FABRIC

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

Set of current data regarding societal dimension

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EXECUTIVE SUMMARY

FABRIC is working on implementing new and innovative concepts on Electric Road Systems (ERS) aiming at supporting EU's target of reducing Greenhouse gases and other emissions affecting the society as a whole and the citizen in particular. Consequently, besides the technical realisations, FABRIC will study economic, environmental and societal aspects relevant to the transition from conventional, hybrid and electric vehicles to dynamically charged vehicles. These aspects will influence a successful uptake of the FABRIC solution or of any other ERS solution, and thus need to be considered at an early stage of the project. Previous work packages have focussed on establishing technical requirements, outlining the ICT infrastructure needed for the introduction of the FABRIC solution, establishing different user scenarios as well as on the technical development.

The main objective of this deliverable is to provide a context and review of existing knowledge regarding the potential blockers for ERS upscaling to the societal level. Given the early stage of this deliverable in the project, and the following deeper analysis in SP5 in later years, the main purpose is to provide sensible pathways and to provide a critical perspective to the potential technology push of ERS.

The results and data presented in this deliverable point at the general feasibility of the ERS at the system scale, but also list a set of challenges to address, like the perceived uncertainty around EMF, the difficulty of predicting the contribution to CO2 reduction despite the proven huge saving in energy consumption from operations, and the need to address ERS in a systematic way with all stakeholders involved to make a coherent system. The methodology followed a fault tree structure as is common in safety studies to assess the feasibility of a safe system.

The current deliverable should be read as an appendix to D5.2.1 in which a full initial feasibility study has been performed for the project. Given the complexity of such study, the current deliverable adds context and data to this that gives the reader information that will help in determining the sensibility of an electric road future.

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LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
ACC	Active Cruise Control
AC/DC	Alternating current/direct current
ADR	International regulations for road bound transports of dangerous goods, Accord européen relatif au transport international des marchandises Dangereuses par Route
ADR S	Swedish version of ADR
ARPANSA	Australian Radiation Protection And Nuclear Safety Agency (ARPANSA)
BEV	Battery electric vehicle
BM	Business models
CAPEX	Capital Expenditure
CEDR	Centre for effective dispute resolution
CH	Clearing House
CIO	Charging infrastructure operator
CO_2	Carbon Dioxide
DXX.X	Deliverable XX.X
DSO	Distribution System Operator
DSRC	Dedicated Short Range Communication
EHS	Electromagnetic Hyper Sensitivity
EIA	Environmental Impact Analysis
EM	Electro magnetic
EMC	Electromagnetic compatibility
EME	Electromagnetic Emission
EMF	Electromotive force
EMR	Electromagnetic Radiation
eq	equivalent
ER	Energy Retailers
ERG	External Reference Group
ERS	Electric Road System
EU	European Union
EV	Electric Vehicle
EVC	Electric Vehicle Customer
EVSE	Electric Vehicle Supply Equipment
EVSP	ERS Vehicle Service Provider
FABRIC	FeAsiBility analysis and development of on-Road chargIng solutions for future electric vehiCles
FEMP	Mobility Platform
FEV	Fully Electric Vehicle
FU	Functional Unit
GHG	Greenhouse gases
HDV	Heavy Duty Vehicle
I2I	Infrastructure to Infrastructure

IEC/DIN EN	International Electrotechnical Commitee /Deutsche Industrie Norm
ICE	internal combustion engine
ICEV	Internal combustion engine vehicle
ICT	Information and Communication Technology
ICNIRP	International Committee on Non-Ionizing Radiation Protection
IPT	Inductive Power Technology
ISA	Intelligent Speed Adaption
ITS	Intelligent Transport System
KPI	Key Performance Indicators
LCS	Lane Control Signal
LC	Life Cycle
LCA	Life Cycle assessment
LDV	Light Duty Vehicle
LDW	Lane Departure Warning
LTE	Long Term Evolution
kHz	Kiloherz
Km/h	Kilometre/hour
MRL	Market readiness level
ms	Milliseconds
MW	Megawatt
MX	Month X
NIST	National Institute of Standards and Technology
NO_X	Mono-nitrogen oxides
O_3	Ozone
OBU	On-board unit
OEM	Original Equipment Manufacturers
QoS	Quality of Service
PHEV	Plugin Hybrid Electric Vehicle
PM	Particulate matter
POI	Points of Interest
PPP	Public-private partnership
PV	Photovoltaic
R&D	Research and Development
RID	International regulations for railway bound transports of dangerous goods, Règlement concernant le transport International ferroviaire des marchandises Dangereuses
RID S	Swedish version of RID
RO	Road operator
ROI	Return on Investment
RES	Renewable Energy Sources
SAE	Society of Automotive Engineers
SLA	Service Level Agreement
SME	Small and Medium Sized

SP	Sub-Project
SPM	Suspended Particulate matter
SuD	System under Design
SVD	Selective Vehicle Detection
SWOT	Strength, weakness, opportunity, threats
TCO	Total cost of ownership
TESPEL	Technological, economic, social, political, environmental, legal
TRL	Technology readiness level
TX.X.X	Task X.X.X
UC	Use Case
UK	United Kingdom
UML	Unified Modelling Language
uT	microTesla
UTMC	Urban Traffic Management and Control
V	Volt
V2G	Vehicle to Grid
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to any component
VAT	Value added tax
VMS	Variable Message sign
WP	Work Package
WPT	Wireless Power Transfer
WTW	Wheel-to Wheel

REVISION CHART AND HISTORY LOG

REV	DATE	REASON
0.1	2014-12-01	Results from Swedish pre-study
0.8	2015-04-30	European perspective, combination with D5.2.1
0.9	2015-07-20	All inputs ready, to do: formatting and clean-up
1.0	2015-11-18	For Review
1.1	2015-12-17	Addressed reviews, for submission

1 INTRODUCTION

Within the FABRIC project, deliverables 5.2.1 and 5.2.2 focus on an initial feasibility study of the Electric Road System (ERS) concept at the scale of societal deployment. The main analysis is presented in D5.2.1, but the amount of data reviewed asks for a background document to be handled separately. This deliverable is this background document and contains a rich amount of background data on ERS.
This document does not reach conclusions, but should be read as an add-on to D5.2.1 for the reader interested in more details about certain aspects analysed in the feasibility analysis.

1.1 Contribution to FABRIC objectives

The FABRIC project addresses directly the technological feasibility, economic viability and socio-environmental aspects of dynamic on-road charging of electric vehicles. Previous work packages have focused on establishing technical requirements, outlining the ICT infrastructure needed for the introduction of the FABRIC solution as well as on developing different user scenarios. The technical realization is a pre-requisite for a successful prototypical implementation as well as a contribution to advances in state of the art from a research and development perspective.
However, even though the technical feasibility can be demonstrated within the lifetime and the scope of the project, this will not ensure long-term sustainability of project results with high deployment, since other factors like economical, societal acceptance and legislative rules play an important role for successful uptake of the prototypical solution. This deliverable develops a framework allowing systematic assessment of possible scenarios considering different perspectives. The framework identifies drivers and barriers within these perspectives. The relevance of the various barriers and drivers will vary for each specific scenario, but the framework will allow investigation of system level impacts of dynamic on-road charging as envisioned by FABRIC for different scenarios. The goal is to identify the overall feasibility of ERS for large-scale deployment in the transport system in Europe. That overall feasibility includes the technical and conceptual progress made during the project by the Sub Projects 2, 3 and 4 so far. The current document should therefore be read as an agenda-setting and nowhere near final assessment of the concept of ERS for transportation in Europe. It does, however, provide insights into the likelihood of success of the concept, and specific challenges and strengths. The FABRIC project is not the only project looking into the potential of ERS. There are several other research activities and initiatives analysing different aspects of ERS. These have been analysed and used as relevant input to this deliverable (See Annex 1).
This systematic approach on the feasibility of ERS in various contexts will make all involved stakeholders aware of barriers, drivers and risks at an early stage and the application of the framework may help in reducing the risks related to ERS deployment.

1.2 Process and Methodology

This section outlines the process we have followed in developing the deliverable as well as describing the methodology we have used. For reasons of these deliverables being meant as each others complimentary, it mainly overlaps with the process towards D5.2.1.
This deliverable describes the background data for the initial feasibility study conducted at an early stage of the FABRIC project, as delivered in D5.2.1., and is the first of several deliverables in SP5 dealing with different socio-economic aspects related to ERS. ERS still requires research and development activities before it will be

mature enough for market introduction. This implies that there are several uncertainties related to the technical solution and the feasibility of deployment. This deliverable is analysing the feasibility from a broad perspective, first trying to make sense of the contextual setting in which ERS will take place, and taking stock of earlier work.

The research approach was mixed using literature review, interviews and action based research methods.

The starting point of this set of data for the feasibility study is the situation of worldwide reported projects on ERS as per end of 2014. As stated in the introduction, in the field of EV using static or plug-in charging technological mature solutions exist and are in operation, even though the deployment in different markets varies very much, and in addition there have been several previous studies carried out on ERS. Due to the nature of our perspective, the literature review was not limited to scientific publications, but also comprising project information, legal and political information as well as economic analysis. Most of these are only looking at static charging solutions and not at ERS and therefore need careful examination. Based upon the findings in the literature review, drivers and barriers as well as main risks were identified. However, the transport system is complex, the barriers and drivers are interconnected, and the relevance of each factor depends on deployment context. We therefore have a tree structure to systematically describe the aspects of ERS and the findings from other projects.

The report has a heavy focus on taking the Swedish ERS attempts as a baseline for studying the feasibility, and aims to make comparisons to light duty vehicles and the rest of Europe based upon this. The reason for this approach is that from the moment of starting this study (early 2014), the Swedish stakeholders were by far the most ahead in Europe in getting towards implemented solutions, with the two major truck manufacturers heavily involved with the public road administration and energy authority to pave a way for ERS. This means that most data has been made available from this, and also that the experts have had many in.depth discussions already on how to make ERS a reality at the system scale. This was the best data to be found for this study.

The methodology followed a fault tree structure as is common in safety studies to assess the feasibility of a safe system.

The technical blockers are quite small according to the technology developers themselves. However after research on the general framework of ERS with inductive charging for trucks, uncertainties in specific fields such as requirements of road maintenance or more broad fields such as impacts in health safety and environment still remain. Therefore those components within the system were distinguished as more interesting to be investigated in bigger depth. First the environmental impact of an implementation of the inductive technology will be investigated in sense of energy use and CO_2 emissions. As final stage an Environmental Impact Assessment for the phases of infrastructure, operation and maintenance will be done. The second factor being investigated is the electromagnetic fields (EMF) produced in the inductive charging technology in combination with the high voltages used by the technology and their impact on health and safety of humans and animals. Regarding the safety aspect, transportation of flammable materials on electrified roads will also be highlighted.

1.3 Deliverable structure

This deliverable comprises two major parts. Chapter 2 systematically reviews the current known data regarding a wide range of aspects important for the feasibility of upscaling ERS. Chapter 3 dives deeper into experiences from other related projects, and to the opinions of experts on the potential blockers identified in Chapter 2.

Since the document is a reference to D5.2.1 it does not conclude any feasibility, but it provides an agenda-setting analysis of the most important uncertainties around large-scale adoption of ERS.

2 ASPECTS OF ERS FEASIBILITY

Transport infrastructure is often complex and difficult to analyse but of great interest from a society perspective (Stripple & Uppenberg, 2010). The move from mobility based on conventional combustion to more electric or full electric mobility gives rise to a number of questions, and the answers on those depend on several interdependent parameters. It is a quite multidimensional matter which gives rise to controversy when it is treated in qualitative terms, why the decisional processes might be slowed down (European roadmap, 2012).

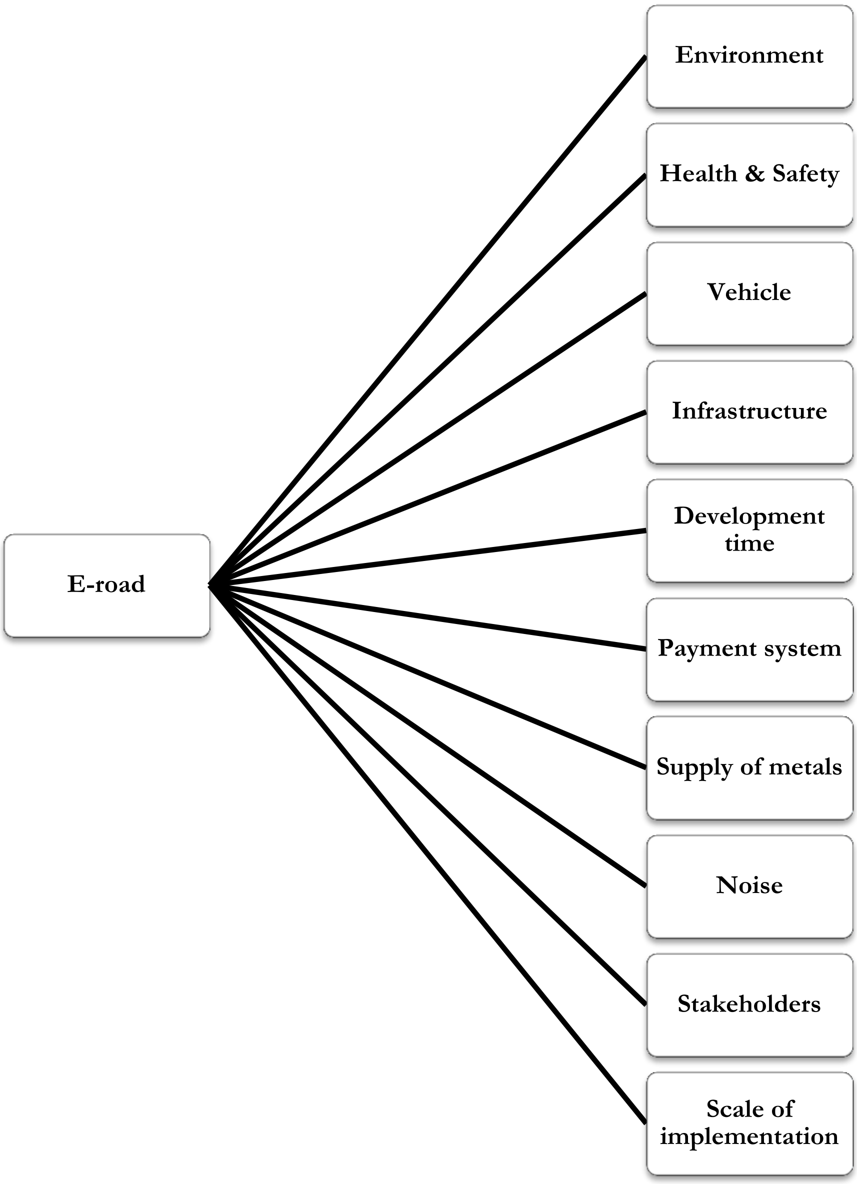

Figure 1: Potential blockers of ERS.

2.1 The system level

As already stated, the ERS is a multidimensional matter that in order to be investigated the different factors and sub factors involved should be defined. In addition the relation between the different parameters is examined through the system level approach.

2.1.1 Interdependent parameters

The most dominant factors for this research were formed into equations in order to define the sub factors (independent parameters) whose values should either be calculated or assumed, see equations in **Table 1**. The energy demand is considered as the energy needed during the installation, operation and maintenance phase. The same three phases were taken into consideration for the CO_2 emissions. The additional vehicle cost (compared to conventional ICE vehicles) is depending on the cost of the electric motor, the battery and the shielding equipment. However only the battery cost seems to be able to be defined with information available. Regarding the Electromagnetic Field (EMF), it is highly dependent on the exposure time, the distance from the source, the frequency range, the field strength and the flux. However, only a few of these parameters are from the current technologies available and the technologies providers. At last the infrastructure equipment is depending on the topography, the grid voltages and level of coverage.

Table 1: Dominant factors and their relation with independent parameters

Equations/Quantitative	
Energy Demand	E (kWh) = {Infrastructure phase}+{Operation phase}+{Maintenance phase} E (kWh) = {Materials production}+{(Driven km)*(Energy consumption, kWh/km)*(1-Energy Losses %)}+{Maintenance procedures}
Particles & Pollutants	CO_2 (g) = {Infrastructure phase}+{Operation phase}+{Maintenance phase} CO_2 (g) = {Materials production}+{Energy production}+{Maintenance procedures}
Vehicle cost	C (SEK) = {Battery (weight-capacity-price)}+{Electric motor}+{Shielding}
Relations/Qualitative	
Electro-Magnetic Fields (EMF)	EMF={(Exposure Time-sec),(Distance from source-m),(Frequency-Hz),(Strength-V),(Flux-T)}
Infrastructure equipment	I = {Topography, Grid voltages, Level of coverage}

2.1.2 Potential blockers

Each factor involved will be faced as a potential blocker for the implementation of the ERS concept. This is done in order to define possible difficulties of those factors adapting to the electrified road technologies which may delay or cancel projects related to ERS.

First, regarding the *electric vehicle*, many factors will differ from the ICE. The ERS technologies will be able to enter the markets as a wise choice only if they are feasible in sense of technology specifics, robustness and higher energy efficiency compared to ICEs. Further the vehicle design and more specifically the shielding has to secure the driver's cabin from the electromagnetic fields and the DC voltage that can be between 400-900 V[1]. The basic component is the *battery*, the larger the capacity the more it weighs and therefore the vehicle will consume more energy and the load capacity of duty vehicles will be affected. The capacity should not be too small either due to the limited range of driving. This limited range could result in that the vehicle is not able to drive the distance in between charging segments on inductive roads. The supply of raw materials needed for the battery manufacturing and their possible shortage is another very important issue.

[1] Interview with Vehicle manufacturer B.

The different components of *infrastructure*, for both inductive and conductive charging should also be investigated. Examples of these components are; installation of electrical components, differences in pavement thickness, maintenance, protection against rough weather and grid efficiency. The system has to be robust in order to be reliable which means e.g. that the electricity supply should be sufficient even in cases of demand rising. Possible incidents such as failure of charging stations or even black-out of the system should also be considered. The installation of the charging segments should depend on the topography in the sense of different energy consumption, e.g. up- or downhill trips.

The energy infrastructure and generation methods are of crucial importance for the overall feasibility and sustainability of an ERS system. If new power plants or changes in the energy mix are the result of a move towards ERS, the system gets into direct competition with other sectors that are electrifying at the same moment, like heat pumps for housing, etc. Given that little information about this is currently known, and that FABRIC SP5 dedicates a whole work package (WP4.5) to this topic, the current deliverable limits itself to the use of energy by the ERS system itself under use.

The electrified roads should be safe for both drivers and surroundings. The electronic components such as wires, inverters, converters, distribution grid and batteries should be completely insulated. There should be no possibility to harm the public and the driver, not even in case of an accident. The driver, passengers and others that could be in contact with the vehicle should be secured from the danger of grounding themselves, e.g. in case of climbing into the vehicle[2]. In addition, noise levels of the fully electric vehicles will be low and therefore ways of making the surrounding people aware that a vehicle is approaching should be implemented. One suggestion is to add artificial sound. Also the Information and Communication Technology (ICT) solutions through which the payment procedure will be done should be secure of hacking. The transportation of dangerous goods and if it would be possible to be done through electrified trucks is also an issue because of the high voltage of the inductive EV charging or because of the sparks that may occur while charging both conductively.

Health constitutes a very sensitive aspect because of the *EMF* that will be generated from the inductive charging. The fields should be strong enough in order for the energy to be transferred efficiently and the charging procedure to be quicker, but at the same time they should not exceed the ICNIRP guideline limits of potential exposure for humans and animals. The EMF used for this technology is within the intermediate frequency range for which studies that have been done on effects on humans and animals are very limited[3].

The *environmental* aspect and the decarbonization of the transportation sector is one of the basic reasons for the implementation of ERS, but research is needed to investigate whether this technology is actually better for the environment. The whole life of the vehicle and the road should be taken into consideration from the extraction of the raw materials, the production phase of both the vehicle and the infrastructure, operation phase, maintenance and in the end the recycling or the end of life. However, only a part of this will be conducted in this study due to confidential data and time limitations.

These potential blockers can differ in case of different kinds of transportation scenarios like the ten identified and analysed in D5.2.1, such as long haulage trips (heavy trucks), metropolitan passenger vehicles and city logistics (lighter trucks and vans).

[2] Interview with Vehicle manufacturer A.

[3] Interview with Researcher A.

2.2 Environment

The world energy consumption will increase by 50% in 2025 compared to the level of 2005 according to the International Energy Agency (IEA), which is 15 billion tons of oil equivalents (European roadmap, 2012). This parameter is likely to be one of the most motivating factors to electrifying transports, due to the EU's growing dependency on primary energy sources. 73% of all oil is consumed by the transport sector in the EU (and about 30% of all primary energy). Regarding the greenhouse gases, 23.8% is caused by the transportation sector while for the CO_2 the percentage is 27.9% within EU (European Commission, 2008). Since transportation is based on fossil fuels by a percentage of 97%, the reduction of the production of ICE cars is a very important step to reduce the use of fossil fuels. On a global basis, the transport sector has a share of 58% of the global oil consumption and approximately 20% of the greenhouse gases production.
Therefore it is of great importance for the transportation sector to become more environmentally friendly. In this section the environmental aspect of the ERS will be approached with a focus on energy demand including losses on a system level, energy supply and particles and pollutants with opinions from the energy providers[4]. The last part consists of an Environmental Impact Assessment (EIA) where the energy demand and CO_2 emissions are being calculated for the different ERS solutions. The phases including in the EIA are the infrastructure, operation and maintenance phases.

2.2.1 Energy and electricity

There are two types of energy, the primary and secondary. According to IRES (International Recommendations for Energy Statistics) the primary energy products are defined as: "…*those products which are captured or directly extracted from natural energy flows, the biosphere and natural reserves and for which no transformation has been made."* (Karlsson et.al, 2012). Wind, hydro, solar power, crude oil, coal and uranium are examples of primary energy sources. Energy products derived from a primary or secondary source are the secondary energy products. Gasoline and diesel are examples of secondary energy products.
The total energy need is a combination of traffic energy need and maintenance and management needs (Karlsson et.al, 2012). The traffic energy accounts for the energy needed for pure speed and losses from forces on vehicles e.g. wind drag, rolling resistance and powertrain. Additionally, braking, speeding pattern and road slope/hilliness affect the energy consumption. During maintenance of the road, energy is needed for the production of vehicles for pavement maintenance, snow and ice removal, but also for transportation of materials and material production e.g. aggregate, bitumen etc. The management energy of roads is primarily consisting of (variable) traffic signs, cameras, sensors and control rooms and is a relatively small part of the total consumption.
By converting the use of fossil fuels to renewable energy sources within the transport sector, the greenhouse gas emissions can be reduced (Karlsson et.al, 2012). It is important to note however, that since fossil fuels are used for production and transport of the renewable energy sources, the GHG emissions will not be zero. If the case would be that there is a scarcity of renewable energy sources, the total energy use has to be reduced by using energy efficiently and wisely. By improving maintenance and construction operations this could be achieved.
As stated earlier, there is an emerging awareness of climate change, and this together with pragmatic economic reasons will motivate the EV user to ask for electricity from renewable energy sources (European Commission, 2008). Internal combustion engines (ICE) are today depending largely on the use of fossil fuel

[4] Interview with Energy Supplier.

(European roadmap, 2012). This creates depletion of the finite reserve of non-renewable energy sources, which furthermore leads to economic and geopolitical concerns. In order to secure fuel supply for ICE's, biofuels and natural gas are playing a role, however only for a small part. Electricity however, can be produced from many different energy sources such as hydro, wind, solar and biomass, which are all renewable. More specifically for Sweden, the electricity production is dominated by hydro- and nuclear power, which are fossil fuel free in the production (Andersson & Edfeldt, 2013). This electricity mix creates low GHG emissions.

Within the transport sector it is commonly believed that electrified roads is one important solution towards a decreased dependency of fossil fuels and to decrease CO_2 emissions (WSP, 2013). The reason for this is the efficient energy transformation from electric to kinetic energy. It is also believed that there are great societal and environmental benefits if heavy road bound freight trucks are electrified, how big depends on what extent the electrification can reach. In order to reduce the anthropogenic impacts on the environment as well as reducing the oil dependency, the convergence of renewable energies and electrified mobility appears the most appealing.

2.2.1.1 Energy demand

The energy demand consists of both the energy that the transportation sector needs for movement and the various losses from the distribution to the energy usage point. According to the interviews' feedback, those losses for the conductive system at the contact point would be approximately 0% while for the inductive around 10%[5]. Regarding the heavy-duty vehicles, 40% of the energy for the ICE trucks goes to transportation work and the rest are losses while if electrical energy is used 90% will be transport work, however always depending on the motor efficiency and the fleet age[6]. Therefore half of the energy amount will be used in terms of kWh compared to fossil fuels. There are also some losses between the production of the electricity and its distribution to the sub station, which are around 4-5%[7]. Another type of losses that should be considered is the distribution losses, which for the railway power supply has been estimated to 12% for the Swedish railways (Stripple & Uppenberg, 2010).

An estimation made during the interviews for energy demand within Europe if all vehicles would be electrified is an increase by 15%[8]. In Sweden, where the electricity produced is approximately 150 TWh, this amount is below 10% and therefore if all vehicles are electrified the electricity demand would be raised by 10-15 TWh. But a more possible first step of electrification is 40% of the transportation sector and therefore an increase of 5 TWh of the electricity. Even though this is a big number it is only a small share of what it is produced in for instance Sweden, around 3 or 4%.

The demand for energy in such scenario will follow the demand of transportation. When considering person mobility, the pattern will follow the peak hours in the morning and afternoon rush hours as are most common in most places in Europe. This might be problematic, since these peaks collide with the existing peaks in energy demand from housing and start-up from industry. In such case, and depending on the localisation, huge demand peaks could appear –depending on the charging speed- that would necessitate new power plants or very expensive, huge energy storage systems unless there is an efficient, centralized or market-driven ICT charging management scheme. However, when talking heavy vehicle electrification, the

[5] Interview with Vehicle manufacturer B.
[6] Interview with Energy Supplier.
[7] Interview with Energy Supplier.
[8] Interview with Energy Supplier.

demand patterns look very different as the use of trucking, especially for the long haulage application, is a 24-hour business with major movements on-going outside peak hours to avoid traffic. Such scenario could actually use the surplus of energy capacity available in the network.

A final word on the exact impact of energy demand distribution on the overall system is therefore highly dependent on the deployment scenario, as discussed in FABRIC D5.2.1.

A key factor defining the energy demand is the energy efficiency, where the EVs seem to be much more efficient than the ICEs (Viktoria, 2013). Estimation for 1997 is that the energy consumption of an ICE truck is 0.43 liters diesel/km (Hammarström & Yahya, 2000), with more current numbers as reported by vehicle manufacturers around 0.35 liters diesel/km (Scania, 2015). A catenary hybrid truck is said to consume on average 2.7 kWh/km (Björkman, 2013). However the feedback of the *interviews* shows that this may be an overestimation and therefore a second estimation for an electricity consumption of 1.5 kWh/km is also included[9]. This number is also consistent with the numbers of Viktoria (2013) where the energy used for travelling from Stockholm to Gothenburg (approx. 470km) with electric truck is 700 kWh. The total energy consumption for a distance of 100 km with these different vehicle energy consumptions is shown in **Table 2**. For the calculations done, the transformation of 1 liter diesel corresponding to 10 kWh is being considered[10].

The table shows that the previously mentioned estimate of 40% energy use for actual transportation and 60% as losses (heat) is very close to the 2015 efficiency and the Viktoria electrified energy consumption comparison.

[9] Interview with Technology provider.

[10] Interview with Energy Supplier.

Table 2: Energy consumption for ICE and EV

	liter diesel/km	Transformation	kWh/km	kWh/ 100km
ICE, 1997 efficiency	0.43	1l diesel=10kWh	4.3	430
ICE, 2015 efficiency	0.35	1l diesel=10kWh	3.5	350
Fully electrified (Björkman, 2013)	-	-	2.7	270
Electrified truck (Viktoria, 2013)	-	-	1.5	150

According to Andersson & Edfeldt (2013) the total energy used for road transport for 2011 is 85 TWh. The percentage of goods transportation is stated to be 31%, which corresponds to approximately 26 TWh. They also estimate that if all heavy vehicles (trucks and buses) are changed into electric vehicles, the domestic diesel consumption could be reduced by 55% (Andersson & Edfeldt, 2013). Furthermore, this would lead to a decreased energy usage by 15 TWh since electric vehicles are more efficient. It would also decrease the national GHG emissions by 15%.

An estimation of the energy demand for year 2030 with base year 2012 is made, see Table 3. This estimation is based on the total kilometres of domestic trips for 2012 which are 2.241.367.000 km (Trafa, 2012). In addition different sizes of fleet being converted, rates of increase and energy consumptions are serving as a base and form the independent input variables.

Table 3: Estimation of the energy demand for years 2012 and 2030.

	2012	2030			
Driven km entire Swedish fleet	2 241 367 000	Yearly increase			Total increase
Driven km 2/3 of the fleet	1 494 244 667	1.20%[11]	1.50%[12]	1.90%[13]	10%[14]
For energy consumption of 2.7 kWh/km (Björkman, 2013)					
Energy demand in TWh/year (entire fleet)	6.1	7.4	7.8	8.3	6.7
Energy demand in TWh/year (2/3 of fleet)	4.0	4.9	5.2	5.6	4.4
For energy consumption of 1.5 kWh/km (Viktoria, 2013)					
Energy demand in TWh/year (entire fleet)	3.4	4.1	4.3	4.6	3.7
Energy demand in TWh/year (2/3 of fleet)	2.2	2.7	2.9	3.1	2.5

Worth mentioning is that the losses are not included in the energy demand calculations due to different amounts of losses between inductive and conductive. As stated before the conductive charging will have close to 0% losses while the inductive will have around 10-15%, depending on the size of the air gap and rate

[11] The increase of 1.2% is estimation for household energy demand increase rate, Vattenfall, 2013.
[12] The increase of 1.5% is an average estimation of ours.
[13] The increase of 1.9% is estimation for transport work increase rate according to Trafikverket (2013) and WSP (2013).
[14] By the year 2030 it is estimated that the transportation sector will have increased by 10 %. This is due to that transportation of people and goods is likely to have a faster growth than the efficiency improvements (Andersson & Edfeldt, 2013).

of alignment due to driver behaviour. (WSP, 2013). As a result, in case of inductive charging the energy demand showed in **Table 3** should be augmented by 10-15%. The estimated energy demand of 8.3 TWh for 2030 constitutes a worst-case scenario since a high energy consumption of 2.7 kWh/km is being considered and a high rate of yearly increase. It is being also assumed that the entire Swedish truck fleet will be transformed into electrified. However even in that case, the estimated energy demand of 8.3 TWh still remains below the 10% of the Swedish energy production per year, 150 TWh, and according to the Energy Supplier[15], this estimation is of the right size.

Estimation about a possible fleet being electrified is between 40%[16] and 65% of the current fleet size (WSP, 2013). Therefore in case that only 65% is being transformed instead of the entire truck fleet, the energy demand is even lower.

However, according to the interviewees, the yearly increase of trucks is not expected to be a smooth curve for the introduction of electric trucks[17]. First demonstration projects will take place, then the early adopters might enter the market and finally it might be a wide acceptance meaning that the number of electrified trucks might increase rapidly. For cars, this might even be more dramatic, as the use of such will only yield value to the buyers of such cars if the network externalities are sufficiently large, which in turn is even more difficult to achieve for the rather diverse car usage pattern compared to the more predictable trucking industry.

Fully electric trucks are considered to be mature enough and the economic gain from using electricity instead of diesel will be such a cut in costs that the transition is believed to look like a step function. For cars, this will be a more mixed pattern. A question remains how the electricity demand will be addressed if this transition happens quickly. During a five-year period it is believed that there might be a need for electricity import in for instance Sweden, but that is also depending on how the grid is being built the coming years and the capacity of the power lines.

2.2.1.2 Energy supply

The electricity supply should be interconnected with the energy demand in order for the system to be efficient. The fluctuations of the energy demand during the day should be satisfied with continuous energy supply without interruptions that is coming from a green electricity mix preferably. For those fluctuations hydropower is useful since it could be run a little up and down by managing the water flow, according to Energy Supplier[18]. On the other hand, wind power depends on the local conditions and it has rougher fluctuations in energy supply. In order for wind power to be used when there is wind, the production of hydro power should decrease at that moment since it is more complicated to stop than nuclear production. There are cases when the wind power locally produced is used in policies such as “charge when it is windy” which are demonstrated in Germany. However it cannot be claimed that some energy source is more efficient than the other[19]. Grid battery storage facilities could be possible to use for stability purposes, but it would be too expensive to store large amounts of energy.

15 Interview with Energy Supplier.
16 Interview with Energy Supplier.
17 Interview with Energy authority.
18 Interview with Energy Supplier.
19 Interview with Energy authority.

