administrations develop appropriate policies which are fit for the national needs but also compatible to regional inter-operability. The latter is often complicated by national patriotism and hence time consuming to reach win-win compromises;

Lessons learned from pilot projects suggest that procuring ERS projects will likely require significant effort by the road administration and this could be beyond their capacity and as such could require outside assistance. This phenomenon would likely not to be different to when public-private partnership roads were first introduced in the 1990s and 2000s;

The most critically important steps for making ERS happen can be summarised as follows:

Set clear goals for ERS in national policies for decarbonising the road sectors,

Continue to demonstrate technologies and create pilots,

Cooperate internationally for proof of concept,

Create national and international roadmaps for deployment, and

Secure inter-operability within each family of ERS systems and in the vehicles to handle both dynamic and static charging; and

Last, but not least, in short, ERS is ready for deployment to help achieve Net Zero, which is a cornerstone of the Paris Agreement that 194 Parties (193 States plus the European Union) have signed up to.

Following from the study conclusion above, the recommendations for road administrations, who are PIARC members, and PIARC itself are as follows:

For those road administrations, which are not yet on board, no time should be wasted to seriously explore how ERS can help meet their road transport decarbonisation objectives;

Countries, even in Europe, should urgently step up to create national and international roadmaps for large-scale ERS deployment;

Meanwhile, road administrations should continue to work with ERS suppliers and other stakeholders to further develop and validate the various ERS technologies;

PIARC Member Countries should stay tuned and continue to share knowledge on ERS. ERS are evolving rapidly and collaboration is a win-win exercise; and

The PIARC Secretariat should step up to pro-actively promote ERS as a practical route to Net Zero to PIARC Member Countries and to vigorously engage with its collaborators and partners, such as the World Bank, OECD and IRF, on the TF’s ERS analyses and findings, and developing a joint roadmap to promote ERS deployment.

7. REFERENCES

[1] Blalack T, 2023. “Private Communication”, 2023.

[2] Chalmers University of Technology, 2019. “Large-scale implementation of electric road systems: Associated costs and the impact on CO2 emissions”, International Journal of Sustainable Transportation, ISSN: 1556-8318 (Print) 1556-8334 (Online), April 2019.

[3] CollERS, 2022. “Regulating Electric Road Systems in Europe - How can a deployment of ERS be facilitated?”, A discussion paper from the CollERS2 project, CollERS, ISBN XXXX, July 2022.

[4] Decisio, 2022. “Cost-effectiveness analysis Electric Road Systems (ERS) for the Netherlands”, March 2022. (Available: https://decisio.nl/wp-content/uploads/Cost-effectiveness-ERS-in -the-Netherlands-Decisio-March-2022.pdf.)

[5] DfT (Department for Transport), 2020. “Road Traffic Estimates: Great Britain 2019”, September 2020. (Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/916749/road-traffic-estimates-in-great-britain-2019.pdf.)

[6] DfT, 2021. ”Transport and Environment Statistics 2021 Annual Report”, May 2021.

[7] DGITM (Directorate General for Infrastructure, Transport and the Sea), 2021a. ”Système de route électrique Groupe de travail n°1 Décarboner le transport routier de marchandise par l’ERS, enjeux et stratégie”, July 2021. (Available: https://www.ecologie.gouv.fr/sites/default/files/GT1%20rapport%20final.pdf.)

[8] DGITM, 2021b. ”Système de route électrique Groupe de travail n°1 Décarboner le transport routier de marchandise par l’ERS, enjeux et stratégie”, July 2021. (Available: https://www.ecologie.gouv.fr/sites/default/files/GT1%20rapport%20final.pdf.)

[9] Dominguez G, 2017. “Societal cost of electrifying all Danish road transport”, EVS 2017 - 30th International Electric Vehicle Symposium and Exhibition, 2017.

[10] Dominguez G, 2018. “Modelling, Optimization and Analysis of Electromobility Systems”, PhD thesis.

[11] Environment and Climate Change Canada, 2022. “National Inventory Report 1990 – 2020: Greenhouse Gas Sources and Sinks in Canada”, 2022. (Available: https://publications.gc.ca/collections/collection_2022/eccc/En81-4-2020-3-eng.pdf.)

[12] Gutiérrez Gardos M, N Martínez and J Villarreal, 2020. “Making Transport Paris-Compatible: A Contribution To The Debate On Electromobility In The Automotive Sub-Sector Of Mexico”, Iniciativa
Climática de México, March 2020. (Available: https://www.climate-transparency.org/wp-content/uploads/2020/04/CT-Decarbonization-Transport-Mexico-DIGITAL.pdf.)

[13] Hall S, S Shepherd and Z Wadud, 2017. “The Innovation Interface: Business model innovation for electric vehicle futures”, January 2017.

[14] Hartwig M, 2020. “Stakeholder model for the financing and billing of electric road systems (ERS)”, IKEM Working Paper, 2020. (Available:

https://www.ikem.de/en/publikation/stakeholder-model-for-the-financing-and-billing-of-electric-road-systems-ers/.)

[15]Hartwig M, A Bußmann-Welsch and M Lehmann, 2020. "Models for the development of electric road systems in Europe", Zenodo, IKEM Working Paper No. 4, October 2020. (Available: https://zenodo.org/record/4327310.)

[16]Hasselgren B, 2020. "*Business models for electric road systems for heavy transport – report 4*. Trafikverket, 2020. (Available : http://urn.kb.se/resolve?urn=urn:nbn:se:trafikverket:diva-5053.)

[17]HEATCO, 2006. "HEATCO: Developing Harmonised European Approaches for Transport Costing and Project Assessment Deliverable 4 Economic values for key impacts valued in the
Stated Preference surveys", Contractor Report, European Commission, February 2006.

[18]INCIT-EV, 2020. "INCIT-EV Project: Innovative Electric Charging solutions to be tested in Europe", Press Release, 22 January 2020. (Available: https://www.incit-ev.eu/news-title/.)

[19]IPCC, 2013. "Climate Change 2013: The Physical Science Basis", ISBN 978-92-9169-138-8. (Available: https://www.ipcc.ch/site/assets/uploads/2018/03/WG1AR5_SummaryVolume_FINAL.pdf.)

[20]ITF (International Transport Forum), 2021. "Cleaner Vehicles: Achieving a Resilient Technology Transition", Policy Papers, No. 90, OECD Publishing, Paris. (Available: https://www.itf-oecd.org/sites/default/files/docs/cleaner-vehicles-technology-transition.pdf.)

[21]ITF, 2022. "Decarbonising Europe's Trucks: How to Minimise Cost Uncertainty", Policy Papers, No. 107, OECD Publishing, Paris. (Available: https://www.itf-oecd.org/sites/default/files/docs/decarbonising-europes-trucks-minimise-cost-uncertainty.pdf.)

[22]Karlsson A, 2022. "Electric drive and charging system for heavy vehicles: Solutions based on Electric Road Systems", PhD thesis. (Available: https://portal.research.lu.se/sv/publications/electric-drive-and-charging-system-for-heavy-vehicles-solutions-b.)

[23]Márquez-Fernández FJ, G Domingues-Olavarria, L Lindgren and M Alaküla, 2017. "Electric Roads: The importance of sharing the infrastructure among different vehicle types", IEEE Conference, Harbin, China, October 2017.

[24]Mastroviti G, 2023. "Private Communication", May 2023.

[25]Nordin L, 2020. "Life cycle assessments for electric road systems: Review and analysis of LCA studies", Statens väg- och transportforskningsinstitut, Linköping, 2020. (Available: http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1444976&dswid=-3065.)

[26]PIARC, 2018. "ELECTRIC ROAD SYSTEMS: A SOLUTION FOR THE FUTURE?", ISBN 978-2-84060-496-9.

[27]PIARC, 2021. “Collection of Case Studies”, Task Force 2.2 Electric Road Systems, PIARC, ISBN XXXX, April 2021.

[28]RISE, 2021. “Research & Innovation Platform for Electric Road Systems", Research Institutes of Sweden, ISBN: 978-91-89385-08-5, March 2021. (Available: http://www.diva-portal.org/smash/get/diva2:1534916/FULLTEXT02.pdf.)

[29]Ritchie H, 2019. “Cars, planes, trains: where do CO2 emissions from transport come from?”. (Available: https://ourworldindata.org/co2-emissions-from-transport)

[30]Sommer B, 2023, “Private communication”, 2023.

[31]Tongur S, 2018. “Preparing for takeoff – Analyzing the development of electric road systems from a business model perspective”, 2018.

[32]Tongur S and M Engwall, 2014. “The business model dilemma of technology shifts”, *Technovation*, vol 34, nº 9, p 525-535, Sept. 2014. (Available: https://doi.org/10.1016/j.technovation.2014.02.006.)

[33]Ueckerdt, F, C Bauer, A Dirnaichner, et al, 2021. “Potential and risks of hydrogen-based e-fuels in climate change mitigation”, Natural Climate Change, vol 11, p 384–393, 2021. (Available: https://doi.org/10.1038/s41558-021-01032-7.)

[34] Widegren F, H Helms, F Hacker, M Andersson, T Gnann, M Eriksson and P Plötz, 2022. “Ready to go? Technology Readiness and Lifecycle Emissions of Electric Road Systems A discussion paper from the CollERS2 project”. (Available: CollERS-2-Discussion-paper-1-Technology-assessment.pdf (electric-road-systems.eu).)

8. GLOSSARY

AC	Alternating Current
BET	Battery Electric Truck
BEV	Battery Electric Vehicle
CBA	Cost Benefit Analysis
CO_2	Carbon Dioxide
DC	Direct Current
DWPT	Dynamic Wireless Power Transfer
EMF	Electromagnetic Field
EMI	Electromagnetic Interference
ERS	Electric Road Systems
EV	Electric Vehicle
GHG	Green House Gases
HGV	Heavy Goods Vehicle
HIC	High Income Country
IPT	Inductive Power Transfer
LCA	Life Cycle Analysis
LMIC	Low to Middle Income Country
SAE	Society of Automotive Engineers
TC	Technical Committee
TF	Task Force
TRL	Technology Readiness Level
WG	Work Group

APPENDIX A – LITERATURE REVIEW LIST

#	Title	Author(s)	Date	Language
1	Electric Road Systems: a solution for the future?	TRL for PIARC	2018	English
2	Electric Road Systems: a solution for the future? Appendices	TRL for PIARC	2018	English
3	Electrical Highway Application	ZHENG Ze-dong, LIU Hao, LI Yong-dong, XU Zheng	2019	Chinese
4	Technical Progress of Electrified Highway and Feasibility Analysis of Its Application in China	HUANG Shao-xiong JIANG Hai-feng YANG Wen-yin LIU Zhi-qiang YUAN Min-min	2020	Chinese
5	Zero pollution tram and zero pollution electric road under positive energy band	ZHANG Zheng	2018	Chinese
6	Practice Strategy of Expressway Electrification Construction	SU Chuanxiang, LI Guohui	2018	Chinese
7	Dynamic Wireless Power Transfer System for Electric Vehicle to Simplify Ground Facilities - Power Control Based on Vehicle-side Information -	Katsuhiro Hata, Takehiro Imura, Yoichi Hori	2015	English
8	Maximum Efficiency in the Dynamic Wireless Charging Systems of Electric Vehicles	Nguyen Thi Diep, Nguyen Kien Trung, and Tran Trong Minh	2019	English
9	Dynamic Wireless Power Transfer Charging Infrastructure for Future EVs: From Experimental Track to Real Circulated Roads Demonstrations	Stéphane Laporte, Gérard Coquery, Virginie Deniau , Alexandre De Bernardinis and Nicolas Hautière	2019	English
10	Overview of ERS concepts and complementary technologies	Martin G. H. Gustavsson1,	2019	English

		Florian Hacker2 and Hinrich Helms3		
11	Real world experiences of ERS	Swedish-German collaboration	2020	English
12	Business models & stakeholders	Swedish-German collaboration	2020	English
13	National & EU strategies for ERS	Swedish-German collaboration	2020	English
14	Electric supply for ERS	Swedish-German collaboration	2020	English
15	Book of Papers from ERS conference 2020	Sweden	2020	English
16	Green Transport Strategy for South Africa: (2018-2050)	Department of Transport Republic of South Africa	2018	English
17	Global EV Outlook 2020	International Energy Agency (IEA),	2020	English
18	Regeringsuppdrag - Analysera förutsättningar och planera för en utbyggnad av elvägar	Trafikverket	2021	Swedish
19	TRV_Behov av laddinfrastruktur för snabbladdning av tunga fordon längs större vägar	Trafikverket	2021	Swedish
20	Decarbonising the UK's Long-Haul Road Freight at Minimum Economic Cost	D.T. Ainalis, C. Thorne, and D. Cebon	2020	English
21	A National Power Infrastructure for Charge-on-the-Move: An Appraisal for Great Britain	Doros Nicolaides; Richard McMahon; David Cebon; John Miles	2018	English
22	Power infrastructure requirements for road transport electrification - Chapter 6	Doros Nicolaides	2018	English
23	Electric Roads: Analyzing the Societal Cost of Electrifying All Danish Road Transport	Gabriel Domingues-Olavarría, Francisco J. Márquez-	2018	English

		Fernández, Pontus Fyhr, Avo Reinap, Mats Alaküla		
24	INDUCTIVE CHARGING THROUGH CONCRETE ROADS: A BELGIAN CASE STUDY AND APPLICATION	Anne Beeldens, Patrick Hauspie, Harold Perik	2016	English
25	Research on an EV Dynamic Wireless Charging Control Method Adapting to Speed Change	Linlin Tan, Wenxuan Zhao, Minghao Ju, Han Liu, Xueliang Huang	2019	English
26	A Corridor-Based Approach to Estimating the Costs of Electric Vehicle Charging Infrastructure on Highways	Emilia Suomalainen, François Colet	2019	English
27	Potential of Wireless Power Transfer for Dynamic Charging of Electric Vehicles	Luke Hutchinson, Ben Waterson, Bani Anvari, Denis Naberezhnykh	2019	English
28	FeAsiBility analysis and development of on-Road chargIng solutions for future electric vehiCles	INSTITUTE OF COMMUNICATION AND COMPUTER SYSTEMS	2019	English
29	WIRELESS CHARGING OF ELECTRIC VEHICLE	Asst Prof. Swapna Manurkar, Harshada Satre, Bhagyashree Kolekar, Pradnya Patil, Samidha Bailmare	2020	English
30	Electrification of Road Transportation - Implication for the Electrification System	Maria Taljegard	2019	English
31	Report draft from project Phase 1 Slide-in Electric Road System Conductive project report	Oscar Olsson	2013	English
32	Report draft from project Phase 1 Slide-in Electric Road System Inductive project report	Oscar Olsson	2013	English
33	Large-scale implementation of electric road systems: Associated costs and the impact on CO2 emissions	M. Taljegard, L. Thorson, M.	2019	English

		Odenberger & F. Johnsson		
34	Electric Roads: The importance of sharing the infrastructure among different vehicle types	Francisco J. M´arquez-Fern´andezy, Gabriel Domingues-Olavarria, Lars Lindgren and Mats Alak¨ula	2017	English
35	Abschlussbericht zum Förderprojekt ENUBA	Siemens AG	2012	German
36	ENUBA2	Siemens AG	2016	German
37	Models for the development of electric road systems in Europe	IKEM - Hartwig | Bußmann-Welsch | Lehmann	2020	English
38	How to decarbonise the French freight sector by 2050	Transport & Environment - Fedor Unterlohner	2020	English
39	Regulations and Standards for clean Trucks and Buses	International Transport Forum	2020	English
40	Trucking into a Greener Future	Cambridge Econometrics	2018	English
41	A new era of sustainable road freight transport	Siemens AG	2020	English
42	電気自動車のモーションコントロールと走行中ワイヤレス給電（Motion Control and Dynamic Wireless Power Transfer for Electric Vehicles） Sec.1, Ch.3, Vol.2 高速道路での走行中給電（Technology of Dynamic Wireless Power Transfer in Expressway）	Kaoru Tanaka, Azuma Shinichiro	2019	Japanese

43	電気自動車のモーションコントロールと走行中ワイヤレス給電（Motion Control and Dynamic Wireless Power Transfer for Electric Vehicles） Sec.3, Ch.3, Vol.2 走行中給電に対応したワイヤレスインホイールモータ（Wireless In-Wheel Motor with Dynamic wireless Power Transfer）	Gunji Daisuke, Fujimoto Hiroshi	2019	Japanese
44	電気自動車のモーションコントロールと走行中ワイヤレス給電（Motion Control and Dynamic Wireless Power Transfer for Electric Vehicles） Sec.5, Ch.3, Vol.2 電界結合方式による EV 走行中給電技術（Dynamic Wireless Power Transfer by Capacitive Coupling）	Satoshi Tsukamoto, Naoki Sakai, Takashi Ohira	2019	Japanese
45	電気自動車のモーションコントロールと走行中ワイヤレス給電（Motion Control and Dynamic Wireless Power Transfer for Electric Vehicles） Sec.7, Ch.4, Vol.2 ハイパワー接触式走行中充電技術（High Power Dynamic Power Charging System）	Tajima Takamitsu	2019	Japanese
46	StratON Bewertung und Einführungsstrategien für oberleitungsgebundene schwere Nutzfahrzeuge	Florian Hacker, Ruth Bmlank, Wolf Görz, Tobias Bernecker, Jonas Speiser, Felix Röckle, Markus Schubert, Gregor Nebauere	2020	German (Executive Summary in English)
47	Oberleitungs-Lkw im Kontext weiterer Antriebs- und Energieversorgungsoptionen für den Straßengüterfernverkehr	Sven Kühnel, Florian Hacker, Wolf Görz	2018	German (Executive Summary

				in English)
48	Concept d'Autoroute Electrique	Ludovic Fragnol	2017	French
49	L'autoroute électrique pour la réduction des émissions du transport routier	VINCI (Pierre Odermatt – COFIROUTE, Pierre Delaigue – LEONARD, Arnaud Banner – OMEXOM, Didier Deschanel – EUROVIA).	2019	French
50	Economic Analysis of the Dynamic Charging Electric Vehicle	Seungmin Jeong, Young Jae Jang, Dongsuk Kum	2015	English
51	ANALYSIS OF WIRELESS AND CATENARY POWER TRANSFER SYSTEMS FOR ELECTRIC VEHICLE RANGE EXTENSION ON RURAL HIGHWAYS	Thomas Navidi	2016	English
52	A feasibility study investigating a possible future of road transportation	Archit Singh	2016	English
53	Plataformas reservadas para autobuses urbanos e interurbanos: conducción eléctrica, autónoma y conectada	César Bartolomé, Rafael Rueda	2020	Spanish (abstract in English)
54	A Review of Dynamic Wireless Power Transfer for In-motion Electric Vehicles	Kai Song, Kim Ean Koh, Chunbo Zhu, Jinhai Jiang, Chao Wang and Xiaoling Huang	2016	English
55	Development of inductive charging pavement for electric buses in urban areas	Mai Lan Nguyen, Pierre Hornych, Sergio Pérez, Eanna Curran	2015	English
56	Design of On-Line Electric Vehicle (OLEV)	N.P. Suh, D.H. Cho, C.T. Rim	2011	English

57	Gesamtkonzept klimafreundliche Nutzfahrzeuge / An Overall Approach to Climate-Friendly Commercial Vehicles	Federal Ministry of Transport and digital Infrastructure	2020	German (English available)
58	Maturity of power transfer technologies for electric roads systems	Martin G. H. Gustavson, Magnus Lindgren	2020	English
59	Study and evaluation of technologies for ERS	Prof. Brenna Morris, Prof. Collina Andrea, Prof. Facchinetti Alan, Ing. Michela LongoIng. Somaschini Claudio, Dott. Zanzottera Luca	2020	English
60	Traffic safety and infrastructure interaction	Prof. Lorenzo Domenichini	2020	English

APPENDIX B – CASE STUDIES

B.1 Alstom-Volvo Slide-In – Sweden

Brief Description	The Slide-In conductive project was a proof of concept managed by Volvo GTT and partly financed by the Swedish Energy Agency (S.E.A.) through the program Fordonsstrategisk Forskning och Innovation (FFI). The objective of the project was to demonstrate the efficiency of a ground-based feeding system for power supply electric trucks in motion. Volvo GTT was in charge on the vehicle part of the ERS system and Alstom responsible of the infrastructure part.
Budget	Overall budget: ~ € 3 900 000 Funding (S.E.A.) : € 1 700 000
Period	2011-2016
Technology Assessment	
ERS technology (type, provider, TRL)	The Alstom's ERS system was a conductive solution based on Alstom's APS system, which is a proven ground-based solution in the railway industry. This system was demonstrated at the Hallered test track in Sweden and based on that, a TRL 5-6 is estimated.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The system consists of three conductive rails which are placed in parallel in the road. The system was designed to minimise implications on road performance and maintenance tasks. Rails were segmented for safety, so that only minimal lengths are electrified at any one time. Live polarity is applied to a virtual zone in the front and rear of the vehicle only when a vehicle at a minimum speed of 60 km/h is detected. As a vehicle passes over the rails, its presence is detected, and an inverted pantograph automatically lowers from the vehicle to contact the rails. Power is then delivered to the vehicles on-board battery charger. The on-board systems include foreign and living object detection capabilities, if obstructions are detected the pantograph automatically retracts. Between each segment (22 m long) a roadside power switching box is required to deactivate the previous segment and activate the next. Additionally, roadside transformers are required every km. This system has been designed for use with heavy duty vehicles; however, it is possible for all types of road vehicles to utilise. The system operated at 750 VDC and 180 Amps. Rated power was limited to 126 kW and 97% power transfer efficiency was achieved.

