FABRIC

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

Report on the maturity, reliability, efficiency and stability of the supply chain

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LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
AADT	Annual Average Daily Total (traffic flow)
APS	Aesthetic Power Supply
BEV	Battery Electric Vehicle(s)
CG	Core Group
CO_2	Carbon Dioxide
DoW	Description of Work
DPT	Dynamic Power Transfer (conductive or wireless)
DWPT	Dynamic Wireless Power Transfer
Dx.x.x	Deliverable x.x.x
EC	European Commission
ECU	Electronic Control Unit
ERG	External Reference Group
ERS	Electric Road System
EU	European Union
EV	Electric Vehicle(s)
EV-DWPT	EVs with dynamic wireless power transfer capabilities
FABRIC	FeAsiBility analysis and development of on-Road chargIng solutions for future electric vehiCles
HDV	Heavy Duty Vehicle(s)
HGV	Heavy Goods Vehicle(s)
HF	High Frequency
HMI	Human Machine Interface
ICT	Information and Communication Technologies
ICE	Internal Combustion Engine
IEA	International Energy Agency
IP	Intellectual Property
IPR	Intellectual Property Rights
LCC/LCA	Life Cycle Cost/Life Cycle Assessment
Mx	Month x of the project
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
OEM	Original Equipment Manufacturer(s)
PE	Power Electronics

PHEV	Plug-in Hybrid Electric Vehicle(s)
SC	Supply Chain
SCM	Supply Chain Maturity
SCR	Semiconductor Controlled Rectifier(s)
SME	Small and Medium-sized Enterprise(s)
SP	Sub Project
TEN-T	Trans-European Networks for Transport
TRL	Technology Readiness Level
Tx.x.x	Task x.x.x
USD	United States Dollar
V2I	Vehicle to Infrastructure
WP	Work Package
WPT	Wireless Power Transfer

REVISION CHART AND HISTORY LOG

REV	DATE	REASON
1	13.12.16	First draft (ICCS)
2	13.01.17	Estimated demand scenarios (ICCS) Input regarding WDPT components added (QiE)
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4	08.03.17	Addition of Volvo ERS conductive charging system description /decomposition (ICCS)
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	08.05.17	Chapter 4. Scarcity of resources added (ICCS)
7	10.09.17	Final version of demand estimation (QiE)
7	12.09.17	Questionnaire results added (ERT)
9	19.09.17	Executive summary added (ICCS) Final revisions of the document
10	16.10.17	Conclusions added (ICCS) / Submitted for peer review
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EXECUTIVE SUMMARY

The present document investigates the feasibility of the dynamic EV charging technology from the supply chain and raw material procurement points of view. The objective is to identify potential bottlenecks that may hinder the large-scale deployment of electric roads or e-roads. It should first be noted, and this is one of the findings of this document, that such a study only provides an educated estimate on the questions that it is called to answer, since this is a novel technology at a prototype level and proper supply chains are not implemented. In addition, the study relies on EV deployment scenarios and such forecasts have notoriously missed real deployment numbers in the past for many novel technologies. The mistake in this case can be multi-parametric: it can be relevant either to the actual EV numbers deployed, or relevant to the EV market penetration time horizon. These milestones are strongly affected by factors that cannot be foreseen and range significantly from country to country such as government policies and incentives as well as macroeconomic and technological factors that may affect the rate of production and the price of materials needed for the construction of dynamic charging prototypes. Finally, since the initial deployment scenario for this kind of technology is taking place at least 10 years in the future, one can understand the difficulty in making the current assumptions since the technology is evolving at an exponential rate in our days in many areas, thus technological developments, changes, and radical improvements of the technology investigated in FABRIC are almost certain.

Taking the above into account, the present document initially decomposes the FABRIC prototypes to component level in an effort to identify the suppliers for each component and form the current primitive supply chain which is expected to evolve, be refined and optimized in the future, in case the technology picks up. It has to be noted that the prototypes selected for this document analysis are the ones developed by POLITO and SAET, and installed in the Italian test track, due to intellectual property restrictions regarding the French prototype that was developed by VEDECOM's subcontractor Qualcomm. The system decomposition in order to identify suppliers is carried out also for Volvo's Slide-In conductive dynamic system, however not in the same detail since FABRIC's main R&D revolves around the **wireless** implementation of this technology.

In parallel to the identification of system component suppliers there was a big effort in making a forecast on the expected demand for the system in the future. This study took into account existing studies on EV market penetration vs time in order to make an assumption on how many vehicles will be equipped with wireless dynamic charging technology in the future and also the European Union plans for the TEN-T road network. These assumptions are necessary in order to pinpoint the most probable road candidates for the wireless dynamic charging lanes (e-roads) implementation and make an assumption on the length of these lanes. One concrete finding from this activity is that based on the most recent developments in electromobility, it seems that older studies should be reconsidered, and the targets for EV market penetration should be raised. This is another example of how difficult it is to predict the future due to unforeseen events, such as the recent "dieselgate" incident which caused ICE vehicle manufacturers and VW especially to divert many billions of euros towards the research of electromobility and the implementation of large-scale charging infrastructure in the USA and Europe. The provision of alternatives to on-road charging is also a key factor: if ultra-rapid static charging (including systems without the need to plug in) are widely deployed and stopping for EV charging

becomes as quick and easy as stopping for petrol in an ICE car is now, then the business case and attractiveness of dynamic systems will be considerably reduced.

The final activity in acquiring information necessary for this study was the creation of a questionnaire for interviewing the component suppliers that have been identified by POLITO (Politecnico di Torino, developer of one of the solutions for the FABRIC Italian test site), as well as other existing or potential suppliers. The aim of this questionnaire was to assess the capability of these manufacturers to upscale their manufacturing capacity in order to meet the future demand. This should allow in theory the detection of potential bottlenecks in production time. In addition there were also some inquiring questions regarding the materials used for the components construction and how the manufacturers assess the possibility of a potential future scarcity. It has to be noted again that one cannot draw definite conclusions on the findings of the interviews since:

- The interviewed entities are not representative of the European or global manufacturing capacity in case there is significant demand increases
- The deployment will be gradual and the supply chains are expected to mature in parallel
- New manufacturing models may appear as is the current case with Tesla Gigafactory which aims to create a vertical manufacturing chain that delivers in-house all the critical components needed to construct the Tesla vehicles and in that way optimize and automate the processes while minimizing the delays and cost

According to the survey responses, the manufacturers do not foresee a significant supply issue since there materials used are not rare, however depending on the deployment rate of this technology there might be a bottleneck regarding specialized personnel for the design and manufacturing of wireless dynamic charging systems.

The final part of this document investigates possible scarcity of crucial materials that are necessary for the construction of the FABRIC prototypes. A maximalist approach was followed to assess the stress that a rapid and very large scale deployment of the technology would have. Specifically in order to see if there will be lack of copper (the material mostly used for the wireless dynamic charging infrastructure) two extreme cases were studied: covering all of TEN-T network in Europe (~136000km) and covering the core TEN-T network (~40000km). Based on the current global copper production data as well as the existing copper reserves it was found that the demand can be covered but the mining capacity of the mines should be upgraded in case the deployment rate is very fast. This is also true for the copper needed for the manufacturing of EVs. In the optimistic scenario taken into account in this report (production of up to 14million EVs/year) the copper demand will rise significantly but it can probably be met by the supply and the recycling of old vehicles. Again, this study should not be taken as definitive guideline and forecast since:

1. It relies upon the future demand estimates which as mentioned before make many assumption that may not hold true in the future and
2. The technology may change significantly in the future and other materials could be used in case scarcity of a specific material appears.

Finally there was an assessment of potential bottlenecks for the connection of the e-roads with the grid. Specifically it was investigated if there will be a problem with the supply of adequate numbers of power transformers (1 transformer of ~40MVA per 25km of e-road). It was found that the additional stress on

the manufacturers will be analogous to the e-roads deployment rate and that even though there already exists significant manufacturing capacity in Europe, there should be very careful planning and gradual e-road deployment in order to avoid bottlenecks, enlarging the already significant lead time (~8months) in the procurement of the transformers.

1 INTRODUCTION

The present document is FABRIC Deliverable 5.4.2 entitled "Report on the maturity, reliability, efficiency and stability of the supply chain". It is the outcome of FABRIC WP54, T5.4.3, whose description in the DoW is the following: "Given that on-road charging is not at an industrial level yet, the supply chain for components and systems will only start to emerge when deployment is started. An instable or inefficient supply chain will harm the implementation. In this task, the future supply chain will be modelled and assessed for its maturity, reliability, efficiency and stability. Many components will be sourced from existing OEM suppliers for other solutions. These suppliers will be assessed for their capabilities to supply the components and systems needed for on-road charging solutions. For some components, the availability of rare earth metals and other raw products may hinder the up-scaling and break the supply chain."

In accordance to the Task description the following were investigated and reported:

Modelling of the supply chain
In order to model the supply chain it is necessary to understand the manufacturing process and identify the components that need to be manufactured, assembled and shipped in order to deploy an on-road charging system.
Two separate supply chains can be defined that are to an extent isolated from each other: the infrastructure supply chain, and the vehicle supply chain. While the first one is expected to be standardized and applicable regardless of the infrastructure customer, the supply chains and procurement lines for the second depend on the vehicle vendors, meaning that vehicle OEMs could have custom implementations of the on-board systems as well as different suppliers.

Estimation of the demand size
Demand estimation is a pre-requisite in order to assess the suppliers' capability to deliver, and the adequacy of raw materials for the manufacturing of critical components. The demand again depends on whether we refer to the infrastructure side or the vehicles side.
To estimate the demand for the infrastructure there should be an analysis on the roads that are most probable to be equipped with dynamic charging equipment in the future. This analysis according to WP description can be done on regional, country and Europe-wide levels. The question is how it can be decided which roads will offer this feature and what is the service provision criterion that will dictate the length of the road. In other words how much energy should the road provide to each vehicle and in which intervals along the road? This depends on the utilization of the roads (business models) the government incentives and international agreements, as well as the existence of standards that will allow the proliferation of e-roads. These are factors that are impossible to predict for 30 years into the future. To address this problem, first a systematic approach was followed in order to make an educated guess on the most probable deployment scenario according to the data we currently have. Then, since this is a supply chain study the most stressful for the supply chains case for the deployment of e-roads

in Europe was considered to assess whether we should expect a materials' scarcity or other bottlenecks.

To estimate the demand coming from vehicles manufacturing there should be an estimate on how many vehicles will feature wireless charging capability as a function of time, in other words estimate the technology adoption rate by vehicle manufacturers. This again resembles a moving target, since all existing projections on the EV market share have failed and need to be revised constantly. In this report the most optimistic scenario was selected since it applies most to the EV adoption rate that is currently witnessed globally.

Assessment of the manufacturers' capability to deliver

Manufacturers can be categorized in two groups: Off-the-self equipment providers and manufacturers that supply new components that are specific to on-road charging technology not available in the market. In the second category, industrial partners from FABRIC consortium and ERG are interviewed (SAET, QC, others from ERG) focusing on their capacity to upgrade production capacity in case there is increased demand and their view on whether there will be a bottleneck in the future relevant to the materials or the supply chains. In addition, the capability of power transformer delivery capacity was assessed. This equipment is necessary for the connection of the e-roads to the electric grid.

Assessment of raw material procurement capacity

Based on the list of components and the raw materials that are needed for their production, the procurement capacity for these materials is assessed for a number of European large-scale deployment demand scenarios.

It should be noted that:

1. FABRIC focuses on wireless dynamic charging technology rather than conductive charging technology. The main bulk of work revolves around the design, development and testing of wireless dynamic charging prototypes and based on the test results provide estimations of future large-scale deployment of the systems. However in the Description of Work it is not clear whether the "on-road charging" refers to wireless charging only or to both wireless and conductive charging systems. In order to address this issue, FABRIC CG made the decision that the main focus of SP5 studies should be on the systems developed within FABRIC however conductive technology should be referred to as well (where relevant), but to a lesser extent. The main issue with the examination of conductive technology is the obvious lack of information from developers of this kind of technology, since they are not part of the FABRIC consortium and the system specifications are confidential.
2. The FABRIC prototypes for wireless dynamic charging are confidential and their description is provided in SP3 confidential deliverables. Since D5.4.2 is a public document there are limitations on the information that can be shared publically regarding the components, design and materials used for the production of the prototypes. To address this situation, data regarding the system description and the components used derives mainly from D3.5.1 "Architecture definition" which was a

public deliverable. The information from D3.5.1 is crosschecked with the more recent and more specific SP2 and SP3 prototype confidential reports to detect significant changes that may affect the supply chain evaluation study. The confidentiality of the wireless dynamic system developed by Qualcomm as subcontractor of FABRIC partner VEDECOM is even stricter thus it was excluded from the study. However the systems of POLITO and SAET are adequate for this investigation since they have the same operational characteristics as the QUALCOMM system.

Document relation to FABRIC Tasks and Deliverables:

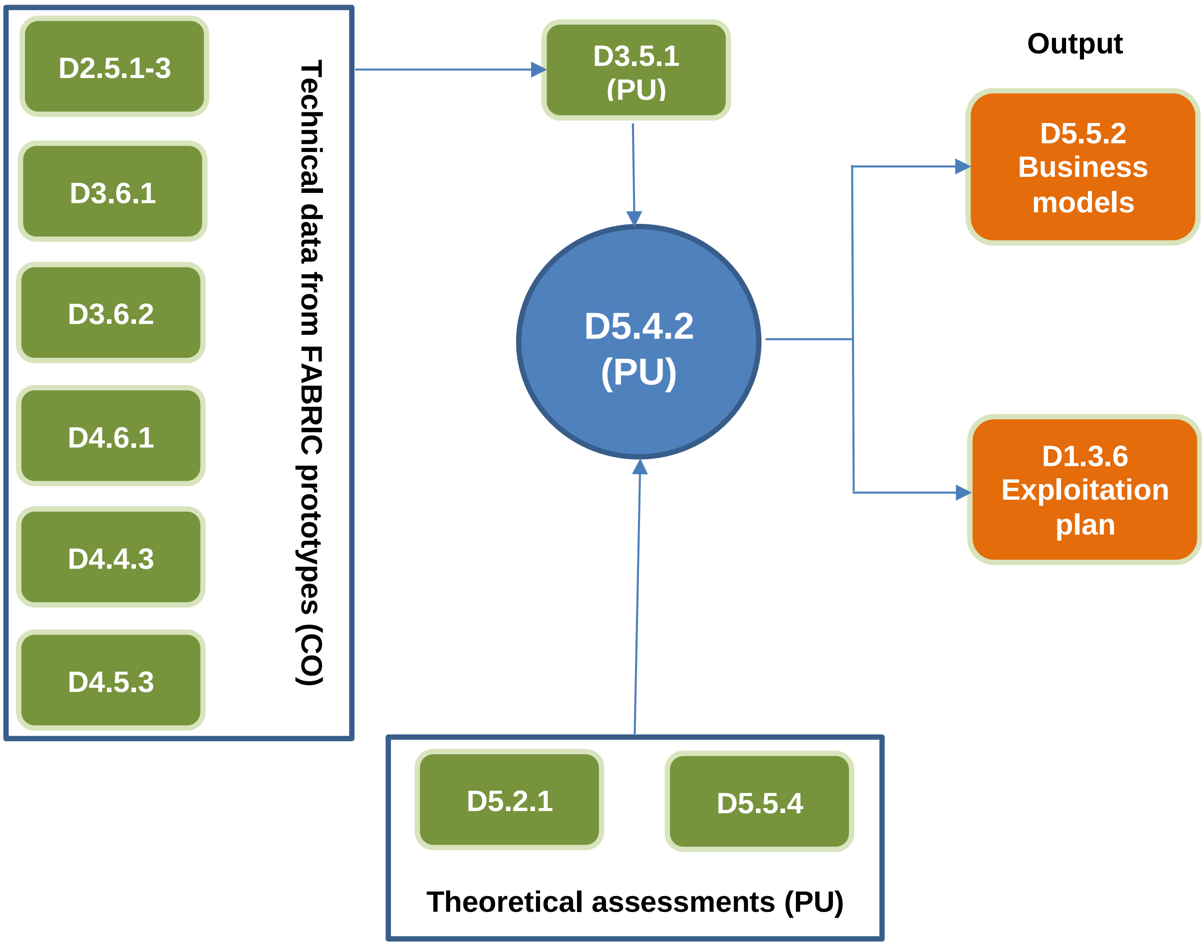


Figure 1: D5.4.2 connection to other FABRIC deliverables

In Figure 1 the interactions of D5.4.2 (M41) with other FABRIC documents is depicted.

- D2.5.1-3 (M26) Prototypes of ICT modules (on-board information strategies, on-board charging system alignment and off-board charge planning system) provide the technical specifications regarding the ICT components (hardware) such as cameras, computers and HMI.