According to the estimations made in **Table 3**, the energy demand for 2030 in case that the entire Swedish fleet would be electrified is 8.3 TWh. According to Energy Supplier[20] this amount of energy will not be a challenge to be provided. The energy supply does not seem to be a problem even in a possible rise of the energy demand by 15%, if all vehicles are electrified. At the same time it is stated that it is possible to produce 8.3 TWh but is also depends greatly on what happens with the Swedish nuclear power production[21]. Since the nuclear power stations are relatively old it is a question whether the Swedish government allows power companies to upgrade existing plants, i.e. reinvest and upgrade in terms of power output in order to have a basic energy supply to support the build-up of renewables.

If we take the Swedish case, and compare this to Europe, it can be said that the share of transportation in the total energy consumption is not so wildly different per country (Source: Eurostat). However, when looking deeper into the balance of electricity production versus transport energy used, the picture becomes more mixed, depending on the integration of electricity networks into a main grid, and the amount of local generation of electricity. In general, it can be said that the entire Northern part of Europe, including Germany, the Netherlands and France have such integrated networks and such production of electricity for industry and other uses on that network that the comparison with Sweden can be made positively. For Eastern and Southern Europe, the differences will be large per region.

What is of great interest for the energy providers is to define the traffic flow per hour in order to calculate the peak of the need for simultaneous energy supply and also make energy estimation for the future. There is a high possibility for the system to be overloaded at some particular parts or during specific hours during the day. Due to that, the grid technology may vary from region to region, since some of them may need additional capacity measures. Some charging techniques may be developed such as evening or night charging, in order to alter the peak demand during the day[22]. Currently the regular ICE trucks are running mainly during night due to congestion, which would probably be the case even if they were electrified. This could be seen as positive for the electricity supply side since there is lower general electricity demand during night than during day.

2.2.1.3 Energy cost

The operation cost for energy needed for the entire fleet will differ a lot from the current situation in the case that it would be transformed from diesel into electric trucks. This happens both because of the high-energy efficiency of the electric vehicles compared to the conventional ones and because of the electricity price that is estimated to remain at low levels even after a possible implementation of electrified transportation[23].

Further it is stated that the electricity price is expected to be rather stable for a long time but not on the low levels that it is today[24]. The electricity price is expected not to differ between household electricity and transportation electricity; otherwise it is considered as a motive for fraud. The extra taxes for the transportation are expected to be defined by the number of kilometers driven and most possible it will not depend on type of energy used or type of vehicle since all vehicles will cause the same road abrasion.

[20] Interview with Energy Supplier.
[21] Interview with Energy authority.
[22] Interview with Energy authority.
[23] Interview with Energy Supplier.
[24] Interview with Energy Supplier.

Estimated energy prices for 2020 regarding the electricity is 1.1 SEK/kWh (including distribution cost, electricity tax, electricity certificate and administrative costs) and regarding the diesel is 13 SEK/liter (Andersson and Edfeldt, 2013). Another estimation made by the Energy Supplier regarding the electricity price is 1.3-1.7 SEK/kWh with a tolerance of 0.1-0.2 SEK on the production side, including distribution cost, environmental taxes and VAT[25]. However it is believed that the price of 1.3-1.7 SEK/kWh will end up in the upper level[26].

A rough estimation of the energy cost gain, for Stockholm, with a fully electrified fleet is shown in **Table 4**. The driven km for year 2020 is estimated with an average yearly increased rate of 1.9 %[27] and having as base the driven km in Stockholm for 2012 from Trafa (2012). The price estimation for year 2020 is made by Andersson and Edfeldt (2013).

Table 4: Price estimation for 2020 for both alternatives of ICE and EV trucks

	Energy consumption (l diesel/km) &(kWh/km)	Diesel consumption (liters)	Electricity consumption (kWh)	Price estimation (2020) (SEK/l diesel) & (SEK/kWh)	Diesel cost (MSEK)	Electricity cost (MSEK)	Cost saving for EV trucks (MSEK)
With estimation of 240 868 836 driven km in Stockholm for 2020							
ICE truck	0.43	103 573 599	-	13	1 346	-	-
EV truck	2.7	-	650 345 856	1.1	-	715	631
EV truck	1.5	-	361 303 253	1.1	-	397	949

2.2.1.4 Particles and pollutants

The electric vehicles (EVs) are considered to be more environmental friendly than the ICEs since they are able to use energy produced from renewable energy sources. Also the CO_2 emissions from the operation of electric vehicles are zero (Haraldsson, 2010). The particles will be the same as they are today since the tires and the pavement can be considered as stable factors. However the production of particles and pollutants for the whole lifecycle of the ERS systems should be considered but is outside the scope of this study as the life-cycle includes the particles produced with repair and re-use of road materials which has an extremely high variation in Europe, depending on the stone type and machines used. More details on this will come from WP5.3 later in the project.

The break-even point for when electrified roads stop being a CO_2-efficient investment is 500 g per kWh (WSP, 2013). However, emissions bigger than 500 g CO_2 per kWh is quite unrealistic in Sweden since energy sources that emit more are hard coal condensation (780 g/kWh) and brown coal condensation (900 g/kWh). A sensitivity analysis for the CO_2 emissions shows that the emission per kWh plays an important role on how an investment in electric roads might affect the CO_2 emissions (WSP, 2013). Therefore the CO_2 emissions during the electricity production are calculated. The calculations were done based on the current energy share and considering an energy demand of 6.1 TWh in base year 2012 earlier referred to, and correspond to that the entire fleet is being transformed into fully electrified trucks.

[25] Interview with Energy Supplier.
[26] Interview with Energy authority.
[27] The increase of 1.9% is estimation for transport work increase rate according to Trafikverket (2013) and WSP (2013).

Table 5 shows the CO_2 emissions if energy production is equal with the energy demand for 2012. The share of each type of energy in the total energy production is calculated based on the net values of 2011 from the Swedish energy agency (Energimyndigheten, 2012). The values for the energy production CO_2 emissions for hydro, nuclear and CHP (combined heat and power) are based on the values from the Swedish energy association (Svensk Energi, 2012b) and the zero values for the wind power from Elforsk (2008). Further, based on these shares and considering the total energy demand of 6.1 TWh for 2012, the amount of each type of energy that will be produced is calculated. The last step is the calculation of the emissions from the production of this energy considering the respective emissions for each energy type.

Table 5: Share of the energy production and CO_2 emissions.

	Hydro	Wind	Nuclear	CHP (combined heat and power)	Total
Share of energy production for 2011 (TWh)	65.8	6.1	58	16.6	146.5
Share (%)	44.92	4.16	39.59	11.33	100
Share of energy types (TWh)	2.718	0.252	2.396	0.686	6.052 (6.1)
CO_2 emission value (gCO_2/kWh)	20	0	20	291	331
CO_2 emissions from electricity production (Ton CO_2)	54362	0.000	47919	199545	301826

As shown in **Table 5**, the CO_2 being emitted in total would be 301.826 tons, which corresponds to 49.9 g/kWh, for the given 6.1 TWh. However the emissions for the construction of the new stations are not included. Based on the "Nordic mix" of 70 grams CO_2 per kWh, the potential of CO_2 reductions from densely trafficked roads is estimated to 5 % of the total CO_2 emissions in Sweden (WSP, 2013).
If the whole Life Cycle of the electricity production is included and the environmental impact is expressed in CO_2 equivalents instead of CO_2, the numbers differ for all electricity sources (Sevelius et al., 2012). When CO_2 equivalents are included, it means that not only CO_2 emissions are included but also other substances are being recalculated to correspond to CO_2 emissions. In **Table 6** the LC (life cycle) values for the production of energy are included. Even in this case there is a big difference between the renewable sources such as hydro and wind, or low carbon such as nuclear, and the carbon intensive sources such as coal, oil and natural gas.

Table 6: The amount of CO_2 eq. emissions per kWh depending on production source (Translated from Sevelius et al., 2012).

Fuel	**Emissions g/kWh**
Coal	955
Oil	893
Natural gas	599
Nuclear	60
Wind power	21
Hydro power	15

2.2.2 Comparative Environmental Impact Analysis (EIA)

This study constitutes an environmental impact analysis on electrified roads regarding the energy consumption and the Global Warming Potential (GWP) through CO_2 emissions for the infrastructure, operation and maintenance of the roads. This analysis will be comparative between the different road alternatives (regular and ERS) and therefore the differences of the ecological consequences on the mentioned three phases are being calculated.

Both ERS technologies, conductive and inductive, require production of additional components such as the overhead lines, pantograph or rail in the road for the conductive systems, and concrete segments consisting of coils, wires, converters, inverters and sensors for the inductive systems. The production and maintenance of those components is interesting to investigate in order to define if during these two phases the new technology will be more emission intensive than the already existing. The emissions during the operation phase seem to be reduced since the energy can originate from decarbonized sources, such as the Swedish electricity mix. The particles do not differ from the already existing roads since the wear and tear is assumed to be the same.

A complete environmental impact analysis for the ERS would be an analysis from a lifecycle perspective for the entire system. However this kind of analysis was not possible to be conducted in this study due to lack of available data for the new ERS technologies and time limitations.

2.2.2.1 LCA tool

The Life Cycle Assessment, LCA, is considered as a powerful tool to evaluate different powertrain types in the sense of environmental impact and primary energy consumption (European roadmap, 2012). The result of calculating the environmental impact of a vehicle with LCA is shown as one single value. By using this approach the environmental impact is approximated, but in terms of providing decision-makers an overview of possible effects of their decisions it fails. One single value is not a good approximation regarding the systems complexity, uncertainty and variability. At the same time, the uncertainties of an LCA should rather be embraced than avoided and made explicit in the result. In order for decision-makers to get a more robust interpretation of the result, the uncertainties should be identified and integrated in the end result.

The energy vectors used by the vehicle have a life cycle, which is considered in a well-to-wheel analysis (European roadmap, 2012). It does not however, consider the entire life cycle of the vehicle. The latter can be grouped into four stages:

- Vehicle production from extraction of raw materials to delivery of complete product.
- Production and transport of the fuel and/or electricity used by the vehicle during its life.
- The impact of vehicle use.
- Vehicle disposal at the end of its life.

Regarding the study of Lucas et al. (2012) there are both direct and indirect processes that should be taken into consideration in the LCA analysis. Some of the factors are raw materials extraction, manufacturing, construction, operation, maintenance of the roads, the vehicle end of life, and the infrastructure and fuels used. The factors used for ICEV (Internal Combustion Engine Vehicle) and EV are not the same. The factors for the ICEV that are considered are the oil well, the platform used, the refinery, the main distribution pipelines and the refueling stations. Respectively for the EV, the factors used are; the natural gas pipeline, which is included in the supply infrastructure, the power plants that are according to an electric mix, the grid used for transport and distribution, and the charging points.

However, as mentioned before, due to lack of data and confidentiality the LCA framework falls without the scope of this study. Further, this motivates the following simplified EIA (Environmental Impact Assessment).

2.2.2.2 System boundaries

The EIA in this study is conducted within specific system boundaries for two reasons. The first reason is that as stated before much of the information regarding the technology specifics is still confidential and the second is the further in depth exploration in later work packages of the project. Therefore the EIA conducted is a comparative analysis among the different types of road; the regular road as reference case, the road equipped for conductive charging and the road equipped for inductive charging. The components of the system being included in this comparative analysis are the construction of the infrastructure, the operation on the road and at last the maintenance of the road. The winter maintenance is mainly regarded since of all weather types, this is the one supposed to impact the operation of ERS the most. All these phases are included in the EIA in terms of energy used, losses and CO_2 emissions The functional unit (FU) used is a road segment 1 km long, including one lane 3.5 m wide and an asphalt layer of 0.165 m, see **Figure 2**. These values are a standard in such studies and typical for general European roads.

Due to the nature of this comparative analysis between the regular road and the different alternatives for ERS, the CO_2 emissions and the energy consumption for the similar components between the systems will not be included in the analysis. Regarding the ERS the calculations are done based on technologies that are available today and on the data that are publically available; official published reports, interviews with the technology providers and information available online (with references added to the websites used).

2.2.2.3 Inputs during the three phases

As shown in **Figure 2** the different components used in all alternatives are included as inputs while components whose amounts are common in all systems such as the gravel and stone material for the base layer of the pavement will not be considered. The production of components such as sensors or converters is assumed not to have significant ecological impact regarding the CO_2 emissions comparing to the volume of the rest of the material.

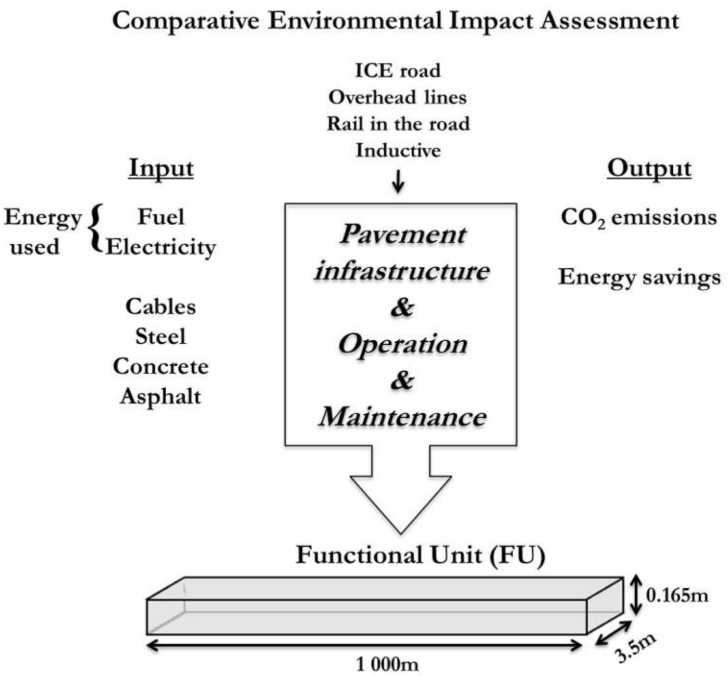

Figure 2: Components of Comparative EIA

2.2.2.3.1 Infrastructure

According to the literature, the carbon footprint is heavily dependent on the production of the components (European roadmap, 2012). The main part of the contributions to all environmental impact categories, except renewable energy resources, comes from raw material acquisition and production of materials used for the construction of the infrastructure, such as steel, concrete etc. (Stripple & Uppenberg, 2010). As one example a few materials dominate the emissions of CO_2 related to production of infrastructure material for the Bothnia Line railway in Sweden. Steel and concrete together stands for 75% of the total CO_2 emissions related to infrastructure material. When building stations and freight terminals the majority of the emissions come from use of steel and concrete, therefore in total, steel and cement stand for 85% of the total infrastructure material related CO_2 emissions.

The infrastructure used for the different ERS technologies in this study varies, as can be seen in **Table 7**. The components in *italics* are those assumed to have an impact of the same order or magnitude regarding CO_2 emissions during production and therefore are not included in further calculations.

Table 7: Differences between different ERS alternatives for the infrastructure phase.

Different systems	ICE roads	Overhead lines (OH)	Rail in the road	Inductive charging
Construction components	*Asphalt*	*Asphalt* *Grid (30kV-130kV)*[28] *Converters* Cables (Copper) Pillars Clearance	*Asphalt* *Grid (30kV-130kV)* *Converters* Rail in the road (Steel)	*Asphalt* *Grid (30kV-130kV)* *Converters* Concrete segments Cables (Copper)

In order to compare the different solutions and the differences in CO_2 emissions during the construction phase, the additional components needed and their production regarding CO_2 emissions should be calculated. All the alternatives are compared to the base alternative of the regular road. Therefore the additional components for the ERS technologies will be the ones showed in **Table 7**, where the asphalt is not included since it is considered as an equal component for all three alternatives. However the difference in production emissions of asphalt and concrete will be assumed in the inductive charging alternative since the segments consisting of concrete and cables are replacing a part of the asphalt.

Regarding the amount of material used for the *inductive charging segments*, the cables and the cement forming the charging segments are the basic components. One example of the technology of inductive charging is the Slide-in project see section 3.1.1. Two possible scenarios are proposed; the full inductive charging where 100% of the road is equipped with inductive charging segments and the opportunistic charging where 35% of the road is equipped. The cable requirements for both scenarios are shown in **Table 8**. For example, the opportunistic charging scenario (35% coverage of the network) requires the installation of charging segments 200 mm thick, 800 mm wide and around 16 km long every 30 km, see **Figure 3** (Viktoria, 2013). The needed cables for the opportunity charging is DC cables 1500 km long for the entire

[28] Grid voltage as stated at Viktoria (2013).

distance of 470 km (Stockholm-Gothenburg) and with a cross-section area of 400mm^2. Therefore, for the functional unit (FU) of 1 km, the total cable length used will be approximately 3.2 km. The installation of the cables for the inductive charging will be similar to the installation for snow melting mats, see **Figure 3**. The respective figures for full inductive charging are shown in **Table 8**.

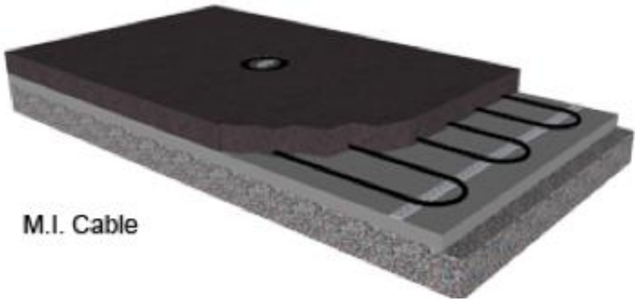

Figure 3: To the left, Primove Highway test track facility. To the right, cables for melting snow in roadways (Viktoria, 2013).

The cable volume for both charging alternatives were calculated based on the respective values for cable length and width (Viktoria, 2013), while for the FU it has been divided by the distance Stockholm-Gothenburg. In **Table 8** the production emissions of cables are calculated considering an average value from the range of 28 - 42 ton CO_2/km of cable stated in Lövgren (2010), hence 35 ton CO_2/km of cable. However, in the case of opportunity charging the CO_2/km of cable were increased with a factor of 400/280=1.4 since the cable is thicker, and decreased with a factor of 200/280=0.7 for the case of full inductive charging where the cable is thinner.

Table 8: CO2 emissions out of DC cables production.

Type of charging	**Full inductive charging**	**Opportunity charging**
For a road distance of 470km from Stockholm to Gothenburg		
Cables length (km)[29]	2 260	1 500
Cables width (mm^2)	200	400
Cables volume (m^3)	452	600
Number of stations	448	50
CO_2 emissions (ton/km of cable)[30]	35 · 0.7=24.5	35 · 1.4=49
CO_2 emissions (ton)	24.5 · 2260=55 370	49 · 1500=73.500
For the Function Unit (FU) of 1km		
Segments volume (m^3) 100%/35% coverage[31]	0.16m · 0.8m · 1 000m=128 m^3	0.16m · 0.8m · 350m=44.8 m^3

[29] Cables specifics, Viktoria (2013).

[30] For cables of the same magnitude of W, 2MW in comparison with the 1.5MW and 3MW that the primove technology uses, in a study made from Lövgren (2010), it is stated that for a cable 280mm^2 which is 3 phases cable (same as the primove), the emissions of the production is 28-42 ton CO_2/km of cable.

Cables volume (m^3/km)	0.96	1.27
CO_2 emissions for cables (Ton/km of road)	117.8	156.4

The charging segment volume has been calculated based on the road equipment for the Primove technology with opportunity charging (Viktoria, 2013). It is stated for the Primove technology that the thickness of the asphalt layer that should be removed is 20 cm. Thus it is assumed that the thickness of the segment is 16 cm and the asphalt layer covering it will be 4 cm. For further calculations of the CO_2 production emissions, only the opportunity charging volumes will be used for the comparison with the other road alternatives. Regarding the emissions for the pavement production the percentage of asphalt that has been replaced by concrete in the segment is excluded from the total production emissions of asphalt.

The *conductive technology with rail in the road* has another type of additional infrastructure in the pavement, which is visible on the road surface. This additional infrastructure will have a cross sectional area of around 10 cm^2 and it will cover the entire road length in the case of integrated implementation, see **Figure 4** (Elways, 2011). The material used is mainly steel, while the grid used for the transmission of electricity is assumed the same as for the inductive solution. The additional component will be installed in the middle of one lane per direction for the entire length of FU of 1 km. In this case, similar to the inductive alternative, the production emissions for the pavement will be calculated after replacing the part of asphalt with the steel rail.

Figure 4: Elways test track at Arlanda (Elways AB, 2011).

The *conductive power transfer through overhead lines* does not require any additional component in the pavement, only the overhead line installation such as the pillars and the cables that are needed, see **Figure 5**.

[31] Winding segments specifics, Viktoria (2013).

Figure 5: E-highway solution (hight3ch.com, 2014).

The type of cables needed for the overhead lines' alternative are assumed to be the same as the full inductive alternative since the energy supply is assumed to be the same in both solutions. The FU used is a road segment 3.5m · 0.165m · 1km= 577.5m^3. The CO_2 emissions for the material production of the infrastructure phase are shown in **Table 9**.

Table 9: CO_2 emissions of the materials production for each road alternative per FU (in tons)

Component	CO_2 emissions per ton material (g/ton)	Density (ton/m3)	Volume of material (m3)	Amount of material per FU (ton)	CO_2 emissions per FU (ton)
Asphalt	19 392	2.40	577.50	1 386	26.88
Asphalt (removed for the inductive)	19 392	2.40	44.80	107.52	2.09
Concrete/Cement	1 000 000	2.40	43.53	104.47	104.47
Asphalt (removed for the Rail in the road)	19 392	2.40	0.010	0.024	0.00050
Steel	2 000 000	7.85	0.010	0.079	0.16
Cables (35% coverage)	-	-	1.27	-	156.40
Cables (100% coverage)	-	-	0.96	-	117.80
CO_2 Emissions per FU per alternative (tons)					
Components Alternatives	Asphalt	Concrete	Steel	Cables	Total
ICE road	26.88	-	-	-	26.88
Overhead lines	26.88	-	-	117.80	144.68
Rail in the road	26.88	-	0.16	-	27.03
Inductive (35% coverage)	24.79	104.47	-	156.40	285.66

The individual components' properties, such as CO_2 emissions and density are based on the study of Butt (2012) for the asphalt component, steel component on Naturvårdsverket (2010) and Åstedt (2009), concrete on Rubenstein (2012)[32] and NRMCA (2003), and cables on Lövgren (2010). As mentioned before regarding the calculation of the components' volume; the replacement of the asphalt to concrete and cables for the inductive charging, and to steel for the rail in the road solution have been taken into consideration. More specifically for the inductive charging, the volume of asphalt for: 350 m length (35% coverage of 1 km) · 80cm width · 16 cm thickness, was replaced by the charging segment including cables and concrete which volumes were also calculated. The same procedure was followed for the rail in the road, where a part of asphalt was replaced by the steel rail. For the overhead lines alternative, the pavement of the road remains the same and extra cables are included in an amount similar to that needed for the full inductive charging alternative.
Based on values from a study by Chehovits and Galehouse (2010), an estimation of the energy needed for the material's production for each solution is also done, see **Table 10**.

Table 10: Energy need during production estimation for each road alternative per FU (in MJ)

Component	Energy per ton material (MJ/ton)	Density (ton/m3)	Volume of material (m3)	Amount of material per FU (ton)	Energy usage FU (MJ)
Asphalt	275	2.40	577.50	1 386	381 150
Asphalt (removed for the inductive)	275	2.40	44.80	107.52	29 568
Concrete/Cement	4 976	2.40	44.80	107.52	535 019.52
Asphalt (removed for the rail in the road)	275	2.40	0.010	0.024	6.60
Steel	25 100	7.85	0.010	0.079	1970.35
Cables	Energy per m material (MJ/m) for cable 1mm²	Cross section area (mm²)		Amount of material per FU (km)	Energy usage FU (MJ)
Cables (35% coverage)	0.47	400		3.20	604 160
Cables (100% coverage)	0.47	200		4.80	453 120
Energy usage per FU per alternative (MJ)					
Components / Alternatives	Asphalt (MJ)	Concrete (MJ)	Steel (MJ)	Cables (MJ)	Total (MJ)
ICE road	381 150	-	-	-	381 150
Overhead lines	381 150	-	-	453 120	834 270
Rail in the road	381 143	-	1 970	-	383 114
Inductive (35% coverage)	351 582	535 020	-	604 160	1 490 762

[32] The production of cement requires 4958 MJ/ton of material and it produces 1 ton of CO_2 emissions (Rubenstein, 2012).

In this energy estimation the energy needed for production of cables is included assuming that the only material used is copper since the detailed description of the cable needed is not available. The energy production for 1 mm^2 cross-section copper wire is 0.472 MJ/m according to Deutsches Kupferinstitut (2012). The cables' properties are shown in **Table 8**. The calculations are done for the FU of 1 km and the cables used in the calculation of the inductive alternative are of the same type as for the opportunity charging alternative, whereas for the overhead lines the values for full charging alternative were used.

2.2.2.3.2 Operation phase

The operation phase is considered to start after the infrastructure is constructed. In this phase the energy considered will be the amount of energy for the entire Swedish fleet to run for a whole year based on values for 2012 (Trafa, 2012). The energy is considered to be fossil fuel i.e. diesel for the conventional road, and electricity for the conductive and inductive solutions with the Swedish electricity mix (Energimyndigheten, 2012). Regarding the CO_2 emissions, the calculations conducted are both for the emissions during the production of electricity and fossil fuels but also for the tail-pipe emissions of the vehicle.

During this phase a bigger CO_2 saving occurs since the energy source for the three ERS alternatives, the fossil fuel is replaced by electricity. The efficiency of the electric motors is also three times bigger than the ICE[33], therefore the ERS seem to be a sustainable alternative even if the electricity production is more carbon intensive than the Swedish electricity mix (Richardson, 2013). However the losses that the inductive technology includes compared to the two conductive should be taken into consideration. In **Table 11** estimations of the energy needed for the entire Swedish registered truck fleet is shown. The energy conversion from diesel to electricity is calculated based on the relation 1 liter diesel equals 10 kWh[34]; the energy consumption of an ICE truck is assumed 0.5 liter diesel/km and the energy consumption of a fully electric truck was assumed to be 1.5 kWh/km.

Table 11: Energy estimation for the different road types, including losses.

Road type	Losses	Energy usage per km		Total km domestic (2012)	Total energy need (2012)	
		liter diesel	kWh		liter diesel	GWh
ICE	-[35]	0.5	5	2 241 367 000	1 120 683 500	11206.8
Overhead lines	0%	-	1.5		-	3362.1
Rail in the road	0%	-	1.5		-	3362.1
Inductive	15%	-	1.725		-	3866.4

The estimation of the CO_2 emissions from the energy production is calculated based on values from the Swedish energy association (Svensk energi, 2012b) while the zero values for wind power are based on values from (Elforsk, 2008). The electricity mix used in **Table 12** is according to values from the Swedish energy agency (Energimyndigheten, 2012). The CO_2 emissions for the diesel production are Well-to-Tank values that are including the emissions from the extraction of raw materials until the diesel is filled into the vehicle tank (Preem, 2014).

[33] Interview with Vehicle manufacturer B.
[34] Interview with Energy Supplier.
[35] The losses for the conventional vehicle are included in the energy usage value.

Table 12: Share of energy types and CO_2 emissions during production, estimation for all road solutions.

Energy sources	Hydro	Wind	Nuclear	CHP (combined heat and power)	Diesel	Total
Power production (TWh)	65.8	6.1	58	16.6	-	146.5
Percentage	45	4	40	11	-	
	Share of energy types for total energy demand				Total	
Conductive (GWh)	1510.1	140.0	1331.1	381.0	-	3 362.1
Inductive (GWh)	1736.6	161.0	1530.7	438.1	-	3 866.4
ICE (GWh)	-	-	-	-	11 206.8	11 206.8
CO_2 emission value for each (gCO_2/kWh) or gCO_2/l diesel	20	0	20	291	400	-
	CO_2 emissions from energy production ($tonCO_2$)				Total ton CO_2 emissions	
Conductive	30 201	0	26 621	110 858	-	167 680
Inductive	34 731	0	30 614	127 487	-	192 832
ICE	-	-	-	-	448 273	-

However the CO_2 emissions that should be included in the operation phase are also the *tail-pipe emissions*. For the case of conductive and inductive on-road charging those emissions are zero since we consider fully electric vehicles. According to EPA (2012) the CO_2 emissions per km for light trucks are 298g CO_2/mile or 187g CO_2/km based on estimation for the Model Years 2012-2016 standards. The total CO_2 emissions for the entire Swedish truck fleet for 2012 are being calculated, see **Table 13**.

Table 13: Tail-pipe emissions for conventional vehicle (SSAB, 2013).

ICE tail-pipe emissions	
CO2 emissions (g CO2/km)	187
Total km (2012)	2 241 367 000
Total CO2 emissions (ton CO2)	419 136

The summarizing results of the operation phase regarding CO_2 emissions are being calculated in gCO_2/km for an easier comparison between the different solutions, see **Table 14**.

Table 14: Summarizing table of usage phase CO_2 emissions for each road alternative.

Road type	gCO_2/km
Conductive	75
Inductive	86
ICE	387

Apart from the energy used from vehicles for operation, the road also needs energy during the operation phase. Some examples of other energy needs are the road illumination such as the pillars in case of conductive with overhead lines, the charging segments in case of inductive and conductive with rail in the road. The charging segments should be illuminated in order for the driver to know where the vehicle can

charge, while the pillars and the charging stations should be illuminated also for safety reasons. However those calculations were not included since the conventional road also needs some kind of illumination during nighttime. As a result the difference in energy need between the different types of road was not considered as significant.

2.2.2.3.3 Maintenance

The maintenance phase is an important part of the road life since it protects the infrastructure of aggravating factors such as wear and tear or weather conditions. However since the ERS does not have an integrated implementation on a public road yet, the need of maintenance can only be based on estimations. The literature on this field is very limited and therefore the calculations in a comparative base with the conventional road were not possible to be done. As a result the approach on the maintenance needed for the ERS solutions will be based on the feedback from the interviews with the technology providers and other people involved in the ERS industry.

According to the experts, the *inductive solution* seems to have an advantage compared to the conductive solutions since the sensitive equipment is embedded in the ground and therefore not exposed. However, in order for the losses of the EMF to be less the distance between the sensors in the pavement and the vehicle charging equipment should be as small as possible. Thus it is important that the layer of asphalt is as thin as possible. Therefore there may be a need for more frequent maintenance of the road by replacing the upper layer of the asphalt. In addition to that, a thick layer of asphalt also has an impact on the EMF efficiency and in case of very rough winter conditions, such as Northern Europe, the inductive system may not function at all[36]. In that case there may be a need for extra road salt to melt the ice, which could result in more CO_2 emissions due to the use of additional maintenance trucks (Trafikverket, 2014g).

For the technology with *rail in the road*, the maintenance procedure does not seem to be a problem (Elways, 2011). An extra component at the plowing machine that can clean the rail could be used. This component seems to be able to clean the rail from water, snow but even ice. An interesting advantage of this technology is that each vehicle using the rail in the road solution, apart from taking energy it contributes to the cleaning and maintenance of the rail since the conductor cleans the rail from water, thin layer of snow or small stones while running. As a result if the traffic is dense the need for plowing machine for the rail cleaning decreases.

Regarding the *conductive solution with overhead lines*, the maintenance procedure might be the same as it is today for the railway overhead lines. However considering that the traffic density of the trucks will be much higher than it is today for the trains, the wear and tear could be more intensive. This results in a possible need for more frequent maintenance compared to the current situation, or a use of another type of construction or more resistant materials.

In the case of a *conventional road*, one of the main reasons for maintaining the road is the rutting. When no maintenance is performed, 3.4 mm of rut is developed each year (Karlsson et.al, 2012).

2.2.3 Discussion

The *energy factor* of the ERS does not seem to be a potential blocker of the feasibility. The energy demand will rise significantly in case of an implementation of ERS, but even in the worst-case scenario the energy demand of 8.1 TWh/year remains below 10 % of the Swedish energy production of 150 TWh/year. In this worst-case it is considered that the entire Swedish truck fleet will convert into EVs, the electricity

[36] Interview with Vehicle manufacturer B.

consumption for trucks is very high i.e. 2.7 kWh/km and the energy demand increase rate is 1.9 % per year. However it is believed that a reasonable assumption of the fleet being transformed into EVs is 2/3, and therefore the energy demand will be less. Even though the supply of this energy demand does not seem to be a problem, the energy supply capability may depend on the Swedish nuclear power production. An estimation of the electricity price after the ERS integrated implementation is 1.3-1.7 SEK/kWh, including VAT. The electricity price is expected to be the same for household and transport electricity in order for people not take advantage of the system. Due to the low electricity price compared to diesel, but also the high efficiency of the electric motors, the cost saving from the energy use is significant. More specifically if electricity consumption of 2.7 kWh/km is considered, the cost saving are 631 MSEK per year, while for electricity consumption of 1.5 kWh/km the cost savings are 949 MSEK per year, regarding the km driven in the city of Stockholm.

The electrification of the roads seems also an optimal alternative from the aspect of *particles and pollutants*. The particles are expected to be the same since the wear and tear of the vehicles and the road are the same. However, big savings are expected for the CO_2 emissions pollutants. Assuming that the Swedish electricity mix is used, the CO_2 pollutants are calculated to 49.9 gCO_2/kWh while if the Nordic mix is used it is calculated that it would be around 70 gCO_2/kWh. According to the literature, the break-even point of a CO_2 efficient investment is 500 gCO_2/kWh.