	Installation: An 80 mm deep and 500 mm wide trench was excavated to place the rails. The depth of this trench corresponds to the road surface layer depth. Rails were placed inside a rubber housing, and the entire installation was secured with an asphalt adhesive. Smaller lateral trenches were required for each segment so that connection to power switching boxes and inverters were established. Maintenance: the system itself did not require maintenance during its lifetime.
Receiving/vehicle's system (type, provider, ERS equipment)	The ERS system on the vehicle included the pick-up system for collecting power from the ground, the radio emitter (used to provide presence signal to the ground and to calculate vehicle speed), a 24 VDC source for the pick-up control and electronic devices. Two different trucks were trialled during the project. The first one was equipped with a resistor bank for power dissipation. The second one was a Volvo hybrid truck where electricity supplied by ERS was directly used by the electric drivetrain. For this demo project, various versions of pick-up systems were experimented. The most prominent one was designed by Volvo. The overall weight of the receiver was about 150 kg.
Use case (length, vehicle speed range, interoperability, cybersecurity)	A 300 m test in Sweden to validate the concept of ERS charging. Vehicles travelled up to 90 km/h.
Current developments	Since 2017, Alstom has been developing alone a new version of ERS which is capable of delivering up to 400 kW of power (sufficient power for traction as well as for charging the on-board batteries). The new system is improved in terms of safety, robustness, and interoperability between vehicles. It would also enable an easier integration with the road infrastructure.
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	Volvo GTT, a Swedish passenger cars and trucks manufacturer; ALSTOM, a French railway solutions manufacturer; Vattenfall, a Swedish energy supplier the Swedish Transport Administration; Svenska Elvägar, a Swedish expert in ERS; Lund University, providing ERS simulation system; and Royal Institute of Technology.
Infrastructure provider costs (cap., oper., maint.)	Capital costs: €1 million per lane per km (including materials, labour, grid connections and transformers) Added cost to the vehicle was estimated at €3,000.

User costs	N/A
Cost Benefit factors	N/A
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	N/A
Proposed subsidies	N/A
ERS policies	N/A
Policy/legislation recommendations	N/A
Key Findings	
The feasibility to use an adapted Alstom's APS system for road application was demonstrated via this proof of concept. A power transfer efficiency of 97% during dynamic charging (up to 90 km/h) was demonstrated for the APS system.	

B.2 ENRX (IPT Technology/ Bombardier Primove) – Sweden/Belgium

Brief Description	The Slide-In inductive project was a proof of concept managed by Volvo GTT and partly financed by the Swedish Energy Agency (S.E.A.) through the program Fordonsstrategisk Forskning och Innovation (FFI) – see also 0: B.1 Alstom-Volvo Slide-In – Sweden. The objective of the project was to demonstrate the efficiency of a ground-based feeding system for power supply electric trucks in motion. Scania was in charge on the vehicle part of the ERS system and Bombardier was responsible for the infrastructure part. References to a bus demonstration in Lommel Belgium are also made as the system combines static and dynamic charging. The aim was not only to test the charging efficiency of the system, but also the verify safety regulations and durability of the road structure.
Budget	Overall budget: ~ € 3,900,000 Funding (S.E.A.) : € 1,700,000
Period	2011-2016
Technology Assessment	
ERS technology (type, provider, TRL)	Bombardier firstly developed Primove system in 2008/2009 but since then, the brand and the assets have been transferred to ENRX. Through the years the company has collaborated with a number of vehicle manufacturers, research institutes and local governments in Europe to improve and develop further the system. IPT Primove is a wireless system based on the inductive method. It was originally designed for static applications, but it has been developed to offer dynamic capabilities as well. A number of demonstrations have been performed and therefore, at the time of the Slide In initiative a TRL 5-6 is estimated.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The Primove highway system is inductive charging with primary windings installed in 20 m segments. Segments are powered when an authorized and primove-equipped vehicle is over the segment, is able to accept energy, and is moving 50 km/h or faster. The Primove system is connected directly to the medium voltage level grid connection (10 kVAC). The power supply steps down the voltage level to 400 VAC and then, it is being converted to 750 VDC. The underground infrastructure is supplied by power which is being converted to AC at 20 kHz.

	Installation: two methods were explored where inductive coils were installed in the concrete structure and in the asphalt layer of the road. Concrete - The installation started with removing the asphalt pavement and base layer of the existing road were over a depth of 200 mm and a width of 4.5 m. The modules were placed on the existing base layer and tie-bars were added at the side. No dowels were used at the transverse joints. Glass-fiber tie-bars were used in order to avoid magnetic interference. An adhesion layer was also poured on the modules and the whole was covered with a concrete layer varying from 200 mm thick next to the modules to 50 mm thick above the modules. Asphalt – A similar approach to that of the concrete. However, special attention was needed towards the temperatures during construction (e.g. asphalt versus max temperature of the cable). The lanes at the side of the modules were first filled with dense asphalt and consequently a top layer was poured over the total width of the pavement. Also, special care by extra shielding was considered, including at the side of the road, to ensure that no electromagnetic field interferes with the environment. Shielding was achieved using aluminium plates of 300 mm thickness.
Receiving/vehicle's system (type, provider, ERS equipment)	The system is compatible with most vehicle types and can be retrofitted, including passenger cars, buses, freight vehicles, trams and trains. Initial developments required the vehicle's system to lower its position towards the ground system for reducing the air gap between the transmitting and receiving components (static charging for heavy duty vehicles); but this is not necessary at recent developments. The permission to use primove and collecting fees for receiving primove energy is regulated by transponders on primove vehicles, similar to systems commonly used on toll highways in many countries. For the Belgian use case, an electric bus was used in the demonstration. The power transfer rate of the system was 100 kW. The size of the vehicle's system was about 2 x 1 m (2 m^2). For the Slide-in project, power transfer was 120 kW to meet the power demand of the tested vehicle. Power transfer up to 200 kW has been demonstrated in other system trials. Primove systems achieved 90% power transfer efficiency or higher, measured from and including the wireless power converter to vehicle onboard electronics.
Use case (length, vehicle speed range,	The system has been demonstrated around the world including Germany, Sweden and Belgium. Most of the trials and commercial

interoperability, cybersecurity)	operations, including buses, passenger cars, etc., have been focused on static charging rather than on dynamic charging. A semi-dynamic approach was tested in Lommel Belgium with a bus, along a 125 m section. The aim was not only to test the charging efficiency of the system, but also the verify safety regulations and durability of the road structure. The Slide-In project was focused entirely on dynamic charging for heavy duty vehicles. The test track facility has a total length of 300 m of which 4 highway segments of 20 m each were built for dynamic transmission.
Current developments	In January 2021, IPT Group BV acquired wireless charging technology from Bombardier Primove GmbH. IPT Group BV is 100% owning IPT Technology GmbH which is a global manufacturer of wireless charging and electrification solutions applied in industrial and e-mobility applications since 1996 In May 2022 IPT Technology GmbH has been acquired from IPT Group BV by Arendals Fossekompani from Norway. By combining the technology and expertise of both companies (Bombardier on light duty vehicles and buses, IPT on light duty vehicles, heavy duty buses and vessels, and industrial solutions, e.g. cross belt sorters, EMS system, skillets, AGVs, Robotics), ENRX is expecting to strengthen its market position and accelerate its business planning. AFK is a green-tech investment company that owns energy- and technology-related companies which enable the transition to a green economy. At the same time, AFK has established a new group, ENRX, which will own both IPT Technology Gmbh and the Norwegian induction heating company EFD Induction. Per March 27th 2023 Industrial induction heating expert EFD Induction and inductive charging and power supply innovator IPT Technology have formed ENRX. With an offer ranging from induction heating to wireless inductive charging and contactless power supply, ENRX is an international powerhouse for equipment and systems based on induction.
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	The project is managed by Volvo GTT and partly financed by the Swedish Energy Agency through the program Fordonsstrategisk Forskning och Innovation (FFI). Volvo GTT is also together with Alstom responsible for the development of a conductive energy transfer solution while Scania and Bombardier together are responsible for the development of the inductive energy transfer solution. Additional partners in the project are Vattenfall, the Swedish Transport Administration, Svenska Elvägar, Lund University and the Royal Institute of Technology (KTH).

Infrastructure provider costs (cap., oper., maint.)	N/A
User costs	N/A
Cost Benefit factors	N/A
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	Increasing global pollution and with Peak-oil approaching or possibly even reached calls for new means of transport, non-dependent on fossil fuels. The energy storage capacity of the batteries is not enough for long-distance transport of EVs and even output power could be a limiting factor. Larger batteries are not necessarily the solution since they require a longer time to recharge or access to charging stations with extreme charge capabilities. Moreover, the battery is a substantial part of the total cost and weight of the EV, which reduces the cargo load capacity, and thereby also the monetary gain for the otherwise less energy-demanding vehicle.
Proposed subsidies	N/A
ERS policies	ERS should be initially focused on short distance sections of road with high traffic flow. Such sections are often to be found in a fixed traffic relationship, a route, e.g. between a dry port and a shipping port, or between production and distribution facilities. This improves utilisation of the system and returns a positive return on investment.
Policy/legislation recommendations	Cooperation in the EU should be initiated to standardize the various input parameters in the system to allow traffic across borders when the system reaches the higher level of deployment.
Key Findings	
System	Bombardier's Primove system was demonstrated at 120 kW power transfer rate achieving an overall efficiency of more than 90%.
Infrastructure	It is likely that new routines and new construction equipment are needed to perform the maintenance of the road with regards to the new electrical installations in the road segment. In order to verify the methods

	for maintenance, both a section of road and the machines must be developed and built. Rutting effect, as a result from several vehicles driving in the same track, is considered to be greater if the route is electrified.
ERS policies	Standardisation is important to allow cross-border utilisation. Electrical safety laws, environmental laws as well as land accesses may impose barriers to ERS implementation. Some of these questions may be easy to solve, but other issues require a real case to be tested and evaluated against the legislation. Therefore, it is important to early analyse where legal barriers may exist and start the legal testing based on a real scenario.

B.3 CIRCE – VICTORIA - SPAIN

Brief Description	The VICTORIA Project aimed to develop the first dynamic inductive load system for a bus line in Spain through which buses are charged wirelessly on the stop and while moving. CIRCE, a research institute in Spain, was responsible for the design and manufacture of dynamic induction equipment (primary, secondary, power electronics and management).
Budget	€3.7 million
Period	Sep 2016 – Dec 2017
Technology Assessment	
ERS technology (type, provider, TRL)	The technology provider was CIRCE, a technology centre funded in 1993, based in Spain, and focused on innovations in the energy and environment sector. They have developed and validated EV charging systems (conductive) offering slow, rapid and ultra-rapid charging. They have made substantial progress with wireless induction charging. Their system enables both static charging and motion charging. Wireless charging has been demonstrated in a number of experiments and real-world demonstrations and therefore, a TRL 4-5 is estimated.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	CIRCE developed a wireless power transfer (WPT) system for static, stationary and dynamic charging. Good shielding was obtained by using large receiving coils and smaller transmitting coils in the ground. The system operates at 50 kW power transfer rate. It is supplied by 650 V DC and it produces DC output power for the on-board battery which is rated 285-400 V DC and 150 Amps. Wireless power transfer efficiency of 91% was demonstrated across an air gap of 15-25 cm. Taking into consideration all parts of the system, then a power transfer efficiency of 80% was demonstrated. The system can be integrated with static battery storage systems.
Receiving/vehicle's system (type, provider, ERS equipment)	The receiving system is larger than the transmitting system which reduces electromagnetic interference. The dimensions of the receiving coil are 0.6 X 2.5 m whereas the dimensions of the transmitting coil are 0.6 X 0.8 m. Relatively high misalignment is tolerated, up to 30% of the coil surface. The trialled vehicle was a Gulliver U520 ESP/LR fully electric bus with self-guided control to ensure proper speed and misalignment alongside the ERS infrastructure.

Use case (length, vehicle speed range, interoperability, cybersecurity)	The project was tested on an electric bus operating in the city on line 16, making Malaga the first city in Spain to incorporate sustainable mobility into its public transport system. The bus was adapted by a triple charging technology with which it can be charged by conventional method when stopped at the bus station at night (using charging points), it can be partially charged at an inductive station at bus stops and it can be charged on the go along its route. The ERS systems was 100 m in length and consisted of 8x separate 50 kW coils.
Current developments	N/A
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	Circe; Universidad de Malaga; Empresa Malaguena de Transportes, S.A.M.; Isotrol; OMEGA S.A.; mc2; Mansel; Conacon; Aicia.r
Infrastructure provider costs (cap., oper., maint.)	N/A
User costs	N/A
Cost Benefit factors	Partial recharging increases the range of e-bus operations which significantly improves the efficiency and profitability of vehicles. This allows the use of relatively small on-board batteries which are most cost-effective than the big batteries required for overnight charging.
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	Reduce CO_2 emissions and move towards sustainable transportation.
Proposed subsidies	N/A
ERS policies	Improves range of EVs; reduces battery weight and increases battery life; reduces capital costs of EVs.
Policy/legislation recommendations	To investigate how smart inductive charging infrastructure can facilitate full EV integration in the urban road systems while improving customer acceptance and perceived practicality.
Key Findings	

The technology was demonstrated in a relevant environment achieving an overall efficiency of more than 80%. The difference coil sizes resulted in significant benefits against electromagnetic interference and misalignment tolerance. Also, the integration of the system with static battery storage was found to be advantageous for maximising the use of renewable energy sources for EV charging.

B.4 Electreon – Tel Aviv

Brief Description	Electreon Wireless Ltd are an Israeli start-up company, founded in 2015, who aim to bring wireless dynamic charging to market for commercial bus operators, passenger cars and trucks. This is the first demonstration of Electreon's system on a public urban road. It's a system along an existing bus route in Tel Aviv, Israel. Installation and testing started in 2018. The demonstration started in Sep 2020.
Budget	N/A
Period	Since 2018
Technology Assessment	
ERS technology (type, provider, TRL)	Electreon Wireless Ltd are an Israeli start-up company, founded in 2015, who aim to bring wireless dynamic charging to market for commercial bus operators, passenger cars and trucks. A TRL 5-6 is estimated for Electreon's technology.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The company has developed a 20 kW modular system which it plans to take forward for further development to reach a power transfer rate of 45 kW. The system utilises electromagnetic coupling between primary coils embedded beneath the road surface and a secondary coil fixed to the vehicle underside. The 20 kW system is able to operate at 88-90% efficiency across an air gap of 24-27cm. Installation: tests have shown that 1 km of coils can be laid, at a depth of 8 cm, in one working day, this does not include establishing roadside transformers and communication systems. It should be noted that a depth of 8 cm was chosen to ensure that planning activities and routine maintenance can still be carried out on the pavement without interfering with the system.
Receiving/vehicle's system (type, provider, ERS equipment)	Urban e-bus shuttle charged by the first wireless electric road system in Israel. Operated by Dan Transportation.
Use case (length, vehicle speed range, interoperability, cybersecurity)	600 m long electric road, part of a 2 km route between train station and Tel Aviv University in Israel. In addition to dynamic charging, the e-bus was also charged statically at the terminal bus stops for complementary charging
Current developments	Future demonstrations include an e-bus shuttle, charged by Electreon's wireless electric road system in Germany. The bus operator is Karlsruhe

	Transport Company, VBK. The wireless electric road system will power a bus line that will connect the new EnBW training centre in Karlsruhe's Rhine harbour to the local public transport system. The project started in Sep 2020 and it is still in pre-deployment status. Also, see two additional Electreon use cases below (0: B.5 Electreon – Smartroad Gotland – Sweden and 0: B.6 Electreon – Italy).
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	The project is part of the pilot carried out in cooperation with the Tel Aviv-Yafo Municipality, Dan Bus Company and Ayalon Highways, funded by the Israel Innovation Authority and the Ministry of Transportation.
Infrastructure provider costs (cap., oper., maint.)	The final system is anticipated to cost less than €1 million per lane per km.
User costs	N/A
Cost Benefit factors	Electric road systems within cities, enable on-going operation of EVs, reduction in battery sizes, and potentially charging of other vehicles using the same infrastructure.
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	N/A
Proposed subsidies	N/A
ERS policies	N/A
Policy/legislation recommendations	The coil infrastructure is not visible as all charging points along the dynamic section are buried below the road surface. This configuration allows installation in any location and provides a complete solution to the Tel Aviv Municipality's vision of efficiently electrifying transportation in the city without adding visual elements taking valuable space.
Key Findings	
It was found that the system works continuously, the coils transmit energy both at the terminal when the bus is standing and while traveling, and the remote control and monitoring system also functions well.	

Further trials and tests are now expected to take place in order to test the performance of the system under varying operating conditions, including different loads and operating schedule.

At the end of the experimental phase, the electric bus is expected to be used as a regular public transportation line that will be operated by Dan to transport students while being charged solely through Electreon's technology.

B.5 ELECTREON – SMARTROAD GOTLAND – SWEDEN

Brief Description	This is an Electron demonstration for inter-city road system suitable for electric buses and electric heavy duty trucks. Electreon coils for wireless power transfer were used to build an ERS of 1.6 km long, along a 4.1 km route between Visby Airport and the city of Visby on Gotland Island, Sweden.
Budget	N/A
Period	2018 – 2020
Technology Assessment	
ERS technology (type, provider, TRL)	Electreon Wireless Ltd are an Israeli start-up company, founded in 2015, who aim to bring wireless dynamic charging to market for commercial bus operators, passenger cars and trucks. A TRL 5-6 is estimated for Electreon's technology.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The company has developed a 20 kW modular system which it plans to take forward for further development to reach a power transfer rate of 45 kW. The system utilises electromagnetic coupling between primary coils embedded beneath the road surface and a secondary coil fixed to the vehicle underside. The 20 kW system is able to operate at 88-90% efficiency across an air gap of 24-27cm. Installation: tests have shown that 1 km of coils can be laid, at a depth of 8 cm, in one working day, this does not include establishing roadside transformers and communication systems. It should be noted that a depth of 8 cm was chosen to ensure that planning activities and routine maintenance can still be carried out on the pavement without interfering with the system.
Receiving/vehicle's system (type, provider, ERS equipment)	An electrified 40 tonne truck and an electrified bus are used as demonstration vehicles. The truck was tested on a part of the route since March 2020 and full-scale operation started during the autumn of 2020. The 40 tonne truck was equipped with five 20 kW wireless modules (100 kW total). According to the latest company news, Jan 2021, an average power transfer rate of 70 kW from the road to the receivers and into the truck's battery up to 60 km/h travelling speeds was achieved during the demonstration.
Use case (length, vehicle speed range, interoperability, cybersecurity)	1.6 km long electric road, part of a 4.1 km route between the airport and town centre of Visby on Gotland Island, Sweden.

Current developments	See following section (0: B.6 Electreon – Italy).
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	Trafikverket (Sweden's Transport Administration); EiTECH (electricity construction company); Matters Group (sustainability consultants); Gotland Ring (race and test track in Sweden); RISE (Research Institutes of Sweden).
Infrastructure provider costs (cap., oper., maint.)	The final system is anticipated to cost less than €1 million per lane per km.
User costs	N/A
Cost Benefit factors	A lot will depend on the final commercial cost of the system and the industry, which would have to agree on a unified solution. The potential cost savings from size reductions of the on-board battery is a significant positive outcome of ERS; at least for applications where routes are repeatable.
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	N/A
Proposed subsidies	N/A
ERS policies	N/A
Policy/legislation recommendations	N/A
Key Findings	
Successful completion of this demonstration was a significant milestone for Electreon, which is on track to meet the preliminary requirements for applying for the large-scale pilot of the construction of a wireless Electric Road planned by the Swedish Road Administration (Trafikverket) of approximately 30 kilometres (18.7 miles).	