- D3.6.1 (M27) “On-road charging solution 1” provides the technical specifications regarding the hardware of the wireless power transfer system produced by Qualcomm (as subcontractor of FABRIC partner VEDECOM). This Deliverable is confidential and used for cross-checking.
- D3.6.2 (M27) “On-board charging solutions 2 and 3” provides the technical specifications regarding the hardware of the wireless power transfer systems produced by POLITO and SAET.
- D4.6.1 (M28) “Vehicle prototypes” provides the technical specifications regarding the hardware modifications for the vehicles of CRF (IVECO) and VEDECOM (Renault Kangoo).
- D4.4.3 (M24) “Implemented grid adaptations per test site” provides the technical specifications regarding the hardware needed to connect the infrastructure (on-road) charging pads to the electrical network (grid).
- D4.5.3 (M24) “Implemented road adaptations per test site” provides the technical specifications regarding the road adaptations and the materials needed in order to embed the charging infrastructure in the pavement.
- D5.2.1 (M18) “Feasibility study on societal perspectives towards on road charging and set of current data regarding societal dimensions” provides initial assessment of the most probable large-scale deployment scenarios. This assessment can facilitate to a degree the estimation of the expected system demand in the future.
- D5.5.4 (M48) “Analysis of deployment scenarios, standardisation and harmonisation” can provide the expected deployment scenarios that will allow a more precise estimation of the expected system demand.

D5.4.2 is expected to provide input to:

- D5.5.2 (M40) “Cost-benefit analysis and business models of large-scale deployment of on-road charging” by identifying the manufacturing and operating stakeholders as well as the expected demand as a function of time.
- D1.3.6 (M48) “Exploitation plan” by producing information that may help FABRIC manufacturing partners identify business opportunities for present and future supply chains.

Timing issues.

From the analysis above it can be observed that D5.5.4 is due M48, seven months later that D5.4.2 so the expected input might not be available on time. In addition D5.5.2 is due M40, one month earlier than D5.4.2 creating another timing conflict. To address these problems, work on these deliverables proceeded in parallel and information was exchanged prior to the finalization and submission of the documents.

2. MODELLING OF THE SUPPLY CHAIN

On-road charging, in particular wireless dynamic charging, which is the main objective of FABRIC, takes advantage of well-known and simple physical phenomena but the technical implementation of a wireless dynamic charging system involves several systems both on the electric vehicle and on the infrastructure (road-side).
In order to perform an analysis on the maturity of a supply chain several steps need to be taken to define the boundaries of the analysis:

- As a first step, one must analyse and catalogue the main components of a wireless dynamic charging system
- Secondly the materials used for the construction of each component must be identified
- Thirdly there should be an analysis on the volume of the materials needed for the construction of the components
- Finally, an assessment of the existing production capabilities on material and component levels should be made in order to establish whether a large scale deployment of the system is feasible and identify the bottlenecks if any.

It is expected that off-the-shelf components will not pose a challenge and the analysis should focus on the novel components introduced by FABRIC-like technologies. However even if significant limitations are identified in relation to the current manufacturing capacity, this does not mean that the system cannot be deployed in a large scale. As several examples have demonstrated (most recently the Gigafactory of Tesla motors[1]) manufacturing can be scaled-up in a short amount of time if there is significant demand.

[1] Tesla Gigafactory https://www.tesla.com/gigafactory

2.1 Wireless dynamic charging system decomposition

The identification of the main components is done based on SP2 and SP3 deliverables that describe the ICT and charging pad modules that were developed in FABRIC. In addition, information from SP4 deliverables (D4.4.3 "Implemented grid adaptations per test site") is used in order to obtain data regarding the connection of the charging pads with the grid, the cabling needed and other crucial components. Schematics that show the concept of real system deployment also provide hints for its up-scaling.
In FABRIC three dynamic wireless systems were developed, two in Italy and one in France. For the Italian systems, the on-board (vehicle) systems are the same. Even though the functionality of the systems is the same, there are differences on the way they are implemented and the components used, as well as the dimensions and volume of the charging pads material. These differences could be factors that may affect the future deployment potential of one solution over another.

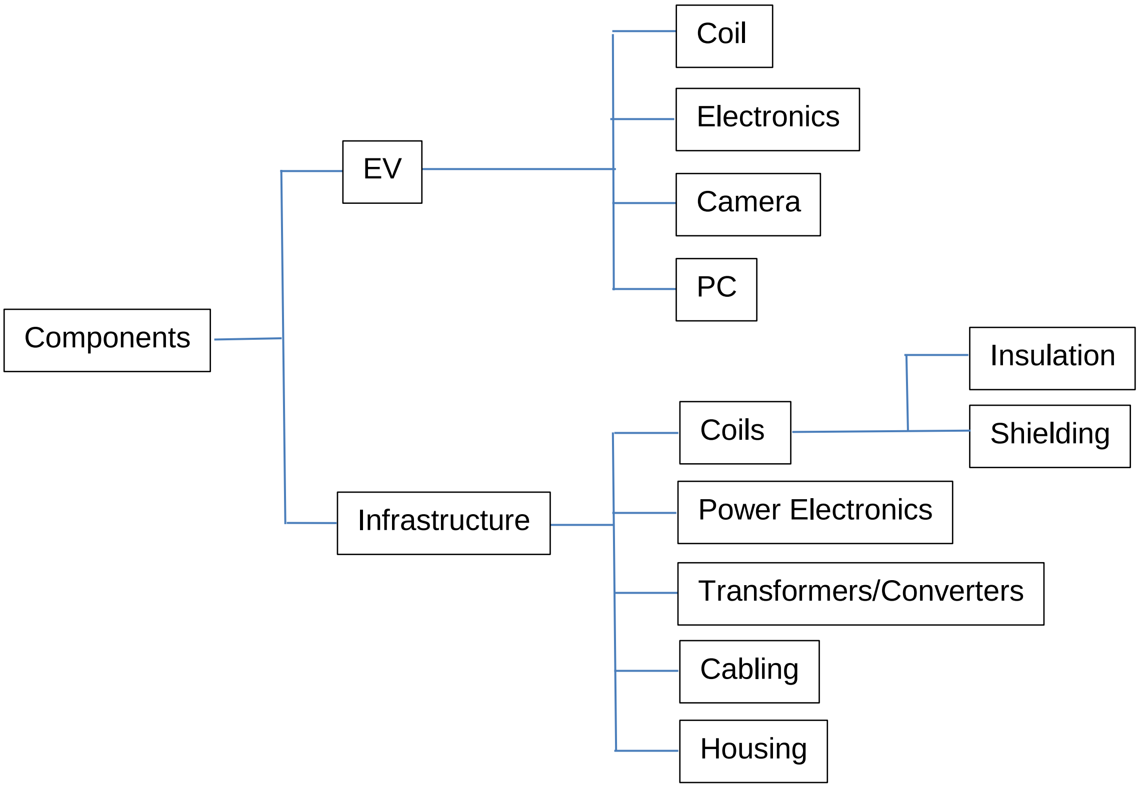


Figure 2: Abstraction of the main components comprising a dynamic wireless charging system.

2.1.1 Electric Vehicle (EV) component analysis

The information that follows derives from FABRIC Deliverable D3.5.1 "Architecture definition" since that was a public document and the included information could be shared. The analysis focuses on the vehicle used at the Italian test site (IVECO) due to availability of publishable data

within D3.5.1. On the other hand the VEDECOM system was mainly subcontracted to Qualcomm who delivered “black boxes” according to the agreement on the two organizations validated by the EC. This does not allow a detailed internal examination of the French site system, however there was a crosscheck with D4.6.1 (confidential deliverable that includes more technical details) to see whether there were significant changes and additional or less components in the Kangoo vehicle used at the French test site. This kind of changes could potentially affect the manufacturing process, the overall cost and the deployment potential of the technology.

FABRIC IVECO Electric Vehicle overview

In the following figures the IVECO vehicle used in Italian tests is presented.

Figure 3: IVECO van used for the Italian tests and its 3D model that was used for charging pad design and mounting simulations.

The following figure shows the main components of the IVECO electric vehicle. The IVECO Daily Electric can have different layouts according to the desired range of autonomy and load capacity. For this reason different modular battery packs (ranging from 2 to 4) can be installed to fit different mission ranges (from 90 to 130 km), on two different Daily configurations, with different weights and, consequently different ranges.

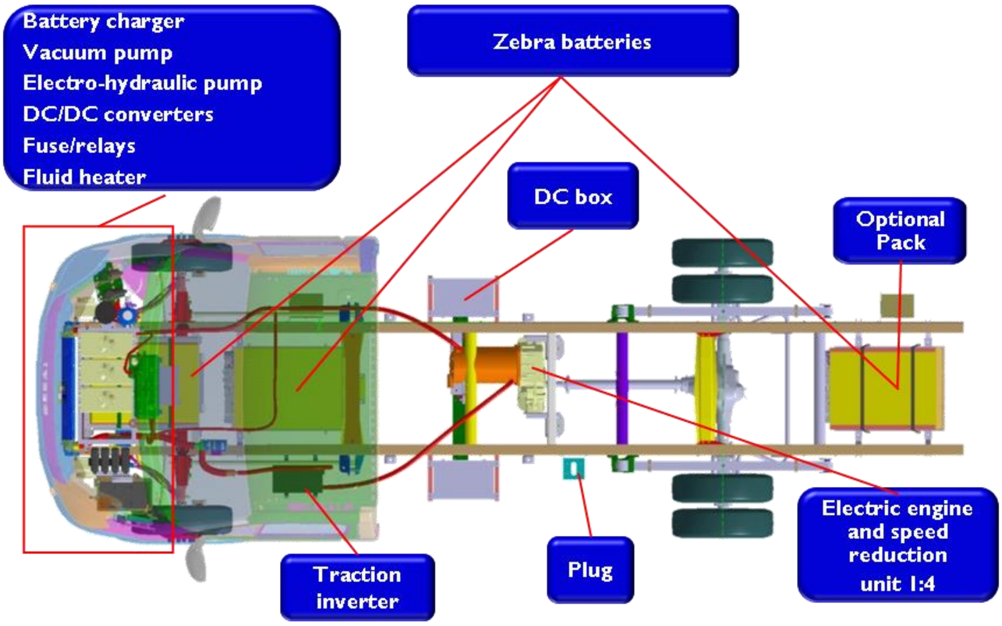


Figure 4: System layout of IVECO electric Daily, as a basis for secondary device installation.

Secondary coil mounting structure

The structure that hosts the secondary coil can be seen in Figure 5. It was installed at the rear part of the vehicle (behind the rear axle, on the rear overhang – see) since this area is the most acceptable for the coil placement, there are no moving parts or other electrical/electronic (E/E) systems that could interfere with the new system.

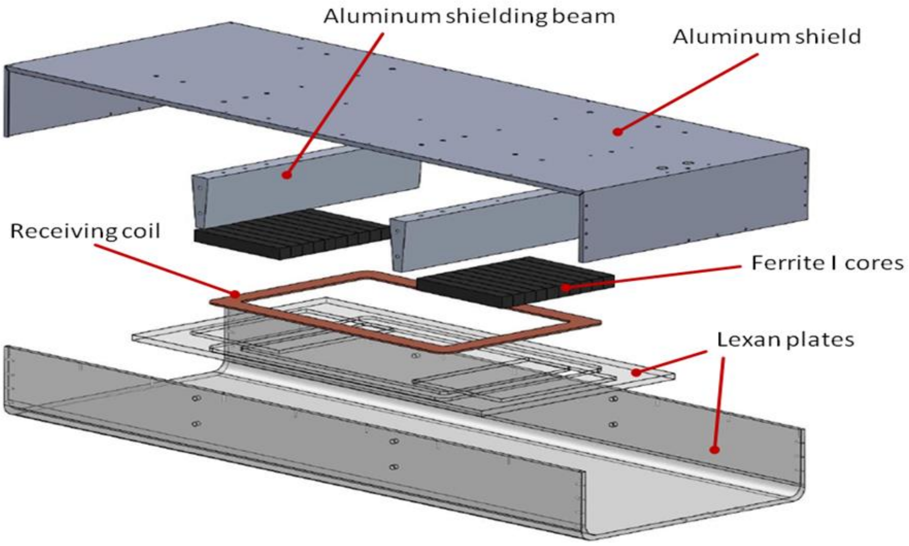


Figure 5: Mechanical structure for hosting and mounting the secondary coil on the IVECO electric vehicle.

Figure 6: Vehicle mounting of secondary coil structure.

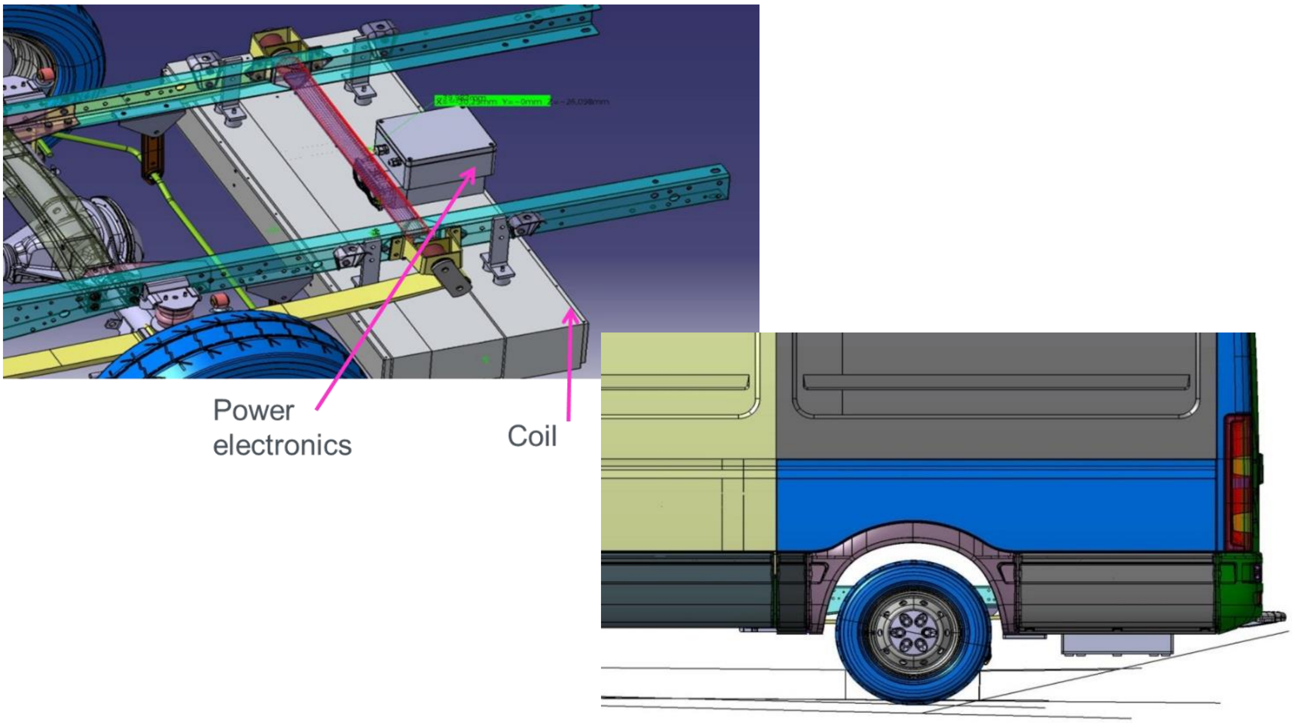


Figure 7: New elements added on the existing electric vehicle and installation side view.

ICT related components

Figure 8 shows the functional architecture of the vehicle side of the charging system. Existing equipment needs to be upgraded with new software to support the additional functionalities (not relevant to supply chain) and new equipment needs to be installed. This includes a simple camera for the operation of the Lane Keeping System, cabling, and additional telecommunications equipment for V2I communication.

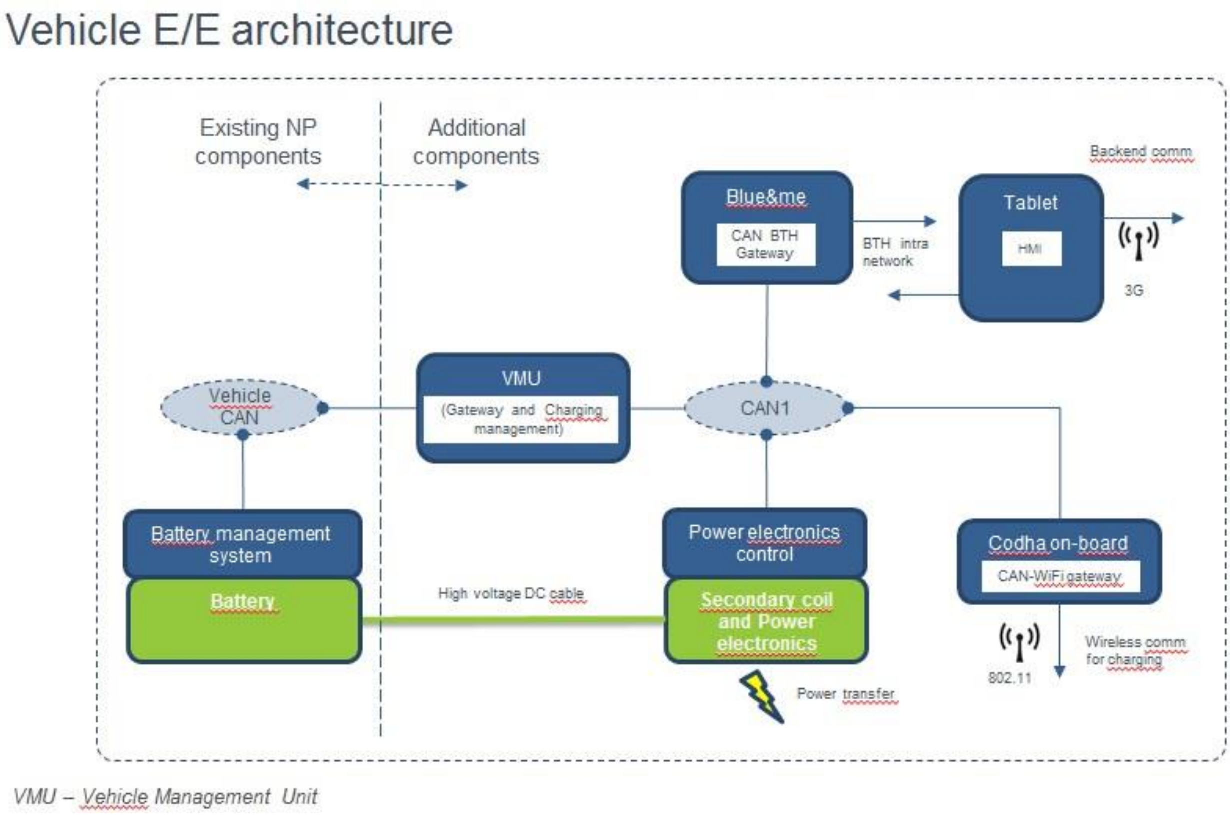


Figure 8: IVECO EV E/E architecture.