Regarding the comparative Environmental Impact Assessment three phases were taken into consideration in the analysis. During the *infrastructure phase*, the inductive solution seemed to be the most emissions intensive one compared to the conventional asphalt road. This is due to the assumed use of concrete for the segments, since concrete is 50 times more emissions intensive compared to asphalt. In case that a less emissions intensive material replaces the concrete, the infrastructure phase of the inductive solution would have a much smaller carbon footprint. However the carbon footprint of both inductive and conductive with overhead lines solutions is being aggravated by the production emissions of the cables used. The CO_2 emissions and energy used for the cables production seem to be very high according to the information sources used and further verification may be needed. On the other hand, the rail in the road solution does not seem to have big difference regarding CO_2 emissions compared to the conventional road. This happens since even though the production of steel is very emissions intensive, only a comparatively small amount of steel is used for the rail in the road solution.

During the same phase the energy used seems to follow the same pattern as the CO_2 emissions. More specifically cement and cables are the materials with the largest energy needs during the production phase and as a result the alternatives of overhead lines and inductive are the ones with the higher production energy demand. As mentioned earlier about CO_2 emissions, a replacement of cement with another material could impact the results significantly.

Regarding the *operation phase*, ERS solutions have very significant CO_2 emissions savings due to energy efficient motors and energy originating from less carbon intensive sources. The energy mix used is the Swedish electricity production mix of hydro, wind, nuclear and a small percentage of CHP. Generally the Nordic electricity mix, excluding Norway belongs to one of the greenest in the world compared to European, Japanese and American electricity mixes[37]. However this is not the case for all the countries, which should try to improve their electricity production regarding use of fossil fuel[38]. Therefore it is important to note that the

[37] Interview with Energy authority.
[38] Interview with researcher B.

CO_2 is a global factor and therefore the environmental impact of the different alternatives may be different on a global scale.

However it can be seen that even if the electricity mix changes, the favorable choice will be the same. In case of a carbon intensive electricity mix during the production, the production of electricity may be as emission intensive as the fossil fuel production. However the electric vehicles will still be the most environmental friendly solution because of the lack of tail-pipe emissions during the usage phase.

The *maintenance phase* was approached in a theoretical way due to the limited literature on the maintenance of ERS subject since no integrated implementation of the electrified roads has been done. It is believed that the inductive system will have a similar type of maintenance as for the today’s network that may need to be more often due to the thinner upper layer of the asphalt, which helps the system to be more energy efficient. However, experts also claim that both the inductive and rail in the road solution would be difficult to be implemented in rough winter conditions since the thick layer of ice would have an impact on the charging efficiency. For the rail in the road solution each vehicle seems to contribute to the rail cleaning when charging if there is a road with dense traffic, providing a way out for permanently driven roads under all winter circumstances only. Regarding the overhead lines the type of maintenance will be similar to the railway, but there might be a need for more frequent maintenance due to the denser traffic of freight vehicles compared to trains on the railway.

2.3 Health and Safety

Together with the new concept of ERS there are some uncertainties regarding health and safety. In each phase of development and planning, emphasis should be put on these concerns. The factor of safety is referring to the identification of possible dangers that the new technologies may cause, while the factor of health concerns the particular effects of the inductive technology to humans and animals through the electromagnetic fields. In this deliverable various safety concerns such as transportation of flammable materials will be investigated along with the possible effects of electromagnetic fields (EMF). In a smaller extent particles and pollutants and accidents with electric vehicles will be analysed.

2.3.1 Health

The uncertainties connected to health effects in relation to ERS are ranging from effects by electromagnetic fields to particles and pollutants. The inductive technology suggested for ERS produces strong electromagnetic fields that could affect people with pacemakers or people suffering from electromagnetic hypersensitivity in addition to other effects related to EMF. However, high voltage power lines, which are used for both railways and the conductive technology with overhead lines, also produce electromagnetic fields. Therefore the main focus in this chapter is the electromagnetic fields and the investigation of existing exposure guidelines and how these might be applied to ERS. Briefer investigations are also conducted for electromagnetic fields in relation to pacemakers and electromagnetic hypersensitivity. As a last part the electric vehicles’ possible contribution to particles and pollutants will be touched upon.

2.3.2 Electromagnetic Fields

If inductive on-road charging is to be implemented in a large scale, the generated electromagnetic fields (EMF) need further investigation. Currently specific information concerning the inductive on-road charging and the EMF is confidential or not known, therefore a comprehensive assessment in this study is difficult to complete. However, it is still believed that a summary of available information could be helpful for future work. The aim of this chapter is to create an overview of electromagnetic fields, existing regulations and

what levels of exposure should be followed during the process of developing inductive charging technologies. The focus is put on time-varying electromagnetic fields while the static fields will only be touched upon, and the reason for this is that electromagnetic fields from inductive ERS are stated to be time-varying (Alexandersson, 2013).

Within the field of electromagnetism there are several distinguished denominations; EMF - electromagnetic fields, EME - electromagnetic emission, EMR - electromagnetic radiation and EMC - electromagnetic compatibility. ICNIRP, International Commission on Non-Ionizing Radiation Protection, is setting guidelines for electromagnetic fields (EMF), which are derived from current scientific knowledge (ICNIRP, 2010a). The guidelines aim at protecting against adverse health effects of non-ionizing radiation. Further in this deliverable EMF and EMC will be considered.

ICNIRP have distinguished general public exposure levels from occupational exposure levels since the occupational exposure occurs in controlled environments where workers should be informed about the possible effects (ICNIRP, 2010a). In addition there is a distinction of basic restrictions and reference values. The basic restrictions are the theoretical values for where the health effects have been established or that ensures no health effects[39] (ICNIRP, 1998). The basic restrictions are difficult to measure and are therefore translated into reference values. Reference values are set to be lower than the basic restrictions and are possible to measure. In other words, the reference levels are used for practical assessment purposes to be able to determine whether the basic restrictions will be exceeded or not. The reference levels are expressed in tesla (T), or more specifically µT or nT.

The Public Health Agency of Sweden confirms that the purpose of reference values is to protect the general public against known health effects of exposure to electromagnetic fields (Folkhälsomyndigheten, 2009). They are set to 1/50th of the confirmed values that have negative health effects. Today's knowledge is not enough to establish any reference values for long term effects. Because of this, the Swedish authorities recommend to follow the precautionary principle.

According to the Swedish Radiation Safety Authority time-varying magnetic fields induce electric currents in the body, and at very high levels it can affect the nerve signals (Strålsäkerhetsmyndigheten, 2010c). Today there is a consensus about the levels that cause acute effects such as nerve- and muscle stimulation; however these levels are far above what normally exists in our surroundings. For about 30 years there has been ongoing research related to whether magnetic fields can cause cancer. Exposure to electromagnetic fields from power lines during childhood years have been shown in several independent studies to give rise to a somewhat increased risk of leukemia. However ICNIRP (1998) state that there is still a limited amount of studies done. Therefore, it is not possible to state a relationship. The World Health Organization (WHO) has classified electromagnetic fields as **possibly** carcinogenic (Strålsäkerhetsmyndigheten, 2010c).

2.3.3 Examples of electromagnetic fields in our everyday life

Electromagnetic fields are everywhere around us (Folkhälsomyndigheten, 2009). Generally electromagnetic fields are difficult to shield against and they pass unhindered through walls and roofs. There are both static and time-varying electromagnetic fields. The most commonly known static field is the one generated by the Earth, which makes the compass point north, with a strength of 50 µT. By static fields it is meant that the field doesn't change over time. Certain industries or medical equipment are examples where the static electromagnetic field is stronger than the Earth's which otherwise is very uncommon. The domestic

[39] Interview with Researcher A.

electricity outputs and the power that is taken from there, generate time-varying electromagnetic fields because of the alternating current. This type of electromagnetic fields is also the one that can be found around power lines and transformer stations, which can have different frequencies. The power from household outputs has a frequency of 50 Hz in Sweden.

There are many electric machines inducing magnetic fields in our households today, such as vacuum cleaners and hair dryers, which are summarized in Table 15 (Strålsäkerhetsmyndigheten, 2011). Another example, however not mentioned in the summary, is the induction cooker. First, ordinary cookers require significant power and hence they generate a magnetic field. Second, induction cookers generate a magnetic field with higher frequency than ordinary cookers, i.e. 25 to 48 kHz depending on manufacturer. According to the Swedish Radiation Safety Authority there is no adverse health effects connected to the electromagnetic field generated by induction cookers. The magnetic fields decrease quickly with distance and thereby it is only close to the induction cooker where values close to reference values can be reached. At a distance of 30 cm the high frequent magnetic field amount to approximately 20 % of the reference values, and at a distance of 60 cm it is less than 1 % of the reference values. The average magnetic field in households has an exposure level of 0.1 µT and in smaller cities approximately 0.05 µT.

Table 15: Different exposure levels from different sources in households at a frequency of 50 Hz (Translated from Folkhälsomyndigheten, 2009).

	Exposure levels at different distances (µT)			**Reference value for the general public (µT)**
Distance (m)	**0.1**	**0.5**	**1.0**	
Drilling machine	20	0.4	<0.05	100
Vacuum cleaner, 1600 W	6	0.3	<0.05	100
Hair dryer	30	0.5	<0.05	100
Microwave oven, 700 W	14	1.5	0.3	100
Computer screen, 19 inch	<0.05	<0.05	<0.05	100
Electric cooker	0.8	0.1	<0.05	100

Another thing that has become more common recently is the RFID readers used within public transport (Strålsäkerhetsmyndigheten, 2010a). With an electronic card you can for example board a bus by putting the card on the badge reader. The card itself has no magnetic field and lacks energy, while the energy is instead transferred from the badge reader that emits weak radio waves with a frequency of 14 MHz. According to measurements done by the Swedish Radiation Safety Authority, the magnetic field adjacent to the badge reader exceeds slightly the reference values. Because of that they also examined the specific absorption rate-value (SAR), and the result showed that there is no danger for the general public.

In every store, shop and library in Sweden there are security gates, i.e. anti-theft devices, when entering and exiting, also called electronic article surveillance (EAS) systems (Strålsäkerhetsmyndigheten, 2010b). There are three types of security gates; electromagnetic, acousto-magnetic and radio frequent. The gate is emitting a magnetic field that creates a monitoring area where activated alarm tags trigger a theft alarm. When the Swedish Radiation Safety Authority was investigating the magnetic fields around these, it could be found that the reference values were exceeded for all electromagnetic security gates and for most acousto-magnetic

security gates. The radio frequent security gates did not exceed the reference values. Further it is stated that passing these gates is not dangerous.

2.3.3.1.1 Low frequency electromagnetic fields

In a fact sheet from ICNIRP (2010a) the low frequency time-varying electric and magnetic fields (EMF) are defined to be in the range of 1 Hz to 100 kHz. WHO (2005a) however, defines low frequencies as between 0 – 300 Hz. When low frequency EMF interacts with the human body electric fields and associated currents in the tissues are induced. In addition, surface electric charge effects could be caused.

2.3.3.1.2 High frequency electromagnetic fields

Guidelines from ICNIRP for frequencies higher than 100 kHz cover the range of 100 kHz to 300 GHz, and these are currently being updated[40] (ICNIRP, 1998). According to WHO (2005a) high frequency fields are between 10 MHz – 300 GHz. As seen, the range of ICNIRP for high frequency fields includes the intermediate frequency fields which means that there are no specific guidelines for the latter. One common effect of high frequency EMF is heating of body tissue. Studies have concluded temperature increases of 1-2 °C which might affect the thermoregulatory capacity of the body and further it is stated that adverse health effects could be caused if temperature rises more than 1 °C in body tissues.

The basic restrictions for both low and high frequency electromagnetic fields are included in Appendix A. Further in this study the reference values will serve as basis since it is not possible to measure the basic restriction values41. A table of reference levels for occupational and general public exposure is compiled from ICNIRP (1998) and ICNIRP (2010b), see Table 16. The compilation is made for several reasons; the stated ERS frequency range is included in both guidelines, the guidelines from 1998 for high frequency fields is currently being updated42, in ICNIRP (2010b) these frequencies are included but in bigger and less intervals. The original tables are included in Appendix A.

Table 16, Compiled reference levels from ICNIRP 1998 and ICNIRP 2010b, and the original tables can be seen in Appendix A.

Reference levels ICNIRP 1998		**Reference levels ICNIRP 2010**	
Occupational exposure			
Frequency (Hertz)	*Magnetic flux density (tesla)*	*Frequency (Hertz)*	*Magnetic flux density (tesla)*
0.82 – 65 kHz	30.7 µT	3 kHz – 10 MHz	100 µT
0.065 – 1 MHz	2.0/*f (MHz)*		
General public exposure			
Frequency (Hertz)	*Magnetic flux density (tesla)*	*Frequency (Hertz)*	*Magnetic flux density (tesla)*
3 – 150 kHz	6.25 µT	3 kHz – 10 MHz	27 µT
0.15 – 1 MHz	0.92/*f (MHz)*		

[40] Interview with Researcher A.
[41] Interview with Researcher A.
[42] Interview with Researcher A.

If applying Table 16 to stated frequency range (10-200 kHz) it can be seen in the 1998 reference levels that the magnetic flux density for 200 kHz (0.2 MHz) is 2.0/0.2=10 µT for the occupational exposure levels. For the general public exposure, with the same frequency, the magnetic flux density is 0.92/0.2=4.6 µT. Due to the bigger intervals in ICNIRP (2010b), only one comparable figure of the magnetic flux density for the entire possible ERS frequency range is available. However it can be seen that the 2010 reference level of 27 µT has increased compared to 6.25 µT in 1998. The reference level used in several reports is 6.25 µT. During one of the conducted expert interviews it was stated that for long-term exposures this level it is still too high[43]. In connection to ERS it is worth mentioning that if technology providers cannot assure that levels within drivers' cabin is zero, and that the drivers might spend around eight hours there for long haulage trucks, the reference level of 6.25 µT is not low enough. Furthermore, if the reference level is increased to 27 µT the importance of having a zero-level of EMF in the drivers' cabin is even higher.

2.3.3.1.3 Intermediate frequency fields

The frequency range of 10 - 200 kHz stated in FABRIC (2013) to be used for inductive on-road charging is considered to be in the intermediate frequency range where there are a very limited number of studies made[44]. In addition there are no specific guidelines for the intermediate frequencies. The definition of intermediate fields is frequencies in the range of 300 Hz to 10 MHz (WHO, 2005a).

As already mentioned, studies conducted for the intermediate frequency fields are limited but areas of use have also been limited until recently. In a study by the Scientific Committee on Emerging and Newly Identified Health Risks it is stated that during recent years, applications in the intermediate frequency range have increased and it is believed that the increase will continue (SCENIHR, 2009). Some examples mentioned in the study are anti-theft devices in shops, induction hobs, electric engines and badge readers. When you are close to some of these systems the reference levels can be exceeded, but this is stated to be under worst case conditions. The report highlights the lack of studies made on previous exemplified applications.

Other examples from SCENIHR (2009) of common EMF sources are visual display units (VDU) and a new type of lighting bulbs. VDUs have cathode ray tubes and emits both in the extremely low frequency range and in the intermediate frequency range with an order of magnitude of 1 - 50 nT. A compact fluorescence lamp (CFL) is a new kind of lighting bulb that in the intermediate fields emit between 1 – 30 nT at a distance of 30 cm. As distance increases from the source, the EMF decreases, therefore the example of CFLs has negligible EMF further than 30 cm away from the source.

Another example is the one of radio transmitters operating in the range of 30-300 kHz (SCENIHR, 2009). These can emit levels higher than reference levels therefore recommendations of precaution are put forward both for occupational exposure and general public exposure. Welding equipment, which could be operated up to a few hundred kHz, is mentioned as complex and emission intensive regarding EMF emissions.

Due to lack of epidemiological studies in the intermediate frequency range, SCENIHR (2009) concludes that there is not enough evidence to form a basis for establishing long term effects even though acute effects are established. As the number of applications within the intermediate frequency range is believed to increase, SCENIHR states that research on EMF regarding e.g. workers in security and certain industries should be prioritized.

[43] Interview with Researcher A.

[44] Interview with Researcher A.

2.3.3.1.4 EMF related research

Roivainen et al. (2014) conducted a study for the electronic article surveillance systems and for people working near them. The study showed that the ICNIRP level of 141 µT for the peak field was not exceeded. The value for peak field is a value that should be considered for frequencies between 3 kHz to 10 MHz. Considering the EAS technologies, there are two different kinds of systems being investigated in the study; the Electro-Magnetic (EM) systems and the Acousto-Magnetic (AM) systems. The first one is operating at a frequency of 18 kHz and the second one at 58 - 60 kHz. In stores where these measurements were done the frequency level was 5 – 7.5 kHz for the EM and 58 kHz for the AM.

When the study by Roivainen et al. (2014) was conducted the ICNIRP (1998) level was 43 µT, and it was often exceeded but not at the cashiers' seat. In particular cases of short periods when e.g. the cashiers had to go through the EAS gates, the limits were exceeded and the measured level was 189 µT. The magnetic flux at the cashiers' seat was however clearly below 141 µT. **Table 17** is showing the measurements that were done for EAS systems in different places. It can be seen that at the cashiers' seat neither the reference level of 6.25 µT nor 27 µT were exceeded at any time. However, both are exceeded between or close to the security gates for many of the measurements.

Table 17: Measurements for EAS systems in different places (Roivainen et al., 2014).

Place of measurement	Type of gate	Magnetic flux density (µT)		
		Cashier's seat (mean and range)	In the middle of the gates (range)	0.2 m from one of the gates (range)
1. Supermarket, entrance	EM	n.a.[a]	11–29	17–37
2. Supermarket	EM	1.6 (1–2)	7–20	33
3. Library	EM	3.0 (1–4)	13–21	16–30
4. Exhibition hall	EM	2–3[b]	10–28	14–79
5. Supermarket	EM	0.94 (0.8–1)	9–29	7–30
6. Supermarket	EM	0.57 (0.4–0.7)	24–31	39
7. Small market	EM	0.96 (0.8–1)	45–46	38–44
8. Supermarket	EM	0.43 (0.4–0.5)	33–38	28–29
9. Small market	EM	0.60 (0.5–0.7)	34	58
10. Hardware store	AM	0.81 (0.4–1)	4–18	2–52
11. Supermarket	AM	0.27 (0.2–0.3)	19	138
12. Post office	AM	0.24 (0.2–0.3)	10–20	31–189

There are some epidemiological studies that have found that there is an increased risk of childhood leukemia among children living in homes with high magnetic field levels i.e. higher than normal [45]. Homes close to power lines have higher magnetic field levels than homes far away even though they are still below the guideline levels. Under power lines of 400 kV and 50 Hz, which belong to the extremely low frequencies, the electromagnetic field level is 10-20 µT and the reference level is 100 µT (Folkhälsomyndigheten, 2009). However, no new studies have been done on animals and neither are there any new experimental studies. Since there is no support from experimental studies or cellular studies, and there is no known biological mechanism, it is not known how the increased risk occurs[46]. The energy produced by the exposure in homes close to power lines is far below what can cause DNA damage and therefore it is not ionizing and it must be some other new unknown mechanism for cancer if this is a true effect. Whether it is true or not is difficult to say with only evidence from epidemiological studies, and without any support from experimental research or biological mechanism it is still regarded as uncertain due to a possibility of bias in the studies. Studies conducted later, during recent years, have not confirmed this association as strongly as the earlier studies, which strengthens the uncertainty. As mentioned before, the ICNIRP guidelines are based on established

[45] Interview with Researcher A.
[46] Interview with Researcher A.

health effects, studies like the previously mentioned are not used as a basis, since if there is a bias and there is a possibility to regulate it, it can have substantial consequences. Only evidence from epidemiological studies are not enough to change the guidelines but it is still enough to take precaution in a way that doesn't mean very high cost or consequences, and therefore many authorities recommend the precautionary approach. One example is daycare centers that could be built close to power lines before, which is not recommended today.

Nevertheless, the results for extremely low frequency fields are quite consistent regarding childhood leukemia and therefore there is a big question mark about long term effects[47]. A large proportion of children's time is spent in their homes and therefore they are very exposed to the electromagnetic fields, even though these are below the limits. When walking around in the city, the embedded distribution lines in the ground emit electromagnetic fields of higher levels than in homes close to power lines. The difference is the time of exposure and the average exposure is lower if you only are exposed a few minutes per day compared to e.g. a full day.

Regarding the radio frequency fields (above 10 MHz), there is a lot of research that have been done but the evidence is much more inconsistent[48]. There is no evidence of environmental studies on animals or cells but studies from one certain resource from Sweden have shown effects of increased risk of brain tumors among people using mobile phones. However it is stated that these results are not plausible because if they would be true, the incidents of brain tumors would have increased over time since mobile phones have been used since the 1990s. Statistics show that there is no change in number of brain tumor incidents, it might be going down a bit but it is within random variation, and this is the case in all countries not only Sweden. Today there are regulations for the SAR values (specific absorption rate) for mobile phones.

The studies related to intermediate frequency ranges are few compared to studies related to low- and high frequencies. EAS mentioned earlier operates in frequencies between 18 kHz – 60 kHz that is within the frequency range discussed for ERS. Even though exposure levels under power lines operating at a frequency of 50 Hz are far below guideline limit, this should not be ignored as a possible risk for the conductive technology with overhead lines. However it is believed that the electromagnetic fields from the inductive technology could pose a higher risk since the conductive solution is considered to relatively similar to railways.

2.3.3.1.5 Electromagnetic fields along the railway

Since there are no electrified roads implemented in a large scale, the railway is one means of transport where electromagnetic fields are created by the overhead lines and thus examined here. Along the railway the electromagnetic fields are strongest underneath the high voltage power lines (Folkhälsomyndigheten, 2009). At a distance of 20 meters when the train is far away the field strength is 0.1 µT, and when trains are close the fields increase for a couple of minutes to 0.3-1.2 µT, see **Figure 6**. Inside the railway wagon the fields are on average 5 – 10 µT and the reference value is 300 µT. Metro trains and trams are mainly surrounded by static magnetic fields and are not further investigated here. There is a possibility that ERS with conductive power transfer through overhead lines can be directly compared to railways due to the power lines far above the ground level. However, it is believed that one important difference between railway and ERS is that railways are often more isolated even if compared with highways. On highways and on a future

[47] Interview with Researcher A.
[48] Interview with Researcher A.

ERS it is not only trucks running; passenger cars, motor cycles, buses and other possible vehicles will move in close proximity to electrified trucks.

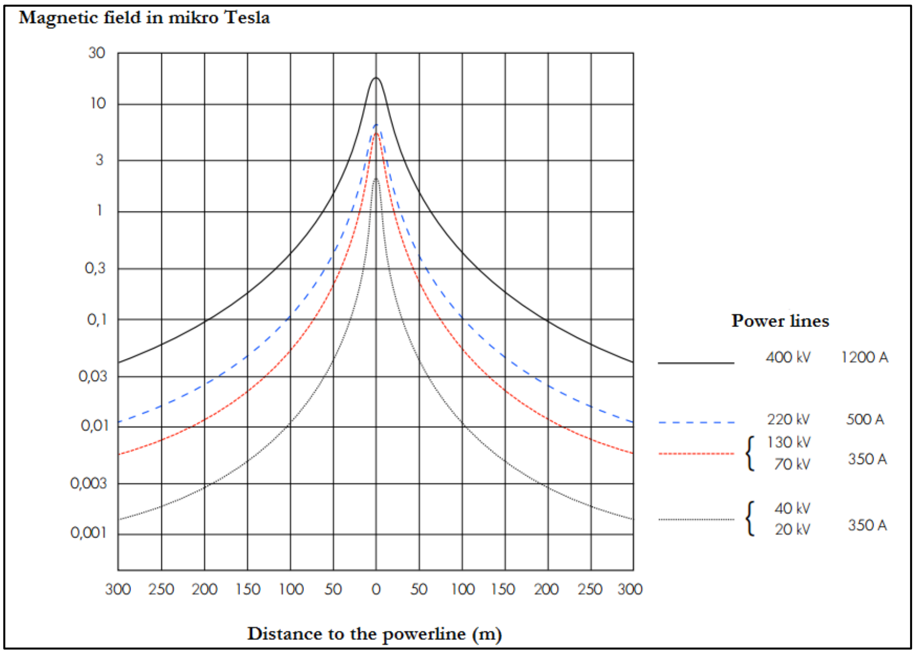

Figure 6: How the magnetic field is decreasing with distance (Translated from Folkhälsomyndigheten, 2009).

2.3.3.1.6 EMF relation to ERS

In Korea, the On Line Electric Vehicle (OLEV) proposed by KAIST University, has a charging mechanism without contact, i.e. inductive (Seungyoung et al., 2010). Multiple techniques implemented in the system are aiming at an EMF reduction. The system is generating high levels of magnetic flux, i.e. strong magnetic fields, which are used to transfer the needed power of 100 kW to the vehicle. The magnetic field is generated with a frequency of 20 kHz and a direction to the pick-up mechanism of the vehicle. There are two different types of flux transferring; the vertical and the horizontal. The vertical is a very efficient power transfer since the direction of the flux through the power lines is the same with the one to the pick-up module. The horizontal one has a less efficient power transfer because of the opposite directional power lines. Hence the magnetic flux density is being cancelled when seen from a distance of 1.7 m from the road center where the measurements are done.

Apart from the efficiency of the magnetic field transferring, the reduction of the magnetic field in order not to harm the surroundings is a very important factor (Seungyoung et al., 2010). One of the most common and efficient techniques is the shielding. The most common material for shielding regarding both simplicity and cost effectiveness is aluminium. There are three ways of shielding mentioned in the study; the vertical shielding plate on the vehicle, the horizontal ground shielding and the vertical ground shielding, where the second is designed to secure humans being on sidewalks from EMF. The vertical ground shielding is in contact with the vehicle and is thereby able to reduce the magnetic flux by 25% more than the horizontal ground shielding.

The most efficient shielding method according to the study by Seungyoung et al. (2010) seems to be the last one previously explained which connects to the vehicle. The more connections, the larger reduction of the magnetic field and thereby less emissions of EMF to humans. On the other hand, the vertical ground

shielding was stated to only reduce EMF by 4% of the initial value even when the shield was in contact with the pavement. The reference level is stated to be 138 mG (or 13.8 µT after conversion) and the implementation of these techniques showed that the EMF can be reduced to 62.5 mG (or 6.25 µT).
According to Dorrier (2013), the KAIST-approach was actually developed by researchers at Berkeley University of California. These researchers, however, feared adverse health effects from the strong EMF and therefore gave up the idea. According to KAIST this problem is solved and their vehicles will be within international standards for health and safety.
Another example is the Primove technology proposed by Bombardier which induces a strong magnetic field with a stated upper limit of 6.25 µT in the driver's environment and at public places (Viktoria, 2013). This limit is further stated to be safe for all modern pacemakers. In case of a system malfunction, the Primove control system will shut off the electromagnetic fields. Noteworthy is that this otherwise quite extensive report by Viktoria (2013) only has a very limited amount of information regarding the EMF.

2.3.3.1.7 EMF and pacemakers

As mentioned before the Primove inductive technology induces strong electromagnetic fields that are stated to be "safe for all modern pacemakers" under normal operation (Viktoria, 2013). During the expert interviews it was also stated that pacemakers are manufactured according to the ICNIRP guidelines[49], meaning they should function properly below guideline levels. Due to these concerns it is believed that the electromagnetic compatibility of pacemakers in connection to inductive roads needs further investigation to actually prove that this is the case, even though there is no current proof of the opposite.. However, confidentiality reasons only allow a brief investigation of current recommendations in this deliverable.
According to the National Institutes of Health (NIH) people with pacemaker should avoid close or extended contact with strong electromagnetic fields (NIH, 2012). Electrical devices or devices that might interfere with the electrical signaling of the pacemaker are exemplified as mobile phones, microwave ovens, high voltage power lines, metal detectors, industrial welders and electrical generators. Many of these were explained earlier in this chapter. There is a risk that such devices stop the pacemaker from proper functioning that also depends on time of exposure and distance to the source.
Recommendations for people having pacemakers implanted include (NIH, 2012); avoid having the mobile phone in a breast pocket, hold mobile phones to the ear opposite to the pacemaker, household devices can be used but proximity and long exposure should be avoided, avoid sitting close to metal detectors/security systems. Both NIH and the American Heart Association states that people with pacemaker should inform airport security before passing security (NIH, 2012)(AHA, 2012).
However, AHA (2012) states that common household devices such as microwave ovens do not affect pacemakers, whereas if you work with electricity, cars or large motors a doctor should be consulted about possible risks;
"*Household microwaves, electric appliances, most office and light shop equipment will NOT affect your pacemaker."*
"If you work around industrial microwaves, electricity, cars or other large motors, ask your doctor about possible effects."
Medtronic (2014) states that possible interference is unlikely to occur from security devices in shops, libraries and airports if the systems are walked through in a normal walking speed. An Electromagnetic Compatibility Guide is available from Medtronic where the relation between pacemakers and

[49] Interview with researcher B.

electromagnetic fields is described. It is stated that pacemakers have protective shields to prevent interference from devices that people often use (Medtronic, 2013). If an electronic device is too close to a pacemaker or if the person is touching something that is not properly insulated causing electric currents through the body, it might affect the pacemaker temporarily. The Electromagnetic compatibility guide furthermore describes recommended distances between different devices common in households or for occupational purposes. A summary of these recommendations is shown in **Table 18**;

Table 18, Summary of risks and distances related to different devices (Medtronic, 2013).

	No known risk	Minimal risk	Special considerations
Household or Hobby devices	**If the device is used as intended and in good working condition:** - Dishwasher - Electric blanket - Kitchen items such as blender, stove and refrigerator - TV - Low voltage power lines	**Maintain at least a distance of 15 cm between device and pacemaker:** - Electric shaver with cord - Hand-held electric kitchen appliances such as mixer - Hand-held hair dryer - Vacuum cleaner (from motor)	**Maintain at least the recommended distance between the device and pacemaker:** **30 cm distance** - Car (from components of ignition system) - Electric fence **60 cm distance** - Induction cooktop stove
Tools and Industrial devices	- Battery powered flashlight - Stud finder	- Drills (battery and electric powered) - Lawn mower (electric powered) - Router	**30 cm distance** - Car battery charger (100 amps or less) - Generators (20 kW or less) **60 cm distance** - Welding equipment (with currents under 160 amps) **Not recommended** - Welding equipment (with currents over 160 amps)

As seen in **Table 18** there is no known risk for some of the common household devices such as dishwashers, refrigerators or low voltage power lines existing in our homes. A recommended distance of 15 cm is set for other common devices such as electric shavers and hand-held electric devices, which could be interpreted as that there is a possibility of interference with pacemakers. Interesting in this table is that there is a larger

recommended distance between pacemakers and ignition systems of cars and induction hobs (cooktop stove), 30 and 60 cm respectively. Induction hobs usually operate under a frequency of 25 – 48 kHz as mentioned before whereas ERS could be operating under 10 - 200 kHz. Intuitively there seem to a possible risk for people with pacemakers implanted to travel on inductive electric roads. This is one of the cases where the vehicle shielding has to prove its promised effectiveness.
Regarding tools and industrial devices it can be seen that generators of 20 kW requires a distance of 30 cm to ensure minimized risk for interference with pacemakers. In the industry of electric vehicles and ERS, fast charging stations of 22 kW [50] [51] are discussed and for Tesla's fast charging station 120 kW is used (Tesla Motors, 2014). It may be reasonable to believe that people will be standing very close to these charging stations and it might be a situation where precautions need to be taken. With inspiration from the Swedish Vision Zero, there is no such thing as saying "people will not stand close to fast charging stations". This together with the previous safety distances make it reasonable to believe that this is a factor that has to be considered during the design and development of infrastructure.
Important to remember is that these devices operate at various frequency levels and not necessarily within the intermediate frequency that is expected for the inductive ERS. However it is believed that the recommended distances are strongly connected to the ICNIRP reference levels since it is clearly established that electromagnetic fields decrease rapidly with distance. Furthermore, as mentioned earlier, NIH (2012) states that the risk of pacemaker malfunctioning due to electromagnetic fields depends on time of exposure and distance to source. In our homes it is believed to be easier to move away from devices that might affect the pacemakers while on an inductive ERS, inside or outside a vehicle, it might not be as easy. During expert interviews it was often pointed out that "it is not possible to stand that close to an inductive road because then the person would get injured by the passing vehicle". But once ERS are implemented they have to be proven safe for all users independent of personal health and strength and regardless of whether it concerns only dynamic charging or static charging or both.

2.3.3.1.8 Electromagnetic hypersensitivity (EHS)

While the Swedish transport administration (TrafikVerket) was working with procurement projects of ERS they received complaints from people suffering from electromagnetic hypersensitivity[52].
As described earlier in this deliverable, there are numerous sources of electromagnetic fields in our everyday life. The National Association of Electromagnetic Hypersensitivity in Sweden states that the first symptoms usually show during use of computers, mobile phones or other electrical devices emitting electromagnetic fields (Elöverkänsligas Riksförbund, 2014a). Even though these devices in many cases enrich our lives, there are concerns regarding health effects of EMF (WHO, 2005b).
EHS or electromagnetic hypersensitivity has become the known term for people experiencing different health problems, which are stated to be connected to EMF (WHO, 2005b). The symptoms are referred to as non-specific and some examples are; concentration difficulties, burning sensations, tingling and dizziness. However, both WHO (2005b) and the Public Health Agency of Sweden state that there is a lack of verification and scientific proof (Folkhälsomyndigheten, 2013).