B.6 Electreon – Italy

Brief Description	This is a pre-development use case of a wireless electric road system that will power a one-kilometre section of road, adjacent to the Highway A35 toll road in Lombardy, Italy. The use case currently involves an IVECO electric bus, a Fiat 500e car, and a Jeep Renegade. A light good vehicle and a heavy good vehicle are also planned to be tested.
Budget	N/A
Period	2021 - 2023
Technology Assessment	
ERS technology (type, provider, TRL)	Dynamic Wireless Power Transer system based on Electreon's system. Electreon Wireless Ltd are an Israeli start-up company, founded in 2015, who aim to bring wireless dynamic charging to market for commercial bus operators, passenger cars and trucks. By the end of this recent demonstration, a TRL 7 would have been achieved.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	In January 25, 2021, Electreon announced the completion of the wireless charging testing in Gotland, Sweden (see 0: B.5 Electreon – Smartroad Gotland – Sweden, which tested long-haul electric trucks. According to Electreon, an average power transfer rate of 70 kW from the road to truck's receivers was achieved. The vehicle was equipped with five (x5) 20 kW wireless modules (100 kw in total). At this stage, there is no further information about the expected power transfer rate of the system in Italy but is expected that the system will achieve power transfer rates of 25 kW per coil. Throughout the demonstration, it is planned to move towards 30/35 kW power transfer rates per coil. The transmitting coils will be buried in the road and supplied through an 800 V DC line. A power substation is also anticipated to convert the AC power from the medium-voltage grid into suitable DC power. The total system is currently sized at 1 MW. One of the project partners, Mapei, is an international company specializing in additives for concrete and bitumen. Mapei will develop asphalts that can improve the efficiency of the wireless power transfer. The estimated global efficiency of the ERS system is 85% AC-DC, when comparing the AC power at the medium voltage grid to the DC power achieved at the receiving coil onboard of the vehicle.
Receiving/vehicle's system (type,	It is expected that multiple receiving coils will be mounted under the trialled vehicles to ensure that substantial energy is transferred. It is

provider, ERS equipment)	expected that one receiving unit is needed for cars, 3 units for the electric bus, and around 5 units for the heavy good vehicle. Electreon is responsible for the inductive-magnetic design of the receiving system, whereas the vehicle manufacturers Stellantis and CNH Industrial (IVECO) are responsible for the on-board power electronics.
Use case (length, vehicle speed range, interoperability, cybersecurity)	The A35 demonstration in Italy will have length of 1 km and the heavy duty vehicles will be tested over a travelling speed of 100 km/h. A section of the ERS track will be curved and wireless power transfer at 70 km/h will also be tested. The use case will also investigate interoperability between cars, light good vehicles, buses, and heavy good vehicles. The trial will also involve tests for cybersecurity and 5G technologies.
Current developments	ERS infrastructure under construction
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	Road operator (BreBeMi), Vehicle manufacturer (Abb, Stellantis, CNH Industrial - IVECO), Energy systems and technology solutions (Prysmian), Telecommunication companies (TIM), and Concrete and bitumen companies (Mapei).
Infrastructure provider costs (cap., oper., maint.)	N/A
User costs	N/A
Cost Benefit factors	N/A
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	Extension on the driving range for light and heavy vehicles, lighter batteries, integration of renewable energies in the DC power supply system. All of which can play an impact towards a more decarbonised transport sector in the future.
Proposed subsidies	N/A
ERS policies	N/A

Policy/legislation recommendations	N/A
Key Findings	
No findings are recorded as this use case is at the stage of pre-development (i.e. track development).	

B.7 ELONROAD – EVOLUTION ROAD - SWEDEN

Brief Description	EVolution Road has been commissioned by the Swedish Transport Administration to build a test and demonstration site for electric roads. The purpose is to gain more knowledge about electric roads and explore the potential of electric roads as a complement in a future fossil-free transport system.
Budget	€9.4 million
Period	2019 - 2022
Technology Assessment	
ERS technology (type, provider, TRL)	ElonRoad AB is a research organisation that has developed, in partnership with Lund University, a conductive rail solution for static and dynamic vehicle charging. This technology allows the power to be transmitted between a rail on top of the road and the vehicle, via a pic-up installed under the vehicle. This provides an efficient power transfer from the rails to the vehicle for both propulsion and battery charging The system is currently under development and therefore, a TRL 5-6 is estimated.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	A rail consisting of short grounded segments arranged along a single track. Every other segment is switched on only when a car passes over it and the car ID is recognised by the system, in order to improve safety and to properly bill the system user. The system is mounted (by bolts and bitumen adhesive) on top of the road surface (essentially creating a longitudinal speed bump in the centre of the carriageway), at maximum 5 cm above the road. A prototype snow plough has been developed and tested. It should be noted that the system has a grounded strip which prevents current from leaking from any charged sections. The current system is capable of delivering 300 kW of power, at 600 VAC. Power transfer efficiency of 97% has been achieved during static and dynamic charging.
Receiving/vehicle's system (type, provider, ERS equipment)	Once an electrified segment is sensed, three pick-ups (inverted pantographs) extend from the vehicle underside to make contact with the rail to draw power. Once the vehicle has passed over the section the rail is automatically switched off.
Use case (length, vehicle speed range,	Early deployments included a system deployed along a street in the city of Lund in the Skåne Region, Sweden. Operation commenced in June 2020 and an electrified bus was used as the demonstration vehicle. A

interoperability, cybersecurity)	power transfer rate of 150 kW was achieved when the bus was stationary and while driving. The system is also being trialled on a 210 m purpose-built test track in Lund, Sweden. The system has been developed for use with a Nissan Leaf. While it is capable of delivering a large power supply it is designed for lower speeds in an urban setting. As part of the Evolution road demonstration, a 1 km electric road has been built with two kinds of rail system: the first one is on top of the road and the second one is submerged into the road. Charging tests are in progress for the first approach whereas installation for the second approach (i.e. rails submerged into the road) are expected to start in March 2021.
Current developments	The installation of the electric road test site began in May 2020 and the project will run until 2022.
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	The Elväg Syd consortium, which includes state, educational and private sector players use technology developed by one of the consortium members, Elonroad. Other members are Innovation Skåne coming on board as project manager, Kraftringen Energi, Lund municipality, Lund University of Technology, Skånetrafiken, Solaris Sverige and Sweden's National Road and Transport Research Institute (VTI). Main project sponsor is Sweden's Transport Administration (Trafikverket).
Infrastructure provider costs (cap., oper., maint.)	Infrastructure costs: €600k - €1.5 million per lane per km Pick up costs: €5,000 for trucks and €2,000 for passenger cars
User costs	N/A
Cost Benefit factors	N/A
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	Charging the vehicle while driving eliminates the need to stop to charge the batteries, which saves time. Electric roads also reduce the vehicle's battery size significantly. This leads to advantages such as less

	environmental impact and lighter vehicles that allow you to carry more goods or passengers.
Proposed subsidies	N/A
ERS policies	In the current phase, knowledge is obtained regarding technology, operations, usage, maintenance, environmental impact and more.
Policy/legislation recommendations	N/A
Key Findings	
Testing of the Elonroad is currently under the process. The key element of the system are short electric segments which are turned on when there is an upcoming vehicle. Designers claim that they are able to remove the snow once special snowploughs are used. In addition, they report mitigation of the electricity leaking problem once the nearby area is filled with salt water. In addition to the more tested solution where the electric rails are attached on the pavement, the alternative is that the electric rails are embedded into the pavement surface. The latter approach, which has not been tested yet by Elonroad, it could potentially improve traffic safety, winter maintenance and driving stability, especially for motorcycles and lighter vehicles.	

B.8 Evias Elways – eRoad Arlanda - Sweden

Brief Description	Elways technology started in 2009 to provide conductive feeding of vehicles in motion. Elways technology is commercialised by Evias. The conductive technology was deployed in a 2 km stretch of public road in Stockholm. Operation commenced in April 2018. One electrified 18 tonne truck performing shuttle operations between Arlanda Cargo Terminal and the Rosersberg logistics area was trialled in the demonstration.
Budget	N/A
Period	2018 – 2020
Technology Assessment	
ERS technology (type, provider, TRL)	Elways AB, in partnership with a number of organisations and government bodies, have developed a conductive dynamic solution that uses electrified rails inserted into the road. Power transfer from the rail to the vehicles on-board systems requires the use of movable pick-up arm, located at the rear of the vehicle. The technology has been demonstrated in test tracks and public roads, and therefore, a TRL 7-8 is estimated.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	Rails are segmented; meaning only the section the vehicle is travelling over is electrified. Furthermore, the actual conductive contact points are located at the bottom of the rail, approximately 6 cm deep. This means that the top of the rail is not charged. Additionally, the rails are only electrified if the vehicle is travelling above a certain velocity. If the vehicle speed drops below this threshold the system will deactivate. The system operates up to 200 kW at 400-800 VAC and 250 Amps. Power transfer efficiency was measured between 85-95% at vehicle speeds between 60-100 km/h. Installation: the installation process is split into a number of stages. Firstly, a trench along the total length of the system is excavated. The segmented rails are inserted into the trench, secured and connected with roadside cables. Prefabricated concrete blocks are used in either side of the rail and the entire trench is then overlaid with asphalt. Each segment is supplied with electricity from a low voltage AC cable, 400-800V. Electric inputs are controlled via a fast switch box. The low voltage cable is connected a medium voltage cable (24-36 kV), both cables are laid side-by-side. A transformer station, located at the roadside at 1-2 km intervals, facilitates transmission between the medium and low voltage cables. The medium voltage cable is connected to the high voltage grid transformer every 50 km.

	Maintenance: it is possible the infrastructure will require regular cleaning/jet washing to dislodge debris amongst other maintenance activities that ensure the rail and its joints are kept in good condition. Additionally, Elways have developed a special ploughing system which removes snow from and around the rail without causing any damage.
Receiving/vehicle's system (type, provider, ERS equipment)	The arm automatically detects the presence of the rail, communicates with the power electronics to lower itself to securely connect with the rail. This allows power to be transferred and charges the vehicles on-board battery. The arm automatically detracts from the rail if evasive or overtaking manoeuvres are sensed. The pick-up arm has a lifetime of approximately 10,000 km due to wear and tear.
Use case (length, vehicle speed range, interoperability, cybersecurity)	A 2 km stretch of the road 893 in the area of Stockholm Arlanda Airport. Operation commenced in April 2018. One electrified 18 tonne truck performing shuttle operations between Arlanda Cargo Terminal and the Rosersberg logistics area was trialled.
Current developments	In Feb 2021, the company announced successful power transfer during a snowstorm where the conductive electric road system was heated to remove snow.
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	NEVS (designs EVs and mobility experiences); NCC (among others they construct and maintain roads); eRoadArlanda (one of several projects in the Swedish Transport Administration's pre-commercial procurement of innovation for the development of electrified roads); The Swedish Transportation Agency; The Swedish Energy Agency.
Infrastructure provider costs (cap., oper., maint.)	Infrastructure costs – current estimate: €450k – €1 million per lane per km Infrastructure costs – projected estimate: about €400k per lane per km (based on a 20,000 km network) Pick-up costs: €500-1000 per unit Maintenance costs: estimated between 1-2% of the capital investment.
User costs	N/A
Cost Benefit factors	The proportion of motorways to be electrified in Sweden needs to be decided based on an optimisation problem where the cost of electrifying the road is compared with the potential cost savings due to the use of significantly smaller batteries.

Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	The cost of fuel will probably rise when the oil peak comes closer and the danger of CO_2 might be confirmed. Then the only reasonable alternative will be electric vehicles. At present the big interest is battery vehicles but the on-board batteries have two major problems, energy density and charging time.
Proposed subsidies	N/A
ERS policies	N/A
Policy/legislation recommendations	Provided an ERS system is available on main motorways, then on-board batteries of EVs would need to provide energy for operations within rural and urban areas. For the case of Sweden, this requirement can be met by currently available EVs. Pop up charging is also possible within cities during stops, such as during loading/unloading at warehouses.
Key Findings	
The Evias Elways conductive system has been tested on public roads since April 2018 using one electric truck modified for this purpose. Over two years of demonstration, the truck was driven 532 km and charged at the same time. Several tests were performed, and a number of technical problems were identified. Those problems are addressed by recent developments of the Elways ERS technology.	

B.9 FABRIC – ITALY

Brief Description	The FABRIC project (FeAsiBility analysis and development of on-Road charging solutions for future electric vehiCles) was a European project with the aim to test three ERS solutions suitable for passenger cars and light good vans. The systems were tested in Italy and France. The three technologies involved IPT systems developed by the Italian POLITO, Italian SAET, and the French Vedecom Institute.
Budget	Overall budget: € 9 090 302 EU contribution: € 6 495 000
Period	2014 - 2017
Technology Assessment	
ERS technology (type, provider, TRL)	ERS technology 1: IPT system developed by Poitecnico di Torino (Polito) in Italy for a real-world demonstration at Susa test site in Italy. ERS technology 2: IPT system developed by SAET Group in Italy for a real-word demonstration at Susa test site in Italy.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	ERS technology 1 – POLITO: The transmitting system is a series of multi-windings coils that are directly connected to the low-voltage distribution network. The system uses power electronics to convert the power and achieve maximum efficiency at operating frequency between 20-200 kHz. Maximum power transfer per coil is 20 kW at 600 VDC; 34 A; ≈1 PF. ERS technology 2 – SAET: the system of SAET is based on a single turn coil in order to reduce coil-related costs and remove limitations regarding the installation of multiple coils in the ground. The system includes dedicated transformer and power electronics to reduce losses and achieve maximum power transfer which is rated at 20 kW. The system operates at 400 V AC three phase. Installation: Installation of the systems on the road was quick, given the shallow construction. A rectangular trench was cut from the pavement surface/binder course. Segments encased in plastic were inserted into the trench. Proprietary bitumen was used to seal the coil, after which asphalt was placed on top and compacted. Trenches for housing cables to roadside power electronics were also needed. Maintenance: No significant structural problems were observed in electric components, e.g. copper cables in the ground. Possible fatigue problems were envisaged in the wear layer of the buried solutions.
Receiving/vehicle's system (type,	ERS technology 1 – POLITO: 20 kW power transfer with efficiencies at 75-80% in static and dynamic modes.

provider, ERS equipment)	ERS technology 2 – SAET: uses the same system with ERS technology 1 above. An electric IVECO Daily light duty van was developed for FABRIC. It was adapted mechanically to host the receiving coils from POLITO.
Use case (length, vehicle speed range, interoperability, cybersecurity)	ERS technology 1 – POLITO: 100 m test section consists of about 50 multi-windings coils. Efficiency of around 80% efficiency at 50 km/h was measured over a 20 cm air gap. ERS technology 2 – SAET: 50 m SAET charging lane & 100 m of Polito's charging lane (see ERS technology 1) for interoperability assessment. Efficiencies around 80% at 80 km/h were measured over a 20cm air gap.
Current developments	ERS Technology 1 – POLITO: the trials have shown that coil characteristics are changed when buried in the ground. Researchers have been working on optimisation techniques to investigate the main parameters that influence the behaviour of the device. More focus is also given on the costs and benefits for implementing an infrastructure of this type. ERS Technology 2 – SAET: Researchers have explored life cycle sustainability assessment of the SAET solution.
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	Vehicle manufacturers: CRF (Italy), VOLVO (Sweden), SCANIA (Sweden) Energy operators: IRE (Italy) Road Managers: TECNO (Italy), SANEF (France) Technology suppliers: VeDeCom (France), SAET (Italy), Hitachi Europe Research Institutes: ICCS (Greece), TRL (UK), TNO (UK), CEA (France), FKA (Germany), UNIGE-DITEN (Italy), CIRCE (Spain), KTH (Sweden), POLITO (Italy), TU (Berlin) SMEs: QIE (Spain), ENIDE (Spain), ATA (Italy), MECT (Italy), AMET (Italy)
Infrastructure provider costs (cap., oper., maint.)	Infrastructure costs were estimated at €2-4 million per km. Maintenance costs for ERS roads were estimated to be 2.5 to 4 times more expensive compared to regular roads.
User costs	Modelling indicated that the road user electricity costs would be in the region of €325/year for a 65 km/day average (saving €1,500 compared to diesel). ERS can be financially viable when the on-board battery is reduced substantially. This requires vehicles with regular routes, e.g. freight

	vehicles and buses. Large-scale deployment of ERS is needed to gain significant benefits from passenger cars.
Cost Benefit factors	ERS is a feasible emission reducing option for vehicles with very regular travel patterns, like buses and specific point to point cargo routes. Large-scale deployment and high utilisation rates are needed to result in economic benefits.
Life Cycle Analysis	ERS will produce less emissions overall in the future, if electricity is produced green and the battery size of vehicles is reduced by 10%. Power transfer efficiency and associated emissions play a key role in LCA.
Policy & Strategies	
Decarbonisation strategies	It is expected that ERS (if widely available) will enable the use of smaller and lighter on-board batteries and will shorten travel times for long trips, as there will be no longer any need for long stops for charging.
Proposed subsidies	Incentives from the government would be possibly needed to make ERS attractive.
ERS policies	N/A
Policy/legislation recommendations	The FABRIC project enabled collaboration between different stakeholders and paid focus on the development of standards between vehicle manufacturers and technology providers.
Key Findings	
Infrastructure	The trial showed that ERS systems can be safely integrated in the road, when using high quality, currently available, binder materials. High temperatures during road construction and maintenance, as well as due to the use by traffic was found a key factor which may compromise the performance of ERS. Materials used for road construction have an impact on ERS performance (coil impedance). Possible fatigue problems in asphalt may require regular maintenance.
Vehicles	Integrating a ‘black-box’ type of receiving system on a car is difficult as several factors need to be considered including modification of electrical systems, magnetic shielding components, communication, etc. Key to ensure that the added ERS equipment on the vehicle does not impact safety.

	Thermal impact due to 20 kW charge can be managed using cooling systems.
Performance	Power transfer efficiencies were measured between 60-80%; good alignment is needed to maintain high efficiencies.
Environment	ERS would be responsible for less emissions if green electricity is provided. Key factors are also the power transfer efficiency and the benefits from reducing the on-board battery.
Economics	ERS seem to be more viable for vehicles which perform regular routes, e.g. freight vehicles and buses, as high utilisation rates can be achieved, and the on-board battery can be substantially reduced.

B.10 FABRIC – FRANCE

Brief Description	The FABRIC project (FeAsiBility analysis and development of on-Road charging solutions for future electric vehiCles) was a European project with the aim to test three ERS solutions suitable for passenger cars and light good vans. The systems were tested in Italy and France. The three technologies involved IPT systems developed by the Italian POLITO, Italian SAET, and the French Vedecom Institute.
Budget	Overall budget: € 9 090 302 EU contribution: € 6 495 000
Period	2014 - 2017
Technology Assessment	
ERS technology (type, provider, TRL)	ERS technology 3: IPT system managed by the French Vedecom Institute and based on the Qualcomm Halo system for real world demonstration in France.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	ERS technology 3 - Vedecom & Qualcomm Halo: the transmitting system of the system consists of a series of transmitting pads; each one of them includes an inductive coil and a controller unit. The maximum power transfer per pad is 20 kW at an operating frequency of 85 kHz. Pads operate with DC power and therefore, AC/DC power supply is established between the pads and the grid. The power supply operates at 400 V AC and up to 64 kW maximum power at three phases. Installation: In flush with the road. A trench was excavated in the middle of the road to install equipment. The trench was covered with a concrete slab, which contained the power transfer coils. Maintenance: No significant structural problems were observed in electric components, e.g. copper cables, or aluminium box (buried solution); Possible fatigue problems envisaged in the wear layer for buried solutions.
Receiving/vehicle's system (type, provider, ERS equipment)	ERS technology 3 - Vedecom & Qualcomm Halo: vehicle components included two receiving coils, a controller unit, and a communications unit. A Renault Kangoo was adapted mechanically to host the secondary coils from QUALCOMM
Use case (length, vehicle speed range,	ERS technology 3 - Vedecom & Qualcomm Halo: integrated along a 100 m section of road consisted of four 25 m segments, each segment

interoperability, cybersecurity)	equipped with 56 charging pads. Efficiency of around 60% efficiency were measured at 100 km/h over a 20 cm air gap.
Current developments	WiTricity acquired Qualcomm's EV wireless charging unit Halo.
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	Vehicle manufacturers: CRF (Italy), VOLVO (Sweden), SCANIA (Sweden) Energy operators: IRE (Italy) Road Managers: TECNO (Italy), SANEF (France) Technology suppliers: VeDeCom (France), SAET (Italy), Hitachi Europe Research Institutes: ICCS (Greece), TRL (UK), TNO (UK), CEA (France), FKA (Germany), UNIGE-DITEN (Italy), CIRCE (Spain), KTH (Sweden), POLITO (Italy), TU (Berlin) SMEs: QIE (Spain), ENIDE (Spain), ATA (Italy), MECT (Italy), AMET (Italy)
Infrastructure provider costs (cap., oper., maint.)	Infrastructure costs were estimated at €2-4 million per km. Maintenance costs for ERS roads were estimated to be 2.5 to 4 times more expensive compared to regular roads.
User costs	Modelling indicated that the road user electricity costs would be in the region of €325/year for a 65 km/day average (saving €1500 compared to diesel).
Cost Benefit factors	From an investment point of view, e-roads are expensive. Their installation is predicted to be in the range of 2-4 million EUR/km, and their maintenance costs are estimated to be 2,5 – 4 times higher than from a regular road. The total costs of ownership of diesel powered, battery powered and Dynamic Wireless Power Transfer enabled vehicles were compared and showed that only in case of the scenario with low speeds (and therefore a high energy transmission per metre of infrastructure) and maximum battery reduction (e.g. buses and freight vehicles with regular routes), can be beneficial for ERS.
Life Cycle Analysis	ERS will produce less emissions overall in the future, if electricity is produced green and the battery size of vehicles is reduced by 10%. Power transfer efficiency and associated emissions play a key role in LCA.
Policy & Strategies	

Decarbonisation strategies	It is expected that ERS (if widely available) will enable the use of smaller and lighter on-board batteries and will shorten travel times for long trips, as there will be no longer any need for long stops for charging.
Proposed subsidies	Incentives from the government would be possibly needed to make ERS attractive.
ERS policies	N/A
Policy/legislation recommendations	The FABRIC project enabled collaboration between different stakeholders and paid focus on the development of standards between vehicle manufacturers and technology providers.
Key Findings	
See section 0: B.9 FABRIC – Italy above.	