From the data above the components necessary for the construction of an EV with dynamic wireless charging capabilities can be identified. These components are listed in Table 1. The present study focuses on the new elements that are introduced to the electric vehicle to enable dynamic wireless charging. Supply chain issues regarding existing elements are considered to be solved by the OEMs. The manufacturers or suppliers of the components have been identified (but not reported in this document) in order to be interviewed for assessing their supplying capability in relation to future system demand

Table 1: Mechanical, electrical and electronic components of FABRIC IVECO EV.

Nº	TYPE	DESCRIPTION	New or existing component
1.1	**ELE**	**VEHICLE POWER MANAGEMENT DEVICES**	
1.1.1	**ELE**	**Vehicle WPT module**	
1.1.1.1	ELE	Secondary Coil	New
1.1.1.2	ELE	Secondary resonance capacitor	New
1.1.1.3	ELE	Diode Rectifier	New
1.1.1.4	ELE	LC filter	New
1.1.2	**ELE**	**DC/DC converter**	
1.1.2.1	ELE	DC/DC converter and control board 12V	Existing

1.1.2.2	ELE	Acquisition Board (MECT with FPGA and NI SOM)	New
1.1.2.3	ELE	Power fuses on the high side of the DC/DC (100A 250V-400 Vmax)	Existing
1.1.2.4	ELE	2 Crowbar Circuits :1 for high voltage protection and 1 for coil identification	Existing
1.1.2.5	ELE	2 IN/OUT Shunt	Existing
1.1.2.6	ELE	Vicor 4 FUN HV/LV - DC/DC converter	Existing
1.1.2.7	ELE	2 Circuit breaker 12V (3Apk - 100mA)	Existing
1.1.3	**ELE**	**Battery module**	
1.1.3.1	ELE	HV Battery Pack (4 Modules - 26 Litium-Ion Cells)	Existing
1.1.3.2	ELE	Battery management system	New
1.1.3.3	ELE	DC-bus capacitors	Existing
1.1.4	**ELE**	**Traction module**	
1.1.4.1	ELE	Traction inverter	Existing
1.1.4.2	ELE	eMotor	Existing
1.2	**ICT**	**VEHICLE ICT COMPONENTS**	
1.2.1	**ICT**	**Vehicle Management Unit (VMU)**	
1.2.1.1	ICT	Vehicle Management Unit (VMU)	Existing
1.2.2	**ICT**	**Bluetooth control device (Blue&me)**	
1.2.2.1	ICT	Bluetooth control device (Blue&me)	Existing
1.2.3	**ICT**	**Codha-on board - Wifi 802.11p Gateway**	
1.2.3.1	ICT	Codha-on board - Wifi 802.11p Gateway	Existing
1.2.4	**ICT**	**Tablet (HMI)**	
1.2.4.1	ICT	Tablet (HMI)	Existing
1.2.5	**ICT**	**Front Camera & Software**	
1.2.5.1	ICT	Front Camera & Software	Existing
1.3	**MEC**	**MECHANICAL VEHICLE COMPONENTS**	
1.3.1	**MEC**	**Chasis and vehicle structure**	
1.3.1.1	MEC	Chasis and vehicle structure	New
1.3.2	**MEC**	**Transmission system**	
1.3.2.1	MEC	Transmission system	Existing
1.3.3	**MEC**	**Security, Advice and control vehicle Systems**	
1.3.3.1	MEC	Security, Advice and control vehicle Systems	Existing

2.1.2 Road side infrastructure component analysis

In FABRIC two test sites have been constructed for the evaluation of the wireless dynamic charging technology. The French test site road infrastructure involves a cement trench where the charging pads are installed and are then covered by special removable covers that allow the easy access to and replacement of the wireless charging components. The charging pads as well as power electronic components are supplied by Qualcomm as subcontractor of VEDECOM. Due to strict IP rights these components are considered black boxes and their technical specifications cannot be disclosed publicly.
On the other hand, the charging coils at the Italian test site have been embedded in the road pavement. This makes the installation more representative of future large-scale implementations since the cement trench method is convenient for testing but not expected to be deployable. In addition the Italian systems by SAET and POLITO have been described in more

detail in the public deliverable D3.5.1 and there is more information that can be disclosed regarding the components used and their manufacturers.
For the reasons above the supply chain analysis is focusing on the Italian dynamic wireless charging systems.
In Figure 9 a schematic of the POLITO wireless charging module can be seen. Besides the coil it includes the power electronics and **proprietary** capacitors with their corresponding protective housings. Several of these modules can be used in series to form a dynamic wireless charging lane as shown in Figure 10.
A similar configuration is used for SAET charging coils, however the coils have different number of turns using significantly less copper.

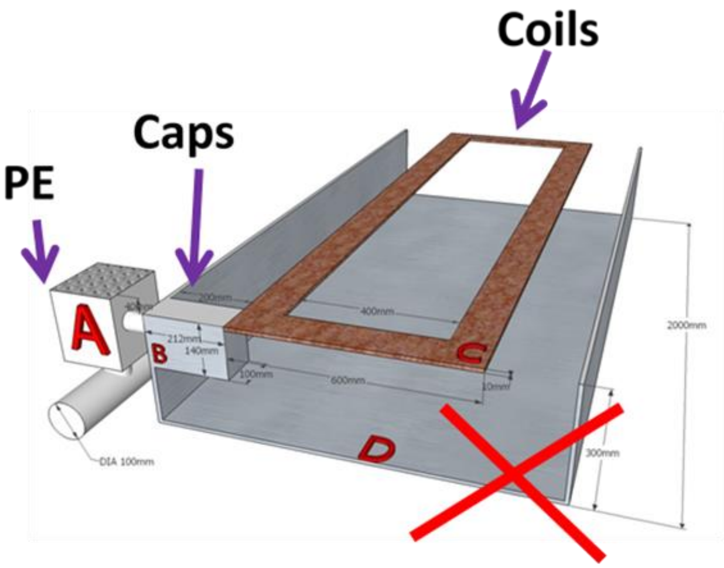


Figure 9: POLITO wireless charging road-side module.

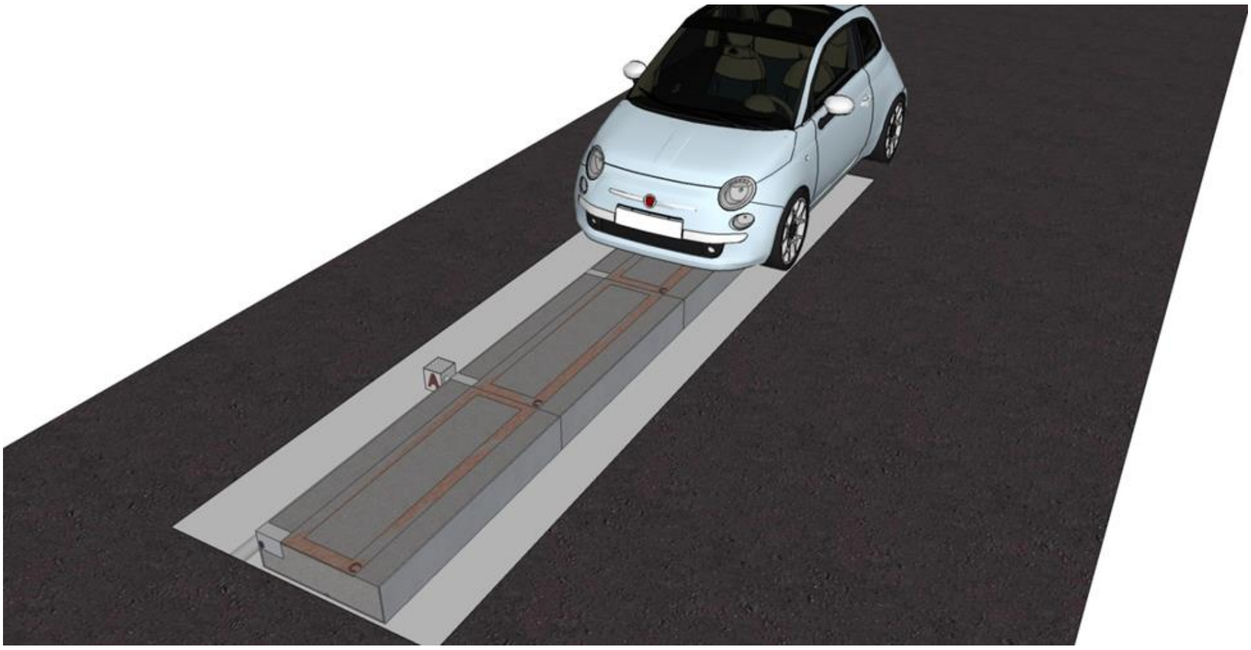


Figure 10: Depiction of a charging lane using the POLITO (or SAET) wireless charging modules, which are embedded in the road pavement (depth = ~5cm).

The POLITO solution consists of 2 branches of 25 coils individually fed by DC/HF converters. Each coil has a DC/HF converter and the distribution is at 600VDC. The feeder can be connected in parallel on the same cable.
In addition, a supercapacitor solution is provided to balance the possible load variations.

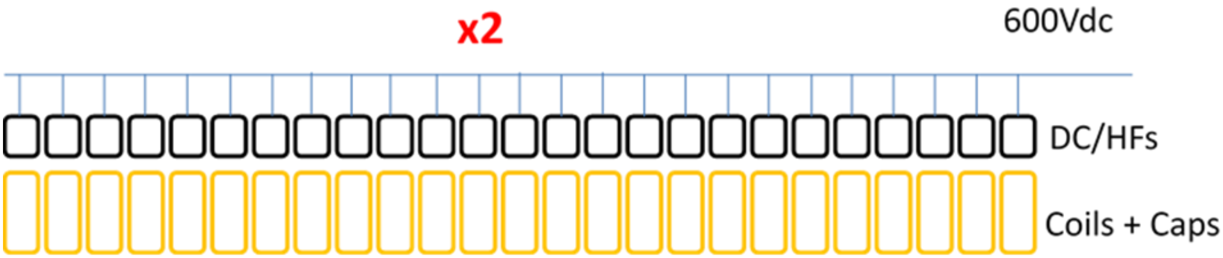


Figure 11: POLITO system test site layout.

This architecture is modular and the segments can be repeated indefinitely to create an e-road in real implementations.

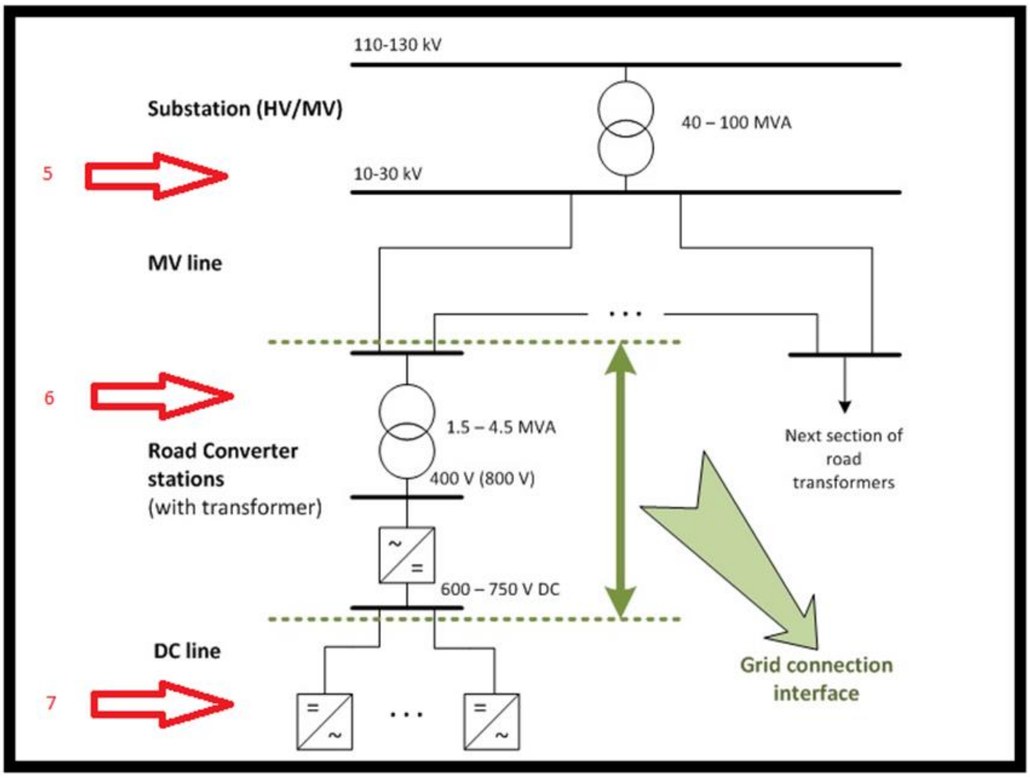


Figure 12: POLITO/SAET systems' connection to the grid architecture

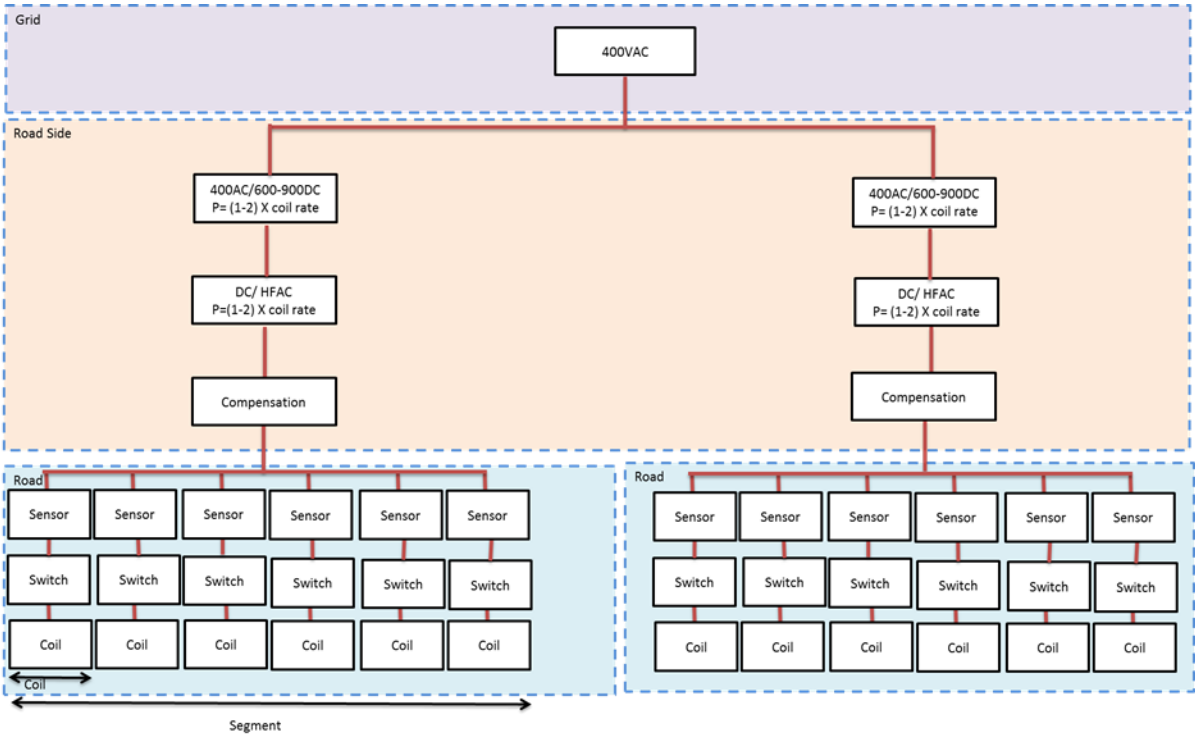


Figure 13: POLITO road side architecture (from level "7" of Figure 12 to the edge implementation of the coils)

From the above, the following list of components can be derived.

Table 2: Road-side components of Italian dynamic wireless charging system.