[50] Heikki Parve, KredEx, Estonia. Clean Fleet Workshop – Expanding charging infrastructure and procuring electric vehicles, May 21-22 Stockholm, Sweden. (personal notes)
[51] Jakob Lagercrantz, the Ecoast-project, Sweden. Clean Fleet Workshop – Expanding charging infrastructure and procuring electric vehicles, May 21-22 Stockholm, Sweden. (personal notes)
[52] Interview with Road authority

There are studies that investigate the correlation between EHS problems and EMF with the purpose of trying to verify the symptoms in controlled environment, i.e. laboratories (WHO, 2005b). The majority of the studies do not show any correlation, not even those conducted under double-blind conditions[53]. Instead there are some indications that the symptoms could be caused by for example stress or pre-existing psychiatric conditions. However, even though EHS is not a medical diagnosis, it is affecting some people and somewhat disabling them to live a normal life. Of course the degree of severity differs between individuals but there are people claiming they feel better in electricity-free environments (Elöverkänsligas Riksförbund, 2014b).

The phenomena of EHS, even though it is not a verified disease, could pose problems for affected people travelling on future electrified roads. If there is a large-scale implementation of ERS, people might not be able to travel the same way they used to on regular roads. Whether the vehicle serves as protection or shielding for individuals suffering from EHS is uncertain since no found reference connects ERS or vehicles to EHS. Once again vehicle manufacturers state that the EMF level inside the vehicle is zero. More studies are needed on both EHS and EMF, especially in connection to ERS to determine the potential risk.

2.3.3.1.9 Discussion EMF

The generated electromagnetic field levels from inductive on-road charging appear to still be confidential, despite the KAIST / OLEV solution study that measures EMF around the charging infrastructure and finds the values to be low. However, that study holds value for light vehicles, with smaller power transfer, and the exact circumstances of measuring also need to be diversified to provide a scientifically rigorous proof.. Because of this, the worst-case scenario needs to be assessed in terms of exposure levels and the shortest distance where people might be. For the FABRIC solutions as specified in the project description, the frequency range stated is not precise enough to determine critical exposure levels. This needs to be further specified once the technical solutions are more matured. Frequency indicates how EMF interacts with the human body but the critical point is the exposure level in both time and intensity within that frequency range. Both are needed to draw conclusions whether inductive roads are safe or not and what measures that need to be taken. The standard acceptable levels of exposure are what the ICNIRP guidelines are based on and furthermore the guidelines are constructed in a way that all available research has been reviewed.

At higher frequency levels, i.e. microwave levels that are covering the intermediate frequency range, heating of tissue is the mode of interaction with the human body[54]. As an example of this, the guidelines are set to protect from heating that exceeds 1°C since lower levels of heating are within the natural variation in the human body. However if the entire body is exposed to high levels, which could be the case from inductive roads if shielding is not done properly, then the body itself i.e. the blood circulation cannot take care of it. The fact that measurements within the human body cannot be done, i.e. it is not possible to put a probe into someone’s head and measure the absorbed rate in the body, makes the estimations crucial.

At the same time as vehicle manufacturers state that vehicles will be equipped with shielding and that it should give a zero-level exposure within the vehicles, it is also said that vehicles actually could shield a lot of the EMF as they are today[55]. However, if vehicles are to be constructed with different materials in the future,

[53] Double-blind conditions means that neither the test persons nor the administrator knows who among the test participants that is exposed (Hansson, 2007).

[54] Interview with researcher A.

[55] Interview with researcher B.

such as carbon material, then they will no longer shield passengers in the same way. But as said before, the potential of shielding technology for strong electromagnetic fields needs to be proven.
What is striking generally when digging in the research regarding electromagnetic fields in relation to ERS is the very limited amount of reports available putting emphasis on this potential blocker. As realized during interviews with people in the industry of ERS, the figures of electromagnetic fields for the different technologies available are still confidential, or at least the interviewees chose not to share the information. This makes it difficult to draw any conclusions in this feasibility study. Of course the technologies are still developing, but in order for authorities to make proper risk assessments, which will have to be done before a large-scale implementation, measured values should become public. People with implanted pacemaker should not be affected negatively from an introduction of ERS, and those suffering from EHS should be explicitly addressed too. The technology providers are only stating that their solution causes electromagnetic fields below guideline levels, but it is important to note that guideline levels only confirm the acute effects of EMF[56]. The long-term effects remain uncertain, which is especially important for EHS.

2.3.3.2 Particles and pollutants connected to health

Generally, the electric vehicles seem to be able to reduce the levels of emissions since a big amount is produced during hydrocarbon combustion in the conventional vehicles (European Commission, 2008). The reduction will occur if the energy production for the electric vehicles will be implemented in an environmental friendly way that will keep the emissions levels low. The problem of tire/road abrasion remains and studies are needed to ensure that they are not worsened because of the different traction characteristics of EVs (European roadmap, 2012). Particles and pollutants such as CO_2 could affect humans using ERS and the surroundings. As a health aspect particles and pollutants are in this section briefly considered and more about the environmental impact is investigated in the EIA in section 2.2.2.
The most common negative effects of Particulate Matter (PM), i.e. suspensions either in liquid or gas, are health problems among humans and animals, adverse effects of visibility and global climate change (Abbasi, 2013). There are various ways that humans are exposed to particles and thereby exposed to risks; dermal exposure - contact with the skin, inhalation - by breathing, ingestion or oral - by eating or drinking, and injection - nanoparticles for medical treatment.
In this deliverable, the three technologies of ERS are considered. Regarding particles it is believed that the conductive technology with overhead lines could be compared with railroads due to similarities of the power lines and the pantograph. The conductive technology with rail in the road is considered to be similar to railroad due to the rail. In this sense, the inductive solution seems to be most similar to a regular road since it is only tire and road abrasion creating particles during operation. For railroads particle sources are mainly non-exhaust emissions that come from the rail vehicle (Abbasi, 2013). These non-exhaust emissions are stated to be more genotoxic than emissions from road transport, since it can affect the amount of chromium, manganese and iron in the blood. In addition, Abbasi (2013) states that in road and rail traffic there are similarities between the characteristics of particles that are being emitted.
Abbasi (2013) also states that in the field of non-exhaust emissions, few studies have been made, and thereby there is limited legislation that can be compared with legislation on exhaust emissions. The non-exhaust emissions from road transport are airborne particles from tires, braking materials and roads, whereas the particles from rail traffic mainly come from wheel-rail contact, braking materials and overhead lines. The particles originating from road transport are considered to be quite well known.

[56] Interview with researcher B.

Due to road transport the percentage of contributions is particularly high within urban areas (European roadmap, 2012). Vehicle pollutants and severe health effects such as respiratory and cardio-pulmonary diseases and lung cancer are connected according to a growing body of evidence. World Health Organization, WHO, states that the emissions from car exhausts are generally responsible for more deaths than road accidents.

2.3.4 Safety

In addition to health concerns there are also safety concerns connected to ERS. Since all three technologies available for ERS include high voltages and more electronic components than regular roads, the electricity safety is one barrier to overcome. Regarding the conductive solution with overhead lines there are also risks concerning the extra equipment needed adjacent to the road such as pillars holding the overhead lines and the power lines themselves. The equipment for the overhead lines may affect road safety in the sense that vehicles might crash into them. The conductive technology with rail in the road poses some safety questions related to the rail. There is also ongoing research whether electric vehicles bring higher risk for emergency services in case of an accident, which will be touched upon in this chapter. However, the main focus in this chapter is the investigation of transportation of flammable materials on future electric roads. Due to some similarities between the conductive solutions and the railway, current safety measures taken in the railway sector are included. The inductive technology is not considered to include any new safety concerns in addition to EMF in this deliverable.

There is a lack of published safety assessments related to ERS, probably due to the fact that it is not yet implemented in a large scale. However, some aspects of the safety issues were achieved during conducted expert interviews. Generally it is believed that ERS should not be considered as dangerous if they are carefully designed without any malfunctions[57]. Further it is stated that the safety aspect is becoming more complex in case of an implementation within the city but that on highways none of the systems would be dangerous. As a counterexample, experts referred to some parts of the railway where there are unsupervised crossings where accidents often occur. These are not being rebuilt and the reason is stated to be that it is considered as logical that people should not cross the railway since it could be dangerous. As another example it was confirmed that there is probably a need for extra protection equipment for the conductive technology with overhead lines to prevent trees falling over it[58].

In the report by WSP (2013) it is pointed out that when having the conductive solution with power transfer through rail in the road, the electricity safety is an important aspect since humans and animals might come in contact with the rail. Further it is suggested that one solution is to sectionalize the rail so that it will only lead electricity when there is a vehicle moving over it. Elways (2011) suggests on their official website that the rail should be sectionalized. Further it is stated for this solution that there is no risk for people stepping on the rail to get electric shocks, and it is also stated that no risks related to electricity in the rail occur in case of rain or snow[59]. One example given of when this solution can be dangerous is if someone would put two metal sticks into the rail and thereby form a closed circuit.

Safety concerns are important to investigate further since ERS should become as safe as the regular roads even though a regular road is far from safe i.e. ERS should not bring decreased safety. With high voltages and

[57] Interview with Vehicle manufacturer B.
[58] Interview with Vehicle manufacturer A.
[59] Interview with Infrastructure provider.

more electronic components, these safety concerns could be even more critical if flammable materials or other dangerous goods are to be transported on ERS.

2.3.4.1 Dangerous goods and electrified roads

Since the concept of electrified roads is relatively new, the issue of operating transports of dangerous goods on these roads is not yet addressed. Hence, regulations and legislations for this application are not currently available. However, it is believed that it is an important issue therefore it is included in this feasibility study. The lack of regulations and legislation for this specific application motivates a summary of current work with dangerous goods on regular roads and railways. Regular roads are symbolizing the vehicles used on electric roads due to visual similarities, however not technical in sense of voltages and motor system. Railways symbolizes the conductive power transfer due to high voltage power lines which are also used for electric roads, either embedded in the road for inductive and conductive rails or in the same way as for railways. The summary presented in this chapter is based on the Swedish systems.

In 2012, 9.1 million tons of the transported goods within Sweden were classified as dangerous goods, i.e. gases, flammable liquids, oxidizing and caustic materials (Trafa, 2012). 66% of the transported dangerous goods were flammable liquids. This gives rise to the question about the feasibility of electric road systems concerning dangerous goods. Will it be a simple task to introduce trucks carrying flammable liquids into the electrified roads?

2.3.4.2 Swedish authorities and regulations

The authority for dangerous goods on road and railway in Sweden is the Swedish Civil Contingencies Agency (MSB), with the task to prevent and mitigate injuries and damage connected to accidents with transports of dangerous goods (MSB, 2014). Their definition of dangerous goods is;

"Dangerous goods are substances and articles that during transport may cause damage to life, health, property or the environment due to their chemical and physical properties."

The concept of transports of dangerous goods covers more than only the movement of vehicles, railway wagon, ship or airplane (MSB, 2013a). Included are also loading, unloading and handling of the goods in connection to transport.

In Sweden, regulations for transporting certain dangerous goods have been available since the 1860s (MSB, 2013a). When the European Commission 1956 published "The Orange Book" the international regulations were introduced. These together formed the basis for the development of the regulations. Since 1974 Sweden has followed the international regulations, and the first law was established in 1982.

The basis for Swedish regulations of transports of dangerous goods can be found in 'The Swedish Transport of Dangerous Goods Act (SFS 2006:263)' and 'The Transport of Dangerous Goods Ordinance (SFS 2006:311)' (MSB, 2014). All conditions, including e.g. responsibility and packaging both for road and rail bound transports, can be found in ADR (***A**ccord européen relatif au transport international des marchandises **d**angereuses par **r**oute*) and RID (***R**èglement concernant le transport **i**nternational ferroviaire des marchandises **d**angereuses*) which are the international regulations.

There are different regulatory agencies for control of dangerous goods being transported (MSB, 2013a). The police are controlling trucks with dangerous goods, the Swedish transport agency has regulatory responsibility for dangerous goods transported on railway, by sea and by air. Dangerous goods in harbor areas are controlled by the Coast guard while the Swedish Radiation Authority has regulatory responsibility for transports containing radioactive materials.

Further, some general requirements of both trucks and drivers will be summarized and presented.

2.3.4.3 General requirements for road transports of dangerous goods

Both MSB and the Swedish Petroleum Institute (SPI) have established some requirements regarding trucks and drivers with the aim of creating a safe environment for these transports. A summary of these will be presented.

The SPI requirements concern equipment and operation, i.e. loading/unloading tanker trucks with petrol, diesel or fuel oils (SPI, 2011). For every vehicle there are established minimum demands;

- The tanker truck has to be approved for the intended purpose.
- For trucks it concerns, they have to be leak tested or the vapour systems have to be visually inspected.
- The truck should have decontamination equipment in order for the driver to take care of a small spillage.
- Extra equipment both for the driver and the truck, such as clothes and seals for tubing.
- If the truck has drainage tubes, these cannot culminate at a larger distance than 10 cm above the road surface.
- The truck should have antistatic material where needed, e.g. for extension tubes.

Further, there are also demands concerning the truck drivers, i.e. they should have the correct education and an experience of at least 3 years of driving a vehicle of the same length and weight (SPI, 2011). In addition, mobile phones and other electronic devices must be switched off when loading and unloading the truck. During driving mobile phones may only be used if hands-free equipment is installed in the truck. Smoking is prohibited when handling goods or inside/close to the truck (MSB, 2013a).

In addition, all extra electric equipment has to fulfill the requirements for explosion safe equipment (SPI, 2011). The earth connection is a very important part of the safety when loading and unloading trucks, especially for flammable liquids with a fire-point below 60°C (MSB, 2013a). The resistance of the earth connection both at towing vehicle and trailer must not exceed 3 Ω (SPI, 2011). This limit has to be controlled. Additionally the filling rate has to be limited in order to minimize the risk of electrostatic charges (MSB, 2013a). When loading or unloading goods at a public space or in urban areas a special permit from the police authority is needed. If outside urban area the police authority only has to be informed.

Obviously there are stringent rules applied on both truck and driver. Some of them might seem basic and obvious but they are needed to assure a safe environment. As mentioned earlier the earth connection is an important factor for loading and unloading flammable liquids and there are means to minimize risk of electrostatic charges. The fact that trucks run on rubber wheels is important since there is no earth connection while driving. For trucks on electrified roads there seem to be a higher risk for electrostatic charges or increased heating of the vehicle depending on chosen technology. When discussing this topic with people in the industry not working with dangerous goods the spontaneous reaction was often "…but we are transporting these materials on the railway today so why should it be a problem?".

The difference between ERS and railways is that the railway track has an earth connection and that the locomotive handles the electricity. It is stated however that the conductive technology with overhead lines will have a two-pole system which would handle the return circuit. Besides, a train could be hundreds of meters longer than a truck which means that it is possible to place flammable material further back in the train, further away from the "electricity source", i.e. the pantograph. The railway wagons are exposed to electromagnetic fields from the high voltage overhead lines but not in the same extent as expected from inductive roads and at a very low frequency, 50 Hz for the railway compared to 10-200 kHz for ERS. Inductive

roads are said to create a lot of heat due to strong magnetic fields[60] which could cause problems for flammable liquids with a fire point below 60 °C. In order to make a fair comparison of dangerous goods on regular roads, railways and electrified roads, the regulations for railways in Sweden is presented.

2.3.4.4 Transport of dangerous goods on railways

In order to investigate the feasibility of dangerous goods on electrified roads it is believed that parts of the railway approach and regulations could be applicable to ERS. Also potential risks connected to high voltages are being highlighted. On railways it is also possible to handle large amounts of dangerous goods that if handled the wrong way could become a disaster. For these reasons, information regarding the Swedish railway system, some railway technology and the operation of dangerous goods is being described.

The Swedish Rail Administration (Banverket) was merged into the Swedish Transport Administration in 2010 (Trafikverket, 2012c). Before merging, they were the authority controlling the state owned Swedish railways. When dangerous goods are being transported on railways in Sweden there are stringent rules on the railway wagons (Banverket, 2007). It is stated that todays' transports of dangerous goods on railways are almost entirely safe as society, working methods and techniques are constantly evolving.

According to EU directive 2004/49 regarding railway safety, railway companies must show their ability to handle risks, and one tool for that is the traffic safety program of the railway sector (Banverket, 2007). Additionally, RID-S (the Swedish version of RID) states that internal emergency plans should be established for switch yards where larger volumes of dangerous goods are handled. The intention with emergency plans is to coordinate rescuing operations in case of an accident in order to minimize risks for humans and the environment.

For specific security components on the train, such as axles and bearings, there is a computer system keeping track on time and number of kilometers for each individual railway wagon or locomotive (Banverket, 2007). If it detects an error the specific wagon or locomotive is steered to a service garage well before the technical life-expectancy has been exceeded.

The railway, as well as possible ERS, uses high voltage power lines in proximity to dangerous goods being transported. In Sweden, there are some characteristics of the railway and the road lighting system that can be compared to what is expected for the electric road system (Andersson & Edfeldt, 2013). The electrical power is delivered from the regional grid, 40 – 130 kV, 3-phase high voltage with a frequency of 50 Hz (Trafikverket, 2014c). Trains are powered by 15 kV, 1-phase with a frequency of 16.7 Hz. Hence, the electric power has to be converted in substations that are located evenly along the railway. The network frequency of 16.7 Hz is only used for railway operation and the reason for that goes back to the time when railways started to get electrified, and at that time it was easier to build motors for locomotives with a lower frequency. In order to supply electric locomotives or other electric vehicles with electric energy, feeding stations are needed, i.e. the substations. These substations generate a sufficient amount of power with correct voltage and frequency. Swedish locomotives, like many in Europe, are built to be operated with 15 kV with a tolerance of +10% and -20%. Heavy freight transport trains need more power and sometimes of such a large volume that the voltage of the power lines decreases drastically. To deal with this problem the railway has its own electricity grid with a voltage of 132 kV.

When comparing the characteristics of the Swedish railway and the lightening systems, it can be seen that the distribution of electricity needed for the ERS system is much more similar to the railway characteristics

[60] Discussion during the Clean Fleet Workshop – Expanding charging infrastructure and procuring electric vehicles, May 21-22 Stockholm, Sweden.

(Andersson & Edfeldt, 2013). The voltage needed for ERS according to Andersson & Edfeldt (2013) is around 12-24 kV, and if the higher limit is used the ERS could be connected to the regional grid. However, the Primove technology is stated to use 30-130 kV (Viktoria, 2013). A voltage lower than 1500 V, is considered to be the definition of low voltage (Andersson & Edfeldt, 2013). The road lighting system is considered to be low voltage and is often connected to local grids.

As a safety measure, there has to be a possibility of shutting the power off quickly as a protection against overload and short circuit (Trafikverket, 2014c). Protection relays and power switches shut the power off within 75-125 milliseconds in case of a short circuit, however this is not fast enough if a person is close to a power line. The electric power takes an exceptional position as a cause of accidents since a voltage of 230 V, or even lower, can be life threatening due to the risk of respiratory paralysis and ventricular fibrillation. A voltage of 15 kV, which is the voltage of railway power lines, can cause flash-overs just by getting close to the power lines. Flash-overs or electric arcs, which could have degrees around 5000 °C (MSB, 2011), cause on a split second severe burns and furthermore often lead directly to death or severe disablement (Trafikverket, 2014c). Because of this there are safety equipment put up along the railway in order to prevent direct human contact and further there are also earth connections.

As described earlier, the ERS could have voltages of 12–130 kV depending on technology. Further the stated frequency range is 10–200 kHz. This means that ERS have similar voltages as the railway but much higher frequencies. Again the fact that trucks run on rubber wheels distinguishes it from the railway since railway wagons automatically have earth connection through the rails. It is important that a human can never become the earth connection between road and truck in the ERS since that could be life threatening. The Swedish transport system adopts a safety vision with the aim of preventing severe injuries and death. It covers both railways and road transport but has a focus on road transports.

2.3.4.5 The Swedish Transport Administration and the Vision Zero

As mentioned before stringent rules are surrounding transports with dangerous goods (Trafikverket, 2014a). A transport with dangerous goods is not necessarily a dangerous transport and the aim is for it to be safe. In Sweden, the Swedish Transport Administration bases their work on the ‘Vision Zero’ which is a vision of a future where humans are not killed or severely injured in traffic. It is both an ethical approach and a strategy to create a safe road network (Trafikverket, 2014b)(Vision Zero Initiative, 2014). A road network according to vision zero considers that ‘the perfect human’ doesn’t exist and that people make mistakes and that traffic accidents cannot entirely be avoided.

Transports of dangerous goods are included under the vision zero and therefore these transports must be safe and protected against external threats already in the early planning phase and construction of infrastructure (Trafikverket, 2014a). When a new road or railway is to be built, or when an existing road or railroad is to be changed, an important aspect is the risk of transports with dangerous goods. In an early phase of the planning process these transports are taken into account in order to minimize the risk of accidents. Risk analyses are done in investigations regarding new infrastructure and are often included in the environmental impact assessment. However, it is not possible to build a society completely without risks therefore in the physical planning risks connected to transports of dangerous goods are weighted against other values in society. The small probability that an accident with transports of dangerous goods occur is often outweighed by the benefits of having a close and accessible transport system. Transport of dangerous goods may raise concerns but many participants are involved together with authorities, as mentioned before, in the work of making sure that these transports are as safe as possible. The safety of infrastructure, usage of robust packaging and tanks, educated staff and safety equipment contributes as well.

A large share of the dangerous goods being transported every year on Swedish roads and railroads consist of oil-based products such as automotive fuel (Trafikverket, 2014a). Connected to accidents with dangerous goods are the risks of fire, explosion and release of toxic and corrosive chemicals. These risks are exactly what define a 'dangerous goods accident' since it otherwise would be referred to as a common accident. However, the seriousness of a dangerous goods accident depend on several factors such as what is being transported, the volume of it and other circumstances of the accident, e.g. weather and wind.

It is believed that the Vision Zero should be applied to ERS as early as possible since there is a possibility of safety problems connected to transport of flammable liquids. Whether there are actual safety problems or if these are significant remain uncertain and further research is needed on design of vehicles and earth connections among other factors. The fact that there is a large amount of dangerous goods being transported, and that a large share is oil-based products, makes it an aspect that needs further investigation to be able to determine whether the combination of ERS and flammable liquids is feasible.

The conductive ERS technologies might have more "visible" problems or safety aspects since the rail in the road or overhead lines actually provide a mechanical connection to the vehicles. Sparks may occur. The energy transfer is controlled and grounding solutions might be easier to solve due to the mechanical contact and to available two-pole systems. The inductive road however, has an "invisible" energy transfer through electromagnetic fields where consequences for humans and surroundings, as well as for the vehicle, are uncertain, especially in a long-term perspective. Due to many uncertainties and lack of assessments addressing ERS in relation to dangerous goods, it was decided to take one step further, i.e. contacting experts within the domain of dangerous goods.

2.3.4.6 Experts opinion

The conducted interviews with experts within the field of ERS did not provide much information about possible concerns for vehicles transporting dangerous goods on electrified roads. Neither did any of the interviewed experts have any comments or beliefs related to this concern. Several stated that they haven't thought of it, and some stated that they had only heard of it. All agreed on that there will probably not be an issue transporting dangerous goods on ERS but the uncertainty factor remains.

Several dangerous goods experts were contacted; however there was a weak response which was probably due to the premature subject and confidentiality of the vehicle specifics. The latter seems to be a dominant factor for them to be able to make a judgment. However, the three experts that chose to share their knowledge and opinions are presented here even though their beliefs come with some uncertainty. When discussing the topic with these experts it was pointed out by them all that ERS in relation to dangerous goods is an interesting topic that easily could be overlooked within the transport sector and the area of dangerous goods. It is further believed that it is a concern which can cause major problems for the ERS implementation.

Schmidt (2014), chemist and security advisor at Sakab which is Sweden's leading environmental company in the handling of hazardous waste, generally does not believe that electrifying these trucks will become any big problem but that some substances or types of trucks may become inappropriate for this purpose. However he illuminates that the regulations for dangerous goods are all about minimizing risks for transports and this is why ignition sources are prohibited. Further his recommendation was to contact the Swedish Civil Contingencies Agency for more information.

According to Zettergren (2014) at the Swedish Civil Contingencies Agency (MSB) a comprehensive risk analysis is needed, and therefore it cannot be considered a simple task to introduce trucks transporting dangerous goods on ERS. Zettergren also explains that there are specific design and construction requirements for trucks transporting explosives. For example, a truck transporting explosives cannot have

batteries of more than 24 volts. Common for all trucks transporting dangerous goods is the requirement of "no smoking close to or inside vehicle when handling goods" which is connected to the risk of ignition. Further Zettergren states that the risk of ignition in case of sparks is the biggest concern within this area of transport and thus motivates a risk analysis. This might become a critical point if conductive ERS with overhead lines is introduced. Considering the inductive ERS, Zettergren highlights that emphasis should also be put on conventional trucks transporting dangerous goods over or close to magnetic fields despite the fact that they currently pass rail crossings.

Löfström Johnsson (2014), fire engineer at the oil company OKQ8, states that todays' tanker trucks are generally very secure. The tanks are well protected against leakage and they are working continuously to minimize the spill-over and emissions of gases to the environment, e.g. through systems for vapor recovery. Thereof the risk of fire or explosion is relatively low, e.g. if someone would smoke next to a tanker truck. However, at the same time there are very strict safety routines when loading and unloading the goods and high demands are put on the construction of the vehicles, stations and depots. For example, the drivers wear anti-static clothes and they have to ground the vehicle in order to minimize the risk of sparks. For the same reason, the gas stations today are built with potential equalization and the depots have advanced extinguishing systems as protection in case of ignition. Hence, the environment surrounding a tanker truck is not a safe place even though there are different kinds of protection systems. Löfström Johnsson also states that a tanker truck containing flammable gases and liquids cannot simply be electrified. To even make the judgment, a comprehensive risk assessment is required and thereafter a revising of the existing ADR-rules before it is possible to make reconstructions and take the vehicle in operation. Löfström Johnsson spontaneously do not believe that it is possible to electrify these trucks since it would probably require comprehensive adjustments and he doubts that there will be reasonable costs for that.

With this information it can be concluded that there is a big uncertainty connected to introduction of trucks transporting dangerous goods on electrified roads. What seems to be the biggest issues are the risk of ignition in case of sparks, large amounts of heat produced by the inductive technology and the much higher voltages than 24 V used in electric trucks. Vehicle manufacturers state that electric trucks have voltages of approximately 500 V and further the power grid feeding the technologies are believed to have voltages between 12-130 kV. As mentioned, dangerous goods are being transported on railways where there are stringent rules on the railway wagons. The main difference compared to ERS seems to be the grounding points in the rails and the possibility of placing e.g. flammable materials further away from the pantograph. In order to determine whether it is feasible to operate trucks with dangerous goods such as flammable materials, further studies and risk analyses are needed. It is believed though, that this is factor that should not be ignored, even if these specific trucks might not be electrified in an early stage. They will however still probably operate on the same roads as ERS are implemented. Further it is believed that solutions could be found solving this possible issue but the factors concerning cost, development time and uncertainty remains.

In addition to the concern of ERS in relation to transportation of dangerous goods there are also concerns regarding increased risk for electric vehicles involved in traffic accidents due to their electric propulsion and battery. There is some ongoing research in this area, which will be presented in next section.

2.3.4.7 Accidents with electric vehicles

There is a stated need of risk analyses regarding accidents or crashes with electric vehicles (MSB, 2013b). Not only does the battery pack in electric vehicleshave high voltage, high electricity capacity and a large power- and energy density, they also have large amounts of combustibles. Knowledge and education is therefore needed in order to maintain a qualified emergency service. The Swedish research project "Räddningskedjan"

(approx. rescue chain) aims at providing emergency services with methods of how to handle accidents with electric vehicles. It is a project within the research program FFI (Fordonsstrategisk Forskning och Innovation, approx. vehicle strategic research and innovation).

In a report by Hoffman (2013), the question whether electric vehicles have a higher risk of catching fire than other vehicles in case of an accident is raised. As one example the two words ‘water’ and ‘high voltage’ and the connected thoughts to the words, both separately and together are highlighted. When these words are put together, thoughts such as errors, fire, damages etc. occur. In society there is a belief that electric vehicles have high voltage batteries, but high voltage is traditionally defined by European standards (e.g. British Standard BS 7671:2008) as voltages higher than 1000 V AC or 1500 V DC and no electric vehicles on the market have batteries of this voltage. Vehicles on the market today have an electric system that has no contact with the chassis therefore it is said that these traction systems are ‘free-flowing’. Due to that, vehicles with electric propulsion cannot form a closed circuit with a person that comes in physical contact with the vehicle structure. Neither will flushing water directly on the traction battery present any risk of forming a circuit with a person. However, there are some examples of electric cars catching fire days after the actual accident. After analysing these cars, Hoffman found that the probable reason is that the 12-volt starter batteries were not disconnected after the collision.

Another study by Larsson et al. (2014) also states that the electric vehicle components referred to as low voltage (12/24 V) and high voltage (300 - 600 V) can be misleading. Further it is also stated that there might be a risk for service staff handling damaged electric vehicles but that there are protection means such as insulation of different types in order to avoid danger. The difference between an electric vehicle and a conventional vehicle is that the conventional car needs a start engine creating a spark that ignites the fuel mixed with air, whereas the battery is storing the energy in an electric vehicle which is released as soon as the two poles of the battery are connected.

The electrolyte in lithium-ion batteries is a liquid or gel containing ions, which is combustible. This, together with battery voltages higher than in conventional cars, poses a possible increased risk for fires (Larsson et al., 2014). The electrolyte is said to have similar properties as gasoline. In addition, there is a risk for battery thermal runaway, which is by the authors defined as usually consisting of:

“*…one or a combination of the following events: rapid gas release, electrolyte leakage, fire, rapid disassembling/explosion.”*

The thermal runaway is often started by overheating which in turn is often caused by short-circuit, overcharge or deformation of the battery (Larsson et al., 2014). The progress of battery happenings if overheated or damaged depends on cell design and chemistry. This has of course led to improvements in battery materials, e.g. new mixings of electrode materials.

Furthermore, Larsson et al. (2014) states that car manufacturers are protecting the battery packs against crashes by putting them into a crash protected box. The authors believe that the future will bring safer Li-ion batteries that could take a higher level of deformation. However it is also stated that it is not possible to create crash protections being able to handle all types of extreme collisions. In case a collision creates a fire in the vehicle, it is stated that fires of electric vehicles are difficult to extinguish. According to the authors, a study by DEKRA in Germany showed that more water was needed in order to extinguish an electric vehicle than a conventional car.

In addition, Larsson et al. (2014) presents some incidents where electric vehicles have been included. In June 2011, a Chevrolet Volt caught fire three weeks after a crash test. NHTSA (National Highway Traffic Safety Administration) found that the causing factor was a leakage of cooling media, which had leaked over the battery and when it dried, crystals remained that short-circuited the battery. In November 2012, a harbor in

New Jersey where some parked brand new Fisker Karma PHEVs and Toyota Prius HEV/PHEV was flooded due to a subsequent water wave caused by hurricane 'Sandy'. The fires might have been caused by short-circuits in the 12 V battery, but this is unconfirmed statements from both Fisker and NHTSA. More incidents are known but haven't reached light of media; however vehicles and their electronics must generally work in rough environments. Furthermore, the authors state that negative publicity of all kinds of new products entering a market is always a problem for public acceptance (Larsson et al., 2014). Since there is still a relatively low number of electric vehicles on the market the possibility of having reliable statistical studies on incidents and safety is limited.

In connection to mentioned concerns there are some common myths circulating regarding batteries together with water, battery incidents in case of a crash, or the risk of people forming a closed circuit if touching the vehicle chassis after an accident. Hoffman, expert on vehicle electricity safety who is earlier referred to, dispels some of the myths in one of Sweden's leading technology and IT newspapers "Ny Teknik" (Von Schultz, 2014);

- **Myth 1:** The chassis could become live and cause life-threatening electric shocks after a crash.

Wrong. Unlike the regular 12-volt battery, the high voltage battery propelling the vehicle is not grounded in the chassis. In addition, the safety system of the electric vehicles is cutting off the connection between the high voltage battery and the driveline. Since the battery is "free-flowing" it has no difference in electric potential compared to the surroundings meaning that people could without risk touch the vehicle. Even if the safety system of the vehicle is malfunctioning or if conducting objects would penetrate both poles of the battery, there is no possibility of electric shocks.

- **Myth 2:** If an electric vehicle would end up in a lake, the lake would become live.

Wrong. Researchers from SP (technical research institute of Sweden) have done tests where fully charged 400 V Li-ion batteries have been lowered in both freshwater and saltwater, and the conclusion is that there is no risk for the lake to become live. The field strengths are so weak that a person cannot perceive them.