B.11 Honda

Brief Description	Honda R&D has been developing their conductive rail dynamic charging solution since 2011. This system is different from alternative conductive dynamic systems as the pantograph extents horizontally from the vehicles side. Power transfer rates of 450 kW over travelling speeds of 150 km/h have been demonstrated. Honda has conducted several tests of their system using ERS routes up to 1.2 km deployed in test tracks of JARI (Japan Automobile Research Institute).
Budget	Honda Innovate UK – ElectroRoad (2021)
Period	2011 - Current
Technology Assessment	
ERS technology (type, provider, TRL)	Honda R&D has been developing their conductive rail dynamic charging solution since 2011. This system, known as High Power Dynamic Charging System, is different from alternative conductive dynamic systems as the pantograph extents horizontally from the vehicles side. Four prototypes have been developed and tested by Honda in test tracks, and a TRL 6-7 is estimated.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The transmitting unit is conductive rails mounted on vehicle restraint systems at the roadside (median strip side, exclusive road, road shoulder side, galvanised steel crash barrier). Since its developments Honda has demonstrated six prototypes which have been subject to extensive track testing and simulation modelling. The current prototype passenger vehicles and heavy-duty trucks (research phase completed) are capable of delivering 450 kW and has been track tested at max. 150 km/h. The system operates at an input voltage level of 840 V-DC and an output voltage of 750 V-DC (vehicle input). Operating current is at 600 Amps and more than 95% power transfer efficiencies have been achieved. Installation: The conductive rails are retrofitted to existing vehicle restraint systems (steel crash guard, aluminum extrusion structure or resin main structure), which are connected via cabling to a high capacity storage battery located at the roadside. The current version still utilise conductive rails connected to the lower portion of a vehicle restraint system.
Receiving/vehicle's system (type, provider, ERS equipment)	Once the vehicle enters the dynamic charging lane, the vehicle operator manually switches on the collection unit, putting it in a ready state. The collection unit then makes contact with the conductive rail, with the vehicle automatically detecting this connection. It then transitions to a

	power supply/charging sequence. Charging is controlled by the vehicles on-board integrated ECU, to realise a set current, power and voltage, whilst also monitoring and controlling the vehicles battery capacity, power levels, and system temperature. Once charging is complete the collection unit retracts and fits back into the vehicles side sill. The guide plates fitted around each terminal on the rail ensure a constant, but not fixed, connection. The collection unit has damper and flexion mechanisms to absorb horizontal and vertical deflections whilst in contact with the rail. The vehicle is still able to automatically terminate charging and retract the collection unit should the driver need to perform evasive/overtaking manoeuvres or leave the charging lane at will. The collection unit is capable of delivering power across a horizontal range of up to 1.3 m between the vehicle and the conductive rail.
Use case (length, vehicle speed range, interoperability, cybersecurity)	Track test are being carried out with 6 prototypes of type-0 to type-5. Type-2 succeeded in supplying power while driving at 155 km/h in the 300 m ERS lane. At this time, the vehicle entered the ERS lane at 123 km/h and increased the speed to 155 km/h while charging the in-vehicle battery. Type-3 (The most current prototype) succeeded in supplying power while driving at 150 km/h in the 385 m ERS lane. At this time, the vehicle entered the ERS lane at 50 km/h and increased the speed to 150 km/h while charging the in-vehicle battery.
Current developments	Type-5 (45 ton) and Type-6 (60 ton) heavy-duty truck prototypes to deliver 450 kW of power at 80 km/h travelling speeds.
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	Japan : Electrical company, Road company, Railway infrastructure company, Road construction company, Power energy company, Battery company, Logistics company etc. UK : TRL, Galliford Try, Miralis
Infrastructure provider costs (cap., oper., maint.)	Research indicates that the cost of the system is potentially substantially cheaper than alternatives. It is estimated to have an installation cost 1/20th the price of inductive systems.
User costs	N/A
Cost Benefit factors	N/A
Life Cycle Analysis	N/A
Policy & Strategies	

Decarbonisation strategies	N/A
Proposed subsidies	N/A
ERS policies	N/A
Policy/legislation recommendations	N/A
Key Findings	
The technical development of Honda's system has been demonstrated in test tracks of JARI (Japan Automobile Research Institute). Power transfer rates up to 450 kW at travelling speeds of 150-200 km/h have been achieved. Cost data is not available, but Honda expects that their system will be substantially cheaper than other alternatives due to minimum implications on the road. Due to the high-power transfer rate, Honda has shown that 1 km of charging could result in a 25 km additional range for passenger cars, which reduces the need of large-scale infrastructure deployment.	

B.12 KAIST – South Korea

Brief Description	To-date the company has a number of commercial operated bus schemes across South Korea. Schemes are variable in size, but all utilise the same technology. All systems fall under the brand name OLEV (Online Electric Vehicle). Commercial operations were implemented in Sejong City, South Korea in 2016, with buses servicing two 12 km routes. In 2017, additional operations were implemented at the University Campus in Daejoenn, Gumi City, and Sejong City.
Budget	N/A
Period	2012 – current
Technology Assessment	
ERS technology (type, provider, TRL)	Inductive charging for buses in operation since 2012; TRL 9 has been reached. The manufacturer is Korean Advanced Institute of Science and Technology (KAIST), Dongwon OLEV (South Korea) and OLEV-Tech (USA) – now under Dongwon Industry Inc.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	Installation: OLEV power supply rails are completely prefabricated, with power cables already encased and connected between modules. This means power cable connections are required during installation. Additionally, as modules are pre-connected, units can be folded side-by-side. This makes the system more compact and easier to transport to site.
Receiving/vehicle's system (type, provider, ERS equipment)	Power rating between 20-100kW was achieved over a 20 cm air gap. The lifetime of the receiving system on the vehicle aligns with the expected lifetime of the EV, so no replacement is needed throughout the lifetime of the EV.
Use case (length, vehicle speed range, interoperability, cybersecurity)	2010: Seoul Grand Park Trolley Demonstration. 3 trolley vehicles servicing 2.2 km route. Additional info: 4x 372.5 m charging sections; 50 kWh battery capacity; 50 kW charging power. 2013: Commercial operation of OLEV bus & infrastructure (KAIST, University Campus, South Korea) – 2 OLEV buses, servicing 3.76 km route. Additional info: 3x 60 m charging sections; 50 kWh battery capacity; 50 kW charging power. 2014: Commercial operation of OLEV (City of Gumi, South Korea) – 6 OLEV buses, servicing 35 km route. Additional info: 6x 144 m charging sections; 100 kWh battery capacity; 100 kW charging power.

	2015: Demonstration Trial (Sejong City, South Korea)
Current developments	The company has been working on a wireless charging for electric passenger cars since 2018, delivering up to 22 kW of charge.
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	Seoul Grand Park – City of Seoul; KAIST – KAIST University ; City of Gumi – City of Seoul
Infrastructure provider costs (cap., oper., maint.)	Capital cost: €2.5 million per km (cost at mass implementation scale)
User costs	There are costs associated with the electricity consumed for charging EVs, as well as cost associated with the charging infrastructure maintenance.
Cost Benefit factors	The demonstrations and real use cases have shown that significant fuel costs can be saved, and CO_2 emissions can be reduced substantially. This is beneficial for urban centres.
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	Prohibiting the use of fossil fuels by 2035 and shifting towards more sustainable energy sources. There is also a national need to test ERS systems by 2030 so the country is ready for large scale deployment.
Proposed subsidies	Subsidies to cover some of the investment costs to facilitate the uptake of EVs and the deployment of ERS.
ERS policies	South Korea to implement wireless charging road lanes by 2030.
Policy/legislation recommendations	Developing international standards for the dynamic wireless power transfer for electric vehicles.
Key Findings	
Semi-dynamic wireless charging for buses in cities has been proven to be a technically feasible and commercially viable solution for decarbonising the road transport sector. Governments have recognised the potential of ERS for passenger cars and have made commitments to support deployment.	

B.13 KAIST/WiPowerOne – Dubai

Brief Description	WiPowerOne, a KAIST spin-off company, tested their technology in Dubai. WiPowerOne's system was tested on two operating frequencies, 20 kHz and 85 kHz. It uses magnetic reasonance for charging electric buses whilst on stop and during driving at 100 kW. The first phase of the project (Phase 1) involved testing of the system and lasted two months. Phase 2 is involving a 10 km track and trial is expected to begin soon.
Budget	N/A
Period	Phase 1: 2019.10 – 2019.12 Phase 2: 2020 – current
Technology Assessment	
ERS technology (type, provider, TRL)	The manufacturer is WiPowerOne. Inc. which is the spin-off company from KAIST. The technology is based on inductive charging using shaped magnetic field in resonance (SMFR) technology that enables the safe transfer of large amount of energy from the power grid under the road to EVs at rest or in motion. TRL 7 has been reached.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	Charging bus units have variable lengths depending on installation and requirements. Buses can be charged on the stop (at the bus stop) and whilst driving away from the bus stop in a more semi-dynamic way. The technology consists of inverters that convert 3-phase 380V power to 20 kHz or 85 kHz power supply lines installed under the road, pick-up device that converts magnetic fields to electric energy. One inverter supplies power to 3 charging segments of 15 m length. The transmitting system operates at 100 kW with charging efficiencies (DC-DC) around 90%.
Receiving/vehicle's system (type, provider, ERS equipment)	Power transfer efficiencies of around 90% at 100 kW were achieved when vehicles were within the lateral misalignment tolerance of 15 cm. The air gap between the transmitting and receiving systems was 200 mm (270 mm between coils).
Use case (length, vehicle speed range, interoperability, cybersecurity)	Electric buses were charged on the stop and whilst in motion. Charging efficiencies more than 85% at 100 kW power transfer were demonstrated when the vehicles were travelling at speeds up to 30 km/h.
Current developments	KAIST/WiPowerOne have recently developed a system capable of delivering 300 kW of power.

Business Models & Stakeholder Engagement	
Stakeholders (type and role)	The RTA is undertaking this project, which is part of Dubai Future Accelerators, in collaboration with Dubai Electricity and Water Authority and Dubai Silicon Oasis.
Infrastructure provider costs (cap., oper., maint.)	N/A
User costs	N/A
Cost Benefit factors	The technology provides a solution to the barriers to commercialising EVs such as high costs of charging infrastructure and batteries, vehicle weight and limited range. The ERS infrastructure costs less because significant reductions in battery sizes can be achieved. ERS infrastructure is required at about 5–15% of the entire service route, including start and end points, bus stops, crossroads and parking areas.
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	N/A
Proposed subsidies	N/A
ERS policies	N/A
Policy/legislation recommendations	N/A
Key Findings	
The first phase of the project is finished and the findings confirm the technical feasibility of the system at an operating frequency of both 20 kHz and 85 kHz. Power transfer efficiencies of more than 85% at 100 kW power transfer have been demonstrated over travelling speeds of 30 km/h. The more extensive Phase 2 of the project along a 10 km track will begin soon.	

B.14 KAIST/WiPowerone – Daejeon South Korea

Brief Description	WiPowerOne, a KAIST spin-off company, has tested their technology at the KAIST campus in the central city of Daejeon, South Korea. A previous version of the wireless charging system is also on trial in Dubai (see 0: B.13 KAIST/WiPowerone – Dubai). WiPowerOne launched a special demonstration to verify the safety and effectiveness of its wireless charging service using 85 kHz frequency. The transmitting power of this system is 150 kW (instead of 100 kW shown in the previous case study) and each inverter is capable of delivering 350 kW (instead of 300 kW). However, this trial involved static wireless charging and semi-dynamic wireless charging (whilst buses take off from the bus stops); but not full dynamic charging.
Budget	N/A
Period	2021 – current
Technology Assessment	
ERS technology (type, provider, TRL)	The manufacturer is WiPowerOne. Inc. which is the spin-off company from KAIST. The technology is based on inductive charging using shaped magnetic field in resonance (SMFR) technology that enables the safe transfer of large amount of energy from the power grid under the road to EVs at rest or in motion. TRL 7 has been reached.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	In addition to the tests in Dubai to verify the safety and effectiveness of its wireless charging service using an operating frequency of 85 kHz (0: B.13 KAIST/WiPowerone – Dubai), KAIST/WiPowerOne were also allowed to demonstrate their system in the KAIST complex, in South Korea. They needed to apply for a special approval from the Ministry of Science in South Korea because the 85 kHz frequency band was not allowed for EV applications due to possible frequency interference impacts on other bandwidth services within cities. The inverter which supplies the transmitting units operates at 350 kW. The nominal power transfer rate of the receiving system is 150 kW which means that 2 vehicles can be charged at the same time.
Receiving/vehicle's system (type, provider, ERS equipment)	Power transfer efficiencies of around 90% at 150 kW were achieved when vehicles were within the lateral misalignment tolerance of 15 cm. The air gap between the transmitting and receiving systems was 190 mm (290 mm between coils).
Use case (length, vehicle speed range,	Three electric buses are under trial in Daejeon's demonstration being charged on the stop and whilst in taking off from the bus stop. There are

interoperability, cybersecurity)	four charging slots along the route, each one of them 5 m in length, capable of delivering 150 kW to each bus. The charging slots are supplied by two inverters which are rated at 350 kW.
Current developments	N/A
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	N/A
Infrastructure provider costs (cap., oper., maint.)	The cost for the 350 kW transmitting power supply system including the four charging slots was estimated at about €80,000 whereas the construction cost at about €420,000 (for the four slots).
User costs	The 150 kW vehicle's system costs €420,000.
Cost Benefit factors	N/A
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	N/A
Proposed subsidies	N/A
ERS policies	N/A
Policy/legislation recommendations	N/A
Key Findings	
Demonstrations are still undergoing but preliminary findings suggest the technical feasibility of the system at an operating frequency of 85 kHz. Power transfer efficiencies of more than 85% have been demonstrated over travelling speeds of 30 km/h.	

B.15 SIEMENS EHIGHWAY – U.S.

Brief Description	Trucks with electric drivetrain (battery electric vehicles, range extended vehicles, hybrid, and hydrogen vehicles) collect electricity via overhead contact lines while in motion. The demonstration run in California near two largest U.S. Ports of Los Angeles and Long Beach. A project developed by Siemens and South Coast Air Quality Management District (SCAQMD).
Budget	About €12 million
Period	2014 - 2017
Technology Assessment	
ERS technology (type, provider, TRL)	Overhead catenary systems (known as eHighway) developed by Siemens. A TRL 6-7 is assumed for the system demonstrated in the US. Note that additional eHighway demonstrations have been performed since 2014 (see following sections). The technology has reached a TRL 8.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The energy supply consisted of a two-wire overhead system, operating at around 650 VDC, with current ratings that match the characteristics of the electric motors on the vehicles. Power transfer level was 200 kW. Similar technology has been used for years for powering trams, trains, and trolley buses. Installation: The majority of the installation was completed at the roadside resulting in minimal disruptions to traffic. Firstly, geotechnical and geophysical surveys were carried out to ensure the site is free from hidden obstructions, and also to establish the type of foundations required for the poles. Excavations for poles were carried out and their steel reinforced concrete foundations were laid and left to cure. Poles were located at regular spacing, around 50 m intervals. Cables were then fed and looped through each pole and tensioned. Roadside power electronics were installed, and grid connections were established. The installation technique was essentially the same as it would be for overhead lines in rail applications.
Receiving/vehicle’s system (type, provider, ERS equipment)	The vehicles collected electrical energy from overhead wires, using a pantograph system that can connect and disconnect autonomously as the vehicle enters and exits electrified sections of road up to 90 km/h. Under a separate contract with SCAQMD, the natural gas hybrid and electric trucks were developed by Escondido-based TransPower. The diesel hybrid vehicle was developed by Volvo's subsidiary, Mack Trucks.
Use case (length, vehicle speed range,	Californian city of Carson, U.S. (near the ports of Los Angeles and Long Beach): Three trucks hauling freight are running along the stretch of

interoperability, cybersecurity)	highway which uses Siemens technology to electrify 1.6 km (1 mile) of highway lanes. The three vehicles were a battery-electric truck, a natural gas-augmented electric truck, and a diesel-hybrid truck.
Current developments	See use case 0: B.16 Siemens eHighway – Sweden and use case 0: B.17 Siemens eHighway – ELISA / FeSH / eWayBW - Germany
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	Technology provider (Siemens); Vehicle manufacturers (Escondido-based TransPower and Mack Trucks - Volvo). The eHighway demonstration project was also funded by the following parties: SCAQMD – South Coast Air Quality Management District China Shipping Fund California Energy Commission Port of Long Beach L. A. Metro Siemens INC (in-kind contributions)
Infrastructure provider costs (cap., oper., maint.)	Capital cost: €1.1-2.6 million per lane per km
User costs	N/A
Cost Benefit factors	Implementing the eHighway system requires investments in both, the roadside electrification infrastructure and the eHighway adapted trucks. However, such capital expenditure could generate a return on investment. The business case for eHighway is influenced by a multitude of factors such as technology costs, efficiency rates, energy pricing, utilisation, transport density, and local infrastructure installation conditions. For individual projects detailed business evaluations are recommended.
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	According to a 2018's report (link), heavy-duty trucks are the number one source of smog-forming emissions in Southern California. Developing a zero- or near-zero emission goods transport system at the ports will

	reduce smog-forming, toxic and greenhouse gas emissions in communities around the ports, which are heavily impacted by air pollution.
Proposed subsidies	N/A
ERS policies	The primary goal of this project was to promote the implementation of zero emission goods movement technologies, and the secondary goal was to demonstrate the most viable technology to be adopted for a future, regional zero-emissions corridor. This was done by combining an overhead contact line based electric road system with trucks from different OEM suppliers utilizing three different drive technologies.
Policy/legislation recommendations	N/A
Key Findings	
The project showed that the eHighway system can be implemented in an existing road infrastructure as a potential zero emission goods transport technology. During demonstration the eHighway system proved to be a viable technology suitable for regional zero criteria pollutant emission corridors. On the one mile demonstration track and beyond – depending on the capacity of the onboard energy storage – the trucks were able to operate without any tailpipe emissions. Based on the demonstration results the eHighway system may be considered as one of the valid options for zero emission road freight transports. Provided that renewable electrical energy is used, significant additional CO_2 reductions can also be realised.	