Nº	TYPE	DESCRIPTION	New or existing component
2,1	**ELE**	**GRID CONNECTION**	
2.1.1	**ELE**	**HV/MV Substation**	
2.1.1.1	ELE	40-100MVA Transformers with 100-130KV/10-30KV	Existing
2.1.1.2	ELE	Power switch	Existing
2.1.1.3	ELE	Transformer sound proof cell	Existing
2.1.1.4	ELE	Earthing system	Existing
2.1.2	**ELE**	**MV to LV connection**	
2.1.2.1	ELE	Wiring from HV (100-300KV) to the electrical Substation	Existing
2.1.2.2	CW	Pole and other structure components	Existing
2,2	**ELE**	**ROAD POWER MANAGEMENT DEVICES**	
2.2.1	**ELE**	**Road converter station**	
2.2.1.1	ELE	1,5-4,5MVA Transformers with 10-30KV/400-800V	Existing
2.2.1.2	ELE	400-800VAC/600-750VDC Inverter, able to connect with the grid	Existing
2.2.1.3	ELE	Power switch	Existing
2.2.1.4	ELE	Transformer´s sound proof cell	Existing
2.2.1.5	ELE	Earthing system	Existing
2.2.2	**ELE**	**Road High Voltage DC bus**	
2.2.2.1	ELE	DC cables from grid converter to HF converters	Existing
2.2.2.2	ELE	DC-bus capacitors	Existing
2.2.3	**ELE**	**Road WPT module**	
2.2.3.1	ELE	Module encapsulation	New
2.2.3.2	ELE	HF converter	New
2.2.3.3	ELE	Resonance (HF) capacitor	New
2.2.3.4	ELE	Primary Coils	New
2,3	**ICT**	**INFRASTRUCTURE ICT COMPONENTS**	
2.3.1	**ICT**	**Design of remote measurement**	
2.3.1.1	ICT	Telecommunication systems	New

2.2 Conductive dynamic charging system decomposition

The conductive ERS is based on the Aesthetic Power Supply (APS) technology developed by Alstom for the tramway in Bordeaux city. The embedded system is made by a segmented road rail and power boxes manholes. The power is transferred through a pick-up arm installed beneath the vehicle (Figure 14).

Figure 14: Volvo conductive ERS “Slide-in”.

2.2.1 Electric Vehicle component analysis

In Figure 15 a system overview of the test vehicle used in the Slide-in[2] project is provided:
The additional new subsystems for the test vehicle are:

1. Extra 24 V battery for pick-up control; (existing)
2. Resistor bank for power dissipation; (existing)
3. Power to vehicle adapter; (new)
4. Camera + display for driver support; (existing)
5. Cameras for logging; (existing)
6. Pick-up mechanical component; (new)
7. Pick-up control box; (new)
8. Radio emitter (including antenna) for ERS (new).

Bullets 1-5 are only for test purposes and will not be needed in future EVs. However there are other components that may be needed:

- To charge the battery while driving (not only transfer power for traction) an on-board charger or DC-DC converter is needed as well;

[2] Slide-in Electric Road System https://www.viktoria.se/projects/slide-in-electric-road-system

- Filter components for surge protection; and
  - Surge arresters
  - Inductors
- Power control.
  - Contactors including pre-charge circuit
  - Fuses
  - Voltage sensors
  - Current sensor
  - Isolation monitor

For the above, supply chains are already in place since they are not custom or new components.

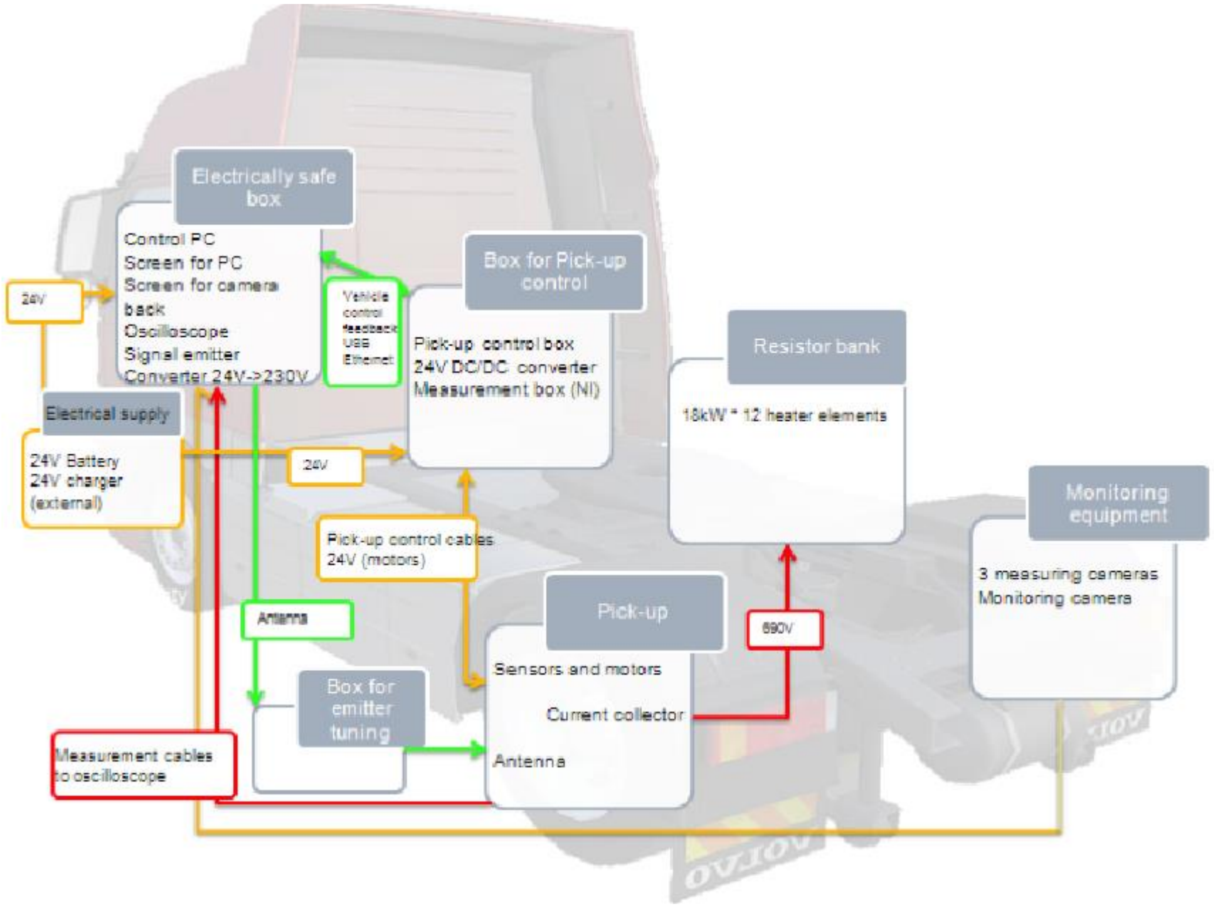


Figure 15: Volvo conductive charging test vehicle (system overview)

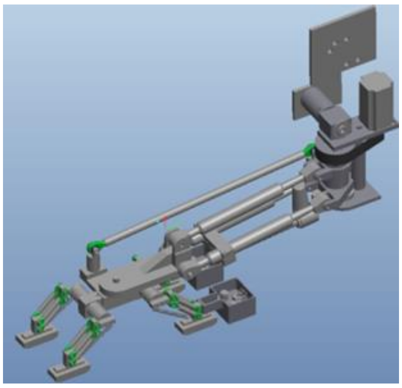
"Pickups" for conductive ERS system

The Slide-in project designed two different pick-up prototypes to enable physical contact between the vehicle and the road rails:

- The "turning pickup": where lateral movement was controlled by a turning, rotational movement, facilitated by an electrical motor that is attached to the

vehicle body. The vertical movement of this turning pickup prototype was enabled by a linear electrical motor, which was part of the pick-up moving body. See left picture in Figure 16.

- The “linear pickup”: where lateral movement was controlled by a linear movement, along a straight axis between the 2 main frames of the vehicle body. The vertical movement of this linear pickup prototype was enabled by a pneumatic actuator, which was supplied with (high pressure) compressed air from the vehicle pneumatic system. See right picture in Figure 16.



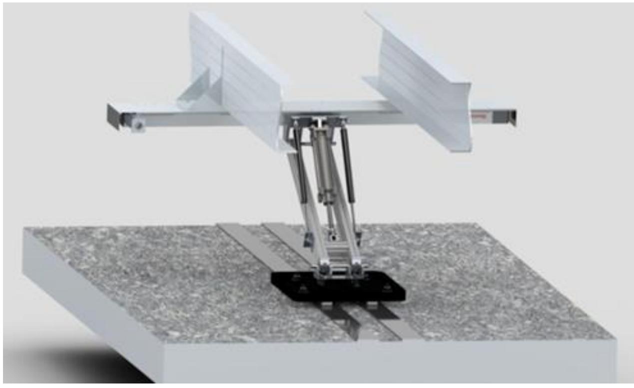


Figure 16: Conductive project pickup prototypes

Both of these pickups have been installed onto the test truck, and both of them have been tested. During early development, in the project, the pickups were tested mounted at the rear of the truck. The turning pickup was designed so that it can be installed under the vehicle, see Figure 17, and positioned safely (in a home position), securing vehicle 25cm of ground clearance, when it was not in operating mode.

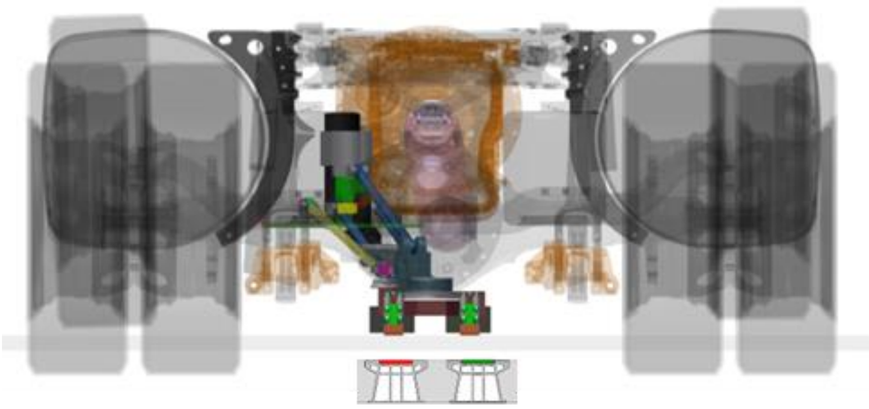


Figure 17: Truck with pick-up and road with two parallel rails

2.2.2 Road-side infrastructure component analysis

Volvo's ERS system is based on conductive energy transfer, the power is transferred from the rails that are in flush with the road, to the vehicle via on-board pantograph (pickup). The ground module consists of positive rail and ground rail in parallel, the system also has an additional ground rail next to the positive rail to prevent creep current over long distances. Figure 18 shows the road-side set up for ERS system. 750 V_{DC} substations are located every 968m to collect power (30 KV), then step this down to 800 V_{AC}, the 800 V_{AC} runs along the roadside and connected to the road side equipment every 88m. There are manholes with two power boxes powering two 44m segments, the power boxes convert 800V AC to 750V DC segments. Each section consists of 22 sets of 44m rails and each segment provides energy to one ERS vehicle at one time. 210 mm^2 copper cables are required for 750 V_{DC} and additionally 210 mm^2 copper cables with 0 V_{DC} for return current. These cables could potentially be formed by 3 x 70 mm^2 cables in parallel. Each power box feeds two road segments.

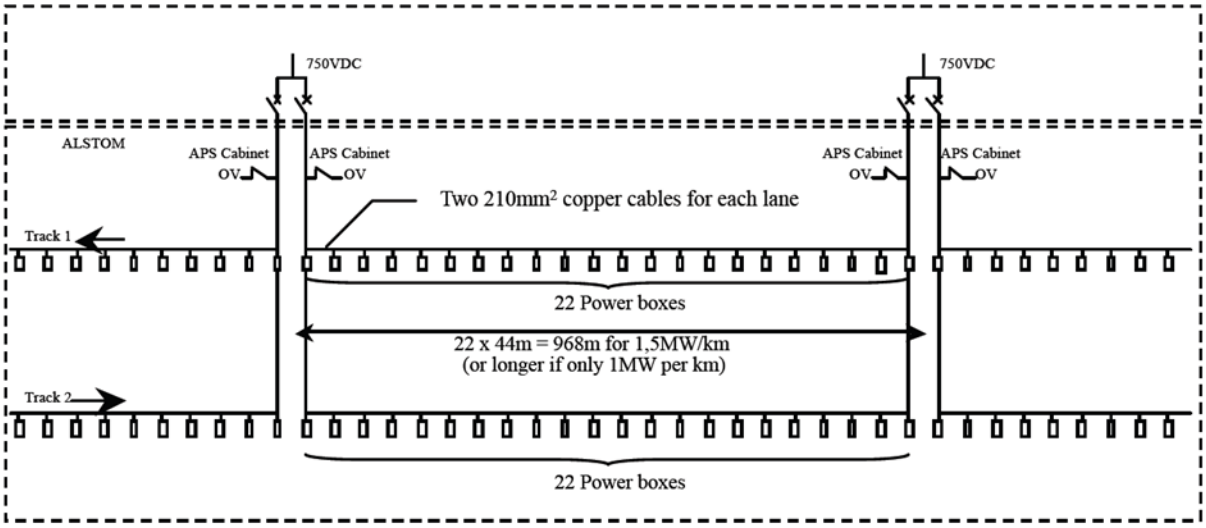


Figure 18: Road-side set up

Figure 19 shows the connection layout in full deployment scenario. The connection from the grid is from a 132 kV feeder point at every 10-40km (dependent on demand). 30kV cable runs along the road side and every 968m, the voltage is transformed down and converted to 750VDC, this power supply runs along 968m connecting to the power transfer segment every 44m.

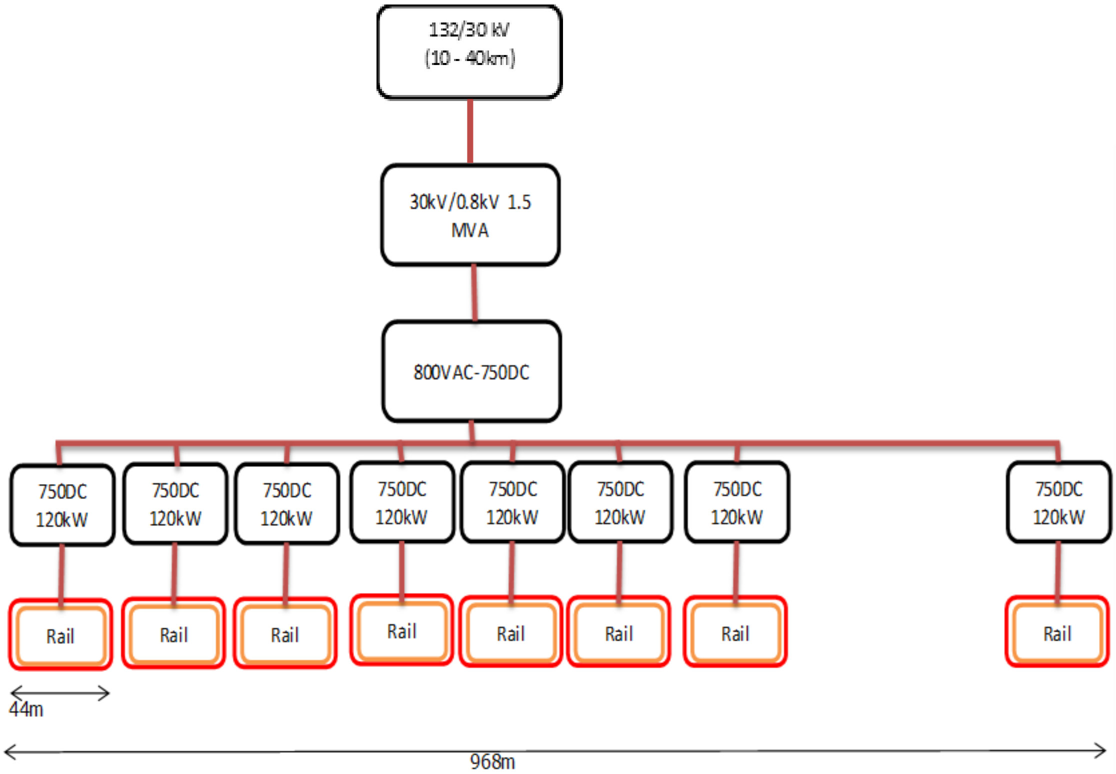


Figure 19: Full deployment layout for ERS system.

Table 3: Volvo on-road solution parameters

Parameter	Unit
Distance between feeder transformers	968
Distance between road side equipment	44 m
Number of roadside equipment per feeder transformer	22
Length of a segment	22 m
Positioning in the road	Central

In the following figures a more detailed architecture is provided showing the necessary components for the connection to the grid. The proposed configuration consists of road substations including two redundant 130/30 kV transformers, and the road distribution network made of 1 or 1.5 MVA substations each km.