- **Myth 3:** Fires in electric cars always start in the high voltage batteries.

Misleading. Fires in electric vehicles have caused quite a commotion. In most cases, fire investigations show that the fires started in the 12-volt battery. In some case it is believed that the cabin heater started the fire, while in some other case there was an explosive fire caused by flushing water on burning magnesium wheels. Still, the high voltage battery is being blamed as the causing factor.

- **Myth 4:** It is life-threatening to extinguish a burning battery with water.

Wrong. If water is flushed directly into a power outlet at home, the human body creates a closed circuit between the electricity grid and the ground. That could be life-threatening. But to flush water on a high voltage battery from an electric vehicle is harmless. The battery is neither grounded with the vehicle chassis or the ground and there is no potential difference between the battery and surrounding (see myth 1).

- **Myth 5:** A damaged battery can leak corrosive liquids.

Mostly wrong. Corrosive liquids exist in batteries with water based electrolyte, e.g. lead-, nickel metal hybrid- (NiMH) and nickel cadmium (NiCd) batteries. But for electric vehicles manufactured 2012 or later, the common battery is Li-ion batteries. In Li-ion batteries, the electrolyte is based on organic solvents, which are not corrosive.

Obviously there is some ongoing research within the field of accidents in relation to electric vehicles. As it seems this is not a big concern even though some uncertainties such as functionality of battery protection equipment and increased risk of fire still remain. Further it seems to be quite technological concerns which are probably solvable by technicians and engineers e.g. within the field of battery chemistry. However it is believed that emergency services might need new ways of approaching accidents where electric vehicles are involved. As mentioned in the beginning, there are projects aiming at finding new tools and educating emergency staff. However, the ongoing research mainly concerns passenger vehicles and not heavy vehicles. Even though there are similar batteries used in trucks, the batteries in trucks will be bigger with even higher voltages compared to passenger vehicles why there is a need for deeper investigations related to heavy electric vehicles and accidents.

2.3.5 Discussion

The concept of ERS brings some concerns regarding both health and safety. It is a new concept even if the technologies in themselves are not entirely new. Also the possible large-scale implementation seems to make the uncertainties more complex since humans, animals and surroundings might be more influenced compared to a regular road. ERS does not only pose uncertainties, it is also believed that there are many benefits such as reduced tail-pipe emissions and lower noise levels. However, these benefits might be held back if uncertainties are not investigated further.

Inductive on-road charging may have health related issues due to strong electromagnetic fields. Different frequencies affect the human body in different ways and therefore each frequency level for each ERS application needs to be checked against guideline levels for public exposure. The ICNIRP guidelines from 1998 are currently being updated which could contribute to new guideline limits to follow. Technology and vehicle providers should keep up-to-date with the upcoming guidelines to ensure that they are not exceeded. As ICNIRP base the reference values on all available research, and since measuring technologies develop, there seems to be a future with more "exact" exposure limits. Levels of exposure should further be referring to the surroundings of the vehicle and vehicles should be designed so that the driver is shielded. The EMF issue is also a matter of convincing people that it is safe, which due to the suspicious attitude of the public and even experts towards such invisible aspects needs to be proven objectively and explicitly.

It could be the case that inductive road systems can be compared to the situation with embedded distribution lines within the city. However, if a considerable proportion of the population is to be exposed for a considerable time period to the resulting EMF should not deviate much from what is found currently in society. With a big uncertainty the exposure level should not raise the average exposure level and the precautionary principle should be used. If the frequency of inductive roads will differ for different applications all possible reference values for different frequency ranges need to be considered accordingly. The Swedish Radiation Safety authority will probably be the body controlling the inductive roads and corresponding EMF and are believed to play an important role if the on-road inductive charging is to be implemented in Sweden.

Further, the electromagnetic compatibility for pacemakers and for people with EHS in relation to ERS should be investigated. It seems important to connect research within technology development of inductive charging with knowledge regarding biological aspects and EMF. This should be valid for all actors and authorities working within the industry of ERS and electric vehicles. The complex of problems related to EMF is valid for all types of vehicles, independent of whether it is a truck or a passenger car. It is believed that invested money will be of no use if the users opt out ERS due to doubts regarding their health and safety. Another important aspect seems to be the ability of experts answering questions from the general public

since unanswered questions might raise further concerns. Exposure to electromagnetic fields is highly uncertain since there seems to be a complex procedure measuring EMF levels. Therefore it is believed that the worst-case scenario should be assessed until it is actually proven that there is no cause of concern for the general public.

Regarding particles and pollutants, ERS seem to offer better environment for road users and for the climate during the operation phase due to e.g. decreased tail-pipe emissions. In addition it is believed that the ERS has the same level of tire and road abrasion as the regular road. The inductive road is therefore believed to have the same impact as regular roads regarding particles, while the two conductive solutions might have higher levels of particles released to the air due to the rail in the road and the overhead lines. As stated earlier, vehicle pollutants cause severe health effects and contribute to climate change, which forms the major driver or motivation for ERS.

One might wonder why accidents with electric vehicles constitute a part of ERS safety. There is on-going research whether electric vehicles have a higher risk of catching fire after accidents, and whether that is true or not remain uncertain. However, studies presented earlier show that there might be a need of disconnecting the 12 V batteries of the vehicles after an accident and that emergency services might need new methods approaching these accidents. There are more electric passenger vehicles operating on European roads than electric trucks but this is something that could change in the future if ERS are introduced. Therefore it is believed that it is an important aspect that should not be ignored. Further, electric vehicles have higher voltages and more electronic components than conventional vehicles, which seems to be a reasonable investigation.

For the conductive technologies it is not the EMF that poses concerns. Within the industry and in literature, there is a belief that the overhead lines or the rail in the road might become safety issues. There seem to be possible issues regarding the pillars holding the overhead lines, and the overhead lines themselves. On railways today there are disturbances in the railway traffic due to fallen power lines. It might be the case that there is an even higher risk for this to happen if trucks are using this system. More trucks could cause more wear and tear on the power lines due to the pantograph, which will be connecting to the system while the truck is in motion. Trains connect and disconnect to the power lines while standing still at stations. This is considered to be a significant difference. Extra safety equipment reducing risks of vehicles crashing into the pillars or in case of fallen power lines seems to be needed. All three ERS technologies seem in addition to have even more complex safety concerns if they are to be implemented within the city.

Another potential blocker of the ERS could be the transportation of dangerous goods. Intuitively, electrifying trucks transporting dangerous goods does not seem like a risk free business. Even though trains are transporting dangerous goods today, there might not be a simple task electrifying trucks for the same purpose. In addition it is believed that current ADR regulations need comprehensive adjustments, as well as the vehicle, which raises the question whether this could be done for a reasonable amount of money. Emphasis should be put on investigating this area of ERS operation. Studies relating to earth connections for trucks are also believed to be needed due to the fact that they are running on rubber wheels. For the conductive solutions this might be an issue easier to face since there is a mechanical contact for the power transfer., even though that these may produce more sparks.

Within the industry it is not believed that transporting dangerous goods will become a problem for ERS. It is also stated that the conventional ICE is running very warm during operation and that the large fuel tank is not risk free. However the question remains whether the effects of EMF would affect the entire truck in sense of possible heating and if it then is a bigger concern than if only the engine gets warm. Safety experts from the transportation industry are afraid that very high voltages pose a risk that the vehicle gets charged

statically and static electricity might create sparks which further increases safety concerns in relation to transportation of dangerous goods.. There is no evidence found for the legitimacy of such fears, but the contrary has not been proven either Comprehensive studies considering the design of the trucks are believed to be needed.

Generally ERS seem to be an important step towards a cleaner environment through the possibility of renewable energy sources. However, many questions remain and uncertainties that could affect a big population should be approached holistically and taken seriously until the contrary is proved. It is also believed that there is a need for intense cooperation between actors to achieve safe ERS that are proven to cause no severe health effects, even though there is very little evidence of any health effects up to this point.

2.4 Vehicle

Vehicles running on electric road systems, independent of technology chosen, need to be adapted for optimal operation. The aim is to provide vehicles that together with the ERS create an efficient system. In this sense the vehicle in addition to the road construction is a crucial factor for ERS. Even though vehicle manufacturers are claiming that they are developing and improving the vehicles in the best possible way, there are still factors that remain uncertain. However, this deliverable does not investigate the vehicle in depth since the technology specifics are considered as solved according to interview with vehicle manufacturers[61]. Nevertheless, a brief summary of current vehicle related issues is believed to be important, and once again the trucks are the considered vehicles.

One of the reasons why long haulage trucks have not been equipped with electric propulsion systems yet is that they are not braking that frequently when running for longer distances[62]. In this sense, it is more difficult for the battery to be recharged from regenerative braking energy. The fuel savings for hybrid trucks in this kind of operation is only about 2% due to heavy load, and therefore such an expensive truck is not a competitive choice on the market. A truck company would prefer to get rid of the battery and to drive more on directly supplied electricity, since both the emissions and the energy cost for the customer would be lower. On the other hand for buses the fuel saving can be 20 – 40% since people are not that heavy load. In addition, buses are braking more often and therefore it is possible to recharge the battery in a bigger extent through regenerative braking energy.

2.4.1 Load capacity

The load capacity of the truck can be reduced in case of a battery electric vehicle due to the battery weight[63]. If load capacity is decreasing, this could pose a problem both for haulage contractor companies and for other means of transport since more trucks are needed to be able to do the same amount of transport work in comparison to ICEs. However, this would no longer be a problem in case of a fully electric truck designed only for electric roads. A fully ERS truck does not have a heavy battery and therefore the load capacity is not affected. This allows the truck to use full load capacity for goods to be transported instead of sacrificing the capacity to batteries. A limitation however is that the fully electric vehicle cannot be used for distribution of goods on non-electrified roads which seems to make this type of truck more feasible for fixed routes, e.g.

[61] Interview with Vehicle manufacturer A & Interview with Vehicle manufacturer B.
[62] Interview with Vehicle manufacturer B.
[63] Interview with Vehicle manufacturer B.

between specific logistics nodes. Larger opportunities for fully electric trucks would become reality if electric roads were implemented in a large scale.

2.4.2 Energy consumption and efficiency

ICE trucks and electric trucks consume the same amount of functional energy if they are doing the same transport work[64]. In addition, the functional energy consumption for trucks is the same regardless of chosen ERS technology[65]. More specifically, the energy consumption of the engine depends on the typology of the vehicle powertrain, the chosen cycle and the energy that is needed in order to cool or heat up the engine (European Commission, 2008).

However, the electric drive train is much more efficient than the ICE in terms of total energy consumption[66]. And what differs between the ERS technologies is the system efficiency which can be up to 98 – 99,99 % for the conductive solutions and approximately 80-85% for the inductive solution (WSP, 2013). This is connected to the efficiency of the power transfer between road and vehicle. According to Nordelöf et al. (2014) well-to-wheel studies have shown that the traffic situation on-roads and the driving behavior is another important factor for the energy efficiency.

2.4.3 Production emissions

The simplified EIA conducted in this deliverable, showed that during the operation phase of the ERS the CO_2 emissions for the electric road seem to be much lower compared to the conventional road. This could happen since the energy used for ERS during production, originates mainly from decarbonized energy sources, i.e. renewable energy. According to SOU 2013:84, the production emissions from a lifecycle perspective for a conventional car are much lower compared to hybrid and battery vehicles calculated on a basis of 150 000 km. More specifically the emissions of an ICE are 46 g CO_2 equivalents/km, 50 g CO_2 equivalents/km for a hybrid and 60 g CO_2 equivalents/km for a battery vehicle. Those figures show that even though the operation phase is much more emission intensive for the conventional vehicles, their performance during the other phases of the lifecycle perspective is much better compared to the hybrid and battery vehicles.

Another carbon emissions analysis made regarding the entire life of the vehicle is shown in **Table 19**.

Table 19: Vehicle entire life emissions analysis (Ricardo, 2011).

	Estimated lifecycle emissions (tonnes CO2e)	Proportion of emissions in production	Estimated emissions in production (tonnes CO2e)
Standard gasoline vehicle	24	23%	5.6
Hybrid vehicle	21	31%	6.5
Plug-in hybrid vehicle	19	35%	6.7
Battery electric vehicle	19	46%	8.8

Based upon a 2015 vehicle in use for 150k KM using 10% ethanol blend and 500g/KWH grid electricity.

The results of this study show that the most emission intensive production phase compared to the total lifecycle of the vehicle is the one of the battery vehicles while the least emission intensive one is the

[64] Interview with Energy authority.
[65] Interview with Vehicle manufacturer A.
[66] Interview with Energy authority.

conventional vehicles. The numbers that those calculations are based upon are considering a relatively carbon intensive electricity source, 500 g/kWh electricity.

In European Commission (2008) it is stated that fully electric vehicles demand less production energy than hybrid vehicles. As a result this difference in production emissions between hybrid vehicles, battery vehicles and fully electric vehicles seem to be due to the battery production, see section 0. Manufacturers of electric vehicles believe that the CO_2 footprint from vehicle production will be high (Andersson & Edfeldt, 2013). In the European roadmap (2012) it is stated that the carbon footprint is moving more towards the production of the components instead of the vehicle as a whole.

According to Nordelöf et al. (2014) another issue with manufacturing processes of vehicles is the local emissions and the corresponding human toxicity potential. The latter is a complex impact category that is often connected to large uncertainties. It is stated that manufacturing of battery electric vehicles has much higher human toxicity potential than manufacturing of ICEs. This depends greatly however on mining processes both for electricity production and vehicle components and that presented results could change with a less fossil fuel dependent energy mix.

2.4.4 Battery

A risk factor and potential blocker within the area of inductive on-road charging concerns the battery component. The energy storage in batteries is considered to be one of the most serious issues since it still suffers from many drawbacks, such as; high CO_2 footprint from manufacturer, short running ranges and long recharging times (European Commission, 2008). This issue furthermore leads to high cost for batteries, high weight and possible safety risk. With a heavier vehicle comes a heavier battery, which furthermore yields that the vehicle becomes even heavier and again the battery must be bigger, and hence we have an vicious circle (Andersson & Edfeldt, 2013). Therefore, the battery as an energy source for trucks will not be enough, which motivates the need of ERS.

Regarding the recharging time, it is considered to be quite long since the efficiency in charging is not as high as for plug-in hybrids. The European Commission (2008) states that some believe that the charging procedure should remain slow until the new generation batteries are used to succeed in longer battery lifetime and energy saving (European Commission, 2008). However, this is no longer the case according to Jessie Gagne from Renault Nordic [67]. With batteries used today (Li-ion) it does not matter in what way the battery is charged, i.e. slow- or fast charging or charging when the battery is empty or half empty. The battery lifetime is not affected as it used to be. However, the battery lifetime is a factor that probably should be taken into consideration since there is a potential risk of lifetime reduction due to several factors such as temperature changes, humidity or vibrations that normally occur at vehicles (European Commission, 2008).

In combination with batteries it is possible to use so called “super capacitors” or “super caps” which is believed to be needed the coming 5-10 years for hybrid heavy trucks[68]. The super caps can receive large amounts of energy when braking that batteries sometimes have a hard time doing. Super caps may lead back energy to the battery slowly and before the breaks or the ICE fill up the super caps again.

[67] Jessie Gagne, Renault Nordic, Clean Fleet Workshop – Expanding charging infrastructure and procuring electric vehicles, May 21-22 Stockholm, Sweden. (Personal notes)

[68] Interview with Energy authority.

2.4.4.1 Battery production and the environmental impact

The battery production is a procedure not environmentally friendly with high CO_2 footprint, which is a motivation to get rid of batteries and to move towards ERS[69](European Commission, 2008). The battery manufacturing for battery electric vehicles is stated to be both energy and greenhouse gas intensive (Ma et al., 2012). Asian companies have seen battery vehicles as an easy way to enter the market but from an environmental point of view it is not a good long-term solution[70]. According to the same Manufacturer A, a Life Cycle Analysis for batteries would not result in meaningful outcomes because the inputs are too uncertain; the tolerance in the inputs would be so large that one would not have a statistical proven result. By interviewed Researcher B[71] it is also stated that the emissions of battery production is a difficult factor in a LCA.

Notter et al. (2010) states that the battery causes between 7 – 15% of the total environmental impact of E-mobility. Furthermore it is stated that in a LCA it is the operation phase that dominated both for electric vehicles and ICEs but that it is much higher for ICEs.

In a study by Sullivan et al. (2010) it is stated that the environmental impact of battery production gives a relatively large additional CO_2 and energy burden for electric vehicles when compared to counterparts of conventional cars. Regarding CO_2 emissions from part manufacturing and vehicle assembly of BEVs, the battery production alone stands for approximately one third of the total CO_2 emissions.

Helmers and Marx (2012) present that it is not the lithium in Li-ion batteries that has the biggest environmental impact. The amount of lithium corresponds to approximately 1 % of the battery, i.e. 80 g Li/kWh energy. Furthermore lithium is not considered to be related to high depletion of resources and the process of purifying lithium is not regarded as energy intensive. However, it is the anode and cathode components that have the highest impact in a LCA, with materials such as graphite, copper and aluminium. The authors furthermore explain that published battery LCAs presents a variety of CO_2 emissions for Li-ion batteries due to the complexity of battery chemistry and available data.

The lithium batteries are the most commonly used batteries in the industry of electric vehicles (Sevelius et al., 2012). The environmental impact of these batteries has been debated a lot. During the production of Li-ion batteries, the CO2 emissions are in the order of magnitude between 52-250 kg CO2/kWh that for a 30 kWh battery means that the battery production contributes to extra emissions of 1,5-7,5 tons CO2. Comparing this with the total emissions from vehicle production, which is stated to be approximately 6 tons, it is stated that on average the battery production emissions correspond to approximately one quarter to even more than the total emissions of the rest of the vehicle, which is in line with the study by Sullivan et al. (2010).

2.4.4.2 Battery price and battery capacity

As mentioned before, the biggest issues with batteries are connected to price, capacity and weight in addition to high CO_2 footprint. The material for battery production is quite inexpensive but the cost is rising at the development and the production phase, according to Energy Supplier[72]. It is also highlighted that pure electric vehicles are currently much more expensive than battery vehicles, but that a battery vehicle needs

[69] Interview with Vehicle manufacturer A.
[70] Interview with Vehicle manufacturer A.
[71] Interview with researcher B.
[72] Interview with Energy Supplier.

large batteries that do not profit from the maturisation that can be expected for pure electric vehicles on ERS[73].

Furthermore it is stated that there is no optimal size of batteries and that the size of battery depends on type of transport and operation[74]. The battery capacity needed is determined by route type, distance between loading points and the time that the vehicle is staying at a specific point.

A study by Lee et al. (2013) exemplifies electric trucks with having a battery with a capacity of 80 kWh. The battery price in 2011 was 625 $/kWh (4094 SEK/kWh) and is expected to decline to 230 $/kWh (1507 SEK/kWh) by year 2020. With given battery capacity, and a weight of 11,4 kg/kWh, the total battery weight with current batteries is 912 kg for a truck with gross vehicle weight of 6 – 12 tons. This weight might be reduced if battery technology further develops. Furthermore the authors state that Li-ion batteries within the automotive industry are not recycled even though recycling is believed to reduce the energy requirements and emissions from battery production. From further studies, some initial programs for battery re-use in homes and industry are starting to appear, though not yet on a massive scale.

A report from DOE (U.S. Department of Energy) states that the price for Li-ion batteries dropped to 500 $/kWh in 2012 from 1000 $/kWh in 2008 (Canis, 2013). Furthermore DOE seeks to reduce the cost even more; 300 $/kWh in 2014 and 125 $/kWh in 2022. Economies of scale would probably force prices of Li-ion batteries down if the production would increase considerably. The potential market of advanced battery production as well as the technology is uncertain since this is a relatively new industry.

2.4.5 Vehicle components and configurations

Not only do electric vehicles require battery packs and chargers, in addition they require other essential components (Tidblad Lundmark et al., 2014). An *electric machine* is needed which works as a traction motor and also a generator. DC/DC- or DC/AC converters, also known as *propulsion power converters*, that operate both in inverting and rectifying mode. The *DC/DC converter* on its own is connected to a battery of 12 V and there is a possibility to replace the alternator in a conventional car with this. It has an output of 12 V that is used for equipment such as heating, lights, GPS etc. Monitoring of the battery and breaking high currents is done by *safety equipment*. Between the battery and power electronics, as well as between power electronics and the electric machine, *high voltage DC cables* are needed which might have a total weight up to 10 kg. In order to keep both batteries and passenger compartment cool an *electric cooling compressor* is needed. Simultaneously, several components of ICE are removed as well. A big question that remained unanswered so far is which vehicle In the end is more complex has more parts and needs less maintenance? Is an electric engine heavier than ICE or not? There is also the weight of the fuel+tank+lines to consider in the ICE vehicles.

2.4.6 Vehicle price

Another important aspect when investigating the feasibility of ERS is the vehicle price. This is believed to affect the haulage contractor companies when ERS are implemented since both the purchase price and the total cost of ownership affects their business case and willingness to enter the ERS market.

As mentioned before, a fully electric vehicle is more expensive than a battery electric vehicle but the batteries are expensive as well. One question discussed in some reports is whether it is cost efficient to

[73] Interview with Vehicle manufacturer A.
[74] Interview with Vehicle manufacturer A.

convert an ICE into a truck with electric drivetrain, which is discussed in next section, or if it is better to invest in new electric trucks.

2.4.6.1 Price of a new EV

As for today, there are not yet competitive market prices for hybrid trucks since the hybrid trucks have not been implemented in a large scale (Andersson & Edfeldt, 2013). Neither have battery electric trucks nor fully electric trucks been implemented in a large scale. This means that the cost for a hybrid vehicle today is higher than for a conventional truck. Mainly this is because a hybrid truck has additional components and complex software functions. Furthermore, this yields that hybrid trucks cannot benefit from the same economies of scale as conventional trucks do. The price of a new hybrid truck is around 1 000 000 SEK[75]. The price of a new fully electric truck is not yet official and vehicle manufacturers are still uncertain about the future market price. It is totally unsure whether the price will be lower or higher than a hybrid. Additional uncertainty comes from the potential incentives that governments might place on introducing this new technology.

2.4.6.2 Conversion from ICE to EV

In the discussion of the potential of converting ICEs to hybrid electric trucks or fully electric trucks there are different opinions. Long haulage trucks run approximately 300 000 km per year which means that in three years they are close to have run 1 000 000 km [76](Trafa, 2012). After this they are usually sold to fill another purpose. The reason for this is because it is risky for haulage companies to have “old” trucks in case of a vehicle failure. This means that every three years the truck fleet for long haulage purposes is more or less changed and thus it would not be cost efficient to transform trucks.

In order to fully transform a truck, all the electrical components should be added [77]. The cost of a large battery can be excluded in case that the truck is fully electric, i.e. running only on electrified roads. In that case only a small battery is needed for the electric motor feeding. Another extra component for trucks running on inductive roads is the shielding needed for the protection against EMF. However if a truck is manufactured from the beginning as electric, it is stated that the cost will be much lower.

However, new solutions enter the market such as the one suggested by e-Traction. One simplified solution of converting an ICE vehicle into a hybrid vehicle is proposed by e-Traction[78]. Only by replacing two of the truck wheels into the e-Traction wheels the vehicle is being converted into a hybrid vehicle. According to the official website of the product, the E-tractions wheels are designed for trucks and buses (e-Traction, 2013). Their technology called “Wheel-in-wheel direct-drive motors”, see **Figure 7**, provides the vehicle with overall efficiency, integrated power electronics, fluid cooling and braking system through the rear-axle frame.

[75] Interview with Vehicle manufacturer A.
[76] Interview with Vehicle manufacturer A.
[77] Interview with Vehicle manufacturer B.
[78] Interview with Technology provider.

Figure 7, The concept of e-Traction wheels (e-Traction, 2013).

2.5 Infrastructure

ERS poses some infrastructural changes since it is a new concept with a new type of infrastructure. Here there are some differences between the technologies since the conductive have visual infrastructure while the inductive infrastructure is embedded in the road. The electricity grid will be similar and the road pavement it considered to more or less remain the same despite some changes. The material needed for the inductive roads is stated to be around 20 - 25 % more and with a 50 % higher complexity compared to the conductive solutions[79]. One example of the complexity is that both the inductive and the conductive systems will need some kind of intelligence or switching devices while the inductive will also need additional materials such as power electronics to create the magnetic field.

2.5.1 Robustness and reliability

The ERS infrastructure should be both robust and reliable to assure road users a safe and stable journey. There is a need for a bidirectional system between the grid and the vehicle that will exchange both data and energy (European roadmap, 2012). The reliability of the ERS is also depending on the constant and uninterrupted energy supply from the electricity grid[80]. This is an essential aspect from the beginning (European Roadmap, 2012). It seems that the possibility of a black-out should not be an issue as it is not currently a problem for the railway[81]. Furthermore it is stated by the Swedish Energy association that Swedish electricity customers are without electricity on average only 1 hour and 45 minutes per year (Svensk Energi, 2012a).

The Swedish electricity production is considered to be CO_2-free to 97 % and the delivery reliability of the Swedish electricity grid is according to the Swedish Energy association 99,98 % (Svensk Energi, 2012a). There are three stated arguments in the report by Andersson & Edfeldt (2013) why ERS are expected to have a high operational delivery security as well. First, Sweden is both an importer and exporter of electricity with a high installed production capacity and with an over-capacity in the grids. Second, since ERS will be sectioned - a section that fails doesn't have to cause a total failure of the grid. The third argument is related to the fact

[79] Interview with Vehicle manufacturer B.
[80] Interview with Vehicle manufacturer B.
[81] Interview with Vehicle manufacturer B.

that hybrid trucks will have the possibility to run on battery or diesel if there is a failure in the electricity grid. The latter is not valid in case of fully electric trucks and it becomes a more vulnerable system.

In order for roads to be electrified, it is also essential that the electricity grid along the road can be connected to the rest of the electric network (Andersson & Edfeldt, 2013). In Sweden there is a national, regional and local grid. The national grid has a voltage power of 400 kV while the regional grid has a voltage power of 20-130 kV. The voltage is lowered step by step from production and out to the network until it reaches 230 V, which is the normal voltage in Swedish households. An electric highway is suggested by Elforsk to be connected to grids of 12 or 24 kV, i.e. local or regional grids.

As another example, the effectiveness of the ERS should not be affected by different weather conditions such as rain or snow (FABRIC, 2013). Furthermore the weather conditions should not affect the safety of humans and animals in the sense of a possible electric shock. That means that the entire system should be completely waterproof. The technology providers state that the rough weather will not be an obstacle for the operation of the ERS [82]. In case of accidents or failure of some of the rectifiers this should be handled without the system losing its reliability. Even though ERS have more electronic components than a regular road, it should still be as safe as other systems in society[83].

2.5.1.1 ICT and ITS solutions

The privacy and security of ICT and ITS solutions connected to ERS are additional very important aspects. Customers' data should be fully secured and there should be no possibility for exposure of personal data. In addition, ICT and ITS solutions are believed to become important parts of the electric vehicles, especially for the fully electric vehicles. *Information Communication Technology, ICT*, can become a big contribution to the solution of the range anxiety of the users and cost of ownership (European roadmap, 2012). It will also enable weight reductions and furthermore complement the advances in battery performance (European roadmap, 2012)(DG Connect, 2012). Technology such as driver assistant systems will provide efficient, comfortable and safe driving, while ICT solutions provide prediction and connectivity. *Intelligent Technology Systems, ITS,* allows infrastructure, vehicles and users to become integrated with ICT (ERTICO, 2010). Some examples of what ITS can do are; keep safe distances between vehicles, detect obstacles on the road before they are visible, inform drivers when it is time to take a break and provide haulage companies with optimized route suggestions.

The implementation, refinement and development of ICT devices and ITS services connected to ERS are crucial factors, which require a completely revised ICT reference architecture, see **Figure 8**.

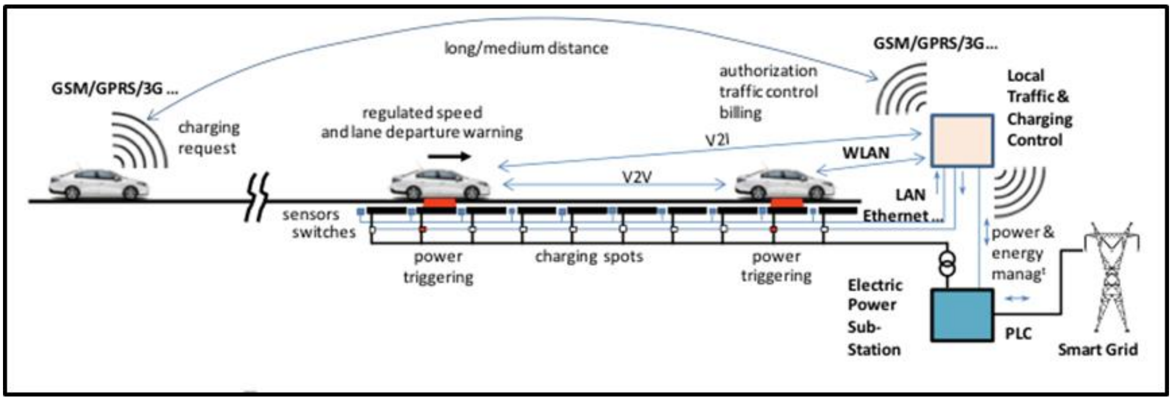

Figure 8, Schematic principle of ICT connected to ERS (FABRIC, 2013).

82 Interview with Technology provider.
83 Interview with researcher B.

Within the ERS industry there are many stated participants willing to develop and improve payment systems[84]. With ICT and ITS solutions it will become possible for every vehicle to be charged wirelessly for the energy used or time spent on the road. Specific details about how the charges should be done are still uncertain. As one example it is suggested for the conductive charging with rail in the road that identification of the truck is required every 50 m. After identification, the truck will be provided with electricity the upcoming 50 m and charging time or energy used will be monitored. This is afterwards summed up and an invoice is sent to the road user. In case that the approaching truck's battery is fully charged, it can use the electricity for propulsion instead. It is also possible to "take" energy needed for both propulsion and charging of the battery from the rail in the road if needed.

2.5.1.2 Maintenance

Another factor that is important for robust and reliable ERS is the maintenance. One suggestion is that the entire procedure of maintenance should be documented in order for all features of conducted work to be available (FABRIC, 2014). Examples of work features are the dates of maintenance, the equipment condition and all the actions held during the maintenance. Extremely significant factor is also the interaction of the maintenance procedure with the entire technological infrastructure that already exists in or below the level that the works are held. As usual, all the safety requirements should be followed both for the employees and the future users of the road. For the technologies, which are built in the road, the maintenance question is crucial (WSP, 2013). For Sweden, or Nordic climate, these electric roads require an adapted snow clearance and are sensitive of cold climate since frozen ground might affect the built-in equipment.

During the expert interviews conducted for this deliverable it was stated that it could be problematic for any of the ERS to function properly in climates such as in northern Sweden. As one example, the air gap between road and vehicle in the inductive solution would be too big due to a thick layer of ice and snow, and therefore there could be need for extra maintenance[85]. It is also possible that some additional repairing will be needed for the cables embedded in the ground if the system is not sealed properly since salt from winter maintenance then could damage the cables. For the conductive solution with rail in the road there could be a need for an extra ploughing machine cleaning the track during wintertime. However, this is furthermore stated not to be the case on-roads with dense traffic since every vehicle will clean the track by using it[86]. Maintenance of the conductive solution with overhead lines is considered to be similar to a regular road pavement wise. However it is stated that the overhead lines could require quite a lot of maintenance due to wear and tear from the pantograph[87].

For southern climates, the maintenance procedure for the inductive road seems to be slightly easier since it would not differ a lot from the maintenance of regular roads[88]. One problem that seems to be common to both inductive roads and conductive roads with rail in the road is the change of asphalt. This should be conducted without affecting the inductive charging equipment or the rail. Another issue valid for all technologies is leakage of water into the road body as it is currently difficult to manage for regular roads[89]. Nevertheless, the maintenance investment is a very important factor for robust and reliable ERS.

[84] Interview with Technology provider.
[85] Interview with Vehicle manufacturer B.
[86] Interview with Technology provider.
[87] Interview with Vehicle manufacturer A.
[88] Interview with Vehicle manufacturer B.
[89] Interview with Energy authority.

2.5.2 Infrastructure cost

For conductive power transfer with overhead lines the cost of building infrastructure has been estimated by Grontmij to 10 million SEK per double directed kilometer, while Siemens have estimated the cost to 20 million SEK (WSP, 2013). The estimation by the Swedish transport administration (Trafikverket) is 12 ± 6 million SEK where demo facilities are in the upper span and the coherent longer road network is expected to be lower. For conductive power transfer with rail in the road, Elways has estimated the cost to 5 million SEK per double directed kilometer.

The “Primove” inductive solution has a cost estimation for two charging coverage alternatives being proposed (Viktoria, 2013). For the full inductive charging alternative, the cost results in 56 million SEK/km for both back and forth together, while for the opportunity charging (fewer charging spots, but at strategic places) it is estimated to 70 million SEK/km double directed per stretch electrified. The question then becomes how much of the stretch needs to be electrified, and this will require careful road profile analysis. In a case of large scale implementation of the inductive charging the costs are believed be lowered to approximately 30 million SEK/km and 36 million SEK/km respectively.