B.16 Siemens eHighway – Sweden

Brief Description	Trucks with electric drivetrain (battery electric vehicles, range extended vehicles, hybrid, and hydrogen vehicles) collect electricity via overhead contact lines while in motion. World's first eHighway in Sweden where ERS system was developed by Siemens in partnership with Scania. This is also the first eHighway demonstration in Europe.
Budget	N/A
Period	2016 - 2018
Technology Assessment	
ERS technology (type, provider, TRL)	Overhead catenary systems (known as eHighway) developed by Siemens. A TRL 6-7 is assumed for the system demonstrated in the US. Note that additional eHighway demonstrations have been performed since 2014 (see following section). The technology has reached a TRL 8.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The energy supply consisted of a two-wire overhead system, operating at around 650 VDC, with current ratings that match the characteristics of the electric motors on the vehicles. Power transfer level was 200 kW. Similar technology has been used for years for powering trams, trains, and trolley buses. Installation: The majority of the installation was completed at the roadside resulting in minimal disruptions to traffic. Firstly, geotechnical and geophysical surveys were carried out to ensure the site is free from hidden obstructions, and also to establish the type of foundations required for the poles. Excavations for poles were carried out and their steel reinforced concrete foundations were laid and left to cure. Poles were located at regular spacing, around 50 m intervals. Cables were then fed and looped through each pole and tensioned. Roadside power electronics were installed, and grid connections were established. The installation technique was essentially the same as it would be for overhead lines in rail applications.
Receiving/vehicle's system (type, provider, ERS equipment)	The vehicles collect electrical energy from overhead wires, using a pantograph system that can connect and disconnect autonomously as the vehicle enters and exits electrified sections of road up to 90 km/h. The trial used two diesel hybrid vehicles manufactured by Scania and adapted, in collaboration with Siemens, to operate under the catenary system.
Use case (length, vehicle speed range,	In June 2016, Siemens launched the world's first eHighway system on public roads in Sweden. It was running on a 2 km section of the E16

interoperability, cybersecurity)	highway north of Stockholm through 2018. Two bio-diesel-hybrid vehicles were used for the project
Current developments	See use case 0: B.17 Siemens eHighway – ELISA / FeSH / eWayBW - Germany
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	The contract was awarded by the Swedish Transport Administration to the County Council of Gävleborg. Stakeholders include technology providers, vehicle manufactures, grid operators, and research institutes.
Infrastructure provider costs (cap., oper., maint.)	Capital cost: €1.1-2.6 million per lane per km
User costs	Electric drives have as main components an electric motor, power electronics as well as an on-board battery or a constant external power supply. Compared to the internal combustion engine, many moving, and maintenance-intensive components are omitted from the technically less complex drive train, which leads to less noise generation, less wear and tear and thus to reduced maintenance costs. Thanks to its higher efficiency electric propulsion provides cost advantages over diesel based propulsion. The reasons for this lie in the high efficiency of the electric motor and the possibility of recovering braking energy.
Cost Benefit factors	The costs for the construction of overhead line infrastructure per kilometre vary due to the expected economies of scale, depending on the length of the routes to be built and route and usage-specific factors and are therefore not generally applicable.
Life Cycle Analysis	Electrified road transport cuts energy consumption in half and reduces local air pollution.
Policy & Strategies	
Decarbonisation strategies	Transport accounts for more than one third of Sweden's CO_2 emissions, with almost half of that coming from freight transport. As part of its climate protection strategy, Sweden has committed to having a fossil fuel independent transport sector by 2030. Due to the expected growth in freight transport, road freight is set to grow even as rail capacity is increased. A solution to decarbonized road freight is therefore necessary.
Proposed subsidies	N/A

ERS policies	During the two-year trial, Sweden's Transport Administration Trafikverket and Gävleborg County wanted to create a knowledge base on whether the Siemens eHighway system is suitable for future long-term commercial use and further deployment.
Policy/legislation recommendations	A powerful electrification infrastructure along the long-haul network that provides a catenary system for heavy-duty trucks requires a concerted effort, clear guidelines, and a clear and consistent vision. The transportation sector shouldn't be considered separately from the energy sector and needs to be coordinated on a national level.
Key Findings	
The aim of this demonstration was to build and operate an electric road, technically and with regard to safety, operation and maintenance issues. This project being an early demonstration offers both a comparative advantage for national transport buyers and also new markets for the companies that deliver solutions. The process of pre-commercial procurement, where knowledge is built, step by step and where knowledge base is built up and previous experience is the basis for making decisions into the future. The demonstration also considers a broad and complex group of factors and individuals which are essential for a full-scale, safe and relevant expansion. Further info can be found in the following report (link).	

B.17 Siemens eHighway – ELISA / FeSH / eWayBW - Germany

Brief Description	Part of the German cabinet's Climate Action Programme 2020 is a field trial to test electric propulsion systems in road freight transport. This project is funded by the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety (BMU) and consists of research and development of road freight transport systems using overhead contact lines. In total there will be three field trials in three different states of Germany: Project ELISA on motorway BAB A5 near Frankfurt (State of Hesse) Project FeSH on motorway BAB A1 near Luebeck (Schleswig-Holstein) Project eWayBW on national road B462 near Gaggenau (Baden-Wurttemberg)
Budget	Infrastructure (ELISA project): €14.6 million for a 5 km bi-directional system; plus an additional €12 million for extending the system by 7 km in one direction. Total infrastructure budget is currently at €26.6 million.
Period	2019 – 2022: ELISA The construction of the initial 5 km bi-directional infrastructure for the ELISA project took place between 2018-2019. The system has been in operation since then and it is expected to last until 2023 (one year extension based on the original plan). The infrastructure is going to be extended by 7 km. 2020 – 2023: FeSH The FESH project covers a shuttle return to the port in Lübeck. This means regular daily tours on the two 5 km overhead lines. 2021 – 2024: eWayBW The eWayBW-Project deals with special challenges as it is based on a national road with tight curves, bridges and also a traffic light crossing.
Technology Assessment	
ERS technology (type, provider, TRL)	Overhead catenary systems for trucks on motorways (known as eHighway) developed by Siemens Mobility, Germany since 2010. Initial conceptional tests were performed in two projects funded BMU: ENUBA (link) and ENUBA 2 (link). After that two demonstration projects

	on public roads took place in the US between 2014 – 2017 (link) and Sweden between 2016 – 2020 (link). The current field trials in Germany with heavy-duty trucks on high-frequented motorway sections and shortly on a national road in normal operation indicate a TRL 8; further info can be found in the link.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The electrified section is divided into two interconnected feeding sections with two substations receiving its electric power from the grid by two feed-in points (3 AC 20 kV). Each substation is designed to deliver a nominal power of 1,000 kVA. Inside the substations the electricity is transferred down to DC 670 V as well as converted from AC into DC. Via feed-in poles the electric power is distributed to the two contact lines (positive pole and negative pole). The power distribution is based on long-term experiences made in railway systems, trams and trolley buses. Power transfer level to the vehicle is around 300 kW. The majority of the installation tasks was done from the hard shoulder resulting in minimal disruptions to the running traffic. Firstly, geotechnical and geophysical surveys were carried out to ensure the site is free from hidden obstructions, cables and channels. Then, steel pipes were rammed into the ground into which the poles were subsequently inserted. Poles were located at regular spacing, every 57 m intervals on average. The cantilevers were attached, and finally the wires and contact lines were installed, adjusted, and tensioned. For the ELISA-Project, a rather specific solution was found for the area of the motorway service station "Gräfenhausen" which is characterized by a filling station on each side and big parking lots for passenger cars and trucks with no space for the pole placement between road and parking area. Poles were placed in the middle strip of both driving directions. Worth highlighting is the eHighway system does neither interferes with the road surface nor with its inner structure.
Receiving/vehicle's system (type, provider, ERS equipment)	The vehicles used on the field trials are five hybrid trucks each (tractor-trailer) type R450 by Scania equipped with an internal combustion engine and an electric machine. Electric power is received either by the pantograph or by the onboard battery. The internal combustion engine is available in different engine sizes. The pantograph can only be raised in case the sensors on the rooftop of the truck detect the presence of the overhead contact lines. The driver can manually raise and lower the pantograph at the touch of a button. The pantograph is automatically disengaged when the drive starts an overtaking, when the vehicle leaves the permissible range of lateral

	movement, and when the vehicle reaches the end of the electrified section. When the raised pantograph connects to the contact lines the hybrid truck's electric engine is supplied with power. It simultaneously charges the vehicle's batteries allowing a further electric drive upon leaving the electrified section. The hybrid trucks were initially equipped with 18 kWh battery, but they will be upgraded to 90 kWh by the end of 2021.
Use case (length, vehicle speed range, interoperability, cybersecurity)	Five regional logistic companies use the overhead catenary trucks on and outside the 5 km long infrastructure in both driving directions (ELISA project) which is set-up for operation in 24/7 mode. The electric infrastructure is connected via fibre optical cables to the traffic control centre of the motorway operator and useful data is obtained for the effective monitoring of the eHighway system. In Schleswig-Holstein one regional logistic company uses the five overhead catenary trucks for harbour shuttle services. Especially the influence of heavy wind and storm is part of the accompanying research in this field trial. Two regional logistic companies are part of the eWayBW-Project. They connect two cities through regular trams of paper from factories to a logistics centre. The aim is to use the trucks in a 24/7 mode and because the track is rather close to villages furthermore to reduce the noise pollution especially at night. The federal state of Baden-Württemberg plans to include further alternative propulsion options and, among other things, to research expected synergies with the overhead catenary system. The connection to the overhead lines via the pantograph can be made at any speed.
Current developments	A separate project has been investigating billing systems and methods for electrically powered trucks and interoperability within the European context. The project is called AMELIE II and is funded by BMWi. It is led by the Institute for Climate Protection, Energy and Mobility (IKEM). Other projects of the accompanying research are working on items like TCO and business models, electrification of the motorways, traffic management, effects on the electricity grid and solutions for rescue teams.
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	**ELISA:** The project consortium consists of Hessen Mobil (Motorway operator, road and traffic Management), Technical University Darmstadt (traffic, energy-related, ecological and economical aspects relevant for an future expansion of the system), and Entega AG (electric power

	generated by renewables during operation as well as the development and application of a model for a future billing system). Five logistics companies transporting different cargo within the region have declared their willingness to incorporate the overhead catenary trucks into their logistics processes and to use the trucks as part of their daily logistics processes: i) Spedition Hans Adam Schanz GmbH & Co. KG; ii) Ludwig Meyer GmbH Co. & KG; iii) Contargo GmbH & Co. KG; iv) Knauf Gips KG; v) Merck KGaA. **FESH**: Beside the Ministry of Energy transition, Agriculture, Environment, Nature and Digitalization and the Ministry of Economy, Transport, Work, Technology and Tourism of the State of Schleswig-Holstein the Research and development center of the Kiel University of Applied Sciences GmbH performs the project. TU Dresden is part of the accompanying research. One logistic company, Spedition Bode Transport & Logistik based in Reinfeld, serves the shuttle traffic to the Port of Lübeck. **eWayBW**: Together with the Ministry of Transport Baden-Württemberg the Administration Presidium Karlsruhe, District Rastatt, SWEG Südwestdeutsche Verkehrs AG and a research consortium are carrying out the project. Spedition Fahrner Gmbh and Huettemann Logistics GmbH are involved in the transports. On the B 462 between Kuppenheim and Gernsbach-Obertsrot they will perform a 24/7 shuttle transport of paper.
Infrastructure provider costs (cap., oper., maint.)	The capital costs (CAPEX) : approx. € 2.3 million per km (both driving directions) depending on number of overhead catenary trucks and power demand, topography, requirements of the motorway operator during construction (temporary and permanent closures), construction space alongside the verge and distance to grid feed-in point. Maintenance costs (OPEX): approx. 2% of CAPEX per year.
User costs	The logistic companies usually lease the overhead catenary trucks from Scania; maintenance is included. The costs for the provision of the electric power received during electric drive at the catenary is funded by BMU. The cost for diesel fuel is paid by the fleet companies.
Cost Benefit factors	The potential of savings largely depends on the differences in prices for electric energy (per kWh) and diesel fuel (per litre or gallon).
Life Cycle Analysis	Interim report by Technical University Darmstadt is expected mid-2021 for the ELISA-Project. For FESH and later eWayBW interim reports will be published in the future.

	The accompanying research has already published reports on TCO, implementation scenarios, potential analysis, legal bases and regulations of road freight transport, greenhouse gas reduction potential, traffic analysis and more (Roadmap OH-Lkw, My eRoads, StratON, StratES, BOLD).
Policy & Strategies	
Decarbonisation strategies	Transport accounts for 20% of Germany's total CO_2 emissions, with almost a third coming from road freight transports. As part of its climate protection program 2030, the transport sector must reduce its emissions by 40 to 42% compared to 1990. The measures already adopted so far cannot meet the targets and alternative methods are needed. In Germany, 73% of all goods are transported by commercial vehicles (over 3.5 tonnes) on roads mainly on motorways. Due to the expected growth in road freight transport, even as rail capacity is increased a solution to decarbonised road freight is necessary.
Proposed subsidies	Funding of vehicles without favouring a specific technology Funding of commercial vehicles Funding of retrofitting vehicles for low or zero emission operation Funding of demonstration projects (infrastructure and vehicles) Funding of R&D
ERS policies	The German Federal Ministry for Transport (Bundesministerium für Verkehr und Digitale Infrastruktur - BMVI) has published a plan for an overall approach to climate-friendly commercial vehicles in Nov 2020. The approach is divided into two parts: The "scale-up phase" involves joining forces with all the stakeholders to start larger trials in real-world logistics processes, support on outstanding development steps, setting standards and develop specific plans for an area-wide deployment of the necessary infrastructure for battery electric drivetrains, hydrogen fuel cell drivetrains and hybrid overhead line drivetrains. In the second phase ("roll-out phase", starting around the end of 2023), the necessary energy supply infrastructures will be deployed in a coordinated manner, focusing on those for alternatively fuelled heavy-duty vehicles. In order to activate the markets for zero emission propulsion technologies for commercial vehicles the BMVI funds corresponding infrastructure and vehicles with €4.1 billion and €1.1 billion respectively (link).

Policy/legislation recommendations	Support on European level for the development and deployment of zero emission technologies for trucks within the context of the recast of the Eurovignette Directive. Differentiation of truck tolls by CO_2 emissions. Temporary exemption of tolling fees for hybrid and zero emission trucks to attract more users. Public financing of the initial infrastructure to kick-start and facilitate a further expansion. Determination of how the use of the infrastructure is to be paid for (e.g. user based, by all road users applicable to tolling fees).
Key Findings	
These are ongoing demonstrations and interim reports are expected e. g. by the Technical University Darmstadt, TU Dresden and other research institutes towards the end of 2021 and beyond. Nevertheless, it has been shown that construction of the system in busy public highways and on national roads is feasible. Also, the system has been used for real road freight transport operations and proved the practicality of climate-neutral freight solutions.	

B.18 UTAH STATE UNIVERSITY – U.S.

Brief Description	The National Science Foundations (NSF) provided a grant in 2020 to Utah State University to establish the Engineering Research Center for "Advancing Sustainability Through Power Infrastructure for Roadway Electrification" (ASPIRE). With its strategic partners, the Center was established to advance sustainable electrified transportation. Research projects have provided valuable insight and information across electric transportation and infrastructure technologies, including static and dynamic wireless charging systems that are integrated into roadways, parking structures, etc. and networked with the electric grid and traffic management systems. Efforts are integrated across multiple disciplines, including engineering, social science, policy, and business through close collaboration with industry, government, and community partners.
Budget	NSF $26 million (€21.6 million) five-year award (renewable to $51 million -€42.3 million- over ten years), $8 million (€2.4 million) match from university partners, anticipated $20 million (€16.6 million) over ten years from industry membership, $8 million (€6.6 million) awarded from Utah legislature (total $87 million -€72.2 million- attributed to initial NSF award); other current budget includes $15 million (€12.5 million) awarded from Utah legislature for pilot project with Utah Inland Port Authority and $20 million (€16.6 million) + in collaborative DOE awards.
Period	2020 to 2030
Technology Assessment	
ERS technology (type, provider, TRL)	Dynamic (in-motion) wireless power transfer. ASPIRE Center developing technology components and conducting or developing pilot project opportunities with commercial providers (e.g., WAVE, ElectReon) and project partners (e.g., Kenworth, Toyota) and others. Dynamic charging at TRL 5-7 depending on pilot use case.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	Dynamic inductive power transfer with a modular approach to provide compatibility across vehicle classes. Transmitting modules being designed for 50 kW to 100 kW per module. Also developing dynamic capacitive power transfer with early demonstrations up to 10 kW per module. DC distribution with both parallel connection at 800V DC and series connection at up to 20 kV DC. Efficiency up to 94%. Concrete and asphalt pavement embedded coils with matching network and electronics co-embedded. Target one grid tie every 1 to 2 km at 1+ MW/km.
Receiving/vehicle's system (type,	Corresponding vehicle side receiver modules also at 50 kW to 100 kW per module, with 2-4 receiver modules installed on larger vehicles with

provider, ERS equipment)	higher power demand. Retrofit/custom for research applications; commercial providers include Electreon (B.4-B.6). Vehicles include vehicle-to-infrastructure communications.
Use case (length, vehicle speed range, interoperability, cybersecurity)	Concrete embedded modules designed for precast lane segments at 3-5 m length, system suitable for full highway speeds and potentially for future high-speed platooning of autonomous vehicles, potentially unlimited range, emphasis on interoperability across vehicle classes and interoperability between static (stationary) and dynamic (in-motion) charging systems. Active projects evaluating cybersecurity risks and mitigation strategies and solutions for smart, secure charge management of ERS.
Current developments	ASPIRE industry partner, Electreon, has on road pilot projects in Sweden, Israel, Germany and Italy and is co-developing a demonstration at Utah State University's research track. ASPIRE has secured \$20 million -€16.6 million- funding (begins July 2021) for a freight electrification demonstration project in collaboration with the Utah Inland Port Authority, which includes dynamic and static wireless power transfer for forklift, drayage, and short haul applications. ASPIRE partnering with a US toll road expressway on a \$10 million -€8.3 million- (funding to be allocated May 2021) pilot project for ½ mile dynamic wireless charging on a new five-mile section of the expressway.
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	ASPIRE is headquartered at Utah State University and operated through strategic partnerships with Purdue University, University of Colorado Boulder, University of Texas at El Paso and the University of Auckland New Zealand. Additional partners include researchers at Colorado State University, University of Colorado Colorado Springs, Virginia Tech, Cornell University and four national laboratories. Global industry members include more than 50 companies and organizations across the transportation and electric utility industries, including vehicle OEMs (e.g., Toyota, Ford, Stellantis, Cummins, Kenworth, Scania, Hyster-Yale, Nikola), charging providers (WAVE, WiTricity, Electreon, Magment), engineering and construction firms (AECOM, Kiewit), charging and electrification equipment manufacturers (Schneider Electric, ABB, LG Electronics) as well as several state departments of transportation and other roadway asset owners.
Infrastructure provider costs (cap., oper., maint.)	Costs vary based on location, power requirements, grid infrastructure, and road type. Estimates range from \$1 million to \$5 million per mile (€0.5 million to €3.8 million per km) at 50% coverage. Once deployed, minimal operations and maintenance cost on the in-road coils,

	upgradability possible with coils deployed in modules, similarly minimal maintenance costs considering few to no moving parts (outside of potential roadway movement)
User costs	Dependent on power provider/local cost per kWh delivered. Significant opportunities for reduced cost compared to extreme fast charging stations due to flexibility in load on large scale ERS where utility scale charge management can leverage vehicles on ERS to balance loading on distribution networks and decrease cost per kWh.
Cost Benefit factors	30-year life ERS estimated to pay for itself with a vehicle toll of only 20% of the fuel cost savings between electric and gas/diesel. Includes 5% IRR on infrastructure investment.
Life Cycle Analysis	Detailed life cycle analysis in progress at ASPIRE, considering a wide range of scenarios.
Policy & Strategies	
Decarbonisation strategies	The transportation sector is responsible for the largest share of greenhouse gas emissions in the U.S., and more than half of these emissions are from passenger cars and light-duty trucks traveling on our Nation's highways (link).
Proposed subsidies	N/A
ERS policies	The government policy is to support pre-competitive R&D that could aid private sector decisions about commercialization potential of new technologies. There also is a government interest in technology testing and demonstration to determine potential public benefits such as reduced mobile source emissions of regulated pollutants to benefit public health and limiting U.S. transportation-related greenhouse gas emissions. In addition, research and investments in new vehicle technologies results in domestic job growth.
Policy/legislation recommendations	N/A
Key Findings	
Significant advantages are achieved in cost, transportation equity, and environmental justice through public, shared charging infrastructure. Shared infrastructure, especially across vehicle classes and passenger and fleet vehicles, provides opportunities for high utilization and low cost per mile driven. ERS solutions integrated with smart routing and utility scale charge management	

provide a valuable resource to the grid through flexible, moving loads with relatively continuous connection to the grid.

ASPIRE researchers are actively involved in developing public-private partnerships for pilot deployments in Utah, our partner states, and across the nation. Pilot projects on public roads are expected to be in operation in the U.S. within a few years with expanded deployment over the coming decade in alignment with planned roadway maintenance schedules.