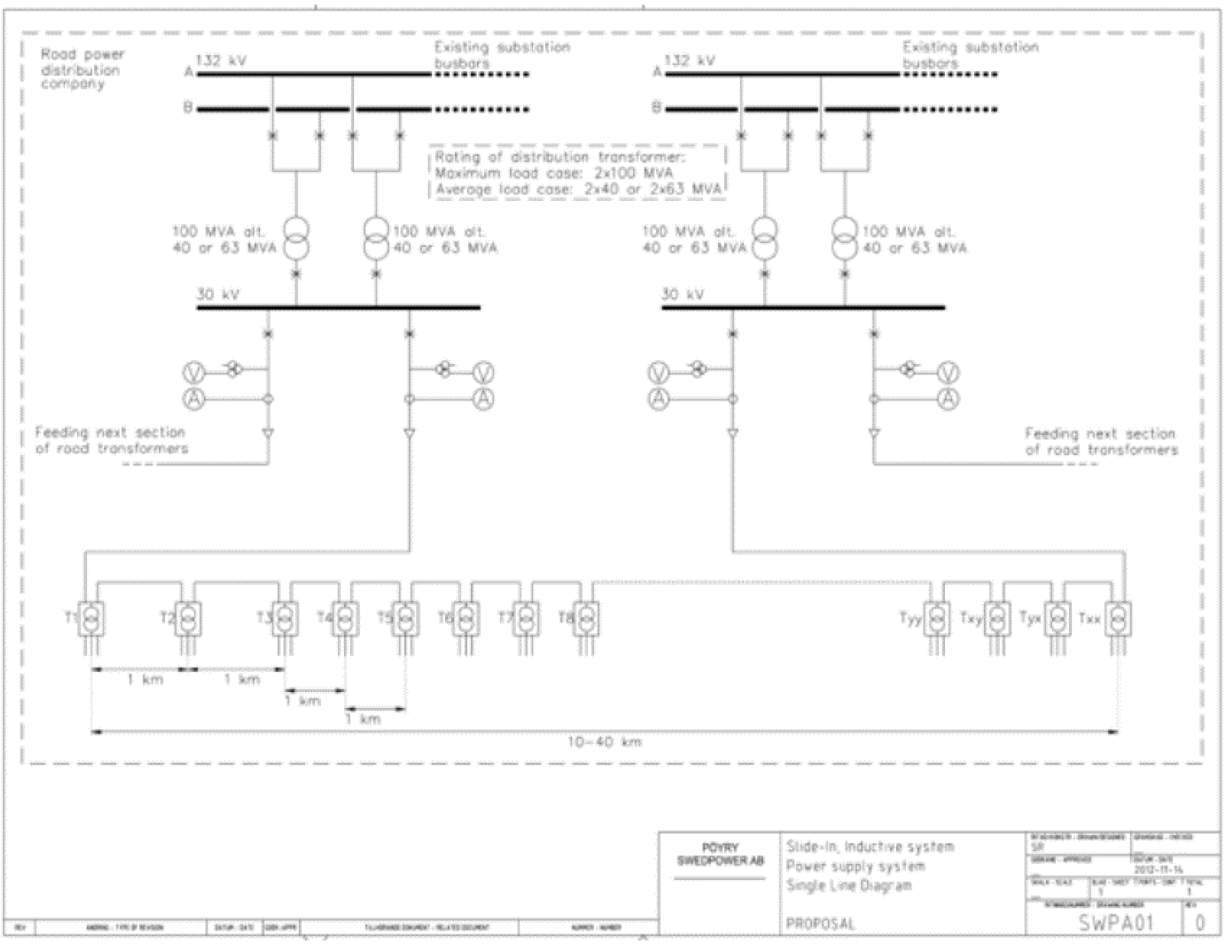


Figure 20: Alstom ERS power grid design from 130 kV down to the distribution (road) substations

The solution was developed in partnership with Alstom and the system was demonstrated in Volvo's test site in Sweden. Alstom has developed the ground systems such as conductive rails, control and protection electronics and connections to the grid. Volvo has developed on-board solutions with support from Swedish Universities and Institutions.

The speed of the vehicle is the key factor on determining the length of the live segments, for safety reasons the power from the ground module to the vehicle will only be activated between speeds of 60km/h to 100 km/h, therefore the systems uses speed detection loops to activate the power supply. Figure 22 shows the speed detection loops that monitor vehicle speed and the direction. The signal from the loops detect the direction of the vehicle with long pulse first, then two short pulses indicating vehicle is moving from left to right, and speed is calculate by the time it has taken to drive over the detection loops.

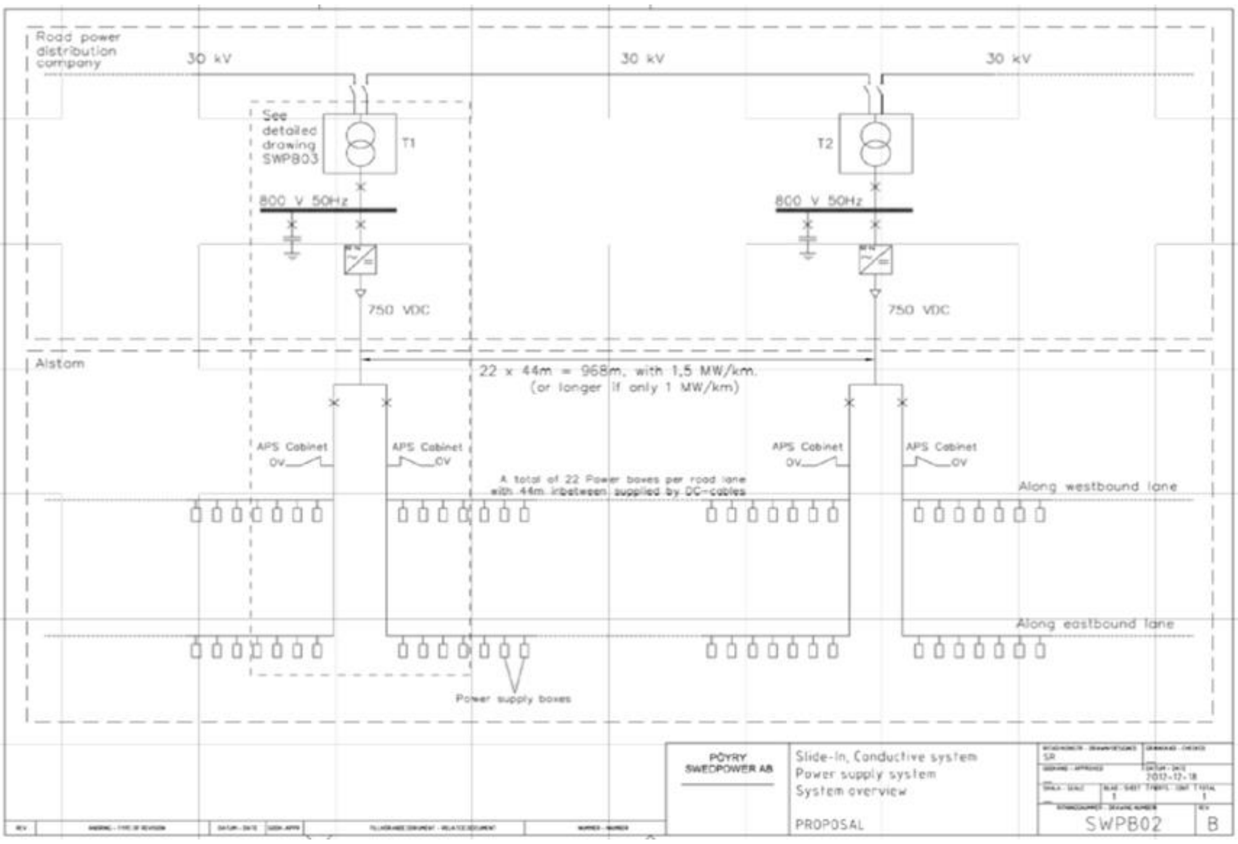


Figure 21: Alstom ERS power grid design from the 30 kV distribution substations down to the road integrated 750 VDC distribution system.

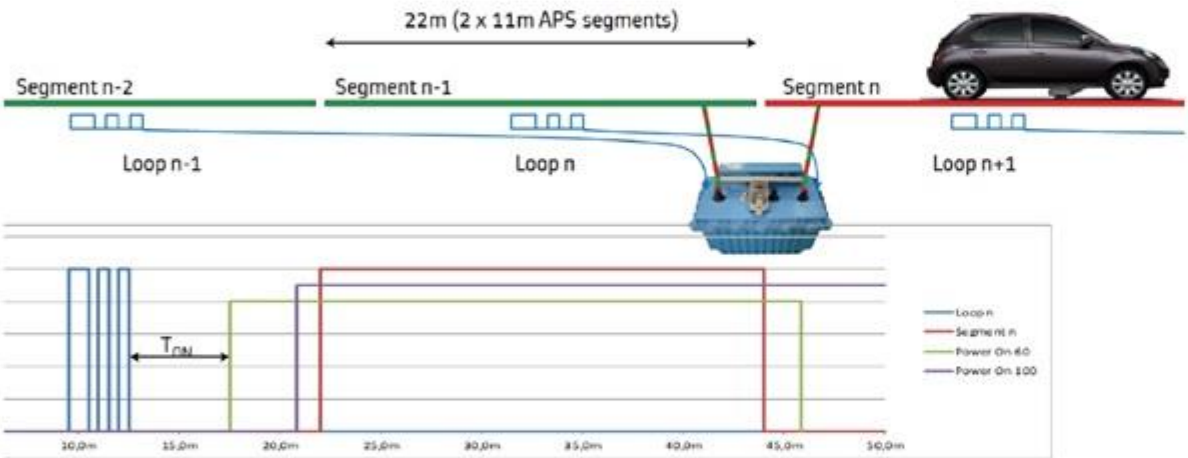


Figure 22: Estimation of vehicle speed.

A power box energises a segment and connects it to the 0 V. It has different switching and supply devices as shown in Figure 23. For example, it contains an electronic unit for the managing of the safety line with the other power boxes; a communication unit for continuously informing the substation about the box status. If the signal does not reach the substation, a short-circuit is closed in order to protect the whole section.

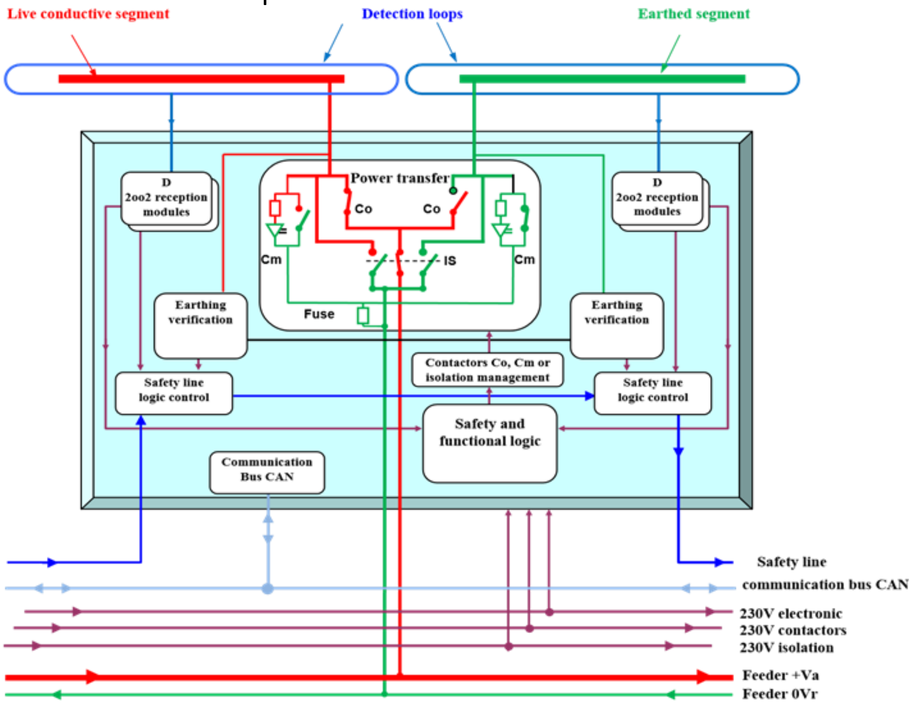


Figure 23: Volvo ERS Power box.

The power rails are installed as a pair of side-by-side conductors, one delivering the "live" voltage and the other held at or near earth potential to provide a return path and hence complete the electrical circuit. Figure 24 shows a cross-section through one of the conductor rails for the APS. Note however that an updated version improved for road integration is under development.

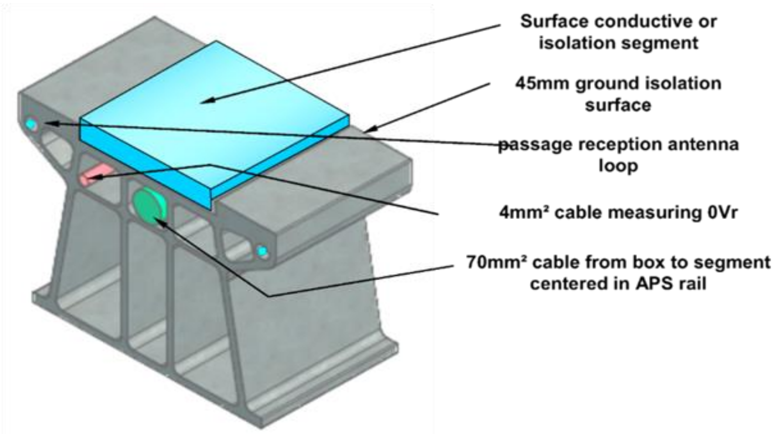


Figure 24: Cross section of the APS rail.

3 DEMAND FORECAST

3.1 Introduction

The estimation of the future e-corridors demand is not simple, as many factors could change in the next years, affecting the final deployment process. The consortium's approach is based on assumptions which will be explained in detail later in this chapter, but are also mentioned below to provide an initial understanding of the method.

- It is clear, that e-corridors are absolutely linked to the EV deployment. Without a sufficient mass of EVs on the roads, any e-corridor will be unsustainable as the investment costs are relatively high. In addition, not all EVs and PHEVs (from here onwards EVs) will be equipped for the wireless or conductive dynamic charging. Thus, an estimation on how many of these vehicles will be suited for this technology is another input parameter.

- Unfortunately, EV penetration is also a parameter that is difficult to estimate. We have identified at least the following affecting parameters;
  - Cost of batteries by energy density (gravimetric kWh/kg and/or volumetric kWh/dm3).
  - Government policies, subsidies or support.
  - Global mandatory CO_2 emission targets, CO_2 fees.
  - Global fuel (oil) prices which also depend on EV deployment itself and other strategic factors (alliances among producers, proven reserves, global consumption).
  - Global strategic alliances (car producers, government compromises).
  - Global charging network deployment.
  - Electricity prices.

  Many of these factors depend also on third level factors which are out of the scope of this analysis.

- After revising a large number of roadmaps for 2020, 2030 or 2050, published from 2010 onward, our conclusion was that deviation from real EV deployment numbers (up to 2017) was increasing with age of the study, but not as one would expect. Indeed, some countries have evolved much faster than expected and some others much slower. Besides, some key factors misaligned with the natural evolution of the market are highly influencing the speed of the deployment process. i.e., political decisions or risky entrepreneurial investments are rapidly modifying the overall picture. For that reason, we believe that the penetration of the EVs will not follow a soft curve but will probably be disruptive and possibly surpass the

most optimistic scenarios. Some of these key factors are: Tesla's Gigafactory sales forecast for the next year 2018 reaches 500,000 (batteries and the corresponding cars) representing, for instance, almost 2/3 of total EV sales in 2016. This will move very quickly the manufacturing cost of the battery to 130$/kWh and later to 100$/kWh (a target initially foreseen for 2020 that will be for sure improved), making EVs more competitive. China is also another key player with an impressive EV sales growth of 48% from 2015 to 2016, compared with 32% in Europe and 30% in the US. Finally, some compromises and active policies promoting electromobility from specific countries such as Norway or the Netherlands are moving the figures up very fast. Market shares reached 23% in Norway and nearly 10% in the Netherlands in 2015[3]. These and other factors led to the view that the market penetration of the EVs will follow a similar pattern as the cell phone deployment (disruptive jumps of sales).

- "Technological solutions' deployment is notoriously hard to predict. Many have missed the mark in the past – for example, McKinsey and Company's 1980 projection of 900,000 mobile phone subscribers by 2000; the number was in fact 109 million[4]."
- Another assumption is that the dynamic charging solutions will be available after the static wireless charging solution is fully deployed. In addition, autonomous driving will be required (or highly desired) for a perfect alignment in the e-corridors to avoid inefficient charging (and accounting disputes between the charging infrastructure operator, the energy supplier and the drivers) and to keep the maximum speed, optimal distance between vehicles permitted in such e-corridors. Some experts consider autonomous driving market introduction from 2025 on, so we fixed 2030 as maybe the entry date for dynamic solutions. Nevertheless, it should be noticed here that Tesla's new Model 3, to be rolled out in the end of 2017, is already equipped with all the hardware necessary for fully autonomous driving as well as have been all other cars made by Tesla after October 2016. Concerning the static wireless charging, some FABRIC partners believe this will happen very soon (maybe next year). For dynamic wireless charging a critical mass of EVs is needed. When static wireless charging is widely accepted the update to dynamic charging will only cost around 400€[5].
- E-corridors will be stretches of one (the most right) lane of regular motorway without any separation and other vehicles (not charging) will also be able to use it, as the charge only applied directly underneath an authorized vehicle. FABRIC experts don't consider the

[3] Global EV Outlook 2016, International Energy Agency

[4] Expect the Unexpected. The Disruptive Power of Low-carbon Technology. Carbon Tracker Initiative.