These figures result in a quite large cost span. However it is concluded that the potential of transferring heavy vehicles to electric operation is quite insensitive to investment costs when the traffic is concentrated to the densest roads (WSP, 2013).

2.5.3 Pavement

According to the Swedish transport administration, the electrified roads include a risk for increased rutting in the road, which furthermore leads to an increased risk for aquaplaning and gathering of ice during winter time (Trafikverket, 2012a). However the industry experts state that it is probably not the case since trucks are always driving more or less at the same position of the road already[90]. In other words, trucks drive on the same lane even at regular roads and as a result the problem will not be bigger than it is today. However, rutting is a factor believed to affect the road safety due to earlier mentioned risks and thus it should be taken into consideration (WSP, 2013). From the analysis in FABRIC WP4.5, however, it is already known that the non-uniform composition of the road body with inductive and conductive solutions in the road construction make the road much more sensitive for damage.

The problem of rutting exists today and what is often debated in media is the use of spike tires and their contribution to the increased rutting (VLT, 2014). One example is the national road 66 between Västerås and Surahammar in Sweden. This road was repaved five years ago and now it suffers from deep rutting even though this type of road is supposed to last for 10 years. In the article it is furthermore stated by the Swedish transport administration that the reason for the early need of repaving is the decreased quality demands on the stone material. What is interesting in this context is that trucks mainly run with winter tires, i.e. friction tires without spikes (Transportstyrelsen, 2014). In difficult winter conditions it is more common that trucks use snow chains or tire chains, but this is rarely necessary on highways or other bigger roads. Therefore it is believed that a high quality of the pavement material is more important than what type of vehicle that uses the road[91]. Further it is important that the ground work is done properly when constructing a road. If a road is heavily used by trucks, the ground work should be optimized thereafter.

The design of the pavement is an important factor for the ERS. More specifically for the inductive charging, its design efficiency is depending on the equipment embedded in the pavement. The equipment should be

[90] Interview with Vehicle manufacturer B.

[91] Interview with Infrastructure provider.

close to the surface of the road in order for the electromagnetic field produced to be sufficiently strong to power the vehicles[92]. However if the thickness of the asphalt layer is too small, e.g. 4 cm, more frequent maintenance will be needed[93]. Experts believe that this will not be accepted by the road administration that may suggest a thicker layer of 10 cm instead.

2.5.4 Geospatial land use

In order for the ERS to be considered as a sustainable solution, the spatial planning of the facilities needed should have the least possible impact on the nearby area. As a result the already existing facilities such as power stations etc. should be used where possible. For the inductive technology and the conductive technology with rail in the road interviewees state that there is no need for additional area since the existing lanes can be used[94]. However for the conductive technology with overhead lines some deforestation is needed for the equipment installation[95]. From the FABRIC test sites however, it is already known that secure cabinets with ICT and electronics need to be placed at regular intervals to connect the charging solution with the grid. The question remains how large these need to be for mature industrial solutions.

An area around the road needs to be clear where the pillars for the electric system should be installed. With deforestation it is meant that there will be an increase of total CO_2 emissions (IVL, 2010).

Around the railway a distance of 20 meters from the railway center is cleared from trees (Trafikverket, 2014f). This is an on-going project to decrease disturbances and damages on tracks and power lines due to falling trees. By doing this, accidents are prevented in a bigger extent than before and therefore it is believed that the railway can strengthen its role as an environmentally friendly transport mode. The technology of conductive power transfer through overhead lines is in this sense similar to the railway. Consequently the roads will probably need more clearance as well in addition to what is needed for the electrical installations., which might be a problem in inner cities.

2.5.5 Topography

The topography is another parameter that should be taken into consideration while installing the charging segments[96]. Assuming that heavy vehicles would be somewhat the first to use an electric road system, it seems wise to put inductive charging stations where the road goes uphill since heavy vehicles’ consumption increases rapidly uphill. Therefore the charging segments should be located close to these parts in the same area where other related vehicle services or where the main roads intersect if possible.

A factor that makes it more difficult for an electric truck to go uphill is that the motor is heating up[97]. In case of a long distance uphill it may be necessary for a hybrid vehicle to switch to the ICE. This is believed to be the case even if the road is electrified uphill unless a very good cooling system for the electric motor becomes available on the market. However this will probably be both heavy and costly. Downhill parts of the road do not need to be equipped with charging segments since the vehicle does not use energy when running downhill[98]. In downhill conditions it is possible to use the regenerative braking technology to

[92] Interview with Vehicle manufacturer B.
[93] Interview with Infrastructure provider.
[94] Interview with Energy authority.
[95] Interview with Vehicle manufacturer A.
[96] Interview with Vehicle manufacturer B.
[97] Interview with Energy authority.
[98] Interview with Vehicle manufacturer B.

recharge the battery. However the uphill - downhill barrier should be possible to overcome since the ERS concept seems to work in a hilly country like Norway, however for electric passenger vehicles[99].

Figure 9 shows en example of uphill-downhill situation in relation with the battery state of charge. The particular example is for the distance between Stockholm and Gothenburg in a study made by Viktoria (2013) where the vehicle is running and battery is charging through the "Primove" technology. The first graph is showing the topography, altitude, of the route, the second shows the battery state of charge (SoC), which never goes below 40 %, and the third shows the power output of the Primove technology in relation to the other two.

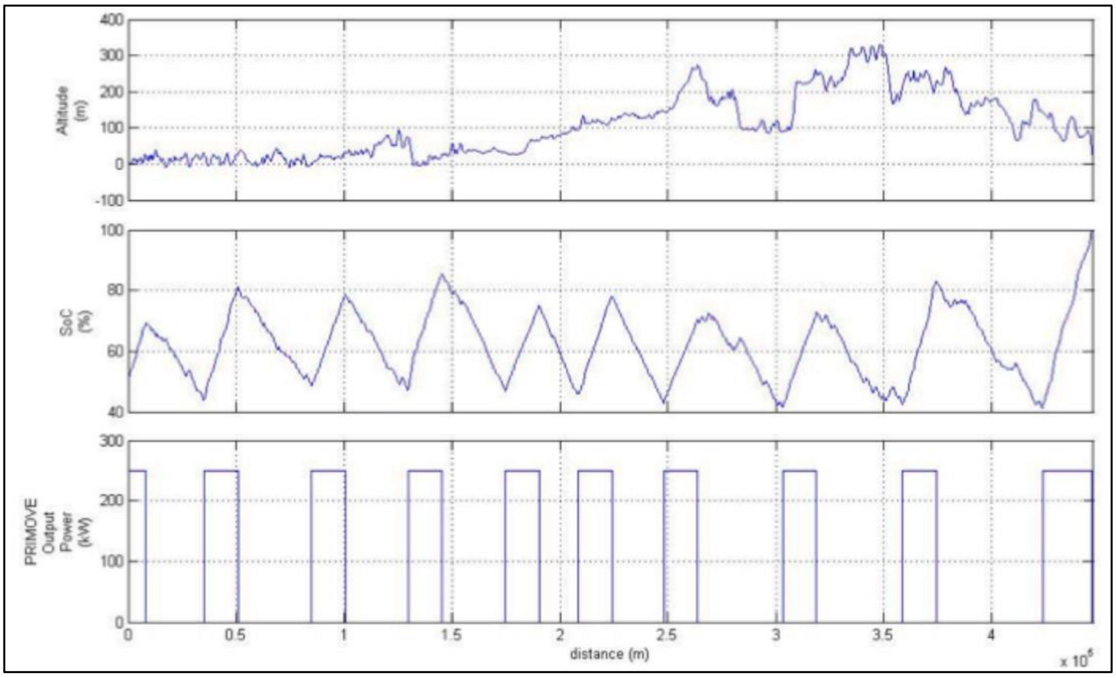

Figure 9, Battery State of charge Stockholm to Gothenburg (Viktoria, 2013).

2.6 Other factors

There are some aspects that are believed to result from an implementation of ERS due to material used and the new technologies. However, these are not believed to determine the feasibility of ERS and therefore they are only touched upon and not further investigated in this deliverable.

2.6.1 Development time

Today there are test facilities for all three technologies, however not on public roads (WSP, 2013). It is believed that a test facility on a public road could be reality in Sweden within the next 5 years, and what limits the development is not the technology itself but regulations, licensing, soil testing, political decisions and financing. If the demo has a good outcome, a commercialization might become reality 3-5 years after that. All involved participants agree that test facilities serve many purposes, e.g. clarify the level of maturity of the different technologies, show that the concept is user friendly and that it solves a transport need, help decide which types of vehicles to include, clarify costs, help to increase public acceptance and to bring

[99] Marianne Mølmen, Agency for Urban Environment, Oslo Norway. Clean Fleet Workshop – Expanding charging infrastructure and procuring electric vehicles, May 21-22 Stockholm, Sweden. (Personal notes)

forward all unsolved questions. The result in the UK by the study done by the Highway Agency (2015) points into the same direction.

In the study conducted by WSP (2013) there is a disagreement among the participants whether the operation of electric roads will have started already by 2020 or if it's only a specific test projects that will be operated. It might also be the case that only the demonstration projects have been evaluated. Some participants believe that a national implementation plan could be adopted by 2020 while some others believe that there will still be ongoing planning regarding an extensive expansion.

The industry point of view through the interviews conducted by WSP (2013) showed that the development time for a fully electric vehicle would be 15-20 years, while as a first implementation the technology of the hybrid vehicle is being recommended[100]. It is further believed by experts interviewed for this deliverable that haulage companies will not take the risk to put a pure electric vehicle on the road and risk their production[101]. In the near future it is believed that it will be hybrid trucks that are equipped with extra components such as pantograph. The major idea of ERS is to finally get rid, or at least significantly reduce the size of the batteries, even though the FABRIC project focuses on just the latter.

2.6.2 Payment system

The idea of ERS is to make the transport system more efficient and therefore it is believed that a proportional payment system is necessary, e.g. in proportion to travelling distance or used energy (kWh)[102][103]. In a long-term perspective it is further believed that there will be a completely wireless system, similar to the one for congestion charging[104]. In that type of system it is possible to have a section system where the vehicle communicates with a device in the road demanding energy supply. The question about future stakeholder taking care of this is a business case not yet established. It is believed that in the beginning of ERS there will be many payment service providers in order to test many options, but as it becomes a national issue it might be a case for the Swedish Transport Agency today controlling the congestion charging.

One possible payment solution discussed is applied in London and consists of an annual fee (TFL, 2014). This could be possible in the start-up phase of ERS but it is believed that as electric traffic increases, this kind of payment system could be seen as motivation to even more increased traffic[105]. Consequently, it is probably not going to be approved by the government. People using energy efficient transports should have an advantage and therefore there is a need for a smart and fully automatic payment system[106].

2.6.3 Supply of metals

A large source of uncertainty is related to the availability of reliable and diversified supply of metals, e.g. copper and permanent magnets (European Commission, 2008). As the demand for electric cars rise it is possible for a shortage of construction materials to occur and therefore the access to needed materials is important to be fair and open for the different industries (European Commission, 2010).

[100] Interview with Vehicle manufacturer B.
[101] Interview with Vehicle manufacturer A.
[102] Interview with Energy authority.
[103] Interview with Vehicle manufacturer A.
[104] Interview with Energy authority.
[105] Interview with Energy authority.
[106] Interview with Energy Supplier.

2.6.4 Noise

There is a need to study exterior noise at different speeds for electric vehicles. One example is the effects on-road safety caused by low noise levels, which has rarely been studied so far and need to be further investigated (European roadmap, 2012). Low noise levels can cause effects on road safety, since people are used to hear the sound of the conventional combustion engine (European Commission, 2008).

2.7 Stakeholders

The implementation of ERS on public roads will be a reality only if all the actors that are involved with contradictory interests agree and cooperate to find the optimum solution. This does not mean that only one technology has to be chosen but that there is a need for a consensus how to implement ERS generally. How the different participants are imagining the future is a central question within the development of electric roads since the cooperation is needed in order for the domain to progress (WSP, 2013). Furthermore it is believed that the cooperation has to become more intense and more concerted. Demo project consortiums and the government looking to control measures will play important roles for the future ERS.

A study made by WSP (2013) has investigated the conditions for cooperation between the different participants, incentives, blockers and attitudes towards electrified roads, but also what role the government should play to support the cooperation. The companies have contributed in this study by sharing their beliefs about the electric road systems in the future. Some of the companies and institutes contributing to this development are AB Volvo, Scania, Volvo Cars, BAE-Hägglunds, ABB, Ericsson, Vattenfall, Göteborg Energi, Eon, Fortum, ICT Viktoria, Chalmers, KTH and LTU.

Andersson & Edfeldt (2013) also investigated stakeholders involved in ERS and there are many different presented. To mention some of them, there are haulage contractor companies, the vehicle industry, the environment and society, political stakeholders, potential investors and the electric road companies, see **Error! Reference source not found.**. It is also stated that the government has to provide long-term incentives in order for the stakeholders to be willing to invest in the electric road system.

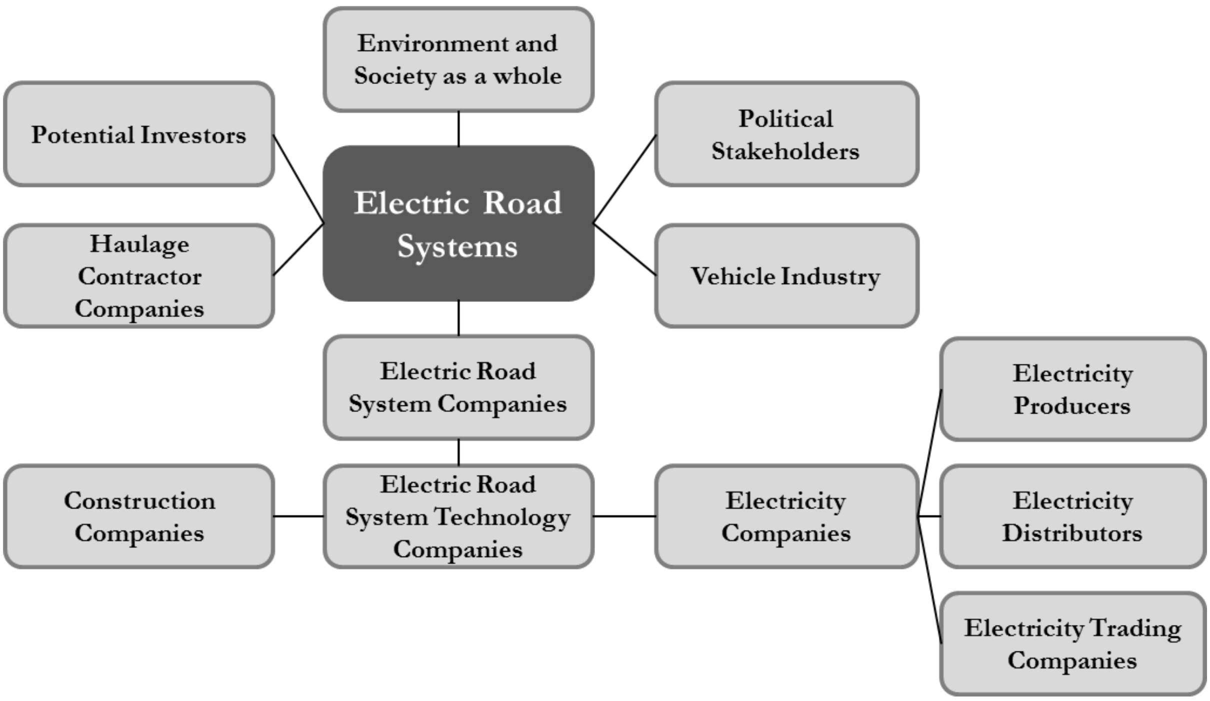

Figure 10: Electric Road System stakeholders (Andersson & Edfeldt, 2013).

As it is today, the main cost for long-distance trucks is the diesel consumed (Andersson & Edfeldt, 2013). Since the first users of ERS are believed to be the haulage companies and since the diesel today constitutes almost 30 % of the total costs, an ERS would decrease energy costs. This is considered to be one of the most important benefits of ERS. Another benefit is that it is believed that the vehicle lifetime will be longer with fewer maintenance cycles. On the other hand, drawbacks could be that the haulage contractor companies have to adapt to a completely new system and that the vehicle price will be higher. It is therefore crucial for these companies that the ERS is guaranteed to be developed and functional in the future, both because of the ability to use the system and the ability of a good second-hand market for the vehicles. The government is believed to be required to do a lot of upfront investments in order for haulage companies to start changing their fleets[107].

For the vehicle industry today, the internal combustion engine (ICE) is what is giving them a competitive advantage (Andersson & Edfeldt, 2013). This component is included even in the hybrid vehicles. It is stated that if the ERS is introduced, the vehicle industry might go through a paradigm shift, which furthermore could lead to that some companies are left behind while some companies can experience first-mover advantages.

Belonging to the electric road system companies would be energy, construction and the ERS technology companies (Andersson & Edfeldt, 2013). ERS are believed to create a new market for these companies, in which those normally not involved in the truck industry could now be involved. A possible allocation of work could be; construction companies could build the infrastructure needed for the ERS, electricity distribution companies could build additional power grid needed, energy companies could take care of the increased demand of electricity, and the ERS companies are those providing the different technologies (Alstom, Bombardier, Elways and Siemens). The latter would for sure experience benefits if ERS were introduced. The risk for this group of stakeholders is that the introduction of ERS is not guaranteed.

Furthermore it is stated in the report by Andersson & Edfeldt (2013) that the decision-makers regarding ERS will be the political stakeholders since these are deciding whether to implement the ERS or not. Even though it is stated that an ERS might lead to decreased energy usage, cost and CO_2 emissions, they highlight that the investment cost is high. Infrastructure investment, research funds, financial support and economic incentives, are included in the investment cost. The current situation is that the uncertainties of ERS are still many but that the politicians want to learn more. The main question is; who will pay? One alternative is that the government pays the investment cost, and then they may or may not charge the users and thereby get paid back. The other alternative is a PPP solution (private public partnership), where an external investment company is paying the initial investment and then charges the users. This arrangement is common in other European countries and is considered to be a low risk and low interest rate affair.

Regarding the environment and the society, Andersson & Edfeldt (2013) state that it seems reasonable that an ERS would be beneficial in a long-term perspective. Despite high investment cost, it is stated that the energy usage will decrease as well as energy costs and CO_2 emissions. However, it means also a decreased income of diesel taxes, but a possibility of increased income from electricity taxes.

2.7.1 Industry point of view

In an assessment by WSP (2013) there are positive aspects from electrified roads such as industrial policies, aspects of economic policy, transport policy considerations and environmental benefits. Here the sustainable

[107] Interview with Energy authority.

motives are clear and it should make electrified roads interesting. Difficulties and drawbacks could be the needs of investment, fear of intrusion effects and accident risks, or the institutional cooperation on a national and international level.

With a certain generalization, it could be said that type of goods together with the need of flexibility and cost, decide what type of transport should be used (WSP, 2013). The truck is considered to be more flexible than both rail and sea transport, so when there is a demand for fast and flexible transport neither rail or sea transport is an option. If then the truck transports become too expensive or resource intensive the solution must be to find another production- or distribution organization. For longer distances and for low value or heavy goods, the rail and sea become alternatives to the truck. A distance shorter than 400 – 700 km is usually said to be the limit within the truck is more beneficial than rail or sea transport. The multi-modal solution is not necessarily more sustainable than pure road transport since only the lifting on and off the train can correspond to an environmental impact of 10-15 km driven by a truck on-road. As a result one benefit of the electric roads for the distribution procedure is that there is no need for extra distribution trucks from the railway to the warehouses, since after the loading and the unloading the truck can directly go to the highway[108].

Furthermore stated in the report by WSP (2013) is the importance that all modes of transport have their role to play and if one alternative disappears, it is more likely that logistics flow will be reorganized rather than changing mode of transport. If today's production- and distribution organization, which is connected to the societal structure, is to be maintained, the choice is thus not to move goods between modes of transport but to make all transport modes sustainable. However it could still be interesting to highlight the possibilities of moving goods between the modes of transport to decrease the CO_2 dependency. Since both air and sea transport is heavily burdened by CO_2 emissions, the only option is for goods to be moved from truck to rail transport.

In the same study made twenty key stakeholders participated to discuss risks that can be identified in the ERS for heavy vehicles above 3,5 tons (WSP, 2013). Those risks where categorized through a SWOT-analysis in sense of different Strengths, Weaknesses, Opportunities and Threats in the project. **Error! Reference source not found.** shows the summary of the identified factors. The SWOT analysis is supposed to be a tool for future works in Sweden when developing an action plan for ERS.

Table 20: Results from SWOT analysis, translated from WSP (2013).

Strengths	**Weaknesses**
- Many want this, attuned stakeholders - Cost efficient and energy efficient transports - Technology experts within the transport sector - Follows transport policy goals - Secure energy supply (domestic) - We have an opened mind in Sweden – we don't get stuck - Quickly implementable, substantial benefits - Good energy mix in Sweden, lower direct CO2 emissions	- Technology development remains - Heavier and more expensive vehicles - Lack of knowledge about technology and maintenance of roads and systems - Sensitive and vulnerable infrastructure - Expensive infrastructure (compared to 0) - Not thinking enough in a long term, sub optimizing (passenger cars? – might lose business case) - We haven't chosen a technology

108 Interview with Vehicle manufacturer B.

- We don't have any oil industry - Relatively cheap, using existing infrastructure (compared to railways) - Far ahead in the development	- We fail to utilize the whole concept, we lack knowledge
Opportunities	**Threats**
- Could take a leading role in the work of standardization - Possibility of "Bonus Malus - truck" (tax-switching policies) - At the European level the cities have started – want to have a better environment - Demo is requested – basic industry enables - Competing technologies delivers sharp solutions - Business to do!	- Sweden may become marginalizing (small country) - Europe could slow down – slower transition, don't see the same possibilities, another electricity mix and agenda - Threatening existing political perceptions and business models - Goes against the existing mantra - Long term profits, the risk is now (needs a push from the public) - Hydrogen might become a competitor - Different standards may be developed - Other potential energy sources

The twenty stakeholders agreed that some of the strengths for ERS in the Swedish market are that many companies are interested, ERS would follow the transport policy goals, Sweden has a stable domestic energy supply and that one advantage is that existing infrastructure can be used. There are also opportunities for stakeholders in a future ERS such as the possibility for Sweden to take a leading role, possibility for the Swedish basic industry to contribute in demo projects and that there of course is business cases ahead. Some of the identified weaknesses of ERS are that the vehicles are believed to become heavier and more expensive and that developments of the technologies remain. The threatening factors identified are that Sweden may become marginalizing since it is a small country, Europe could slow down due to slower transition, different electricity mix etc., and that standards and different energy sources may be developed.

One issue that participants disagree on is whether to include passenger cars in the first implementation or not (WSP, 2013). Some believe that there is a big potential for passenger cars why they should be dealt with in the beginning, while some other believe that it is the heavy vehicles that lacks solution why focus should be put on them.

2.7.2 Government

Before future ERS can become widely implemented it is believed that the government will play an important role in infrastructure investment, incentives and decision-making. It is stated that the government will have

to invest a lot of money upfront to make future users believe in the system[109]. It is probably necessary to electrify before haulage contractors and others will invest in ERS.

In a report by European Commission (2008) it is stated that the existing government green policy should be taken into consideration in each step of each project. In order to achieve energy efficiency improvements, CO_2 emissions reduction, reliable logistics and mobility, there are three "pillars" representing key areas, namely; electrification of road transport, long distance transport, logistics and co-modality. The climate awareness, the CO_2 policy and the aims of a CO_2-free vehicle fleet make the electric roads interesting as a solution (WSP, 2013). It will most likely also affect the supply and demand of freight transport and also the basics for today's freight transport prognoses. One question highlighted is how the freight transport market could react on new transport-, energy- and climate policies.

According to WSP (2013) there are different kinds of policies within the transport sector which are usually divided into information, regulations, administrative and economic instruments. In order to achieve system changes it is the administrative and economic instruments that are the most efficient, where the first concerns regulations of vehicle and infrastructure design and the latter concerns investments, subsidies, taxes and fees. Generally today's policies will probably need adjustments if electrified roads are to become a part of the regular infrastructure planning process. This planning process has today an orbital of 12 years and since electrified roads are not a part of the regular planning process there will probably a few more years. However this may change if the government decides upon new planning processes.

2.7.3 Commercialization of ERS

As mentioned earlier some of the biggest blockers for development of ERS concerns legal issues, policy decisions and courage to invest in new technology. Another blocker is if a demonstration facility does not come about or if it ends up with negative results. One issue that is especially highlighted is the one concerning public acceptance. It is believed, generally, that the acceptance could be difficult to achieve. The main drivers however, concern environmental benefits, independency of fossil fuels and business opportunities for the industry. This means that there could be large benefits for the society.

According to WSP (2013) there is not yet a set business model for the electrified roads, but it will be developed during time. Many of the participants in Sweden believe that electric roads are to be seen as any other infrastructure system and that users will pay for usage and electricity. It must be profitable for users to invest in new technology and important factors from a user's perspective is the flexibility, the load capacity, the second hand value, customer demands and long term conditions regarding costs and taxes.

In order for ERS to commercially succeed, the price of the vehicle should not be higher than 25-30% of the conventional car according to European Commission (2008). If that is to be the case, the prediction of future demand of electric vehicles is 500 000 EVs/year for the EU. One factor that could lead to a higher EV price is shortage of production materials. A higher price could furthermore affect future EV users in the sense of willingness to pay.

Norway seems to be ahead regarding passenger EVs and their adaptation to the transport system. The government has established various incentives for the EV users since the late 1990's (Mølmen, 2014). Those incentives will remain the same until 2017 or until the EV fleet reaches 50 000 vehicles. Regarding vehicle prices, the incentives established are that the ICE vehicles have 25 % extra taxes while the EVs have no taxes or fees. More specifically, an extreme example of ICE vehicle price is the Chevrolet Camaro which with high taxes in Norway is 174 500 Euros while in Sweden with lower taxes it is 47 100 Euros. In the case of an EV

[109] Interview with Energy authority.

such as Tesla Model S, the price in Norway is 63 000 Euros while in Sweden it is 80 000 Euros. In addition to reduced EV price, the EV owner in Norway is having free access on-roads with tolls, free parking, allowance to drive on bus and taxi lanes and free transport on ferries (Mølmen, 2014). The local and national infrastructure project for EVs from 2008 provide the users with 4 000 normal and 80 fast charging stations. All incentives mentioned seem to make EV a good choice compared to ICE, which should motivate and encourage people to buy EVs. It also seems like a good way to reach public acceptance.

Another aspect believed to influence the public acceptance is the future energy price. It is stated in the report by WSP (2013) that neither diesel price nor electricity price is believed to change dramatically considering both short and long term. However, this is consumer market prices which do not include future taxes and fees and could be subject to change due to future political decisions. Furthermore, the energy shift as currently on-going in the European Energy sector, and the recently reached Paris climate agreement provide major uncertainties for this future projection.

Due to the believed difficulty of gaining public acceptance it is suggested that a communication plan is developed (WSP, 2013). This communication plan should identify the message that should be brought forward, target groups and communication channels. Further it is believed that the big challenge is not to prove that ERS is harmless for the entire population, but to assure individuals about their safety[110]. People are afraid of being in close proximity to electricity such as in case of changing tires, stepping on objects with voltage or the uncertainty of being affected by electromagnetic fields. Probably the technologies do not need any changes but there is a need for detailed description of the technologies; how they work and what the possible risks are.

2.7.4 Discussion

The view on which technology to be chosen is diverse among the participants since some believe that the solution has to include passenger cars, some don't, some other believe that it is the urban public transport or an implementation along the biggest roads that will yield the biggest effects (WSP, 2013). Whether to include passenger cars or not is partially based on the potential for a decreased use of oil, which would be bigger if not only trucks were to be electrified. On the other hand, if passenger cars are included, the alternative of conductive power transfer with overhead lines is excluded due to height limitations of the power lines. The ones believing that electrified roads are for trucks state that it is the trucks that lack solutions in order to become less fossil fuel dependent which focus should be put on them. What to include and not include in the electric road system, i.e. the level of ambition, is according to the industry what will decide which technology to use.

A verified utility for the users and for the society is also needed in order to get economic support (WSP, 2013). It is also believed that European and new ISO-standards are needed even though the different countries might end up with different technical solutions because of the diverse climate. Strategic decisions concerning the development of the transport sector must be based on solid facts concerning both the transport infrastructure and the traffic on the infrastructure (Stripple & Uppenberg, 2010).

Among the actors involved it is believed that it is fully possible to implement the electric road, but the major questions concern the time period and exact technology (WSP, 2013). It is stated that it is important to not get stuck with one solution too early but to try and evaluate them all. Electric vehicles and ERS will have societal implications since they are believed to have a large impact on society and how transportation is

110 Interview with Energy Supplier.

done, i.e. how the mode of transport is chosen[111]. The latter is related to behavioural sciences, which are believed to play an important role in the ERS implementation. Whatever technology is chosen in the end, it is commonly believed that the trucks should have a hybrid drive train since this helps overcome obstacles as overpassing crossings or interruption of the electricity supply[112] [113](WSP, 2013).

So far, the cooperation between stakeholders seems highly collaborative and smooth. However, there are obvious tensions among industry participants, which were experienced during this deliverable. There was almost no willingness to share data due to confidentiality and business secrets – the stakeholders want to earn money of their solution of course. The interviewed authorities further verified this. Even if the different technology or vehicle providers cooperate in some extent, there will always be secrecies that could hide real problems or really good solutions. Our guess is that demonstration projects need to be implemented to pass the first obstacle of business secrets.

[111] Interview with Energy authority.
[112] Interview with Vehicle manufacturer B.
[113] Interview with Vehicle manufacturer A.

3 OTHER PROJECTS AND EXPERTS' PERSPECTIVE

In order to compensate the overall increase of fuel consumption and its effect on the carbon footprint, investigations of new technologies of freight transport are requested (European Commission, 2008). This is where the ERS are believed to be an important step. However, before implementation of electric roads, there is a need for demonstration projects that could verify the different technologies (WSP, 2013). For Sweden, three different goals have been formulated with different levels of ambition depending on how the electric roads are developing until 2030. Furthermore, milestones for 2015 and 2020 have also been formulated. The milestones for 2015 concerns started demonstration projects, started standardization work and that the concept of electrified roads are beginning to take shape as a commonly known concept which all political parties agree on having benefits. For 2020 the milestones concern commercial operation on electric roads, research and developed planning and regulations.

3.1 Technology providers and various projects

As described in Chapter 2, the ERS can be divided in three different types of technologies; conductive with overhead lines, conductive with rail in the road and inductive on-road charging through electromagnetic fields (EMF). It appears that the first implementation of ERS is more suitable for heavy vehicles why the ongoing demonstration projects play an important role. Further in this chapter, different technology providers are presented as well as ongoing projects. Finally the ongoing Swedish procurement projects for heavy vehicles are presented accordingly with available public information.

Table 21 Wireless Charging cases comparison

Project Name	Country	When to Implemented	Scale	Type of vehicle	Goal	Main partners
ORNL(Oak Ridge National Laboratory)	US			GEM electric truck	90-94%transfer efficiency @ 25 cm air gap; >4 kW demonstrated; 7 kW targeted in 2012	
TBD	US				90% transfer efficiency @ 15 cm; 3.6 kW; in development with prototypes deployed.	Siemens & BMW
Plugess Power	US				PEV retrofit solution. 3.3kW output; 90% transfer efficiency claimed (earlier reports indicated 70%); product launch in April 2012. $5000 projected installed price.	Evatran Partner with Yazaki,Google
Delphi Wireless Charging system	US				Sharply resonant magnetic coupling (not inductive); 3.3 kW across 20 cm air gaps; product in development – early launch in progress	Partner with startup WiTricity (MIT technology licensee). WiTricity also engaged with Toyota.
Wave project	US		In 4 cities	Bus & Trolley		University of Utah,Monterey-Salinas Transit, McAllen Metro,Antelope Valley Transit Authority,BYD

Project Name	Country	When to Implemented	Scale	Type of vehicle	Goal	Main partners
qualcommhal o	US					
Toyato	Japan			Prius Plug-In		WiTricity
KARIYA	Japan	2014,02-2014,12	Test in Toyota City,Aichi Prefecture	Yamato Transpo rt delivery truck	The electricity charged in the truck's battery is then used to power the refrigeration system while the engine is stopped during pickups and deliveries. Not only will the system improve convenience, but it will also help reduce emissions of refrigeration trucks since the battery will continue to power the refrigeration system even when the engine is off.	
OLEV	Korea	2009		Bus		
ZTE	China	2015	50 to 100 cities in China	Bus	Aggressive targets for vehicle fuel efficiency	Local transport authority
Scania	Sweden		Södertälje	Heavy vehicle		
Volvo C30 Electric	Sweden			Volvo C30	OEM wireless charging solution	Partner with Belgium's state-owned Flanders' Drive
hybrid wireless buses recharge at stops	UK	2014	London city bus route	Enviro4 00H E400 hybrid buses	The Mayor of London wants the city to be the world's first Ultra Low Emission Zone by 2020.	Transport of London
Bombardier's PRIMOVE System	Germany		Braunsch weig	Bus		Transport operator Braunschweiger Verkehrs

3.1.1 Primove by Bombardier

Bombardier is one of the technology providers of the dynamic inductive on-road charging that proposes a new technology named "Primove" (Bombardier, 2014). This technology can be adapted to different types of vehicles and it follows a specific moving and stopping charging pattern. The Slide-in project, where the Primove technology is used, investigates inductive on-road charging in terms of needed power supply, system design and cost analyses for the total electrical distribution system (Viktoria, 2013). The solution to the EVs problem is not the use of bigger batteries since this would mean that more space and weight tolerance from the vehicle would be needed. The inductive on-road charging could be a very efficient solution with a need of much smaller batteries. When the "Primove"-equipped vehicles are moving with 50 km/h or faster the charging segments are being activated. The charging technology is installed in the upper layer of the pavement in a similar way to the snow melting cables, see **Figure 11**. This project proposes to different charging alternatives, the full inductive charging alternative with 100% coverage of the road with charging segments and the opportunity charging with 35% coverage. The cost calculation has been made for two different charging alternatives. The Primove technology with a 160 - 200 kW power system has been

tested in Lommel Belgium through hybrid buses and in Augsburg Germany through a disused tramway. This is the technology and its technology specifics are serving as a basis in this deliverable.