B.19 ENRX – RWTH – BASt InductInfra (Germany)	
Brief Description	The InductInfra project is funded by Federal Ministry for Digital and Transport - Bundesministerium für Digitales und Verkehr (BMDV) through the BASt (German Federal Highway Research Institute). Partners of the project are the Institute of Highway Engineering (ISAC, RWTH Aachen University), the Institute of Electrical Machines (IEM, RWTH Aachen University), BERGER Bau SE, and Energie Südwest AG. The project is also composed of the associated partners ENRX (former IPT Technology GmbH), the Ifak Magdeburg and Wirtgen. The InductInfra project aims to demonstrate in a real scale configuration the 3 phases wireless dynamic charging system based on the ENRX dynamic inductive power transfer concept. The RWTH in charge of the InductInfra, with all its partners, brings forward an important development combining the 3 phases inductive sinusoidal design with a highly technical approach for the conception of roads. In this approach, functionalized materials for highway pavement in modular design are combined with a method where the three fields of application of road construction technology, of energy supply for vehicles while driving and traffic data acquisition can be combined. The RWTH has been implementing further the 3 phases ENRX approach to include specific development for the electronic components and the primary side to be installed in the pavement in order to ensure its adaptability to the pavement construction specifications in Germany. The "InductInfra" project is designed to develop new structural engineering concepts and materials systems for dynamic inductive power transmission and their fundamental integration into concrete pavement structures. To accomplish this, modular solutions are being developed in the form of prefabricated concrete elements that already contain a roadside charging coil. Furthermore, this project investigates the materials used in concrete to ensure efficient heat dissipation, ease of construction, and excellent durability. The potential, operational safety, and economic efficiency of supplying the induction modules with regenerative energy are also being examined.
Budget	1.900.000 €
Period	01.11.2020 until 31.10.2023
Technology Assessment	

ERS technology (type, provider, TRL)	The ERS technology is based on the conceptual approach provided by ENRX through its contributions in its advisory role. ENRX has largely collaborated with the RWTH and the BASt in the dynamic inductive demonstrator in Aachen introducing the new dynamic generation aligned with the 85 kHz new setup for the standards. ENRX joined to its own technology the technology developed by Bombardier Primove to further develop the ERS technology since 2021. With these assets, ENRX has the ownership of the dynamic wireless system developed by Bombardier since 2009 based on the 3 phases inductive method. ENRX, adding its own IPs, has been working since then on the next generation of the 3 phases dynamic inductive technology to optimize the current generation in terms of its functionalities and operational advantages. Additionally to the new higher frequency, the current efforts have been centred into bringing the technology to be inter-operable at 4 different levels. The new generation is designed in order to be inter-operable in terms of type of gaps between the primary and the secondary according to the different highs of vehicles, in terms of power levels according to the type of vehicle, in terms of its ability of providing charge to any winding topology, and finally in terms of been able to charge statically and dynamically with the same conceptual design. This demonstrator is under construction and will be under demonstration during the 2023/2024, with a TRL 6.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The InductInfra highway system is an inductive charging with primary windings installed based on the 20 m segments based on the ENRX system further developed by the consortium in order to ensure its ability to be implemented in the German highways. These segments are constructed based on modular concrete precast technology which can be installed in a new pavement or retrofitted in an existing pavement. Segments are powered when an authorized and properly equipped vehicle is over the segment, is able to accept energy, and is moving 80 km/h or faster. The system is connected directly to the medium voltage level grid connection. The underground infrastructure is supplied by power which is being converted to AC at 85 kHz. The efficiency is set to be 90% or higher. The system is foreseen with the capability of been scalable and conceptually conceived to produce an homogenous magnetic field protecting the battery from pics in the power transfer, and with a specific geometry providing the highest possible lateral field cancellation to reduce dramatically emissions beyond the vehicle footprint area.
Receiving/vehicle's system (type, provider, ERS equipment)	ENRX is providing the receiver equipment with a capability of 200 kW that will be used in a configuration of 100 kW during the InductInfra tests.
Use case (length, vehicle speed range, interoperability, cybersecurity)	The system has been tested in static charging in Europe, IPT has successful use cases in Germany, UK, Italy, Spain, Netherlands, Belgium and Norway. The dynamic track under construction is 40 meters long, where the vehicle will be able to attain 50 km/h. The system is conceived to be interoperable at 4 different levels: Different receiver brands/topology Different air gaps Different power levels Dynamic / Static

Current developments	In January 2021, IPT Group BV acquired wireless charging technology from Bombardier Primove GmbH. IPT Group BV is 100% owning IPT Technology GmbH which is a global manufacturer of wireless charging and electrification solutions applied in industrial and e-mobility applications since 1996 In May 2022 IPT Technology GmbH has been acquired from IPT Group BV by Arendals Fossekompani from Norway. By combining the technology and expertise of both companies (Bombardier on light duty vehicles and buses, IPT on light duty vehicles, heavy duty buses and vessels, and industrial solutions, e.g. cross belt sorters, EMS system, skillets, AGVs, Robotics), ENRX is expecting to strengthen its market position and accelerate its business planning. AFK is a green-tech investment company that owns energy- and technology-related companies which enable the transition to a green economy. At the same time, AFK has established a new group, ENRX, which will own both IPT Technology Gmbh and the Norwegian induction heating company EFD Induction. Per March 27th 2023 Industrial induction heating expert EFD Induction and inductive charging and power supply innovator IPT Technology have formed ENRX. With an offer ranging from induction heating to wireless inductive charging and contactless power supply, ENRX is an international powerhouse for equipment and systems based on induction.
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	RWTH Aachen University leads the project and implements its knowledge to implement and asses the technology in the Durabast test track of the BASt. The institutes active in the project for the RWTH are the Institute of Highway Engineering (ISAC) and the Institute of Electrical Machines (IEM). BERGER Bau SE is the construction company bringing a long experience on concrete highway implementation, and is implementing the prefabrication of the modules introduced in the ERS. EnergieSüdwest AG contributes with feasibility analysis of the grid implementation, and the Ifak Magdeburg institute contributes within the research topics related with the norms and the magnetic compatibility. As associated partner Wirtgen contributes with its expertise in the concrete pavement construction technology.
Infrastructure provider costs (cap., oper., maint.)	N/A
User costs	N/A
Cost Benefit factors	N/A
Life Cycle Analysis	N/A
Policy & Strategies	
Decarbonisation strategies	
Proposed subsidies	

ERS policies	
Policy/legislation recommendations	
Key Findings	
System	N/A
Infrastructure	N/A
ERS policies	N/A

B.20 ENRX – CFX FLORIDA – ASPIRE (USA)	
Brief Description	Central Florida Expressway Authority has engaged ENRX Corporation to provide its IPT Charge interoperable dynamic wireless charging product to be installed as part of a new highway to be constructed approximately 17 miles west of downtown Orlando. The system will be first constructed and tested at the EVR test track facility from ASPIRE located in Logan, Utah, and then constructed and in operation at the State Route 516 in Florida (SR 516 - also known as the Lake/Orange Expressway). In both sites the dynamic wireless charging road will be implemented considering the specific project requirements established during our different meetings.
Budget	Not to be disclosed yet
Period	2023 until 2026
Technology Assessment	
ERS technology (type, provider, TRL)	The ERS technology is based on the current ENRX new generation aligned with the 85 kHz new setup for the standards. ENRX joined IPTs technology to the technology developed by Bombardier Primove to further develop the ERS system since 2021. With these assets, ENRX has the ownership of the dynamic wireless system developed by Bombardier since 2009 based on the 3 phases inductive method. ENRX, adding IPTs IPs, has been working since then on the next generation of the 3 phases dynamic inductive technology to optimize the current generation in terms of its functionalities and operational advantages. Additionally to the new higher frequency, the current efforts have been centred into bringing the technology to be inter-operable at 4 different levels. The new generation is designed in order to inter-operable in terms of type of gaps between the primary and the secondary according to the different highs of vehicles, in terms of power levels according to the type of vehicle, in terms of its ability of provide charge to any winding topology, and finally in terms of been able to charge statically and dynamically with the same conceptual design. This demonstrator is under construction and will be under demonstration during the 2023/2024, with a TRL 8.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The CFX highway system is an inductive charging with primary windings installed based on the 20 m segments based on the IPT system further developed by the consortium in order to ensure its ability to be implemented in the German highways. These segments are constructed based on modular concrete precast technology which can be installed in a new pavement or retrofitted in an existing pavement. Segments are powered when an authorized and properly equipped vehicle is over the segment, is able to accept energy, and is moving 80 km/h or faster. The system is connected directly to the medium voltage level grid connection. The underground infrastructure is supplied by power which is being converted to AC at 85 kHz. The efficiency is set to be 90% or higher. The system is foreseen with the capability of been scalable and conceptually conceived to produce an homogenous magnetic field protecting the battery from pics in the power transfer, and with a specific geometry providing the highest possible lateral field cancellation to reduce dramatically emissions beyond the vehicle footprint area.

Receiving/vehicle's system (type, provider, ERS equipment)	ENRX is providing the receiver equipment with a capability of 200 kW, 100 kW and 50 kW to be implemented with vehicles belonging to the ASPIRE partnership pool.
Use case (length, vehicle speed range, interoperability, cybersecurity)	The system has been tested in static charging in Europe, ENRX has successful use cases in Germany, UK, Italy, Spain, Netherlands, Belgium and Norway. The EVR dynamic track of 40 meters long, will precede the construction of the highway dynamic charging pavement of 1,2 km where the vehicle will be able to attain 80 km/h. The system is conceived to be interoperable at 4 different levels: Different receiver brands/topology Different air gaps Different power levels Dynamic / Static
Current developments	In January 2021, IPT Group BV acquired wireless charging technology from Bombardier Primove GmbH. IPT Group BV is 100% owning IPT Technology GmbH which is a global manufacturer of wireless charging and electrification solutions applied in industrial and e-mobility applications since 1996 In May 2022 IPT Technology GmbH has been acquired from IPT Group BV by Arendals Fossekompani from Norway. By combining the technology and expertise of both companies (Bombardier on light duty vehicles and buses, IPT on light duty vehicles, heavy duty buses and vessels, and industrial solutions, e.g. cross belt sorters, EMS system, skillets, AGVs, Robotics), ENRX is expecting to strengthen its market position and accelerate its business planning. AFK is a green-tech investment company that owns energy- and technology-related companies which enable the transition to a green economy. At the same time, AFK has established a new group, ENRX, which will own both IPT Technology Gmbh and the Norwegian induction heating company EFD Induction. Per March 27th 2023 Industrial induction heating expert EFD Induction and inductive charging and power supply innovator IPT Technology have formed ENRX. With an offer ranging from induction heating to wireless inductive charging and contactless power supply, ENRX is an international powerhouse for equipment and systems based on induction
Business Models & Stakeholder Engagement	

Stakeholders (type and role)	The Central Florida Expressway Authority (CFX) is an independent agency of the state that owns, operates and maintains a regional network of expressways for 3.3 million residents and more than 72 million visitors in Brevard, Lake, Orange, Osceola and Seminole Counties. CFX's 125-mile user-funded system includes 865 lane miles, 73 interchanges, 14 mainline toll plazas, 5 mainline gantries, 74 ramp toll plazas and 343 bridges and eight named expressways. ASPIRE is headquartered at Utah State University and operated through strategic partnerships with Purdue University, University of Colorado Boulder, University of Texas at El Paso and the University of Auckland New Zealand. Additional partners include researchers at Colorado State University, University of Colorado Colorado Springs, Virginia Tech, Cornell University and four national laboratories. Global industry members include more than 50 companies and organizations across the transportation and electric utility industries, including vehicle OEMs (e.g., Toyota, Ford, Stellantis, Cummins, Kenworth, Scania, Hyster-Yale, Nikola), charging providers (WAVE, WiTricity, Electreon, Magment, ENRX), engineering and construction firms (AECOM, Kiewit), charging and electrification equipment manufacturers (Schneider Electric, ABB, LG Electronics) as well as several state departments of transportation and other roadway asset owners.
Infrastructure provider costs (cap., oper., maint.)	Costs vary based on location, power requirements, grid infrastructure, and road type. Aligned with ASPIRE estimations the ERS in development range from $1 million to $3 million per mile. The specific concrete design implicates minimal operations and maintenance costs in terms of its infrastructure, on the side of the vehicle also minimal maintenance costs are foreseen considering the absence of moving parts.
User costs	N/A
Cost Benefit factors	N/A
Life Cycle Analysis	Life cycle analysis will be aligned with the ongoing ASPIRE analyses on the matter.
Policy & Strategies	
Decarbonisation strategies	The transportation sector is responsible for the largest share of greenhouse gas emissions in the U.S., and more than half of these emissions are from passenger cars and light-duty trucks traveling on our Nation's highways. The target of the interoperative solution implemented in the CFX network is to provide a solution for all the vehicles, in particular the logistic trucks and the heavy duty trucks in the first implementations.
Proposed subsidies	N/A
ERS policies	The government policy, through the active participation of ASPIRE, supports the R&D development leading to commercialization of new technologies. The direct participation of ASPIRE in the SAE international standardisation committee sets the requirements of the ERS projects in order to comply to the potential initiatives able to feed the ERS standards guiding the ERS Policies in the U.S. technological environment in the automotive sector.
Policy/legislation recommendations	N/A

Key Findings	
System	N/A
Infrastructure	N/A
ERS policies	N/A

B.21 Electreon - Port of Karlsruhe (EnBW) (Germany)

Brief Description	100m of wireless Electric Road for dynamic charging of an e-bus, with additional static wireless charging station, operating on a private road at the EnBW training campus facility in the Port of Karlsruhe, Germany.
Budget	XXX
Period	2020 - 2023
Technology Assessment	
ERS technology (type, provider, TRL)	Electreon Wireless Ltd is an Israeli start-up company headquartered in Bet Yannai, Israel. It was founded in 2013 with the aim to bring wireless dynamic charging to the market for commercial bus operators, passenger cars, LMD vehicles, and P2P trucks to be able to charge via an Electric Road System (ERS) while they drive, thereby enabling more sustainable transportation solutions through less charging infrastructure real estate usage, a shared charging platform, cleaner cities, more vehicle uptime, and smaller battery requirements. The company has also developed static wireless charging technology for vehicles to be able to also charge wirelessly while parked/stationary. A TRL 6-7 is estimated for Electreon's technology. Electreon Germany GmbH is a subsidiary of Electreon Wireless Ltd. based in Cologne and overseeing German projects.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	Electreon has developed a modular system of receivers; for passenger vehicles, the power capabilities per receiver include 11 kW – 20 kW; for larger vehicles (e-vans, e-buses, and e-trucks), the power capabilities per receiver start at 25 kW per receiver, and the company has tested 30 kW as well. Electreon has plans in their technology roadmap of 45+ kW per receiver. Electreon's wireless power transfer rate has been tested in real world settings and conditions to provide up to 87% efficiency in the dynamic (in-motion) charging mode, and up to 92% efficiency in the static (stationary/parked) charging mode. Installation: tests have shown that 1 km of coils can be laid, at a depth of 8 cm, in one working day, this does not include establishing roadside transformers and communication systems. It should be noted that a depth of 8 cm was chosen to ensure that planning activities and routine maintenance can still be carried out on the pavement without interfering with the system.

Receiving/vehicle's system (type, provider, ERS equipment)	This project featured an e-bus with three vehicle receivers.
Use case (length, vehicle speed range, interoperability, cybersecurity)	Urban public transportation on a private campus road: 100m of wireless Electric Road for dynamic charging of an e-bus, with additional static wireless charging station, operating on a private road at the EnBW training campus facility in the Port of Karlsruhe, Germany.
Current developments	Recent activities Upgrading and installation of static charging station Current activities Upgrading bus assemblies Upcoming activities Testing of the bus post-upgrades
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	EnBW is the project sponsor Higer is the OEM partner as the manufacturer of the e-bus being tested in the pilot. The e-bus is being operated by VBK, the Karlsruhe Transport Company, the municipal transport company of the city of Karlsruhe. Technical support for the bus is being provided by Chariot Motors, Higer's distributor in Europe. The road work was done by the infrastructure company Eurovia and electric work by Omexom, both subsidiaries of Vinci.
Infrastructure provider costs (cap., oper., maint.)	XXX
User costs	XXX
Cost Benefit factors	XXX

Life Cycle Analysis	XXX
Policy & Strategies	
Decarbonisation strategies	N/A
Proposed subsidies	N/A
ERS policies	N/A
Policy/legislation recommendations	N/A
Key Findings	
The initial project was installed in a 100-meter section of road. After successful testing, it is expected that it will expand to a 500-meter section directly into the city. The success of the dynamic charging for this project facilitated the partnership between Eurovia with Electreon to continue as part of the E|MPOWER (Autobahn) project, which will see Electreon install 1 km of dynamic charging on the Bavarian Autobahn, as well as the partnerships between EnBW and Higer with Electreon to continue as part of the ELINA (Balingen) project, which will also see the installation of 1 km of dynamic charging with additional static charging in the town of Balingen, Germany.	

B.22 ELECTREON - BASt (GERMANY)

Brief Description	100m of wireless Electric Road for dynamic charging of an e-van at the DuraBASt, the German national road test facility, track near Cologne, Germany.
Budget	1.9 million euros (project funding)
Period	2021 – To be confirmed
Technology Assessment	
ERS technology (type, provider, TRL)	Electreon Wireless Ltd is an Israeli start-up company headquartered in Bet Yannai, Israel. It was founded in 2013 with the aim to bring wireless dynamic charging to the market for commercial bus operators, passenger cars, LMD vehicles, and P2P trucks to be able to charge via an Electric Road System (ERS) while they drive, thereby enabling more sustainable transportation solutions through less charging infrastructure real estate usage, a shared charging platform, cleaner cities, more vehicle uptime, and smaller battery requirements. The company has also developed static wireless charging technology for vehicles to be able to also charge wirelessly while parked/stationary. A TRL 6-7 is estimated for Electreon's technology. Electreon Germany GmbH is a subsidiary of Electreon Wireless Ltd. based in Cologne and overseeing German projects.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	Electreon has developed a modular system of receivers; for passenger vehicles, the power capabilities per receiver include 11 kW – 20 kW; for larger vehicles (e-vans, e-buses, and e-trucks), the power capabilities per receiver start at 25 kW per receiver, and the company has tested 30 kW as well. Electreon has plans in their technology roadmap of 45+ kW per receiver. Electreon's wireless power transfer rate has been tested in real world settings and conditions to provide up to 87% efficiency in the dynamic (in-motion) charging mode, and up to 92% efficiency in the static (stationary/parked) charging mode. Installation: tests have shown that 1 km of coils can be laid, at a depth of 8 cm, in one working day, this does not include establishing roadside transformers and communication systems. It should be noted that a depth of 8 cm was chosen to ensure that planning activities and routine maintenance can still be carried out on the pavement without interfering with the system.

Receiving/vehicle's system (type, provider, ERS equipment)	This project features an e-van with one-two vehicle receivers.
Use case (length, vehicle speed range, interoperability, cybersecurity)	Inter-city highway application testing on private research road: 100m of wireless Electric Road for dynamic charging of an e-van at the DuraBASt, the German national road test facility, track near Cologne, Germany.
Current developments	Recent activities Production of equipment and initial deployment of ground assemblies Current activities Additional work and improvements on ground assembly Upcoming activities Road endurance tests (summer 2023) Vehicle integration (summer 2023)
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	The transport operator and project sponsor is the German Federal Highway Research Institute (BASt) The OEM partner is Volkswagen, who is providing an e-Crafter electric van to operate as part of the pilot The road work design and construction will be done by the infrastructure company Eurovia, a subsidiary of Vinci, and will be coordinated with VIA IMC, a separate subsidiary of Eurovia. Electrical work will be done by Omexom, also a subsidiary of Vinci. Braunschweig University is a research partner involved in the project
Infrastructure provider costs (cap., oper., maint.)	XXX
User costs	XXX

Cost Benefit factors	XXX
Life Cycle Analysis	XXX
Policy & Strategies	
Decarbonisation strategies	N/A
Proposed subsidies	N/A
ERS policies	N/A
Policy/legislation recommendations	N/A
Key Findings	
Live project; pending vehicle integration completion and endurance test completion in summer 2023.	