[5] Opinions of Renault (VEDECOM) experts.

variability of speeds or the higher probability of foreign objects on the corridor as a problem.

- Some controversies have also arisen among main FABRIC researchers in relation to the battery size concept. From the LCA implemented by POLITO in the EVs, a bigger size of the battery will lead to a major environmental impact at factory premises than manufacturing a conventional petrol vehicle. That moved some researchers to propose reduced size of batteries and a huge deployment of e-corridors. However, the energy captured with small batteries will not increase substantially the vehicle autonomy and thus will maybe jeopardise the decision-making process of the vehicle owner. For the special case of the heavy vehicles (trucks and buses), this will be the case (reduced batteries) as bigger batteries are not possible due to space constraints and the only solution to substitute the very pollutant conventional heavy vehicles is adapting a small battery and the easy access to dynamic or static charging facilities. For the light vehicles case, the range extended concept (with a medium to large battery) will be more appreciated by the end users, so this will be the business model selected. So, it is assumed that the e-corridor will be long enough to provide an extended range of autonomy to the light EVs permitting them to travel an additional distance (first estimations of 20% of the autonomy), specially for intercity travels.
- It is important to estimate the average autonomy of the EV by 2030, when the uptake of this technology is expected. There is a consensus between 400 km to 600 km for light vehicles and vans. For the special case of the e-trucks and e-intercity buses, some of these vehicles are already available (China) with autonomies of 200-300 km of range on average.
- Due to the space constrains of these e-corridors, major motorways (with more than 3 or 4 lanes) are considered as most probable for initial deployment. These large motorways are identified within the TEN-T EU network which it is also planning to be upgraded in some sections with green corridors for electric and hydrogen vehicles. So, distances of about 400 to 600 km between cities will be perfect to install one or two e-corridors per traffic direction. For the HDV and intercity buses connections of large cities with surrounding areas (villages, distribution and storage centres, etc.) the suitable distance will be between 200 to 300 km (required autonomy for the daily operation in the tertiary sector). Conductive technologies will be also possible in these cases.
- A final assumption is that congested motorways will be candidates for the technology deployment with trucks and busses on short haul repetitive routes being the first to be introduced.

3.2 E-Corridors demand calculation

As outlined in the introduction, the e-corridor potential market has been estimated taking into account the factors shown in the following table:

Table 4: Methodology to calculate the e-corridors forecast

	STRATEGY TO CALCULATE E-CORRIDORS FORECAST
1	Analysis of historic EV sales & stock data in Europe and rest of the world
2	Benchmark external roadmaps for EVs (BEV + PHEV) penetration till 2050
3	Identification of major key factors affecting the EV sales
4	Identification of new key factors unknown in previous reports
5	Forecast EV stocks from literature (EV + PHEV) till 2050 (deregistration after 10 years)
6	Identification of more active EU countries in promoting EV cars
7	FABRIC EV deployment Scenario
8	Definition of business models; Light EV in trips among cities and HDV in short distance trips
9	Location of widest and congested motorways between cities at distance 400-600 km
10	Location of widest and congested motorways in neighbourhood traffic at distance 200-300 km
11	Revision of TEN-T plans to enlarge some congested motorways adding a green corridor
12	Matching active countries supporting EV and widest congested motorways for 2 business models
13	The effects of the e-corridors in the EV market
14	Other aspects affecting the demand.

3.2.1 Analysis of historic EV sales & stock data in Europe and rest of the world

Though electric cars have a very long history, the modern intent to introduce them to the mass markets is motivated by the necessity to decarbonize the transport system. A noteworthy amount of EVs is first seen in 2010. Since then, certain countries have managed to grow their EV market in close to exponential manner (USA, China, Japan, Netherlands, Norway, France, UK and Germany). A lot of this growth is correlated to political incentives. Later in the document the incentives and how they are structured in the most advanced European countries will be analyzed.

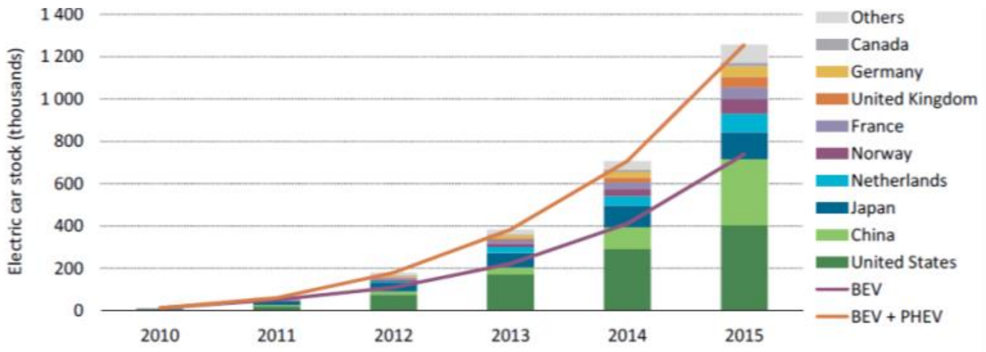


Figure 25: Evolution of the global electric car stock 2010 – 2015[6].

The EV Sales followed a similar steep growth path. Maybe there is just an unusual amount of EVs being sold in recent years, but considering the combination of favorable conditions more likely the long awaited EV-boom has begun.

The distribution of EVs (BEV and PHEV) by continent is depicted below:

Table 5: EV Sales distribution by region (2010-2016)[7]

Electric Car Sales (BEV and PHEV) 2015 [1]							
Thousand units							[2]
AREA	2.010	2.011	2.012	2.013	2.014	2.015	2.016
EUROPE	1,07	9,77	24,29	42,61	82,83	167,37	221,00
AMERICA	1,19	18,25	55,26	99,82	123,85	120,83	157,00
ASIA	4,28	18,43	36,41	45,27	85,59	236,85	351,00
AFRICA	0,00	0,00	0,00	0,03	0,01	0,24	0,29
OTHERS	0,00	1,74	2,76	4,28	10,83	25,30	21,50
TOTAL	6,54	48,19	118,72	192,01	303,11	550,59	750,79
Share of electromobility/car sales							1,00%
Sales estimates (all light vehicles)							75.079,00

[6] IEA: Global EV Outlook 2016

[7] Data Global EV Outlook 2016. Beyond one million electric cars, OECD/IEA, 2016, International Energy Agency [2] Provisional data. Source. Press release, light Vehicles Forecast 2050 just for Europe, April 2017, Schlegel und Partner

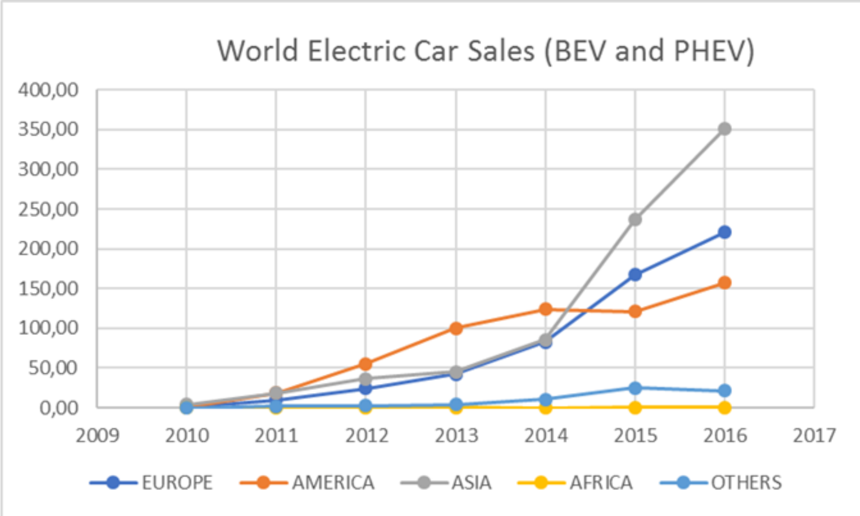


Figure 26: EV sales distribution by region

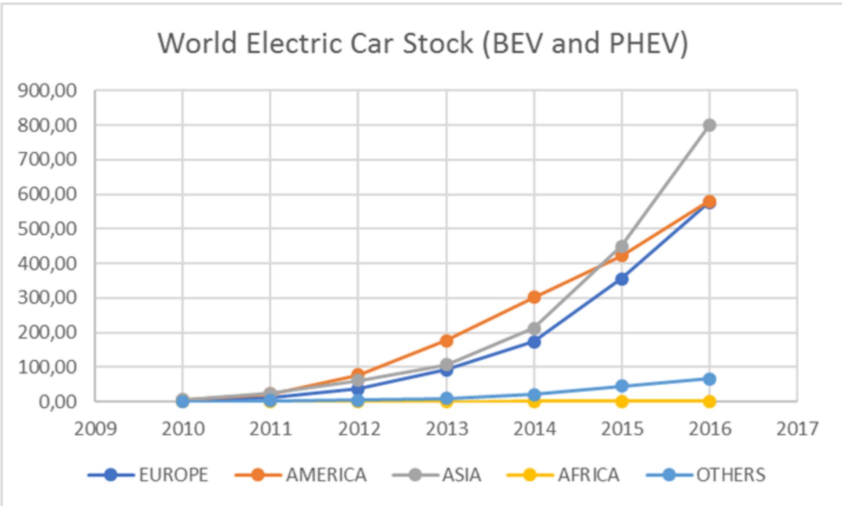


Figure 27: EV stock distribution by region

Table 6: EV Stock distribution by region (2010-2016)

Electric Car Stock (BEV and PHEV) 2015 [1]							
Thousand units							[2]
AREA	2.010	2.011	2.012	2.013	2.014	2.015	2.016
EUROPE	2,82	12,58	36,82	91,36	173,92	355,54	576,54
AMERICA	3,77	22,02	77,34	177,15	301,00	422,54	579,54
ASIA	5,89	24,31	60,59	105,78	212,19	449,04	800,04
AFRICA	0,00	0,00	0,00	0,03	0,05	0,29	0,58
OTHERS	0,00	1,73	4,48	8,76	19,59	44,89	66,39
TOTAL	12,48	60,64	179,23	383,08	706,75	1.272,30	2.023,09
Share of electromobility/car sales							1,00%

The distribution by country of new registrations and the available stock by country is depicted in the following tables.

Table 7: Electric car stock breakdown (2010 -2015)

Electric Car Stock (BEV and PHEV) by country 2010-2015 [1]

Thousand units		2.010	2.011	2.012	2.013	2.014	2.015
EUROPE		2,82	12,58	36,82	91,36	173,92	355,54
	Netherlands	0,27	1,14	6,26	28,67	43,76	87,53
	Norway	0,79	2,80	7,21	15,42	35,21	70,82
	France	0,30	2,93	9,25	18,88	31,50	54,29
	United kingdon	0,29	1,37	3,78	7,28	21,86	49,67
	Germany	0,25	2,34	6,13	13,25	26,03	49,22
	Sweden	0,19	0,37	1,25	2,65	7,09	14,53
	Italy	0,64	0,76	1,42	2,47	3,99	6,13
	Spain	0,07	0,65	1,20	2,21	3,66	5,95
	Portugal	0,02	0,22	0,32	0,53	0,82	2,00
	Austria						5,30
	Denmark						8,10
	Ireland						2,00
AMERICA		3,77	22,02	77,34	177,15	301,00	422,54
	Unites States	3,77	21,50	74,74	171,44	290,22	404,09
	Canada	0,00	0,52	2,60	5,71	10,78	18,45
ASIA		5,89	24,31	60,59	105,78	212,19	449,04
	China	1,43	6,50	16,40	31,74	104,91	312,29
	Japan	3,52	16,14	40,58	69,46	101,74	126,40
	India	0,88	1,33	2,76	3,13	4,02	6,02
	Korea	0,06	0,34	0,85	1,45	1,52	4,33
AFRICA		0,00	0,00	0,00	0,03	0,05	0,29
	South Africa				0,03	0,05	0,29
OTHERS			1,73	4,48	8,76	19,59	44,89
TOTAL		12,48	60,64	179,23	383,08	706,75	1.272,30

Table 8: Electric car new registrations (2010-2015)

Electric Car New registrations (BEV and PHEV) by country 2010-2015 [1]							
Thousand units		2.010	2.011	2.012	2.013	2.014	2.015
EUROPE		1,07	9,77	24,29	42,61	82,83	167,37
	Netherlands	0,12	0,88	5,12	10,33	15,09	43,77
	Norway	0,40	2,01	4,41	8,20	19,79	35,61
	United kingdom	0,10	1,08	2,41	3,51	14,58	27,81
	Germany	0,14	2,10	3,79	7,12	12,78	23,19
	France	0,18	2,63	6,33	9,62	12,63	22,79
	Sweden	0,00	0,18	0,93	1,55	4,67	8,59
	Spain	0,07	0,57	0,55	1,01	1,46	2,29
	Italy	0,04	0,12	0,66	1,06	1,53	2,14
	Portugal	0,02	0,20	0,09	0,21	0,30	1,18
AMERICA		1,19	18,25	55,26	99,82	123,85	120,83
	Unites States	1,19	17,73	53,24	96,70	118,78	113,87
	Canada	0,00	0,52	2,02	3,12	5,07	6,96
ASIA		4,28	18,43	36,41	45,27	85,59	236,85
	China	1,43	5,07	9,90	15,34	51,15	207,38
	Japan	2,44	12,63	24,44	28,88	32,29	24,66
	Korea	0,06	0,28	0,64	0,67	1,26	2,81
	India	0,35	0,45	1,43	0,38	0,89	2,00
AFRICA		0,00	0,00	0,00	0,03	0,01	0,24
	South Africa				0,03	0,01	0,24
OTHERS			1,74	2,76	4,28	10,83	25,30
TOTALS		6,54	48,19	118,72	192,01	303,11	550,59

3.2.2 Benchmark external roadmaps for EVs (BEV + PHEV) penetration till 2050

After analyzing a large number of forecasts conducted by different kinds of institutions, we can present a picture of what is vastly believed to be the rate of market penetration for EVs.

It is concluded that practically no one is doubting the fact that EVs will play a major role in decarbonizing the transportation system. Only the rate at which this will happen and the magnitude of said role is under question.

To estimate the future number of electric passenger cars (to which battery electric vehicles (BEV) as well as Plug-in Hybrids (PHEV) are included), a meta-study of all reports and forecasts relevant to the estimation of EVs on Europe’s roads up until 2020, 2030, 2040 and 2050 was carried out.

With sufficient data available, too old reports that were rendered obsolete by current data were excluded. Any forecast study older than 2010 was not taken into account. Even in the most updated reports (2016), some new important developments affecting the market penetration of EVs, were not considered. To address this, the most likely scenarios of these reports were taken as basis and calibrated to produce estimations that incorporate the latest trends and data.

In Figure 28 we depict all the roadmaps[8] considered.

Another complication was the fact, that many reports solely provided future sales estimations. However, the objective was to provide a clear number of cars in use (stock) to be able to derive from this how many of these cars might use any form of wireless charging.

Therefore, we did our own calculations on how the sales might accumulate to a certain number of cars in use in the future. Since none of the reports estimated or at least didn't publish data for every single year, an extrapolation was performed, assuming a market uptake trendline based on the available data points (2020, 2030, 2040, 2050) that were given by the reports. This trendline was formulated to

(1.) Match the given data points ($R^2 \rightarrow 1$) and

(2.) Make sense as to what a trendline for a market uptake of a disruptive technology is expected to look like (S-shape, when possible).

Further it was assumed that the life time of a car will be 10 years. This number is debatable, since on one hand EVs are expected to need much less maintenance and will last much longer than conventional ICE cars. On the other hand, it is a new, fast evolving technology. Customers might want to have the newest version with the newest features (self-parking, autonomous

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[8] - Winton N. (2016): Electric Car Sales Forecasts Crank Ever Higher, But In Europe Buyers Remain Unconvinced; *Forbes*, *(https://www.forbes.com/sites/neilwinton/2016/12/09/electric-car-sales-forecasts-crank-ever-higher-but-in-europe-buyers-remain-unconvinced/2/#4ec3f3b55df2)* → *Reference mentioning the Berenberg Bank, Morningstar and VDA*
- PWC (2016): Autofacts® Trends & Challenges of the Automotive Industry
- PWC (2016): Mit Elektrifizierung und Verbrennungsmotoren auf den Weg in die Zukunft der Mobilität
- McKinsey (2014): Electric Vehicle Report 2014
- IEA (2012): Energy Technology Perspective
- G. Pasaoglu et al. (2011): Potential vehicle fleet CO2 reductions and cost implications for various vehicle technology deployment scenarios in Europe

driving, advanced car sharing features, higher range). With this assumption (10 years average life), the deregistration rate based on the accumulated sales was accounted.

According to the IEA report, in Europe (2016), the total number of cars was 235,4 Mio units with 70.569 km of highways bringing the EV market share to 1,10%.