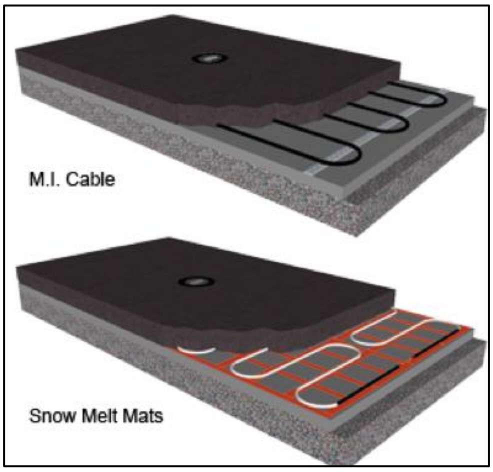

Figure 11, Cables for melting snow from roadways (Viktoria, 2013).

3.1.2 WEVC by Qualcomm

Qualcomm is a leading developer and manufacturer of Wireless Electric Vehicle Charging (WEVC) equipment, which aims to the elimination of the Plug-in technique for both EVs and Plug-in Hybrid Electric Vehicles (Qualcomm, 2013). Qualcomm implemented a “first-in-its-class” trial commercial of 50 EVs in London.

3.1.3 Conductive charging by Elways

Elways propose a new solution of conductive charging that allows travelling long distances without any need for stop and recharging of the vehicles (Elways AB, 2011). This solution can be applied to all types of vehicles and the charging is done from the pavement to the bottom side of the vehicle through flexible sliding contacts, see **Figure 12**. More specifically the arm installed below the vehicle is going back and forth while the contact of the road remains within the width of the vehicle. When the contact point goes outside the vehicle width the arm goes up. The feeding cables at the road side have medium voltage of 24-36 kV which is being transformed to some hundred volts before being transferred through contacts, switches and fast switches to the sections in the road.

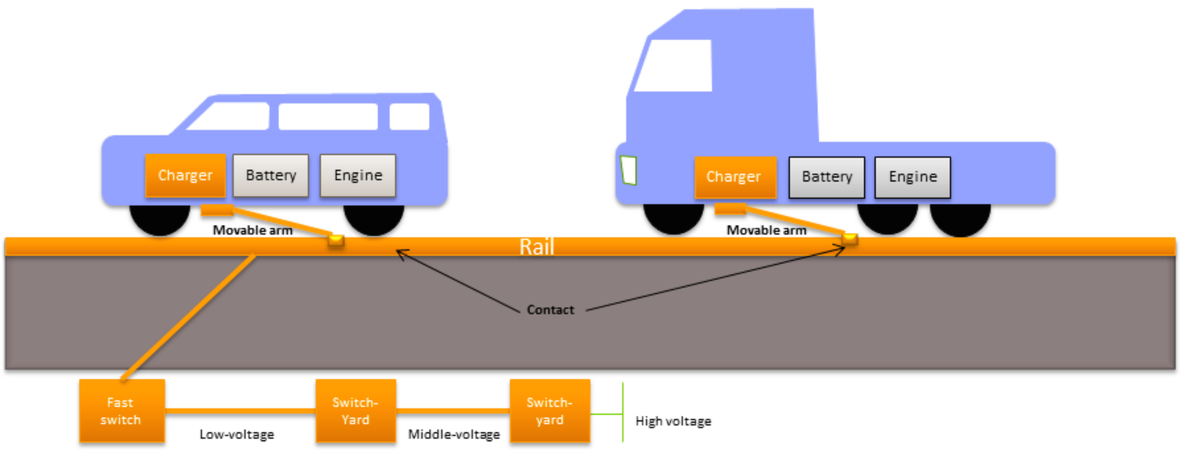

Figure 12: Elways conductive charging solution (Elways, 2011)

3.1.4 eHighway by Siemens

Siemens has developed the concept of "eHighway" which is a conductive solution with overhead lines where the trucks are equipped with intelligent pantographs (Siemens, 2014). This technology has three main components; diesel-electric hybrid technology, electricity supply through overhead lines and regenerative braking system, and intelligent flexible pantograph for energy transferring. Siemens states that the efficiency of the electric motor together with exchange of energy via overhead lines provides a very energy efficient system.

3.1.5 Conductive charging by Alstom

Alstom has together with Volvo been responsible for development of conductive charging with rail in the roads with some difference compared to the Elways' solution (Viktoria, 2013). The technology includes two power lines embedded in the upper layer of the asphalt, see **Figure 13** (Volvo Group, 2013). The truck is equipped with a current collector, which with mechanical contact enables energy transfer. Furthermore the technology allows vehicles to be continuously powered without the need of large batteries. There is a 400 m test track available outside Gothenburg. It is stated however that more research is needed to investigate factors such as current collector development, road construction and maintenance among others.

Figure 13, The conductive solution by Alstom and Volvo (Volvo Group, 2013)

3.1.6 OLEV in Korea

The on line electric vehicle (OLEV), is a technology of contactless on-road charging developed by KAIST University in Korea (Seungyoung et al., 2010). The power transfer system that is shown in **Figure 14** consists of an inverter, power lines that can be located in two different ways, a pick up module, capacitors, battery and a motor. The inverter converts 60 Hz of power to 20 kHz, and the power lines are running by a current of 200 A.

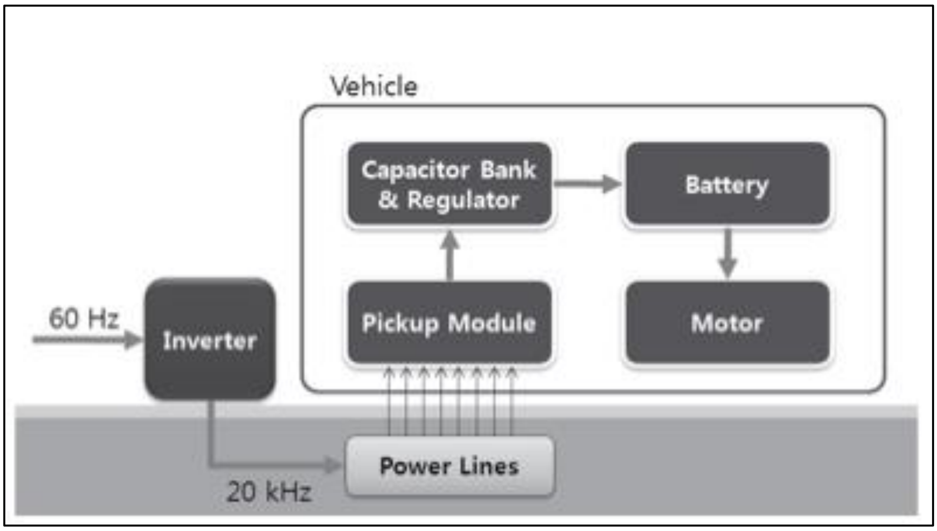

Figure 14: The overall power transfer system for OLEV. Power is transferred from the power lines to the pickup module without contact (Seungyoung et al., 2010).

The technology of OLEV with the help of the coil in the battery can transform the electromagnetic field into electricity at a distance of more than 0,15 m above the road segment, see **Figure 15** (Beker, 2013). OLEV is capable of recognizing the vehicles equipped with this technology and the ones that are not. There is no need for big batteries when the vehicle can be charged directly from the road (Dorrier, 2013). The buses that are operating under this technology between Gumi, Korea and the In-Dong district, are running on charging segments with a length of approximately 12 km that costs four million dollars to build (Dorrier, 2013 and Brown, 2013). A round trip for these buses is approximately 24 km. The power sources charging the buses are embedded in the road and have a power of 180 kW (Dorrier, 2013). The technology providers support that only 5-15 % of the existing network has to be rebuilt to adapt to the new wireless charging technology. By 2015 Gumi City is aiming of having 100 more buses running in the OLEV network (Brown, 2013).

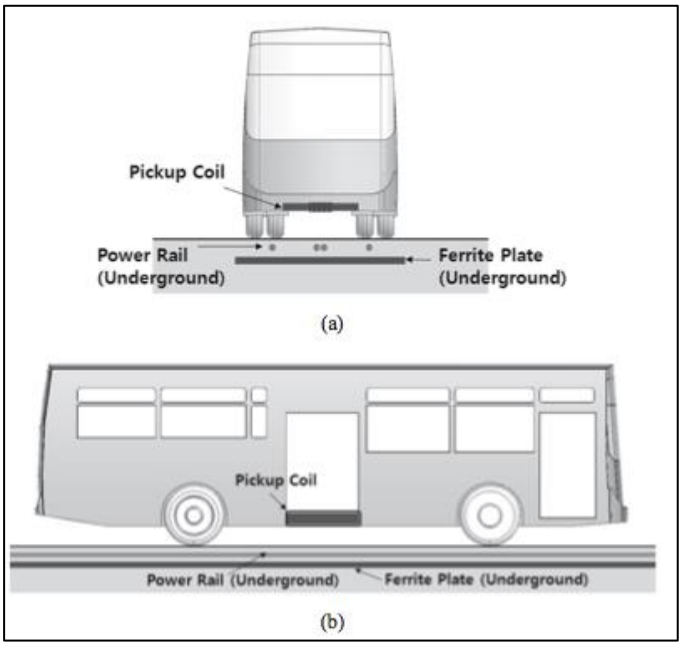

Figure 15: The OLEV power transfer system using power lines embedded in the road surface for wireless charging, (a) front view, (b) side view (Seungyoung et al., 2010).

3.1.7 Passenger EVs in Norway

One of the countries in the world with highest number of battery electric vehicles (BEV) per inhabitant is Norway (Hagman et al., 2011). There are several different strong economic policies that stimulate the market of battery electric vehicles, i.e. purchasing, importing, production and development. According to Hagman et al. (2011) the main argument for these incentives supporting BEVs is due to the high-energy efficiency of electric motors compared to conventional combustion engines. It is stated that the “tank-to-wheel” efficiency may be 85 %, which makes BEVs superior to other alternatives.

At the moment it is believed that electric vehicles should remain small and driven for limited distances (Hagman et al., 2011). In order for electric vehicles to attain a large market share it is stated that realization of increased battery capacity and minimized costs is required. As the Swedish industry, Norway believes that the fossil fuel dependency and decreased emissions of CO_2 have to be met through several measures. Their relatively large fleet of electric passenger vehicles is one part.

By installing fast-charging stations the range anxiety is believed to be overcome (Hagman et al., 2011). However, this could pose problems for the regional and the local electricity grid due to the fact that neither of them is built for high electricity tapping during short time periods. Another issue with the relation of electricity and vehicle is the batteries. As mentioned before, batteries today are heavy, expensive and the range of operation on battery remains uncertain. In 2011, it was more expensive to produce a battery for a small car than buying it put together. One example mentioned is a battery with a range of 100 km which is weighing approximately 200 kg and costs 100 000 NOK (approx. 112 000 SEK). Furthermore the authors state that regarding the batteries, the possibility of development and improvements is existing but that the cost is the main issue. The cost of the otherwise simple technology of an electric vehicle and the cheaper propulsion system highlights the issue of battery cost.

Hagman et al. (2011) estimated that all light vehicles could be powered by 7 TWh of electricity and this corresponds to approximately 5 % of the total electricity production in Norway.

Another report by Hannisdahl et al. (2013) analyzes the so-called revolution of battery electric vehicles in Norway and policy measures taken in comparison with other European countries such as Sweden. In the end of 2012 more than 9500 BEVs and 330 Plug-in Hybrid Electric Vehicles (PHEV) were driving on Norwegian roads. This can be compared with the 500 BEVs registered in Sweden June 2012. Since Norway has approximately 5 million inhabitants it is remarkable sales of BEVs, which in size can be compared to countries like Germany, France and the UK. The Norwegian incentives for battery electric vehicles are;

- Compared to most European countries, conventional ICE cars are heavily taxed since the tax is determined by weight, CO_2 emissions, NO_X emissions and motor effect. Additionally comes a VAT (value added tax) of 25 %. Both BEVs and fuel cell electric vehicles (FCEV) are freed from import tax and VAT.
- BEVs and FCEVs are allowed to drive in bus lanes and do not pay any congestion fees. They also only pay for the driver and not the car on national road ferries.
- BEVs and FCEVs have also access to free parking in public parking spaces in addition to the reserved parking spaces only for EVs.

In the conclusion, Hannisdahl et al. (2013) highlights that it is not Sweden or Germany with automotive industries that have been most engaged in electric vehicles, but Norway. It is also stated that both push and pull incentives are needed to reach success in terms of number of electric vehicles. Finally a "lesson learned" figure is presented which suggests solutions for countries how to move from market immaturity, to mass market and in the end to a mature market. This is summarized and presented in **Figure 16**;

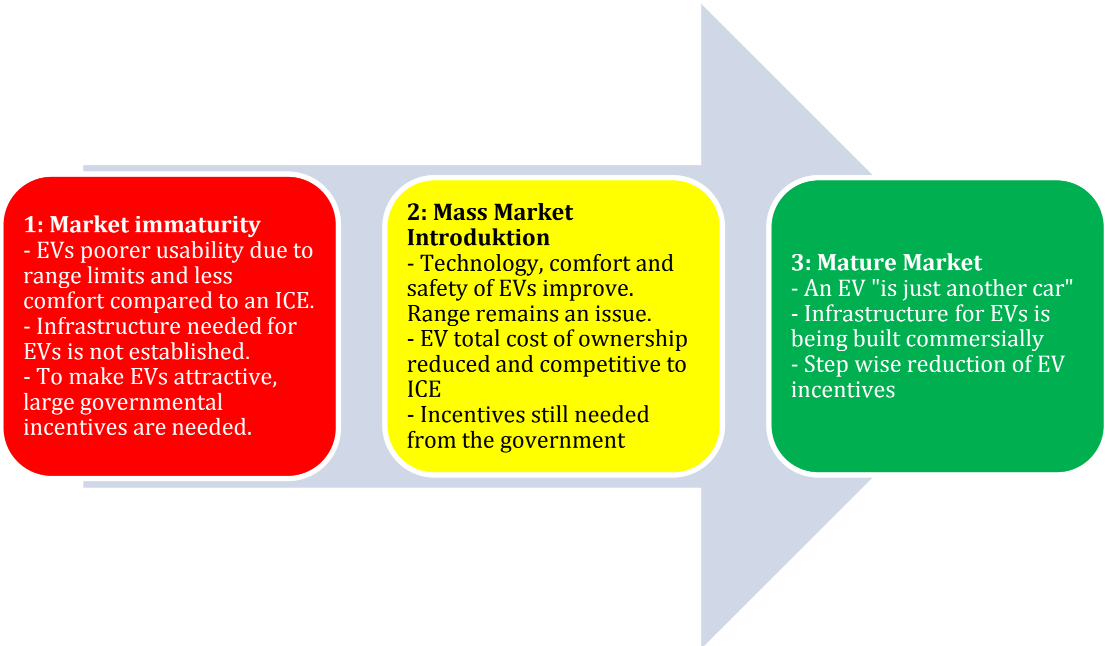

Figure 16, Summary of lessons learned from Norway (Hannisdahl et al., 2013).

As seen in Norway, there are many issues being dealt with, many of them are being brought up in this deliverable. Even though this example relates to passenger cars, it is still believed that measures taken and the approach of making EVs more attractive on the market can be seen as inspiration for other countries. Factors in **Figure 16**, such as range limits, comfort and EV infrastructure seem to very important for the public acceptance which has to be achieved in order for EVs to be chosen instead of ICEs. It is probably the case that the Swedish government has to develop several economic incentives both for passenger and freight transport to reach the goal of a fossil fuel independent vehicle fleet by 2030.

3.2 Interviews with experts

Earlier mentioned projects face some difficulties of different types depending on each technology used. Some of the difficulties might be similar for both inductive and conductive charging whereas other differ. The purpose of conducting interviews was to get a glimpse of the industry perspective of different potential blockers. The technology and vehicle providers were at the time mainly involved with conductive solutions while most of the other interviewees had knowledge about ERS as a whole. However almost all experts had knowledge about the inductive solution in some extent, hence there were interesting outcomes regarding all three technologies of ERS.

The interviews were conducted with a specific framework for all participants. First the ERS with inductive charging was discussed in general to define both our area of in-depth analysis and the whole concept of this deliverable. Also their area of research was discussed in order to find out the most suitable issues to discuss to get as much information as possible. As stated before, vehicle and technology providers, energy experts as

well as general experts within the field of ERS participated in the interviews and shared their knowledge, concerns and opinions. However, the confidentiality of specific information posed a problem and limited the outcomes in some of the interviews.

As an intermediary solution between confidentiality and results, the interviews have been anonymised.

The next step of more particular questions was adapted to each person interviewed. Those questions involved both the general framework of ERS and more specific queries for the in-depth analysis of this study. The questions asked during the interviews are shown in Appendix B. During this part, the procedure was based on the questions but not entirely ruled by them. This was due to the interviewees that in some cases wanted to derogate some from our questions and touch another subject that they believed to be more interesting or important.

The final part of the interviews consisted of the gross list of factors that are considered to be challenging to adapt to the inductive dynamic on-road charging for freight vehicles. The interviewees were asked to rank them in a qualitative scale of adapting challenge (big challenge, difficult, neutral, simple, no challenge). Factors of the general framework of ERS for inductive charging, possible deployment cases as well as factors of health, safety and environment were presented. Each interviewee put their opinion on degree of adaptation difficulty. Due to confidentiality reasons, all results from the interviewees are presented anonymously.

3.2.1 Interview questions

As explained earlier, some of the interview questions were adapted to each expert interviewed, while others remained the same for all. Various subjects were discussed which are here divided into groups of respective main topic, see **Table 22**;

Table 22: Subjects discussed during the interviews

Factors	Energy	Vehicle & Battery	EMF	General ERS aspects
Examples of subjects discussed	**E**nergy demand **C**apability of energy supply **E**lectricity taxes **N**ew electricity price **C**onversion of liters diesel to kWh **E**lectricity mix etc.	**E**nergy consumption **L**oad capacity **V**ehicles conversion **B**attery production **E**nergy for vehicle production etc.	**F**requency range **S**hielding of driver's cabin **I**mpact to the surroundings **P**acemakers **G**uidelines, reference levels etc.	**I**nvestment cost **M**aintenance **S**cale of implementation **T**ransportation of flammable materials **P**ublic acceptance **P**ayment system etc.

The detailed list of questions discussed for each topic can be found in Appendix B.

The information gathered during the interviews was essential in many stages of this study. Several information gaps could be filled despite the lack of available information for some specific ERS topics.

3.2.1.1 Analysis of the feasibility

As one of the final steps, an analysis of the feasibility is presented. Potential blockers that were defined and that formed the gross list are now reviewed in different extent. Once again, the potential blockers were approached on a system level where a few are investigated in a bigger depth such as EMF and dangerous goods. Through deployment scenarios and an EIA some of the factors were assessed in case studies. The aim of the analysis is to interpret synthesized reports for a system level deployment.

Electrified transportation seems to offer many benefits in comparison with traditional vehicles. Electric vehicles such as hybrids and battery electric vehicles are believed to have both economic and environmental benefits but are partially held back by the issues of batteries, motors and the questionable future availability of crucial materials. Therefore ERS seem to be one possible solution and one step towards a cleaner transport system due to the continuous power transfer. The scenario of ERS and fully electric vehicles only is not believed within the industry to become implemented the next few years. Instead it is argued that combinations of solutions are needed such as hybrid vehicles using electricity in combination with other fuels. Further, other main motivations for ERS are the increasing general awareness of climate protection, primary energy savings and public health. Other incentives to develop new technologies are the high fuel prices together with the stringent European emission regulations. With ERS and dynamic on-road charging there is a European potential of full freedom in mobility.

Projects such as OLEV in Korea and Primove in Germany are examples of possible implementations of ERS technologies. In addition the on-going procurement projects in Sweden show through several interested stakeholders that there is a considerable interest in developing and improving technologies as well as finding a solution for freight vehicles. There are already test tracks in Sweden where the first tests and improvements have been done for both inductive and conductive ERS. The procured demonstration projects are aimed at being built during 2015 in order to show strengths and weaknesses of the technologies under Swedish conditions. Another aim for demonstration projects is to study health and safety issues, e.g. EMF exposure, and to further prove the technologies beneficial for both users and the environment. The rough Swedish winter will also allow proving system robustness and reliability as well as evaluating the maintenance procedures. The outcomes of these projects seem crucial for future implementation on public roads in Sweden.

The main belief within the industry is that public transport and long haulage freight vehicles will benefit most from the electric roads. Decreased CO_2 emissions, improved energy efficiency and decreased oil dependency are important for the societal benefits from an environmental point of view. What is considered uncertain is whether the electrified roads will mean lower costs for the users, depending on how the electricity will be taxed. However, the electric drive itself will yield decreased costs. One benefit of ERS worth mentioning is for example that the existing system will be used and there is no need for building new roads. Compared time- and cost-wise to railways it seems a more reasonable solution with more benefits. Compared to a “do nothing” scenario it seems like a favourable choice. In case of e.g. a storm, the conductive power transfer with overhead lines seems to be the most vulnerable solution. Inductive roads have no exposed components, which is a benefit. Further it is widely believed that the great challenge with electrical roads is not their technical complecity; it is the ability for the different stakeholders to cooperate to create this system.

ERS poses in addition a political hurdle to overcome regarding health and safety aspects. There is a belief that there will be discussions about ERS in connection to railways and why all economic means are not going to improvements of railways. The aim of ERS is not to compete with railways and it should be seen as coexistence with railways since they serve different purposes. This would probably be the most favourable for both systems. As it is believed now, the cost of building a new railroad is many times higher than building

ERS. In addition, the railway system is much more vulnerable and a less flexible system in case of an incident. Hence, there is a need for a coexistence of different kinds of “green” transport modes where an accessible and safe transport system can be maintained.

The factors considered as potential blockers of the ERS are ranked through a hierarchy graph showed earlier. Their respective sub factors and their feasibility of adapting to the ERS are analysed through the traffic light logic. The red colour represents a big challenge to adapt; the green shows that the factor faces no significant challenge, while the yellow indicate uncertainty of adaptation and possible difficulties. However the level of uncertainty for each sub factor can vary between the different information sources which it is not illustrated in the following graphs. It should be mentioned that the difficulty of adapting the sub factors defines the adaption difficulty of the factors. Each ERS factor is shown in **Figure 17** and their respective sub factors are further discussed.

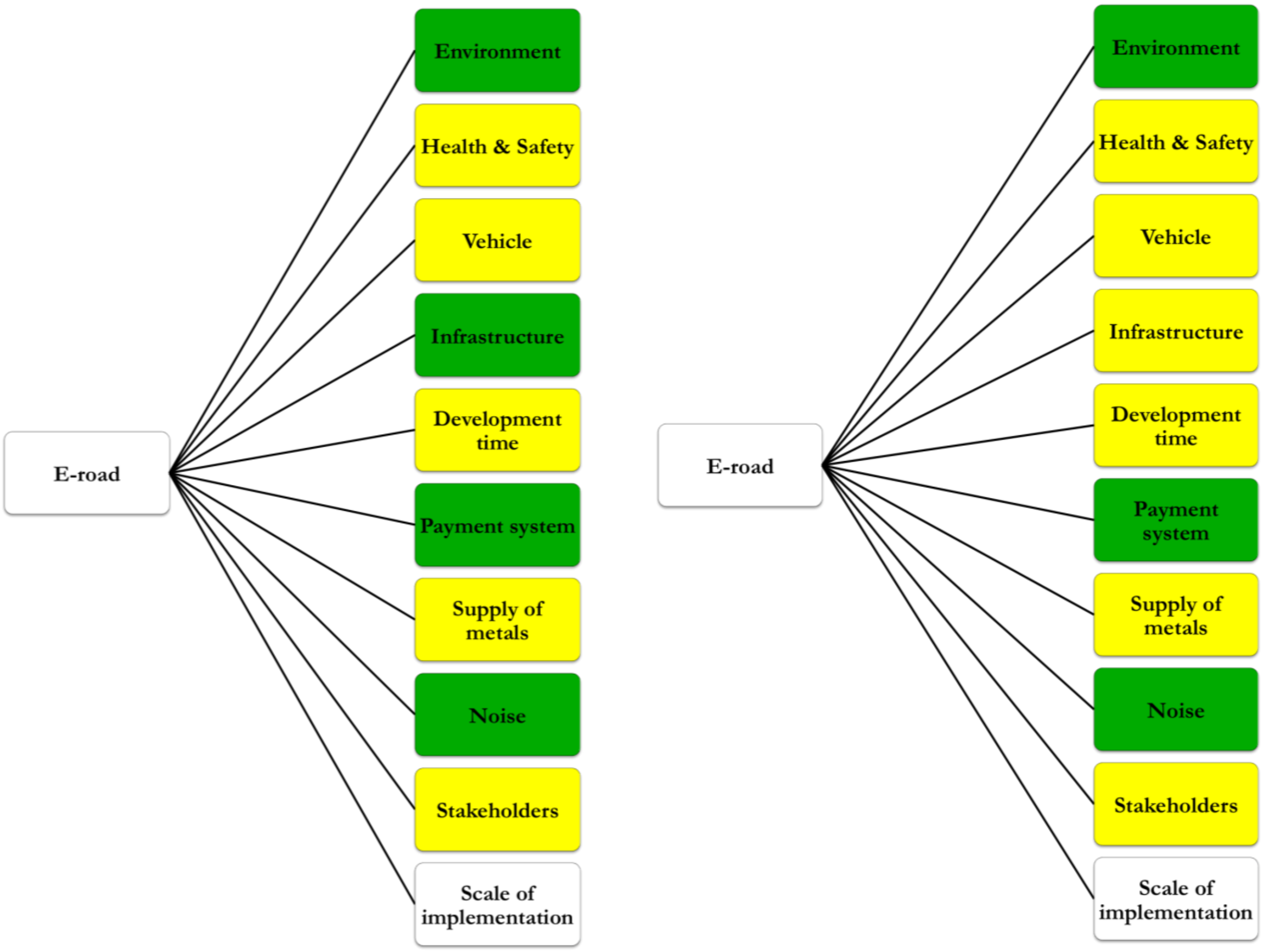

Figure 17: ERS factors for inductive (left) and conductive (right).

3.3 Environment

The ERS from an environmental point of view is a promising alternative for a decarbonized future, for both conductive and inductive solutions. This results after considering that the battery dependency will be reduced significantly after integrated implementation of the ERS. Even in case of converting the entire Swedish truck fleet into electrified vehicles, the energy demand does not seem to be a challenge to be covered compared to the yearly Swedish electricity production. Energy supply from the Swedish perspective is highly dependent on the investments on nuclear power stations, since nuclear has a high share in the green Swedish electricity mix. The future cost of electricity is still uncertain but it is not expected to exceed diesel cost in terms of energy density. Therefore the economic savings for the customers using EVs are expected to be high in combination with the higher energy efficiency of the electric motors. Further the ERS technologies have relatively low losses. From the particles and pollutants perspective both inductive and conductive outweighs the conventional vehicles. ERS are free from tail pipe emissions since they are using electricity, which can originate from renewable or less carbon intensive energy sources instead of fossil fuels. Even if the electricity production were based on fossil fuel the saving could remain because of the high efficiency of the electric motors. In addition, the inductive solution outweighs the conductive since the latter is expected to have additional particles, such as iron powder from the contact points. The particles originating from the tires and the friction with the asphalt will remain the same with the conventional road.

When analysing the infrastructure phase the ERS solutions and their environmental impact are uncertain. This is due to the use of extra components such as metallic parts, concrete and cables. However the operation phase seems as a significant driver for the ERS implementation since they contribute to less energy usage from the motors and zero tail pipe emissions in case of fully electric vehicles. The maintenance phase is very uncertain at the moment since the technologies are still in an experimental stage and there is no large-scale implementation. **Figure 18** and **Figure 19** show all evaluated sub factors.

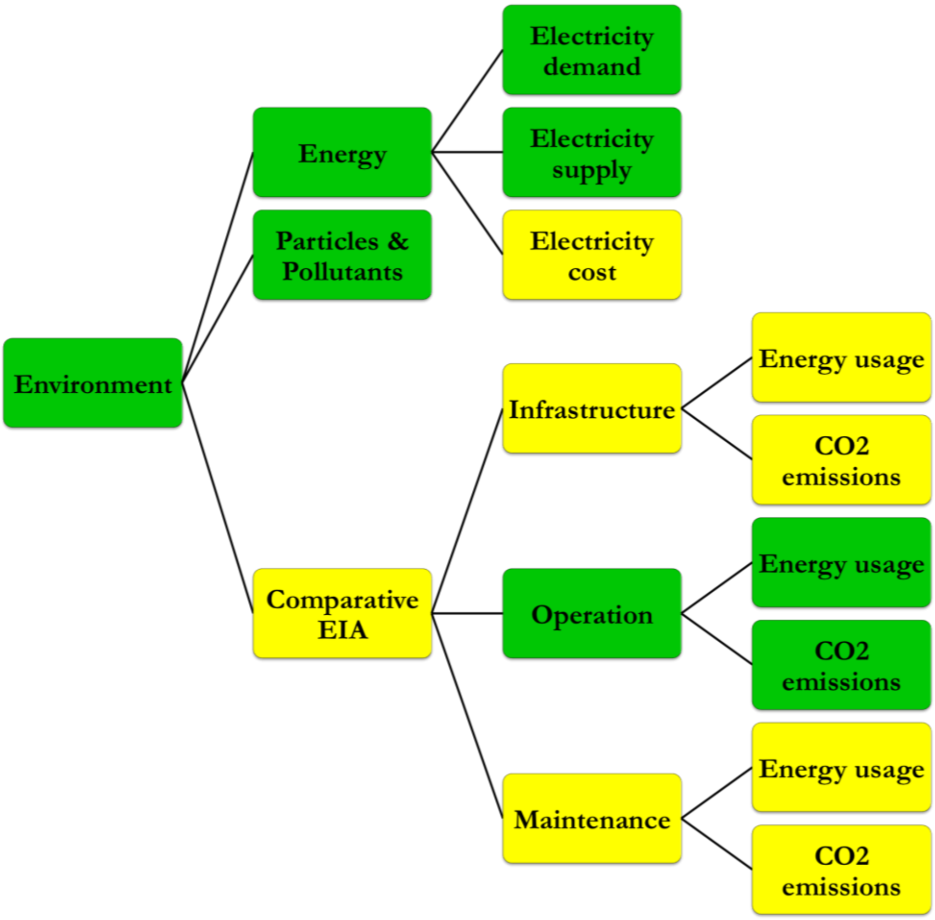

Figure 18: Environment sub factors for inductive ERS.