B.23 Electreon - E|MPOWER (Germany)

Brief Description	1 km of wireless Electric Road for dynamic charging of multiple vehicle types operating as part of a public section of road on the Bavarian Autobahn.
Budget	7.2 million euros (project funding)
Period	2023 – 2024
Technology Assessment	
ERS technology (type, provider, TRL)	Electreon Wireless Ltd is an Israeli start-up company headquartered in Bet Yannai, Israel. It was founded in 2013 with the aim to bring wireless dynamic charging to the market for commercial bus operators, passenger cars, LMD vehicles, and P2P trucks to be able to charge via an Electric Road System (ERS) while they drive, thereby enabling more sustainable transportation solutions through less charging infrastructure real estate usage, a shared charging platform, cleaner cities, more vehicle uptime, and smaller battery requirements. The company has also developed static wireless charging technology for vehicles to be able to also charge wirelessly while parked/stationary. A TRL 6-7 is estimated for Electreon's technology. Electreon Germany GmbH is a subsidiary of Electreon Wireless Ltd. based in Cologne and overseeing German projects.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	Electreon has developed a modular system of receivers; for passenger vehicles, the power capabilities per receiver include 11 kW – 20 kW; for larger vehicles (e-vans, e-buses, and e-trucks), the power capabilities per receiver start at 25 kW per receiver, and the company has tested 30 kW as well. Electreon has plans in their technology roadmap of 45+ kW per receiver. Electreon's wireless power transfer rate has been tested in real world settings and conditions to provide up to 87% efficiency in the dynamic (in-motion) charging mode, and up to 92% efficiency in the static (stationary/parked) charging mode. Installation: tests have shown that 1 km of coils can be laid, at a depth of 8 cm, in one working day, this does not include establishing roadside transformers and communication systems. It should be noted that a depth of 8 cm was chosen to ensure that planning activities and routine maintenance can still be carried out on the pavement without interfering with the system.
Receiving/vehicle's system (type,	This project will feature a light duty vehicle.

provider, ERS equipment)	
Use case (length, vehicle speed range, interoperability, cybersecurity)	Inter-city highway application on a public road: 1 km of wireless Electric Road for dynamic charging of multiple vehicle types operating as part of a public section of road on the Bavarian Autobahn.
Current developments	XXX
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	The road work design and construction will be done by the infrastructure company Eurovia, a subsidiary of Vinci, and will be coordinated with VIA IMC, a separate subsidiary of Eurovia. The transport operator will be the Autobahn ('Die Autobahn') The project sponsor is the German Federal Ministry for Economic Affairs and Climate Action (BMWK) Risomat will be a partner in the supplier of electrical motor supplies as part of design and deployment of the ERS Several universities and institutes will also partake in the project as research partners: FAU, FAPS, and Institute ELSYS
Infrastructure provider costs (cap., oper., maint.)	XXX
User costs	XXX
Cost Benefit factors	XXX
Life Cycle Analysis	XXX
Policy & Strategies	
Decarbonisation strategies	N/A
Proposed subsidies	N/A

ERS policies	N/A
Policy/legislation recommendations	N/A
Key Findings	
N/A – not yet in operation	

B.24 Electreon - ELINA (Balingen) (Germany)

Brief Description	1 km of wireless Electric Road for dynamic charging of an e-bus, with additional static wireless charging stations along the bus route, operating on a public road in the town of Balingen, Germany.
Budget	3.2 million euros (project funding)
Period	2023 – To be confirmed
Technology Assessment	
ERS technology (type, provider, TRL)	Electreon Wireless Ltd is an Israeli start-up company headquartered in Bet Yannai, Israel. It was founded in 2013 with the aim to bring wireless dynamic charging to the market for commercial bus operators, passenger cars, LMD vehicles, and P2P trucks to be able to charge via an Electric Road System (ERS) while they drive, thereby enabling more sustainable transportation solutions through less charging infrastructure real estate usage, a shared charging platform, cleaner cities, more vehicle uptime, and smaller battery requirements. The company has also developed static wireless charging technology for vehicles to be able to also charge wirelessly while parked/stationary. A TRL 6-7 is estimated for Electreon's technology. Electreon Germany GmbH is a subsidiary of Electreon Wireless Ltd. based in Cologne and overseeing German projects.
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	Electreon has developed a modular system of receivers; for passenger vehicles, the power capabilities per receiver include 11 kW – 20 kW; for larger vehicles (e-vans, e-buses, and e-trucks), the power capabilities per receiver start at 25 kW per receiver, and the company has tested 30 kW as well. Electreon has plans in their technology roadmap of 45+ kW per receiver. Electreon's wireless power transfer rate has been tested in real world settings and conditions to provide up to 87% efficiency in the dynamic (in-motion) charging mode, and up to 92% efficiency in the static (stationary/parked) charging mode. Installation: tests have shown that 1 km of coils can be laid, at a depth of 8 cm, in one working day, this does not include establishing roadside transformers and communication systems. It should be noted that a depth of 8 cm was chosen to ensure that planning activities and routine maintenance can still be carried out on the pavement without interfering with the system.

Receiving/vehicle's system (type, provider, ERS equipment)	This project will feature an e-bus with three vehicle receivers.
Use case (length, vehicle speed range, interoperability, cybersecurity)	Inter-city urban road application on a public road: 1 km of wireless Electric Road for dynamic charging of an e-bus, with additional static wireless charging stations along the bus route, operating on a public road in the town of Balingen, Germany.
Current developments	Recent activities Production of all management units and coils Current activities Bring-up and integration of all 1st phase assemblies Upcoming activities Deployment of 1st phase (400m dynamic stretch + 2 static charging stations) - March 2023 Commercial operation of 1st phase - May 2023 Deployment of 2nd phase - September 2023
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	The German Aerospace Center (DLR) is the project sponsor Higer is the OEM partner as the manufacturer of the e-bus operating in the commercial project Karlsruhe Institute of Technology is a research partner Stadtwerke Balingen is a public work company involved overseeing infrastructure deployment EnBW will be involved in project management specifically of the charging infrastructure
Infrastructure provider costs (cap., oper., maint.)	XXX

User costs	XXX
Cost Benefit factors	XXX
Life Cycle Analysis	XXX
Policy & Strategies	
Decarbonisation strategies	N/A
Proposed subsidies	The project is being sponsored by the German Aerospace Center (DLR) with Electreon receiving up to 3.2 million euros in funding for deployment an operation of the wireless ERS in Balingen.
ERS policies	N/A
Policy/legislation recommendations	N/A
Key Findings	
N/A – not yet in operation	

B.25 VEDECOM - IncitEv (France)	
Brief Description	Demonstration of dynamic inductive charging system for urban applications , in the framework of the European project INCIT-EV
Budget	Around 1 million €
Period	2021-2024
Technology Assessment	
ERS technology (type, provider, TRL)	ERS Type : dynamic inductive charging system for cars and light utility vehicles Provider : VEDECOM TRL : from 4 to 7
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The ground system consists of primary inductive coils, 1 m long, embedded in the pavement structure, at low depth. The coil elements include litz wire loops, ferrites, and capacitors, protected by a plastic frame . The coils are placed in a trench milled in the middle of the road lane, sealed with a resin, and covered with a new asphalt wearing course, about 5 cm thick. The electric supply is ensured by inverters (one per coil), placed in a trench on the road side. they generated the high frequency AC current (79 to 90 kHz frequency) required for the supply of the coils They are responsible for the power supply, electrical measurements and communication with the next and previous inverter modules and with a track supervisor interface. The inverters are powered by a DC power source (400 to 600 V), capable of delivering a power of 120 kW per 25 m of track. The charging power is 30 kW per coil, and the expected efficiency is about 90 % . The system is designed for cars and light utility vehicles.
Receiving/vehicle's system (type, provider, ERS equipment)	The vehicle system is developed by VEDECOM, and consist of one or more secondary coils (litz wire), placed under the vehicle, and an AC / DC converter, which converts the current induced in the coil into a DC current which can be used to charge the battery. Cars are equipped with one coil, which leads to a charging power of 30 kW. Light utility vehicles are equipped with 3 secondary coils, to increase the charging power to 90 kW A communication system between the vehicle and the road infrastructure is also developed to ensure detection of the vehicle, to authorize charging, and to assist with the alignment of the vehicle.
Use case (length, vehicle speed range, interoperability, cybersecurity)	The demonstrator will be built in a street in Paris, open to normal traffic; the charging section will be 30 m long, and will consist of 30 coils. The system is designed for urban traffic speeds (0 to 50 km/h). It will be tested with 3 different vehicles : two cars, and one light utility vehicle.
Current developments	The ground system is ready. The integration of the secondary system in the vehicles is being finalized. The demonstrator will be built around mid-2023. Then , tests will be carried out for several months to evaluate its performance.
Business Models & Stakeholder Engagement	

Stakeholders (type and role)	Inductive charging system developer : Research institute Research and evaluation of the system : Research institute Road integration / construction of the demonstrator : Road construction company Electricity supply : Electricity distribution system operator Supply of vehicles : vehicle manufacturers Road owner : city authorities
Infrastructure provider costs (cap., oper., maint.)	To be defined after the experimentation
User costs	To be defined after the experimentation
Cost Benefit factors	To be defined after the experimentation
Life Cycle Analysis	To be performed later
Policy & Strategies	
Decarbonisation strategies	Not addressed in this project
Proposed subsidies	Not addressed in this project
ERS policies	Not addressed in this project
Policy/legislation recommendations	Not addressed in this project
Key Findings	
Design of the inductive charging system, compatible with the constraints of the urban environment, and validation of its performance at laboratory scale. Design of the road integration solution and validation at laboratory scale, and by accelerated pavement test. The demonstrator will be built around mid 2023, and a detailed evaluation of its performance will be carried out	

B.26 Alstom - eRoadMontBlanc (France)	
Brief Description	Electric road demonstrations of the Alstom's ground-level conductive solution on a test track and then on a permanent highway section (public road).
Budget	~21M€
Period	2023..2027
Technology Assessment	
ERS technology (type, provider, TRL)	ERS provider: Alstom ERS type: ground-based conductive solution TRL: from 3-4 to 7-8
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	The feeder track consists of a structure made of insulating material (rubber) which supports 3 conductor segments placed in parallel (the conductor in the centre, the return current on one side and a voltage barrier on the other side). The feeder track is installed in the middle of the slow track in a groove (50cm X 7cm). The top of the feeder track is level with the road surface, there are no obstacles on the road. Each feeder segment is a maximum of 11m long, and is only powered when covered by an operating ERS vehicle. Power is only delivered when the vehicle is travelling within a given speed range (30..90kph) and when all safety conditions are met (vehicle identified, current collector shoes on, no obstacles, etc.). The segments are powered by a power switch box buried at the roadside. Each communication box safely manages 2 conductive segments. These boxes are supplied by an electrical substation which transforms the medium voltage (20KVA for instance) into 750VDC. The system is designed to be used by all types of vehicles from cars to heavy-duty trucks.. The system is designed to transfer up to 400kW (750 VDC, 533 Amps)with a 97% power transfer efficiency.
Receiving/vehicle's system (type, provider, ERS equipment)	The ERS system on the vehicle side is mainly composed of : A retractable current collector device for collecting power from the ground and transmit the return current to the feeding track A radio transceiver (used to provide presence signal to the ground and to calculate vehicle speed), Smart sensors used to detect obstacles in front of the vehicle and at the rear for the short ones, and on the feeding track The retractable current collector device placed underneath the vehicle, is equipped with an automatic lateral positioning system allowing the good location of the collector shoes on the conductive segments whatever the position of the vehicle within a maximum distance of 0,5m from the centre of the lane. The current collected from the feeding track is used for propelling the vehicle and/or recharging its batteries while driving.

Use case (length, vehicle speed range, interoperability, cybersecurity)	Phase 1 on test centre: 450m, speed up to 100kph, with 1 heavy-duty truck and 1 light vehicle Phase 2 on highway (in a 4% slope with bridges, curves, entrance and exit): at least 1km permanent section, speed up to 100kph, with 1 heavy-duty truck, 1 coach and 1 light vehicle.
Current developments	ERS on-board equipment
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	ERS supplier: Trackside part of ERS system Highway Operator: Leader and operation of the pilot project on its network Research Institute: Research and Validation of the system Vehicle transformer: Supply of the ERS truck and coach Automotive supplier: ERS On-bord equipment and light vehicle integration
Infrastructure provider costs (cap., oper., maint.)	This will be published later in the frame of this project.
User costs	This will be published later in the frame of this project.
Cost Benefit factors	This will be published later in the frame of this project.
Life Cycle Analysis	This will be published later in the frame of this project.
Policy & Strategies	
Decarbonisation strategies	It will be defined by the road authorities (partly on the basis of the results collected in this project).
Proposed subsidies	It will be defined by the road authorities (partly on the basis of the results collected in this project).
ERS policies	It will be defined by the road authorities (partly on the basis of the results collected in this project).
Policy/legislation recommendations	It will be defined by the road authorities (partly on the basis of the results collected in this project).
Key Findings	
This will be published later in the frame of this project.	

B.27 CRRC - Zhuzhou (China)	
Brief Description	First China's electrified highway field located in CRRC Zhuzhou Research Institute Co., Ltd., Tianyuan District, Zhuzhou City
Budget	Unknown
Period	Start of the field test in March 2023
Technology Assessment	
ERS technology (type, provider, TRL)	Overhead catenary line System provided by CRRC Zhuzhou Research Institute. TRL 5
Transmitting/ground system (configuration, power transfer, voltage, efficiency)	Overhead catenary line solution.
Receiving/vehicle's system (type, provider, ERS equipment)	The vehicle system converts electric energy into power through the pantograph device to drive the vehicle on the road and realize dynamic charging. The truck is provided by Sany Group.
Use case (length, vehicle speed range, interoperability, cybersecurity)	The demonstration line is a two-way two-lane road with a width of 7 meters. It has 53 assembly poles, 1.8km catenary and 1 box-type substation. The line covers a variety of road conditions such as straight lines, curves, ramps, concave-convex roads, wading test areas
Current developments	Unknown
Business Models & Stakeholder Engagement	
Stakeholders (type and role)	Research Institute, Ministry of Transport, University
Infrastructure provider costs (cap., oper., maint.)	Unknown
User costs	Unknown
Cost Benefit factors	Unknown
Life Cycle Analysis	Unknown
Policy & Strategies	
Decarbonisation strategies	Unknown
Proposed subsidies	Unknown

ERS policies	Unknown
Policy/legislation recommendations	Unknown
Key Findings	

APPENDIX C – PROJECT PROFILES

C.1 Alstom

Project Name	1- Slide-In (2012..2018) 2- R&D Infrastructure Test tracks (2019..2022) 3- ERS Test track (from 2023) 4- Pilot Project in the Alps (from 2025)
Project short description	1- Ground-based conductive solution with a feeding track integrating 2 parallel conductive segments 22m long (one for the power transfer and the other one for the return current). 3&4- Ground-based conductive solution with a feeding track integrating 2 parallel conductive segments 11m long (one for the power transfer and the other one for the return current).
Project short description of Technology used	Electric road length: 310m (2012-2018) 50m & 20m (2019-2022) 450m close area (From 2023) 1-2km (permanent) on highway in Alpes (From 2024) Ground-based conductive solution with a feeding track integrating 2 parallel conductive segments.
Number and type of vehicles tested	2 Volvo Trucks tractors N/A 2 Light duty vehicle; 1 Heavy duty truck; 1 coach 2 Light duty vehicle; 1 Heavy duty truck; 1 coach
Number of km run in ERS mode (effective power transfer from ERS infrastructure)	Few tens of km (2012-2008) N/A (2019-2022) Few tens of km (in planning 2023) Between 15 000km and 25 000km the two first years (in planning 2024)

Power Supply installed by km	0,25MW (limited by the project requirements) N/A 1 MW 1 MW
Number of Power Supply Substations by km	One (1)
Maximum Energy Transfer transferable by the ERS infrastructure installed	126 kW (limited by the project requirements) N/A 400 kW (for heavy-duty truck) 400 kW (for heavy-duty truck)
Maximum voltage transferable by the ERS infrastructure installed	690VDC N/A 750VDC 750VDC
Maximum current transferable by the ERS infrastructure installed	180A (max.) N/A 533A (max.) 533A (max.)
Maximum Power transferred during the experimentation	126 kW (limited by the project requirements) N/A 400 kW (planned for heavy-duty truck) 400 kW (planned for heavy-duty truck)
Average Power transferred during the experimentation	Not measured
Average vehicle speed during energy transfer (for each vehicle type)	From 60kph to 90kph
Maximum vehicle speed during energy transfer (for each vehicle type)	90kph N/A 90kph (planned) 90kph (planned
Average efficiency measured in terms of power transfer	97%
Maximum efficiency measured in terms of power transfer	97%
Maximum efficiency measured in terms of power transfer at maximum speed	97%
Maximum current collection width	1m

Number of faults registered by 1000km run	~0
Typology of faults recorded Duration of the installation	N/A
Duration of the installation	Not relevant (installation like in railways in a concrete slab) 1 day
Lessons learned	
Focus: The focus was to proof the concept (No.1), test the infrastructure (No.2), validate the system (No.3, planned for 2023) and to operate the ERS (No.4, planned in 2025). Project duration: First project started in 2012, 2024 and ongoing. Infrastructure: It is foreseen to install up to half a kilometre of ERS by day (without night working). It is better to close a section of the road for the security of the workers and the speed of installation. Safety: No further protection needed. Test done in 2019 shown that once wet, the rubber surface (even engraved) of the feeding track was too slippery. This lead us to modify the surface of the feeding track by adding aggregates on the top layer, with very satisfying result in lab test (SRT pendulum and Wehner et Schulze test device). Water, snow and ice: A current leakage test campaign using low voltage, has demonstrated that whatever the ice melting solution used (and even the more conductive one using brine in addition to salt), that the power transfer will possible even just after an winter maintenance operation (the only impact would be a low and temporarily decrease of the efficiency of the power transfer).. Acceptance: Not yet done. A process of participation is planned on the pilot project on open road..	
Best practice	
Very low impact on the road in terms of visibility Can be used for all types of vehicles The infrastructure system is compatible with usual winter maintenance (salt, snow-ploughing) No special protection is needed Road must/should be closed for installation The surface of the pavement is touched It is possible to develop an efficient lateral positioning system ensuring that the collector shoes are continuously well positioned on the conductive segments It is possible to integrate all the ERS components on an hybrid tractor without modifying its dimensions Once installed, the feeding track and its conductive segments protruding 2 mm are not considered an obstacle by motorcycles (tested up to 180 km/h)	

C2 Electreon

Project Name	Smartroad Gotland
Project short description	Wireless (Inductive) Electric Road System for dynamic charging of vehicles in motion, as part of a 4.1 km route between the airport and the town center of Visby. In 2023, static charging was also deployed and is in full operation
Project short description of Technology used	Length of the ERS section: 4.100 m. Wireless inductive charging
Number and type of vehicles tested	2 vehicle types, 3 individual vehicles from 3 different OEMs have utilized the ERS since the initiation of the project ● Electric bus: oHiger 12.5 m bus ● Electric truck: oEFORCE, 40 ton truck, oGINAF, 40 ton truck
Number of km run in ERS mode (effective power transfer from ERS infrastructure)	●1.65 km of wireless (inductive) Electric Road System ●Static charging system also installed (2023)
Power Supply installed by km	● The EFORCE truck has 5 receivers ● The GINAF truck has 7 receivers ● The Higer bus has 3 receivers In late 2022, 450 meters of newer generation of segment coils were added to the ERS, each capable of supplying up to 30 kW of power and have a better connection to the Management Unit.
Number of Power Supply Substations by km	The project is divided into two section. The low speed section (400 m) is powered by a energy storage with solar cells. The high speed section (1250 m) is fed by a traditional substation.

Maximum Energy Transfer transferable by the ERS infrastructure installed	Electric bus (3 receivers) ● 30 kW dynamic segment coils: 90 kW of total power Electric truck (5 receivers) ● 30 kW dynamic segment coils: 150 kW of total power Electric truck (7 receivers) ● 30 kW dynamic segment coils: 210 kW of total power
Maximum voltage transferable by the ERS infrastructure installed	● The vehicle receiver can transfer energy to battery at 380 - 800 Volt DC.
Maximum current transferable by the ERS infrastructure installed	250 A
Maximum Power transferred during the experimentation	150 kW
Average Power transferred during the experimentation	● Average power transfer from the electrified roadway (truck): 120 kW ● Average power transfer from the electrified roadway (bus): 90 kW
Average vehicle speed during energy transfer (for each vehicle type)	60 km/h (speed limit of the road)
Maximum vehicle speed during energy transfer (for each vehicle type)	80 km/h (speed limit of a heavy truck with trailer, tested during high speed tests)
Average efficiency measured in terms of power transfer	85 % (grid to battery)
Maximum efficiency measured in terms of power transfer	90 % (grid to battery)
Maximum efficiency measured in terms of power transfer at maximum speed	90 % (grid to battery)
Maximum current collection width	+/-20 cm
Number of faults registered by 1000km run	During the first months of operation there was registered with no charging. The current system is operated without problems.
Typology of faults recorded Duration of the installation	The problems were SW issues mainly related to the access control and communication which now is solved.