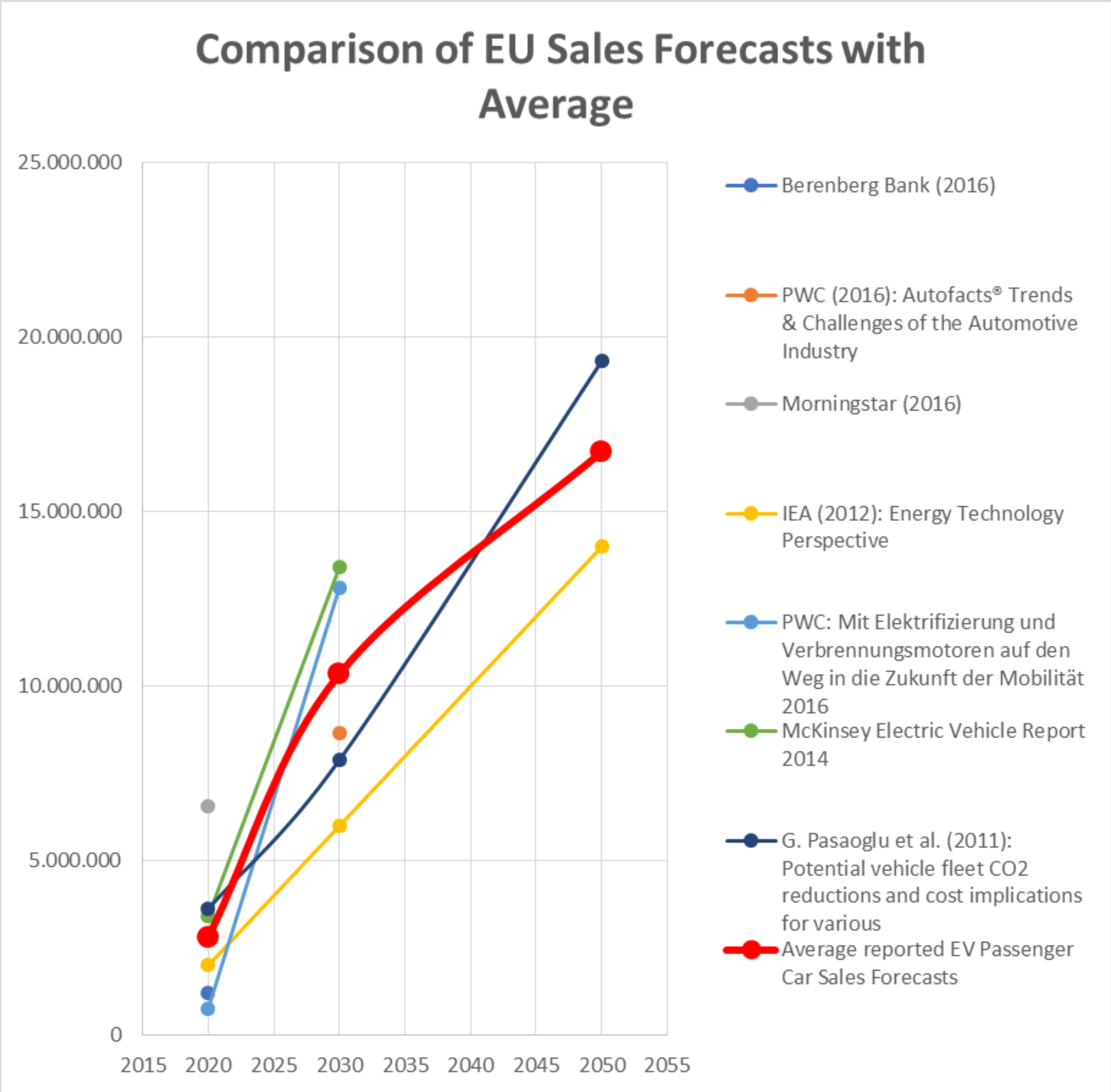


Figure 28: Overview of third Party Reports on EV Sales Forecasts and their Average

The following graph shows the European EV stock and sales forecast based on accumulated sales predicted by various reports in their high penetration scenario. For reasons explained later in this report, this will be considered as the **base scenario.**

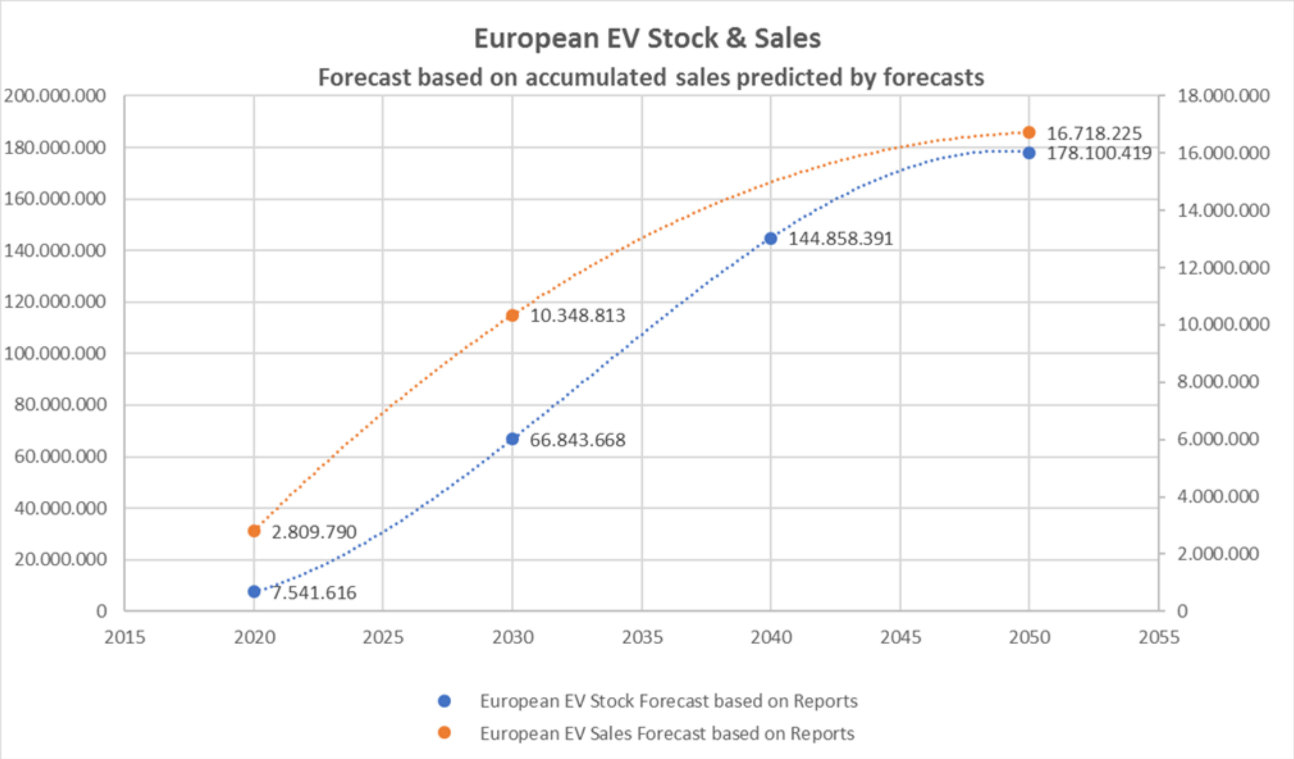


Figure 29: EU EV Stock & Sales forecast base scenario based on accumulated sales predicted by reports

3.2.3 Identification of key factors affecting the EV sales

The following list provides a short overview of the most important determinants of global EV sales and, where possible, their expected developments.

3.2.3.1 Cost of Batteries

The cost reduction declines faster than foreseen. The breakeven cost compared with conventional vehicles is set at 130$/kWh.

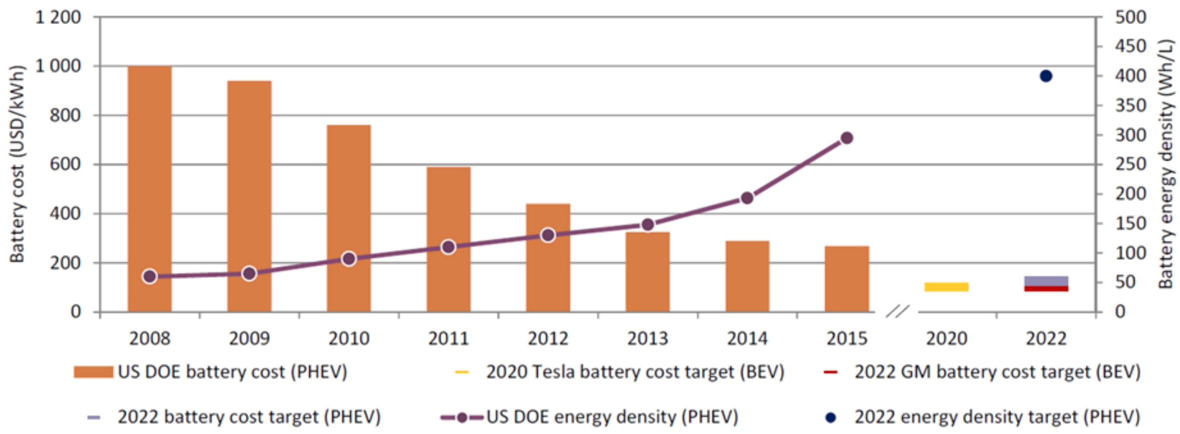


Figure 30: Evolution of battery energy density and cost[9].

3.2.3.2 EV battery range

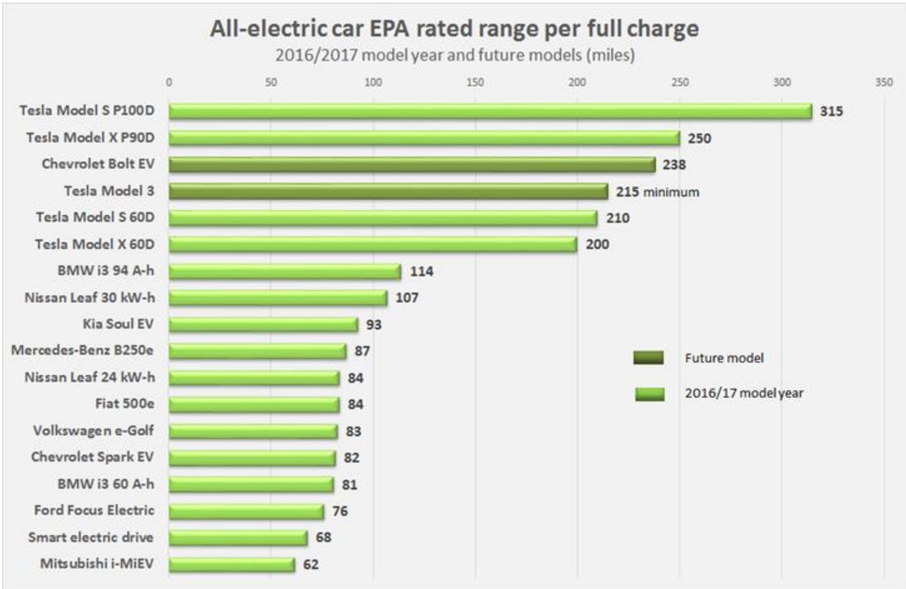


Figure 31: EV range.[10]

The EV range is also being improved faster than most optimistic former forecasts reported.

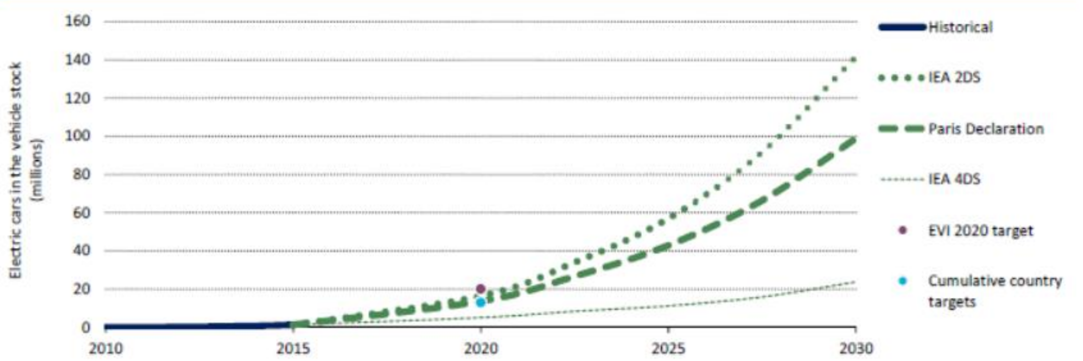
[9] IEA (2016): Global EV outlook 2016

[10] Mariordo (Mario Roberto Durán Ortiz) - Own work, CC BY-SA 4.0

3.2.3.3 Government Subsidies

In next paragraphs, the government subsidies will be reviewed for the most active countries in the EV promotion. The government support is still considered the strongest key factor for the fast introduction of electromobility.

3.2.3.4 Global CO_2 Emission Targets



Note: 2DS = 2°C Scenario; 4DS = 4°C Scenario.

Sources: IEA analysis based on IEA (2016), UNFCCC (2015b), the EVI 2020 target and the country targets assessment made in Table 3.

Figure 32: Deployment scenarios for the stock of electric cars to 2030

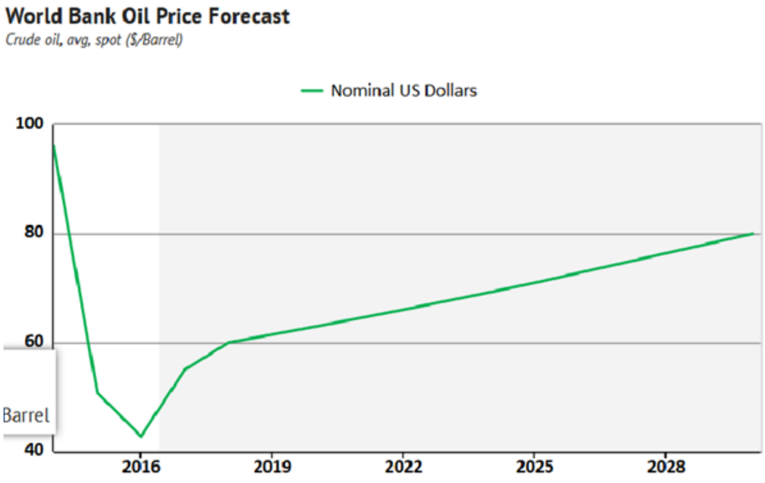
Most experts' consensus is that the most efficient way to reach the IEA 2D scenario will be through active policies in the transport sector. In Europe, Greenhouse gas emissions from all transport modes increased by 0.6% to 1,153 million tonnes of CO_2 equivalents (MT CO_2eq in 2015). Emissions from sectors other than transport decreased. So, the European Commission needs to work with Member States to develop an ambitious 'efficiency and electrification' strategy for transport with new cars and trucks CO_2 standards by 2025.

3.2.3.5 Global Fuel (oil) prices

Although the crude oil prices are nowadays in their lower levels, all institutions believe as the one represented in the chart above, that prices will rise again due to the continuous reduction on reserves and increasing consumption.

Nevertheless, it should be kept in mind that massive deployment of EVs is not foreseen in these scenarios. There are studies which suggest that oil demand might peak due to EVs before reserves are depleted and oil might become scarce and very expensive. A report by Carbon Tracker Initiative (CTI) in collaboration with Grantham Institute at Imperial College London estimated that oil demand might peak in the decade of 2020. This is a contradiction to all classical forecasts which do not take into account a disruptive development of EVs. The CTI report does consider this and comes to results which are much more in line with the expectations of the authors of this report. As a conclusion, we do not consider sustainable

increase in fuel prices as forecasted by the World Bank for example (see chart below), but rather consider stable prices at current levels.



	2017	2018	2019	2020	2021	2022	2023	2024	2025	2030
Nominal US Dollars	55,0	60,0	61,5	62,9	64,5	66,0	67,6	69,3	71,0	80,0

Figure 33: Crude Oil Price Forecast

3.2.3.6 Global Charging Network

The global EV Charger (EVC) market is forecast to grow from more than 1 million units in 2014 to more than 12.7 million units in 2020, according to a new EV Charging Infrastructure report[11] by IHS Inc.

3.2.3.7 Electricity prices

The electricity price is also tricky to forecast. In general, it is on the rise, but in countries that are more advanced in renewable energy it is falling. In fact, the spot market price is falling due to over-generation, but end-customer prices are rising for a number of reasons. Assuming ongoing political measures taken in most European countries to transit to renewable energy sources and considering the technological advances made, e.g. solar energy is becoming cheaper than fossil energy sources in many countries, it is safe to consider that the world as well as Europe will see declining energy prices within the next decades. However, in the short term the electricity prices will be kept constant as decrease in price in the short term might be cancelled out by the increase in demand (move from ICE to EVs)

[11] IHS Markit. Global EV Charging Stations to Skyrocket by 2020, IHS Report Says

3.2.4 Identification of new key factors unknown in previous reports

A regular report made by the Energy Information Administration (EIA) (the U.S. most influential forecast on the energy market), stated in their newest report the "Annual Energy Outlook 2017" that nearly 10 times of what they predicted in 2014 and the double from last year for EV penetration on the global market was achieved.
In other cases, the reports are just too old and often rely on models not factoring in enough the progress that has been made in technology and industry.
In the following, a list of factors is provided that will directly or indirectly influence the price of electric cars in the future and have not been considered or simply could not be known yet by most of the reports.