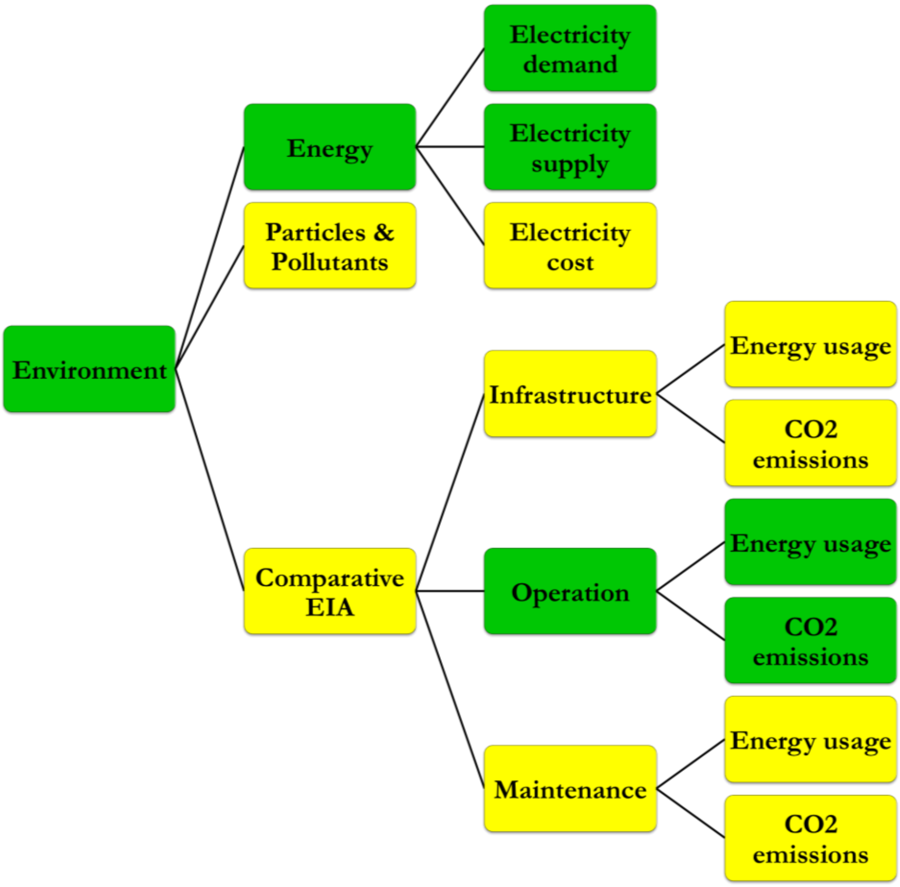

Figure 19: Environment sub factors for conductive ERS.

3.4 Health and safety

The area of health and safety in relation to ERS includes several uncertainties. Saying that a factor is uncertain does not necessarily mean that there is an established problem but that further investigation is needed with more specific parameters. There seem to be differences between the inductive and the conductive technologies in the evaluation of the uncertain factors, see **Figure 20** and **Figure 21**.

Mainly it is the inductive on-road charging technology that raises concerns about electromagnetic field exposures. In comparison with the inductive technology, which is based on electromagnetic fields, the conductive solutions are considered to have less significant EMF levels and thus not further investigated but remain uncertain. The frequency range of 10-200 kHz for the inductive technology is considered to belong to the intermediate frequencies where there are limited conducted studies. Since the ICNIRP guidelines are based on conducted studies, the updated guidelines could show a completely different picture for the future if additional studies have been made and taken into consideration. Exposure levels where people might be, must be below reference levels stated by ICNIRP since those are the levels where acute effects are established. The frequency is not enough to determine exposure levels and each ERS application with corresponding frequency need to be considered. What levels of exposure there will be outside the vehicle are at writing point still confidential from participants in conducted interviews for truck cases. For light vehicle duty, numbers are available from the KAIST OLEV case. If inductive ERS is to be implemented, regardless of specific application, it must be ensured that people can never be exposed to fields that are above the guideline levels on accessible areas.

Electromagnetic fields could also affect people with pacemakers and those suffering from electromagnetic hypersensitivity (EHS). It is stated that pacemakers seem to be able to function properly if exposure levels follow guidelines, but also that there might occur malfunctioning even in the case where exposure levels are below the ICNIRP guidelines. The knowledge about possible effects of ERS on these two parameters seems to be very limited but should not be ignored. Further studies are needed on electromagnetic compatibility for pacemakers and EHS.

Particles and pollutants from a health point of view seem to benefit from ERS in the sense of reduced tail-pipe emissions. However, tire and road abrasion is considered to remain the same from the three ERS technologies in comparison with regular roads. It could be the case that the conductive solutions have slightly higher particle emissions due to the rail in the road and the overhead power lines. It is believed though that this would not become a significant problem for the inductive technology but remain uncertain for the two conductive solutions.

The safety concerns are uncertain considering transportation of dangerous goods and accidents involving electric vehicles, for both inductive and conductive technologies. Regarding dangerous goods the opinions diverge within the industry whether it could be a challenge to operate freight vehicles on high voltage ERS. Interviewees within the ERS industry do not believe that it would become a significant challenge while the dangerous goods industry argue that it might not be an easy task due to comprehensive adjustments of both vehicles and regulations. As one example of vehicle adjustment there is a concern regarding how to create an earth connection for freight vehicles operating on inductive roads. On inductive roads the vehicle on rubber wheels has no mechanical contact that could serve as earth connection, which is one main difference from the conductive technologies. Possible heating from electromagnetic fields or possible sparks from the conductive solutions and whether it might affect transportation of dangerous goods remain uncertain as well. Studies related to accidents with electric vehicles concern mainly passenger cars but raise an interesting safety aspect. There could be an increased risk of EVs catching fire after an accident and studies also show that extinguishing an EV on fire requires a larger volume of water compared to a conventional vehicle. In addition emergency services might need new approaches when entering an accident with EVs involved. In the same way it seems reasonable to further investigate the same aspects for both inductive and conductive ERS in relation to freight vehicles.

Thus, up to this point with described background available, it is not possible to determine for sure whether the health and safety aspect is feasible or not for ERS. More studies on most of the sub factors are needed to reach a higher point of certainty.

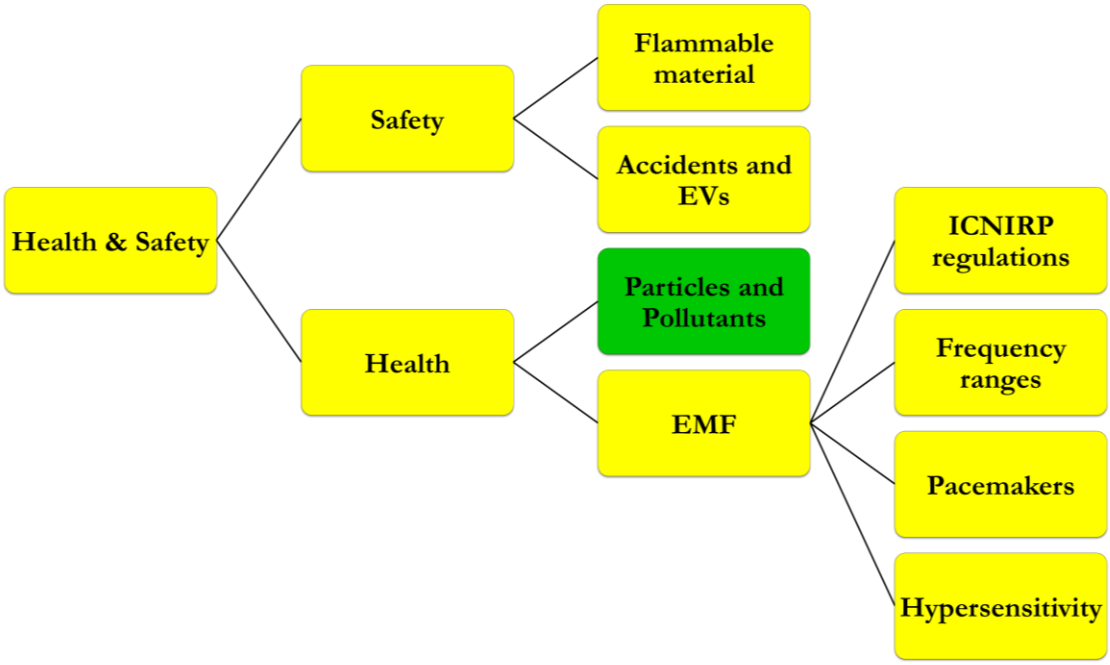

Figure 20: Health & safety subfactors for inductive ERS.

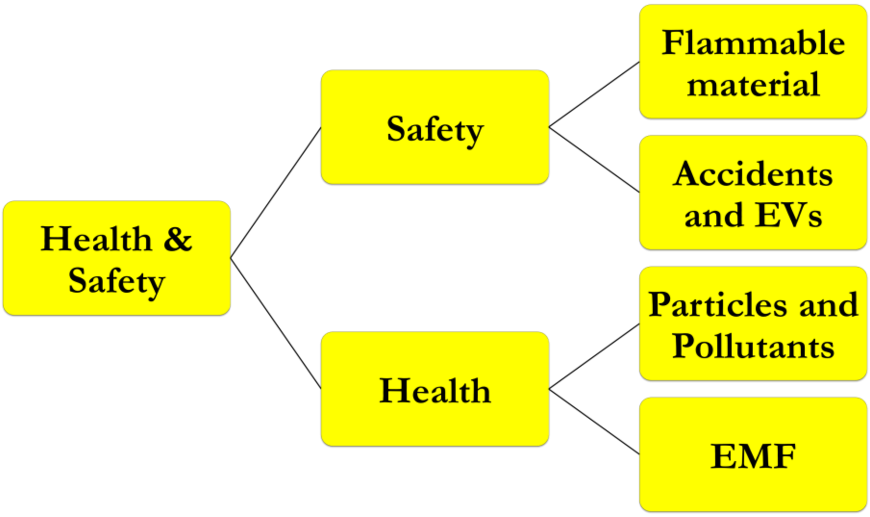

Figure 21: Health & safety subfactors for conductive ERS.

3.5 Vehicle

The vehicle and its adaption to the ERS still remain uncertain, as it is shown in **Figure 22**. Even though it does not constitute an engineering challenge there are various sub factors that contribute in making it a complex component of the ERS. Most of the uncertainties are common for both systems. The load capacity of the vehicle depends apart from the battery weight also on the electric motor and problems such as overheating when going uphill. The energy consumption for both technologies is expected to be lower than the regular ICE vehicle due to the high energy efficiency of the electric motor. The vehicle's electrical components are believed to not be a challenge even though they have not been tested yet in a large extent. The production emissions for the additional components needed for the conductive charging technologies are still uncertain, while the production emissions for the fully electric vehicles are expected to be low after the limitation of the battery component. The battery factor and its size reduction is one of the main drivers for the ERS

implementation. This is because the emissions during the production of the battery are a factor that aggravates the overall emissions during the production of the vehicle. The battery will remain as a component even in the case of a fully electric vehicle in order to ensure smooth driving. However its size will be significantly reduced. The battery price and the relation between capacity and weight are currently barriers but they are expected to be improved in the future and therefore are considered as uncertain. The vehicle price remains uncertain since only some estimation has been made on this field. Some technology providers are suggesting that the conversion of the vehicle can be done by adding electrified wheels but not much is known or integrally implemented yet. However this is not believed to be cost efficient for Swedish long haulage trucks since the fleet is being replaced every 3 to 5 years.

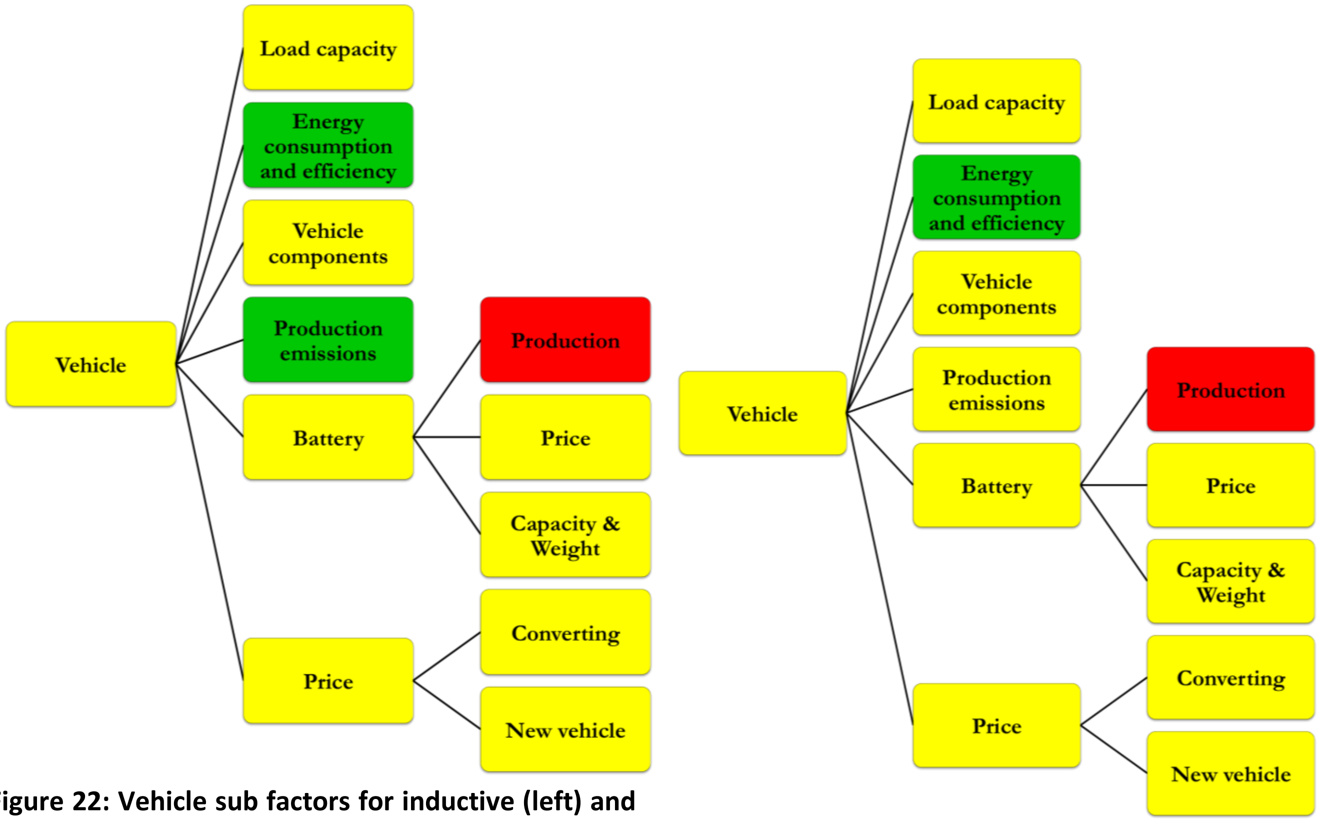

Figure 22: Vehicle sub factors for inductive (left) and conductive (right) ERS.

3.6 Infrastructure

The component of infrastructure does not seem an engineering challenge either. Parameters such as maintenance and precise cost of the infrastructure are factors that still remain uncertain, while others such as robustness of the system and topography does not seem to be a barrier for ERS. More specifically regarding robustness and reliability, both the inductive and conductive solutions seem not to face significant difficulties overcoming issues such as hacking. The same happens with the power grid at least in the case of Sweden where the delivery security for electricity is very high. The weather conditions and how it can affect the robustness of the system, even though it does not seem as a significant barrier for countries with mild winter, becomes more uncertain in countries like Sweden. Similar is the case of maintenance, which can be a very complex procedure in areas where the layer of ice is very thick. The factor of rutting does not seem to deviate significantly from the current situation. The technology behind the equipment installed in the pavement for both inductive and rail in the road conductive seems to be solved from the technology

providers' side. Possible improvements for a public implementation do not seem to be very challenging to be done either. The same happens with the topography, which can be a barrier in case of uphill but at the same time it can be used in favour of the system in case of downhill, where no pavement equipment is needed. The factor of geospatial land use indicates some differences between the inductive and conductive solution. This is because the inductive charging can be implemented by equipping the already existing traffic lanes and there is no need for additional infrastructure. Some transformer stations will be built but at a general scale the geospatial land use does not seem to increase significantly. However regarding the conductive with overhead lines there is need for extra infrastructure such as pillars and safety equipment. Also the deforestation needed for the overhead lines infrastructure forms a barrier regarding the geospatial land used and the impact to the surroundings. The performance of the sub factors is shown in **Figure 23**.

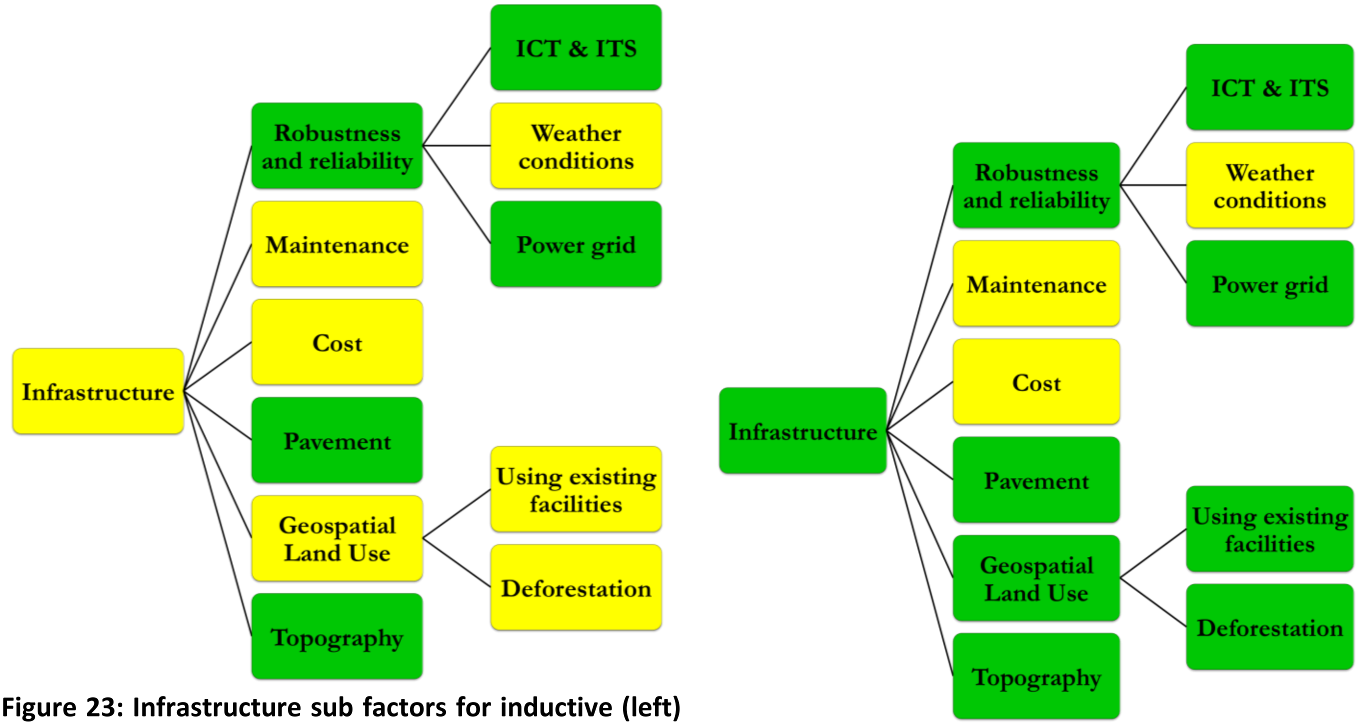

Figure 23: Infrastructure sub factors for inductive (left) and conductive (right) ERS.

3.7 Other factors

The ERS feasibility was also approached from the aspect of other various factors shown in **Figure 24**. However those factors are not investigated in bigger depth since their barriers do not seem to determine the feasibility of ERS. Those factors appear to have the same performance for the ERS technologies. The development time from the industry point of view is not needed to be long, however the acceptance through political decisions and the development of a business case behind ERS seem to be more complex. The payment system is considered to be an easy task that can be implemented through many different ways. The noise of fully electric vehicles running on ERS, or more specifically the lack of it, can be considered as negative from the aspect of safety or as positive from the aspect of noise pollution within the city. The safety issue however is possible to overcome easily by adding artificial noise. The factor of scarcity of metals needed for the ERS infrastructure is a possible barrier why it is considered as uncertain but it is not considered to have a significant impact on the overall ERS feasibility, at least not in the near future.

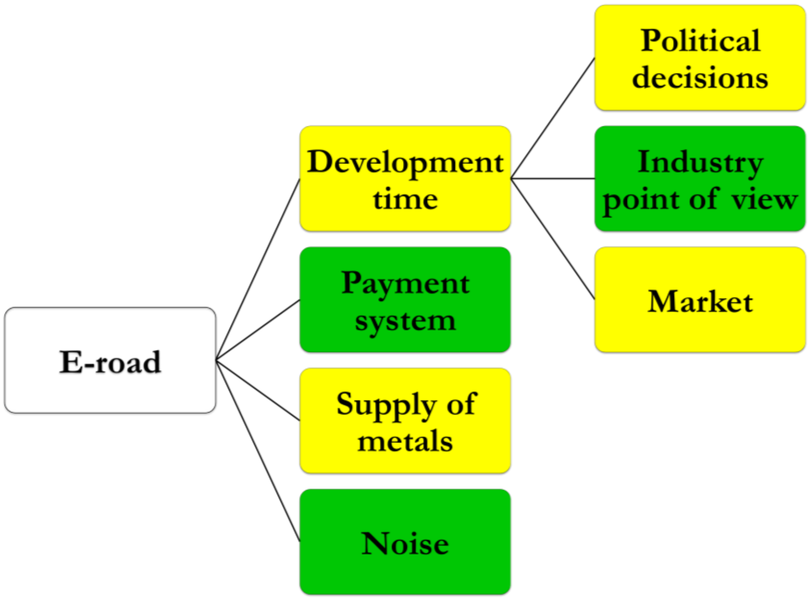

Figure 24: Other factors and sub factors mutual for both inductive and conductive ERS.

3.8 Stakeholders

Different authorities and politicians are believed to play an important role in the development of electric roads since they have to drive the development forward and decide upon legal issues, implementation and financial issues. Vehicle manufacturers and technology providers also play important roles when it comes to technology development and export possibilities. In the Swedish industry, it is believed that the Swedish transport administration will have the most important role since they need to have the holistic approach. The interaction between the different participants is an important aspect to drive the development forward and is seen as natural and necessary. However, it seems that there are some obstacles in achieving a good interaction; uncertain acceptance among politicians due to several uncertain factors connected to ERS motivates demonstration projects. In addition there seems to be a need for a clearer picture of user benefits from this new concept and it needs to be proven safe.

Further the technological stakeholders have technologies both for inductive and conductive ERS ready to be tested and further developed. In that sense the industry willingness is not believed to be an issue while the governmental decisions, possible incentives, and the commercialization issues remain uncertain. **Figure 25** shows the evaluated sub factors.

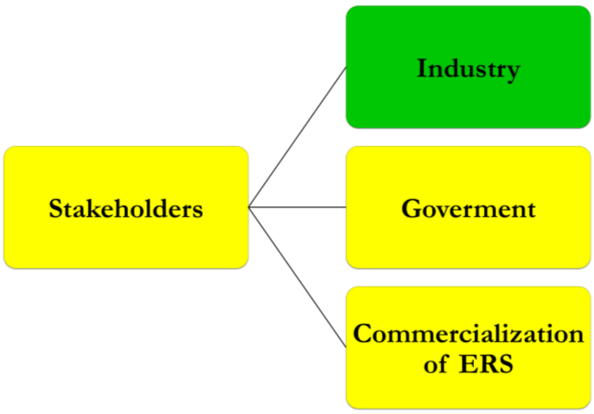

Figure 25: Stakeholders sub factors mutual for both inductive and conductive ERS.

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APPENDIX A

EMF ICNIRP basic restrictions and guidelines

Table 23: Basic restrictions for time varying electric and magnetic fields for frequencies up to 10GHz (ICNIRP, 1998).

Exposure characteristics	Frequency range	Current density for head and trunk (mA m^{-2}) (rms)	Whole-body average SAR (W kg^{-1})	Localized SAR (head and trunk) (W kg^{-1})	Localized SAR (limbs) (W kg^{-1})
Occupational exposure	up to 1 Hz	40	—	—	—
	1–4 Hz	40/f	—	—	—
	4 Hz–1 kHz	10	—	—	—
	1–100 kHz	f/100	—	—	—
	100 kHz–10 MHz	f/100	0.4	10	20
	10 MHz–10 GHz	—	0.4	10	20
General public exposure	up to 1 Hz	8	—	—	—
	1–4 Hz	8/f	—	—	—
	4 Hz–1 kHz	2	—	—	—
	1–100 kHz	f/500	—	—	—
	100 kHz–10 MHz	f/500	0.08	2	4
	10 MHz–10 GHz	—	0.08	2	4

[a] Note:

1. f is the frequency in hertz.
2. Because of electrical inhomogeneity of the body, current densities should be averaged over a cross-section of 1 cm^2 perpendicular to the current direction.
3. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $\sqrt{2}$ (~1.414). For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$.
4. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate basic restriction.
5. All SAR values are to be averaged over any 6-min period.
6. Localized SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for the estimation of exposure.
7. For pulses of duration t_p the equivalent frequency to apply in the basic restrictions should be calculated as $f = 1/(2t_p)$. Additionally, for pulsed exposures in the frequency range 0.3 to 10 GHz and for localized exposure of the head, in order to limit or avoid auditory effects caused by thermoelastic expansion, an additional basic restriction is recommended. This is that the SA should not exceed

Table 24: Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values) where f is the frequency (ICNIRP, 1998)

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field (μT)	Equivalent plane wave power density S_{eq} (W m^{-2})
up to 1 Hz	—	1.63×10^5	2×10^5	—
1–8 Hz	20,000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	—
8–25 Hz	20,000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	—
0.025–0.82 kHz	500/f	20/f	25/f	—
0.82–65 kHz	610	24.4	30.7	—
0.065–1 MHz	610	1.6/f	2.0/f	—
1–10 MHz	610/f	1.6/f	2.0/f	—
10–400 MHz	61	0.16	0.2	10
400–2,000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	f/40
2–300 GHz	137	0.36	0.45	50

[a] Note:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width, does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. Electric shock from low impedance sources is prevented by established electrical safety procedures for such equipment.

Table 25: Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values) where f is the frequency (ICNIRP, 1998)

Frequency range	E-field strength (V m^{-1})	H-field strength (A m^{-1})	B-field (μT)	Equivalent plane wave power density S_{eq} (W m^{-2})
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4{,}000/f$	$5{,}000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

[a] Note:

1. f as indicated in the frequency range column.
2. Provided that basic restrictions are met and adverse indirect effects can be excluded, field strength values can be exceeded.
3. For frequencies between 100 kHz and 10 GHz, S_{eq}, E^2, H^2, and B^2 are to averaged over any 6-min period.
4. For peak values at frequencies up to 100 kHz see Table 4, note 3.
5. For peak values at frequencies exceeding 100 kHz see Figs. 1 and 2. Between 100 kHz and 10 MHz, peak values for the field strengths are obtained by interpolation from the 1.5-fold peak at 100 kHz to the 32-fold peak at 10 MHz. For frequencies exceeding 10 MHz it is suggested that the peak equivalent plane wave power density, as averaged over the pulse width does not exceed 1,000 times the S_{eq} restrictions, or that the field strength does not exceed 32 times the field strength exposure levels given in the table.
6. For frequencies exceeding 10 GHz, S_{eq}, E^2, H^2, and B^2 are to be averaged over any $68/f^{1.05}$-min period (f in GHz).
7. No E-field value is provided for frequencies <1 Hz, which are effectively static electric fields. perception of surface electric charges will not occur at field strengths less than 25 kVm^{-1}. Spark discharges causing stress or annoyance should be avoided.

Table 26, Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values) where f is the frequency (ICNIRP, 2010b).

Table 3. Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values).

Frequency range	E-field strength E (kV m^{-1})	Magnetic field strength H (A m^{-1})	Magnetic flux density B (T)
1 Hz–8 Hz	20	$1.63 \times 10^5/f^2$	$0.2/f^2$
8 Hz–25 Hz	20	$2 \times 10^4/f$	$2.5 \times 10^{-2}/f$
25 Hz–300 Hz	$5 \times 10^2/f$	8×10^2	1×10^{-3}
300 Hz–3 kHz	$5 \times 10^2/f$	$2.4 \times 10^5/f$	$0.3/f$
3 kHz–10 MHz	1.7×10^{-1}	80	1×10^{-4}

Notes:
- f in Hz.
- See separate sections below for advice on non sinusoidal and multiple frequency exposure.
- To prevent indirect effects especially in high electric fields see chapter on "Protective measures."
- In the frequency range above 100 kHz, RF specific reference levels need to be considered additionally.

Table 27, Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values) where f is the frequency (ICNIRP, 2010b).

Table 4. Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values).

Frequency range	E-field strength E ($kV\ m^{-1}$)	Magnetic field strength H ($A\ m^{-1}$)	Magnetic flux density B (T)
1 Hz–8 Hz	5	$3.2 \times 10^4/f^2$	$4 \times 10^{-2}/f^2$
8 Hz–25 Hz	5	$4 \times 10^3/f$	$5 \times 10^{-3}/f$
25 Hz–50 Hz	5	1.6×10^2	2×10^{-4}
50 Hz–400 Hz	$2.5 \times 10^2/f$	1.6×10^2	2×10^{-4}
400 Hz–3 kHz	$2.5 \times 10^2/f$	$6.4 \times 10^4/f$	$8 \times 10^{-2}/f$
3 kHz–10 MHz	8.3×10^{-2}	21	2.7×10^{-5}

Notes:
- f in Hz.
- See separate sections below for advice on non sinusoidal and multiple frequency exposure.
- In the frequency range above 100 kHz, RF specific reference levels need to be considered additionally.

APPENDIX B

List of questions asked during interviews.

General ERS aspects
○ Primove technology proposes 35 % coverage of the road, considering regenerated energy from braking and charging islands every 30 km. Also the state of charge for the battery should not go below 40%. Is this a reasonable assumption according to you?
○ What about the investment cost of the different technologies?
○ Do you think that the inductive ERS will provide us with as safe roads as we have today even with the EMF and or rails in the roads that Elways propose?
○ Compared to the ICE roads, are the ERS less CO_2 emissions intensive and less energy demanding regarding the infrastructure, usage and maintenance phase?
○ How do you see a solution to a possible system failure, such as black-out, since the new technology is very electricity dependent even with hybrid function?
○ How do you see this to work with the city logistics, distribution trucks?
○ How can the payment system be implemented? Like in London case the will have an annual fee, or pay as you go system?
○ Transportation of flammable materials on electric roads and your opinion both for conductive and inductive.
○ Which are the most difficult factors of the ERS to implement?
○ What about the lack of available public data?
○ How are you planning on gaining public acceptance?

Energy
○ If all the Swedish trucks will be transformed into EVs, the electricity demand will be 8.3 TWh for 2012. Will this number be possible to be produced only for transportation usage?
○ How will export-import look given the implementation of this technology?
○ Estimation for 2010 considering 1.2% increase, (source EEA) is energy demand of 6.7 TWh. Does it seems like a small increase?
○ What could a reasonable estimation of new electricity taxes, be?
○ What about the "new electricity price" for vehicles compared to household electricity. An estimation of 1.1 SEK/kWh for 2020 is reasonable?
○ What would be the conversion for liters diesel to kWh in terms of energy?
○ How will the electricity mix look like in the future? Can we decide from where the electricity for the inductive system will come from mostly?
○ What about the on/off peak demand? How will this be faced energy wise?
○ Could superfluous energy be used for, eg. Street lights?
○ Can all the kinds of energy (hydro, wind, etc.) be used with the same efficiency to provide the grid with power? We read somewhere that wind power can be very efficiently used from the electric grid than for other uses. Is that correct?

Vehicle and battery
○ What will the estimated energy consumption be (2.7kWh/km is referred in Björkman's thesis) and what about fluctuation with different speeds? Difference in energy consumption between

city and regional transport. (This affects the energy demand)

- Is it valid that the load capacity for the electric trucks will be lower than for the ICEs? Connections to the vehicle weight.
- Will it be cost efficient to convert the today existing ICEs to Electric Truck or do they have to be replaced? In a report from Energimyndigheten it is stated that the cost for converting an ICE is around 5MSEK. What's the price of a new ICE and electric truck?
- What about the battery production? Will the procedure be CO2 intensive compare to a regular battery of an ICE truck? The battery right now for a long haulage truck is around 12V? (Regarding cost and emissions compared to the current situation)
- Is a battery capacity of 100kWh, that Primove proposes, an efficient battery capacity according to you? What is the possible voltage for that size of battery?(flammable…limit of 24V)
- Does the recycling of the batteries or the EVs' parts are expected to require more energy than the conventional ones?
- What about the electricity consumption during production of EVs? Will it differ a lot from an ICE truck or a hybrid?

Maintenance
○ Will the procedure of maintenance and recycling change or remain the same as it is today (as stated in the Chalmers thesis, Björkman, 2013), in sense of cost, complexity and emissions?
○ What about the maintenance of the inductive roads? Do you think that it would be a difficult procedure because of the sensors in the pavement or is it a difficulty easy to overcome?
○ Conductive with overhead lines and the problem of power lines falling down-high traffic density
○ What about the rails in the road solution. Do you think that there will be a problem with the winter maintenance? What about the conductor and its maintenance and resistance against wear and tear?
○ What about the rutting? Will that be a bigger problem than it is today? Trucks do not have any special winter tires…What is the relation of the pavement materials and thickness between Nordic countries and rest of Europe?

EMF
○ Considering the electromagnetic fields, FABRIC proposes a frequency of 10-200kHz. Do you think that this frequency level is going to be used? Could a more limited range be stated or it's still uncertain which frequency to use? What about the flux and the field strength?
○ In the "Slide in inductive project report" it is stated that under normal operation the magnetic field will be less than 6,25 µT in all public areas and in the drivers cabin. This will be assured by design and operational controls and demonstrated by testing. This field level is lower than the recommended level for public exposure (ICNIRP, 2010a) and is safe for all modern pacemakers (VDE, 2002).
○ What about the "new" reference limit of 27 µT? (ICNIRP, 2010a)
○ Will the driver and the surroundings be secured from the EMF?