Duration of the installation	● Construction began in November 2019 ● Approximately 1 km was installed overnight; replacement of 450m of coil segments with higher power generation coils was also completed in a few hours. ● Operational until September 2023
Lessons learned	
Focus: The focus was to test a wireless inductive solution on a public road. Project duration: November 2019 to September 2023. Infrastructure: The deployment ... Safety: The project showed that it is safe for people and animals under all traffic situations and all weather conditions. No problems with friction. Water, snow, ice: No problems occurred. Substations: ? Acceptance: Due to the lesser visibility the acceptance is high.	
Best practice	
low visibility could be used for all types of vehicles the system do not need to be deiced no special protection is needed road must be closed for installation the surface of the pavement is not touched	

C3 Elonroad

Name of test trial	EVolution Road
Project short description	Trial of Elonroad conductive e-road technology on public road
Project short description of Technology used	Power from ground feeding rail. One-meter segments placed in series switch on power under vehicle. Every second segment switch to +650V, The others have 0V. Rail installed in a milled grove 6cm deep and 30cm wide in level with asphalt. Conductive technology allowing for power transfer to vehicle of 277kW today and 400kW in future. Smart road with sensors, access control and billing system built inside the rail
Number and type of vehicles tested	1 Solaris Trolley bus, 1 e-Crafter, 1 Nissan Leaf. 1 Trailer with heat fans.
Number of km run in ERS mode (effective power transfer from ERS infrastructure)	Approximately 600km
Power Supply installed by km	300 kW installed at demo ERS in Lund. Possible 3MW power station every 1.5 km.
Number of Power Supply Substations by km	0.55 to 1. Or as many as needed. Only one power feed from power station to electric rail every 1,9km.
Maximum Energy Transfer transferable by the ERS infrastructure installed	In Lund demo 300kW in power station. In new project 3MW /power station every 1.9 km. Possible to install power stations more frequent if needed. No other sub stations along the road.
Maximum voltage transferable by the ERS infrastructure installed	650 – 750 V today, Not decided. Waiting for ERS standard.

Maximum current transferable by the ERS infrastructure installed	500A from Power station installed in Lund. 1400A /lane planned for Örebro ERS. 2800A from Power station both directions. Maximum length between power feed 1,9km
Maximum Power transferred during the experimentation	277kW in 80 kph
Average Power transferred during the experimentation	265kW
Average vehicle speed during energy transfer (for each vehicle type)	Trialer, w onboard heat fans 277kW at 80kph Solaris bus, w onboard charger: 220kW at 40kph Nissan Leaf w onboard charger: 12kW at 50kph ECrafter w onboard heat fans: 20kW at 75kph Due to the short demo road in city environment high speed test were done with closed road.
Maximum vehicle speed during energy transfer (for each vehicle type)	Trailer: 81kph Solaris bus: 40kph Nissan Leaf: 60kph ECrafter: 75kph
Average efficiency measured in terms of power transfer	From 650VDC output at power station to onboard vehicle (after rectifiers) : 97,5% From grid to 650VDC output in power station: 1,8-2% (with trafo and rectifier, not optimized)
Maximum efficiency measured in terms of power transfer	98,5% (close to power feed from power station)
Maximum efficiency measured in terms of power transfer at maximum speed	97%
Maximum current collection width	Our test pickup admits 70cm side moving but can be built for 1m. The sliding contact is only 60mm wide and follows the rail automatically via AI system.
Number of faults registered by 1000km run	Numbers not registered due to only test and demo use of road.

Typology of faults recorded Duration of the installation	Some problems due to moist in the switching electronics in early design of rail. Some pic up side moving issues due to led light malfunction and early software versions. This issues have been solved in new version of rail and pic up. Installation in Lund since 2020, (Outdoor prototype since 2017) .
Duration of the installation	24 month for the submerged. 36 month for the on top mounted rail. Earlier test site 2017-2019, 24months.
Lessons learned	
Focus: Trial of Elonroad conductive e-road technology on public road in Lund/Sweden. Project duration: 36 + 24 months Infrastructure: It took two days to conduct 600m of rails. Construction can be faster with planning, more people and more machines. Easy maintenance. Replace 10m railbox in 15 minutes. Tests at Swedish road Institute VTi shows that the rail will last for 15 years. Asphalt shows no sign of breaking after tests at VTi. No mechanical problems of rail at city street in Lund after 24 months. Rail winter tested in Kramfors and Skellefteå. Friction test ok. Normal snowplough used. A lot of snow will hinder the pic up to get contact and needs to be ploughed away. Switching with 1-meter segments works with 5mm rain. Switching with 1-meter segments works with normal use of winter salt Automatic side moving pickup system works. Pick Up sliding contacts tested in carusell. Last for 10 000km Safety: Powe only under the vehicle. No power in front or after EV. Skid resistance (friction) approved after improvement. Substations: In Lund demo 300kW installed and worked. 2-3MW power station every 1-1,9 km planned for highway use. Acceptance: The municipality of Lund is directly involved in the project. Good public acceptance. Some motor bikers where sceptic but we have an approved skid resistance.	
Best practice	

Ground feeding rail works for all types of vehicles. Trucks, buses, minivans, cars

Easy installation , only 6cm deep 30cm wide grove in asphalt

One power station connects directly to the rail every 1,9km, no substations needed along the road.

Access control and billing system for individual EVs measurement inside the rail

Can help autonomous EVs to position w 1cm accuracy and look ahead for traffic jam

High power 250-400kW

C4 EVIAS

Project Name	eRoadArlanda – RUAB
Project short description	Elways Eroad solution during at least two Swedish winters when delivering cargo for Postnord from Rosersberg to Arlanda Airport.
Project short description of Technology used	Length of the ERS section: 2,000 m. Conductive charging through an embedded rail in the road
Number and type of vehicles tested	Two (2). One 18t truck. One truck (full tests) + One Personal car (mechanical tests)
Number of km run in ERS mode (effective power transfer from ERS infrastructure)	Two (2)
Power Supply installed by km	100 kW - 200 kW in total
Number of Power Supply Substations by km	One (1)
Maximum Energy Transfer transferable by the ERS infrastructure installed	200 kW
Maximum voltage transferable by the ERS infrastructure installed	800 V
Maximum current transferable by the ERS infrastructure installed	250 A
Maximum Power transferred during the experimentation	200 kW
Average Power transferred during the experimentation	100 kW
Average vehicle speed during energy transfer (for each vehicle type)	50 km/h
Maximum vehicle speed during energy transfer (for each vehicle type)	70 km/h this is the speed limit of the road
Average efficiency measured in terms of power transfer	90 % Grid to battery 99 % rail to on board charger
Maximum efficiency measured in terms of power transfer	90 % Grid to battery 99 % rail to on board charger
Maximum efficiency measured in terms of power transfer at maximum speed	90 % Grid to battery 99 % rail to on board charger

Maximum current collection width	120 cm (accepted sideways sway of vehicle with maintained full charging from rail, if more sway, current pickup will undock from the rail)
Number of faults registered by 1000km run	~1
Typology of faults recorded Duration of the installation	Short circuits. Had no impact - fast restart
Duration of the installation	The ERS was operational for 3 ½ year
Lessons learned	
Focus: The focus was to test solution during at least two Swedish winters when delivering cargo for Postnord from Rosersberg to Arlanda Airport. Project duration: June 2015 to June 2021. Infrastructure: The deployment would theoretically would be one kilometre per hour. Safety: The project showed that it is safe for people and animals under al traffic situations and all weather conditions. No problems with friction. Two wheelers tested the surface and the Swedish police used the test track to train the drivers of motorbikes. A special protection is not needed. Thermal expansion: Problems with thermal expansion occurred due to stell in the road. These have been solved through a change of design. Water on the road: Is not a problem because of drainage system. Snow, ice: Heating cables in the track provided the track from icing. Substations: Are needed every 200 up to 400 m. Installation takes about one to two days per kilometre. Connection to the power grid also takes time. Time crucial is the delivery of transformers and the connection to the grid. The system can handle peaks and low consumption. The power supply can be regulated in a tender, depending on the regulations in different countries Acceptance: Due to the lesser visibility the acceptance is high. Nevertheless, residents have been informed through newspaper articles and information events.	
Best practice	
low visibility could be used for all types of vehicles the system can be deiced easily no special protection is needed road must be closed for installation the surface of the pavement is touched	

C5 Siemens Mobility	
Project Name	eHighway
Project short description	Dynamic charging of HDVs using overhead contact lines (OCL) on motorways in three field trials in Germany and in two demonstration projects, one in Sweden and one in the US.
Project short description of technology used	Length of the ERS sections in Germany: ELISA (Hesse): 5 km in one direction, 12 km in the other direction. FESH (Schleswig-Holstein): 5km in both directions. eWayBW: Nearly 4km in each direction. Dynamic charging via overhead catenary system and pantograph. ERS section in Sweden was 2 km in one direction, in the US it was 1 mile (1.6 km) in both directions.
Number and type of vehicles tested	20 Scania hybrid trucks (40-ton tractor units, with up to 70kWh usable battery) and two Scania BEV (29-ton rigid trucks, with 200 kWh usable battery) for regular operations by trucking companies. Previously two Scania hybrid 40-ton trucks were used by the transport company Ernst Express during the Swedish demonstration project (2016-2020). Additional six vehicles are in use for research purposes (e.g. IVECO, Isuzu and DAF trucks, as well as trucks made by Scania) with more to come. Previously three US Class 8 trucks were tested in a California demonstration project. These were a diesel-hybrid from Mack (part of Volvo group) and two trucks from Transpower (one natural-gas hybrid, one full-electric)

Number of km run in ERS mode (effective power transfer from ERS infrastructure)	On German field trials in total from 1st of January 2020 until June 2021: Number of km run in ERS mode: App. 53.900 km. Effective power transfer from ERS infrastructure: App. 53.100 kWh.
Power Supply installed by km	With this system the power supply is scalable to the demand. In the existing projects the power supply was chosen to fulfil the project objectives: field trials with a limited number of vehicles : 2 MW for 10 STK (Single-Track Km).
Number of Power Supply Substations by km	In the existing projects 2 substations over 10 STK
Maximum Energy Transfer transferable by the ERS infrastructure installed	In the existing projects 2 MW continuous, for short periods overloads are possible
Maximum voltage transferable by the ERS infrastructure installed	In the existing projects the operational voltage is 650 V. Generally speaking, the infrastructure is capable of an operational voltage of 1,5 kV
Maximum current transferable by the ERS infrastructure installed	900 A can be continuously transmitted per contact line from each substation. Each lane has two lines. Assuming vehicle operation only on 14 hours out of 24 (lower traffic density at night) and a distance between substations of 1600 m this will allow for sufficient energy supply to operate >16.500 vehicles per day. Short term overloads can be managed. In case necessary, reinforcement lines can be added.
Maximum Power transferred during the experimentation	300 kW (at 650 V DC)
Average Power transferred during the experimentation	100-125 kW. The vehicles are the determining factor for the power transfer. Most trucks using the system are hybrids. These mainly need traction power and have small batteries. Therefore they don't need to fully utilize the potential of the system to charge dynamically.
Average vehicle speed during energy transfer (for each vehicle type)	Conventional speed of trucks on highways (app. 80 km/h) and as the field trials are on public highways the average speed in the field trials has been dependent on the traffic situation.
Maximum vehicle speed during energy transfer (for each vehicle type)	Conventional speed of trucks on highways (up to 90 km/h)
Average efficiency measured in terms of power transfer	From substation in-feed to wheel of truck 80-85%

Maximum efficiency measured in terms of power transfer	From substation in-feed to wheel of truck 85%
Maximum efficiency measured in terms of power transfer at maximum speed	From substation in-feed to wheel of truck 85% at 90 km/h
Maximum current collection width	The Pantograph consists of two pairs of carbon strips, each app. 800mm wide
Number of faults registered by 1000km run	98% availability in ELISA, 96-99.6% availability in FESH (see report : https://www.ifeu.de/publikation/current-technical-findings-on-the-ehighway-system-from-field-tests-and-accompanying-research-in-germany/)
Typology of faults recorded	Predominately faults not related to the system. Conventional traffic disruptions (e.g. broken down vehicles)
Duration of the installation	Installation: app, 6 months Operation: 4 years and counting
Lessons learned	
Infrastructure: Construction on densely used highways possible within time and budget, even in first time applications. From this it possible to derive, that under the right circumstances it is possible to quick roll out a nation-wide system (e.g. construct 500 km per year). Road surface: As this system does not come into contact with the infrastructure, there are no adverse effects. Safety: Security concepts have been developed and the cooperation with the police and rescue services is working perfectly. Operation: System works as predicted and provides the economic and ecologic benefits expected. Acceptance among trucking companies (small and large) is high, thanks to the performance of the solution. This bodes well for ensuring public support also going forward. Acceptance: As part of the legally required approval processes, municipalities along the route have been involved as public interest groups and asked for their consent. Furthermore, the regional council, operators of routes within the framework of the motorway and others have been part of the participation process.	
Best practice	

Having a clear focus, i.e. identifying a promising use case and pursuing it's real world implementation and preparation for large scale roll out. Identify the most promising use case: numerous studies point to dynamic charging of HDVs on motorways as the most promising and relevant field for ERS. Having this scientific backing and transparently sharing and explaining it, is important when convincing stakeholders and decision makers. Implement it in real world operations: Showing that the solution works both for trucking companies in their daily operations, with all the different situations that entails, is essential for growing support in the trucking and automotive industries. Showing that the ERS can be integrated and work as planned on busy highways, where 1000s of HDVs operate daily, and over many years and seasons, is an important proof point for highway operators and owners (e.g. transport ministries). All key stakeholders (trucking operators, automotive industry, highway operators and political lever) now agree: the technology is now ready for the next, large step. Prepare for large scale roll-out Leverage existing supply chains, e.g. for railway applications there already is global knowledge and industrial capacity (with an annual turnover of ca. 10bn EUR) which means that scaling up can happen much quicker than if starting from scratch. Standardization work has been done for the OCL system that makes is clear what other suppliers of OCL or Pantographs must achieve to be interoperable. Alignment with other countries, esp. neighbours. Implementing the system and the international feedback has underlined the importance of using a mature technology with know-how and supply chains globally available.

APPENDIX D – SURVEY QUESTIONNAIRES

D.1 STAKEHOLDER SURVEY

To: PIARC Member Countries, ERS Providers, Financiers, Universities, Workshop Participants

Title: Electric Road Systems Survey

Languages: English, French, Spanish

Links:

English	https://docs.google.com/forms/d/e/1FAIpQLSda99rnX9M-SEUUBJTulPKJ16eKBRlNi9jRf4VD2KATJW09dw/viewform?usp=sf_link
French	https://docs.google.com/forms/d/e/1FAIpQLSd88K-QxIoXUoh51rWKBf5XKxC8CzbwGqL6MSbvPyJA7sUOpQ/viewform?usp=sf_link
Spanish	https://docs.google.com/forms/d/e/1FAIpQLSelrNki9txdxXUF-sJ7F0vV9GrxfXaltOVgTwkRaSXF9z-Muw/viewform?usp=sf_link

Introduction

Electrically powered vehicles are increasingly seen as a solution to reduce transport carbon emissions. One potential method of charging electric vehicles is through Electric Road Systems (ERS) – dynamic on-road charging. This survey aims to capture information and views of key stakeholders regarding the development and implementation of ERS. The survey is part of a PIARC project being carried out which aims to build and share a common picture of ERS development and potential implementation.

We would be grateful if you could take 10 minutes to complete our questionnaire. Individual answers will not be published without permission. If you have any questions about the survey or project please contact Ruan van Breda at vbredar@sanral.co.za.

Many Thanks

PIARC Task Force 2.2

Question 1

Please select the description that best describes your organisation type:

Ministry of transport	
Government (other)	
National agency with road and transport expertise, government advisor	
Research institute	
Technology Manufacturer	
Electricity supplier (Electricity Production)	
Power grid company (Electricity Distribution)	
Road owner	
Road operator	
ERS technology provider	
ERS operator	
Freight Operator	
Other (please specify)	

Question 2

In which country is your organisation based?

Question 3

Has your organisation been involved in any of the following activities regarding Electric Road Systems? Tick all relevant boxes (skip if none).

	Inductive	Conductive Road	Conductive Side of Road	Conductive Catenary
Operate				
Road Trials				
Laboratory Trials				
Track Testing				
Desktop Evaluation / Survey				

Question 4

Which of the following descriptions best describes the current state of Electric Road Systems in your organization/country? Please choose only one option.

Consideration of ERS has not started

ERS has been considered but is not being pursued

ERS pilot project/s are being considered

ERS pilot project/s have been or are being implemented and assessed

ERS project/s are in the feasibility / or design stage

ERS project/s are being implemented

Question 5

Is your organisation planning to become involved in Electric Road Systems related projects?

Yes, within the next 24 months

Yes, not within the next 24 months

No

Question 6

What type of vehicle should be primarily targeted by Electric Road Systems?

Three wheelers/scooters/tuk tuks

Light Vehicles (LV) - less than 3500 kg

Buses

Heavy Goods Vehicles (HGV) – commercial vehicles more than 3500 kg

Question 7

Please rate the potential impact or benefit of Electric Road Systems on the current road transport system, if they were to be implemented to their full potential and capacity

	Significant Adverse Impact	Adverse Impact	Neutral Impact	Minimal Benefit	Significant Benefit
Greenhouse Gas Emissions (Lifecycle Analyses)					
Local Air Quality					
Operation Costs for Road Administrators (e.g. source of income or additional costs)					
Vehicle Operating Costs					
Noise					

Question 8

Please rate the impact of the following challenges in implementing Electric Road Systems.

	Insignificant	Minor	Moderate	Major	Severe
Costs associated with ERS - Vehicle					
Costs associated with ERS - Installation					
Costs associated with ERS – Maintenance and Operations					
Impact on Road Infrastructure - Lack of available space for ERS equipment within the road corridor					
Impact on Road Infrastructure - Additional constraints leading to increased maintenance costs for existing infrastructure					
Impact on Road Infrastructure - Increase maintenance costs for the new infrastructure					
Impact on Road Infrastructure - Reduced network availability due to increased maintenance demands					

User Acceptance and Public Opinion					
Technical Feasibility					
Electricity Production					
Electricity Distribution					
Safety and Security					
Regulations					
Business Models					
Reliability and Availability of the Network					
Ownership					
Political Influence					

Question 9

Please describe any other challenges that your organisation/country may be facing in relation to Electric Road Systems.

Question 10

What Technology Readiness Level (TRL1-9) do you perceive each of these technologies to be in? (Refer to table for reference)

TRL 9
Actual system successful operations
TRL 8
Actual system completed and tested and demonstrated
TRL 7
System prototype demonstration
TRL 6
System/subsystem model or prototype demonstration in a relevant environment
TRL 5
Component and/or breadboard validation in relevant environment
TRL 4
Component and/or breadboard validation in laboratory environment
TRL 3
Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 2
Technology concept and/or application formulated
TRL 1
Basic principles observed reported

Inductive (static)	
Inductive (dynamic)	
Conductive (dynamic overhead)	
Conductive (dynamic in-road)	
Conductive (static overhead)	

Question 11

Please indicate when do you think these technologies will have matured to a point where they will be deployable.

	Short Term (1-3 Years)	Medium term (3-10 Years)	Long Term (More than 10 Years)	Never
Inductive (static)				
Inductive (dynamic)				
Conductive (dynamic overhead)				
Conductive (dynamic in-road)				
Conductive (static overhead)				

Question 12

Would you be willing to discuss your experiences with Electric Road Systems with the project team? (If yes, please provide a contact person and details)

Question 13

Please provide the contact details of any other organisations that you may be aware of that are actively involved with Electric Road Systems projects within your country or region.

D.2 Project Profile Survey

Interview – General questions on ERS

The following questions will help you prepare for the agreed interview. We would like to give you an impression of the fields of action that we would like to discuss with you during the interview. In the interview, these questions serve as an introduction. In the further course, we will ask more detailed questions and follow-up questions.

General description of the project, stakeholder	
Project Name	
Focus areas of the project	
Project members	
Location	
Length of the ERS section experimented	
Main characteristics of the ERS section (ramp, curves, cant, tunnel, bridge, etc)	
Use case (highway operation, road operation, bus line)	
Number vehicles used	
ERS technical solution experimented	
Project duration	
Vehicles	
Which vehicles/vehicle types are used in your project?	
How does the communication between the vehicles and the ERS-System work?	
What alterations are needed to convert a vehicle for ERS use?	
Depending on the vehicle type, what maintenance cycles have been necessary?	
Road	
What impact can be expected on the road after an upscale of the technology, in terms of rutting, cracks, or settlements?	
What kind of faults have occurred with the infrastructure?	
If accidents on the road happened, what kind of accidents have these been?	

Does the ERS technology under study affect regular maintenance operations?	
Infrastructure	
How long did it take to install the infrastructure? Was it necessary to close the road?	
If accidents on the road happened, what kind of accidents have these been? Was the infrastructure damaged?	
Does the infrastructure need special protection or have requirements?	
Does the ERS technology has influence on the maintenance works?	
Energy, Consumption, Measurement, Payment	
How is payment planned for each vehicle?	4 possibilities Flat rate toll system split of measurement device on the trucks. kWh.
Which data/information is needed from the power supplier and vice versa?	Identification keys, number from the meter, meter would communicate with the backend system. Only when the panto is connected the meter counts.
How many vehicles have been using the same ERS road at the same time?	
Acceptance	
Has there been a process of participation?	
What requests have there been by the public or local authorities?	
How do the direct users of ERS rate the respective technology?	

World Road Association (PIARC)

La Grande Arche, Paroi Sud, 5e étage, F-92055 La Défense cedex