3.2.4.1 New key factors affecting EV forecast

Table 9: New factors affecting the EV market (not considered in previous forecast analysis)

Source	New Key Factors
Electrek.co	Germany pushes for Europe-wide ban on gas-powered cars by 2030.
Tesla and Panasonic will build batteries of type 20700 in Gigafactory (Tesla und Panasonic werden Zellen vom Typ 20700 in der Gigafactory herstellen) Study: Tesla-Gigafactory to threaten other battery producers (Studie: Tesla-Gigafactory bedroht andere Batteriehersteller)	The Gigafactory was supposed to produce 35 GWh of battery capacity until 2020 (more than the Li-Ion-battery production of the whole world.), but then it announced to reach this capacity already 2018 and that it will triple its production until 2020, which also means that it will produce three times the amount of batteries that the whole world produced in 2014. 40-45$/kWh lower costs per kWh for Tesla battery pack due to Gigafactory (price per kWh 2014 190-200$/kWh) ➔ 190 $/kWh – 45 $/kWh = 145 $/kWh ➔ It is commonly agreed up on the threshold of 130 $/kWh battery price for EVs to become price competitive with ICE cars. Tesla Model 3 will cost 35000$ before incentives in the most basic version with a minimum range of 346km
IEA Global EV Outlook 2016	General Motors announced that battery costs for its 2016 Chevrolet Bolt had fallen to USD 145/kWh by October 2015, and that it hopes to reduce costs below the USD 100/kWh mark by 2022
http://www.ev-volumes.com/country/china/ China impressive growth in EVs	The year 2016 finished with 351.000 Plug-in passenger cars delivered, which makes China by far the largest market for Plug-ins (or New Energy Vehicles, NEV, as they are called in China). The increase over 2015 was 85 %, which is much less than in previous years, but more than in any other of the large economies. Share in Passenger Car sales was 1.45 % for the year, which is still far away from leading Norway (24 %), but best among all larger car markets with total sales above 1 million, China's PHEV share is similar to France and UK for 2016. The overall passenger car market in China increased by 15 % or 24.3 million units in 2016
"The Rise of EV & Hybrid Cars"	"According to various Investment Banks such as Citigroup, Deutsche Bank,

	Credit Suisse and HSBC, the current low price of roughly $55 for a barrel of WTI crude is not sustainable long term. While we will not go into too much detail, these Investment Banks expect WTI crude to eventually trade in a range between $70-$90/barrel for the next several years. Taking the low-end of this estimate, we can deduce a long-term average US gasoline price of roughly $3.00 per gallon, which coincides with a battery price of approximately $225-$200/kWh.”

3.2.4.2 A closer look on Battery Prices, their forecasts and real developments

The figure below shows how reports tend to underestimate the price fall of batteries for years. As we know now in the beginning of 2017 the “magic” price between 130 and 140$/kWh for batteries will be reached within the next year at least by the market leaders like Tesla or General Motors.

The forecasts depicted in the figure foresaw this to become reality at the earliest in 2025. There is a difference of 7 years between reality and projections. In the case of General Motors, which reached a battery price of 145$/kWh as early as October 2015, this difference between projection and reality is even 10 years.

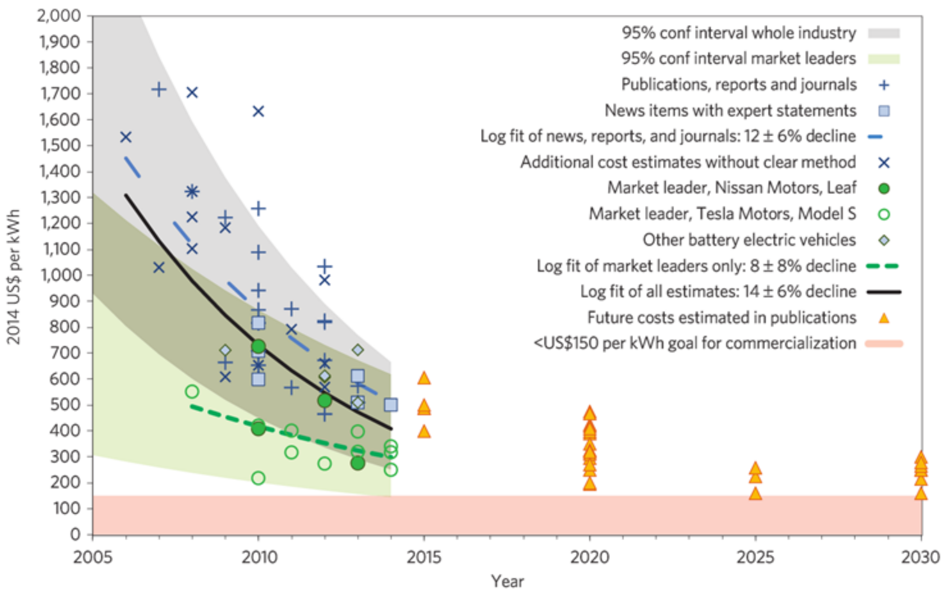


Figure 34: Björn Nykvist & Måns Nilsson: “Rapidly falling costs of battery packs for electric vehicles” Nature Climate Change (2015)

3.2.5 FABRIC Forecast EV stocks (EV + PHEV) till 2050 (Global and Europe, deregistration after 10 years)

In the next pages, we have implemented an analysis of the most likely evolution of the EV sales in the key countries identified as the most active in promoting electromobility, according to recent accounted factors and we will discover by the sum of the figures that the FABRIC estimation must be incremented over the moderate scenario described before. We will call that scenario the **FABRIC scenario for EV deployment** in Europe.

3.2.5.1 Germany

Total Passenger Cars: 43.851.000[12]
Highway (km): 12.845 km
EV stock 2015: 49.220
EV market share 2015: 0,11%

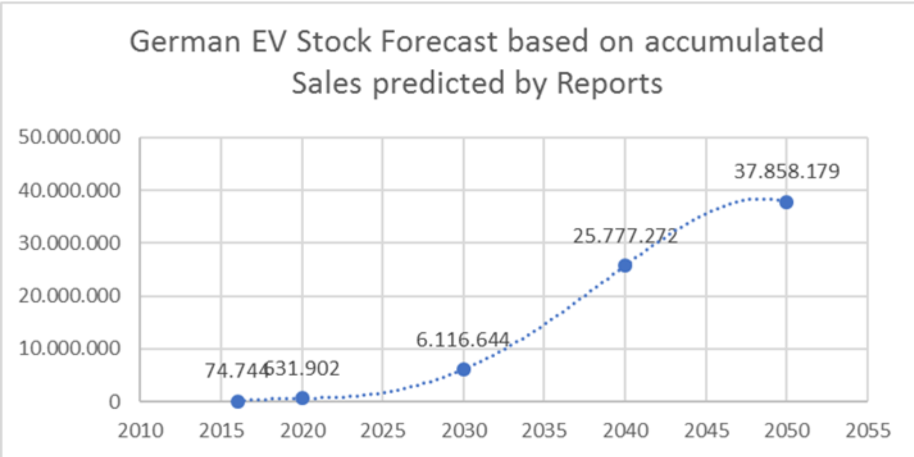


Figure 35: German EV Stock Forecast based on accumulated Sales predicted by Reports[13]

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[12] ACEA, European motor vehicle park 2014

[13]
- Kihm A. et al. (2014): The new car market for electric vehicles and the potential for fuel substitution; *Institute of Transport Research, DLR German Aerospace Center*
- Karsten P. et al. (2014): Two electromobility scenarios for Germany: Market development and their impact on CO2 emissions of passenger cars in DEFINE; *Öko-Institut e.V.*
- Karsten P. et al. (2016): Erarbeitung einer fachlichen Strategie zur Energieversorgung des Verkehrs bis zum Jahr 2050; *Umweltbundesamtes*
- Kienbaum Consultants International (2014): Marktentwicklung Elektromobilität in Deutschland
- Wietschel M. et al. (2013): MARKTHOCHLAUFSZENARIEN FÜR ELEKTROFAHRZEUGE; *Fraunhofer-Institut für System- und Innovationsforschung ISI*
- EV-Step (2015): Sustainable Technical and Economic Pathways for Electrified Mobility Systems in EU28 by 2030
- Statista (2016): Anzahl der Elektroautos in Deutschland von 2006 bis 2016; (https://de.statista.com/statistik/daten/studie/265995/umfrage/anzahl-der-elektroautos-in-deutschland/)

Table 10: German Incentives

Incentive category	Description
Purchase Subsidies	▪ For pure electric cars, there is a grant of 4,000 euros. For hybrids, it is 3,000 euros. ▪ Rewards are only for cars with a list price of a maximum of 60,000 euros (base model). ▪ The promotion lasts for a maximum total of 400,000 cars. ▪ The federal government contributes a total of 600 million euros. The cost should ever share federal and automakers half. Overall, the funding is therefore EUR 1.2 billion. ▪ The promotion ends in 2020.
Ownership Tax Benefits	Exemption for the first 10 years for cars registered until Dec 31 2015, 5 years from then on to Dec 31, 2020
Company Tax Benefits	Tax deductions on company cars
Local Incentives	BEV benefits: ▪ Free Parking ▪ Reserved Parking spots ▪ Bus lane use

❖ **For easier reading of this document, the analysis and country-specific incentives for Norway, UK, France and Netherlands are reported in Annex II.**

3.2.5.2 FABRIC EV deployment Scenario

Considering all these factors, the forecast about the EV market penetration should look quite different from what has been forecasted so far.

There is a report from February 2017 by Carbon Tracker Initiative (CTI), an independent financial think tank specialized on the financial markets in the context of climate change. The report, named "Expect the Unexpected: The Disruptive Power of Low-carbon Technology", is the only one considering most of the presented new factors influencing the market penetration of EVs. Another recent report from Morgan Stanley considers a base case BEV penetration with 16% penetration of EVs in 2030 accelerates to 51% by 2040 and 69% by 2050 (1 billion electric cars on roads). In their bull case, based on an even more aggressive regulatory regime to accelerate the reduction of emissions, they get to 60% penetration by 2040 and 90% by 2045. Therefore, both projections are way more optimistic than any other reports'. The scale of this optimism can be shown by direct comparison with the IEA report which predicts globally 150

- Statista (2016): Anzahl der Neuzulassungen von Pkw in Deutschland von 1955 bis 2019 (in Millionen); (https://de.statista.com/statistik/daten/studie/74433/umfrage/neuzulassungen-von-pkw-in-deutschland/)
- Doetsch J. for ed-info.de (2014): Pkw-Entwicklung bis 2040 in Deutschland; (http://www.ed-info.de/edplus/ArtikelAnsichtArc.php?newsId=365)

million electric cars by 2040, while CTI forecasts 1.1 billion EVs in the same year. Recalling the cell-phone example, CTI might get much closer to the real number which might even be higher.

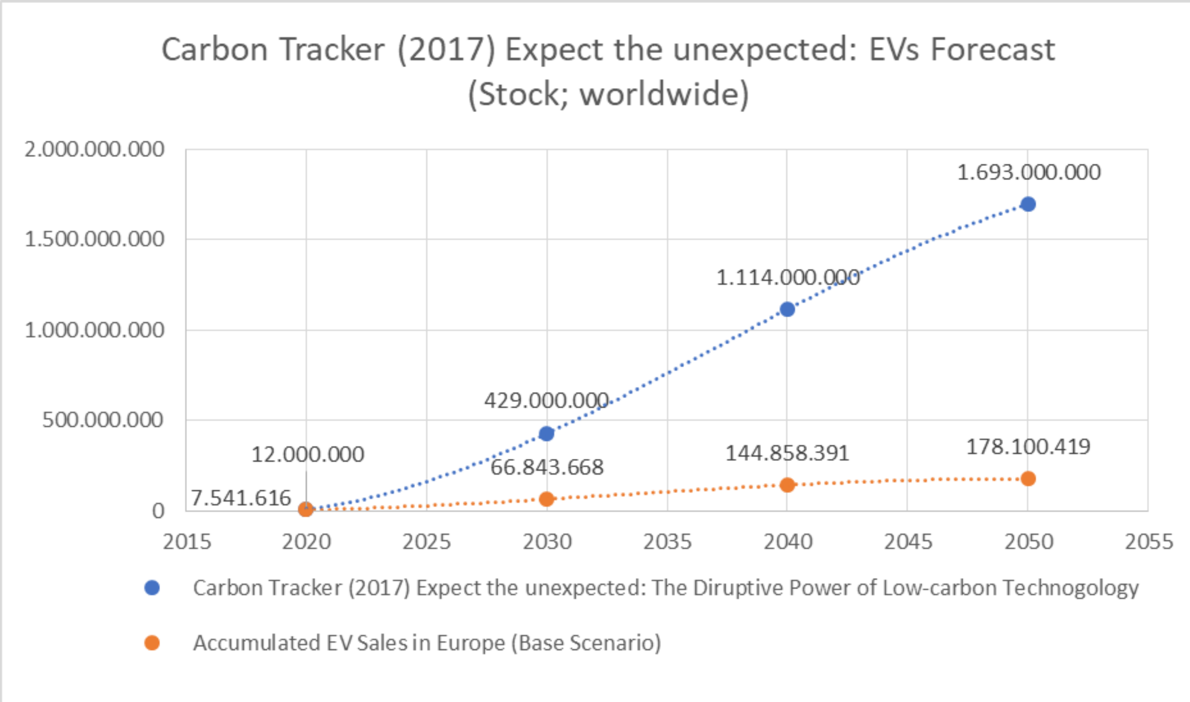


Figure 36: Carbon Trackers EV Stock Forecast

Under this light even the high penetration scenarios of the other reports appear to be pessimistic. Considering that Europe may have around 270 million cars on its roads by 2050 and therefore growing much less than most of the world, the relative number of cars in Europe will be a much smaller percentage by 2050 than it is today.

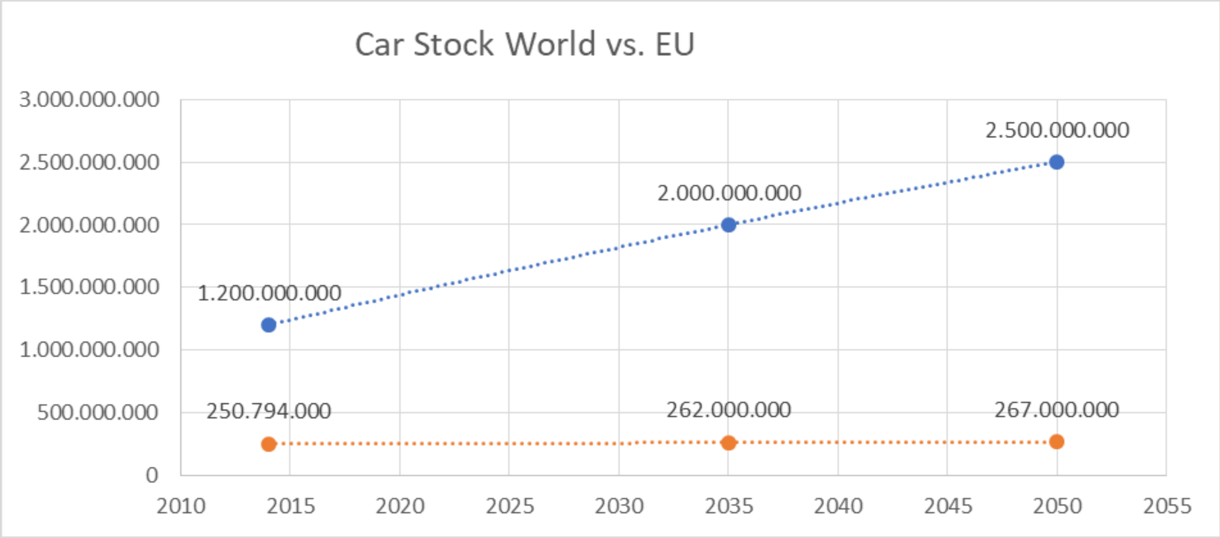


Figure 37: Car Stock World vs. EU

Which means the EU will change from 21% today to 11% of all cars in the world in 2050. If the same percentage is assumed among EVs (though the EU might be a bit stronger especially in the next years due to incentives and higher spending capacity), according to the Carbon Tracker's report 186.23 million electric cars can be expected in Europe in 2050 (a share of roughly 70% of European fleet).

If we consider now all the factors identified in the table above about recent developments on the EV market, our forecast might look even more optimistic.

Following plans by the government of Norway to ban cars fueled by petrol or diesel by 2025, several other countries in Europe are formulating similar programs to phase out fuel-powered transportation (Netherlands, Sweden and in a minor extent, France and Germany). Moreover, sources close to the European Parliament say that once multiple member states pass such a ban as is expected later this year, the European Union will attempt to enforce these rules throughout its territory. If for example Germany would be successful in its attempts to prohibit any sales of cars using fossil fuels from 2030 on, we could assume that by 2040 nearly all new cars in Europe will be electric.

Though, as soon as battery prices come down enough to make EVs cheaper than ICE cars and the range also increases to levels that are even more acceptable than they already are (in conjunction with lower charging times due to much higher power transfer – at the time of writing 250kW is available and 350kW chargers are being prepared for roll out, bringing the charging time for a Tesla P100 down to 15 minutes for an 80% charge), people will automatically prefer to buy a cheaper cleaner car with lower maintenance and fuel costs. Latest at that point, pulled by the early adopting countries, the rest of the Europe will start to catch up and become flourishing EV markets.

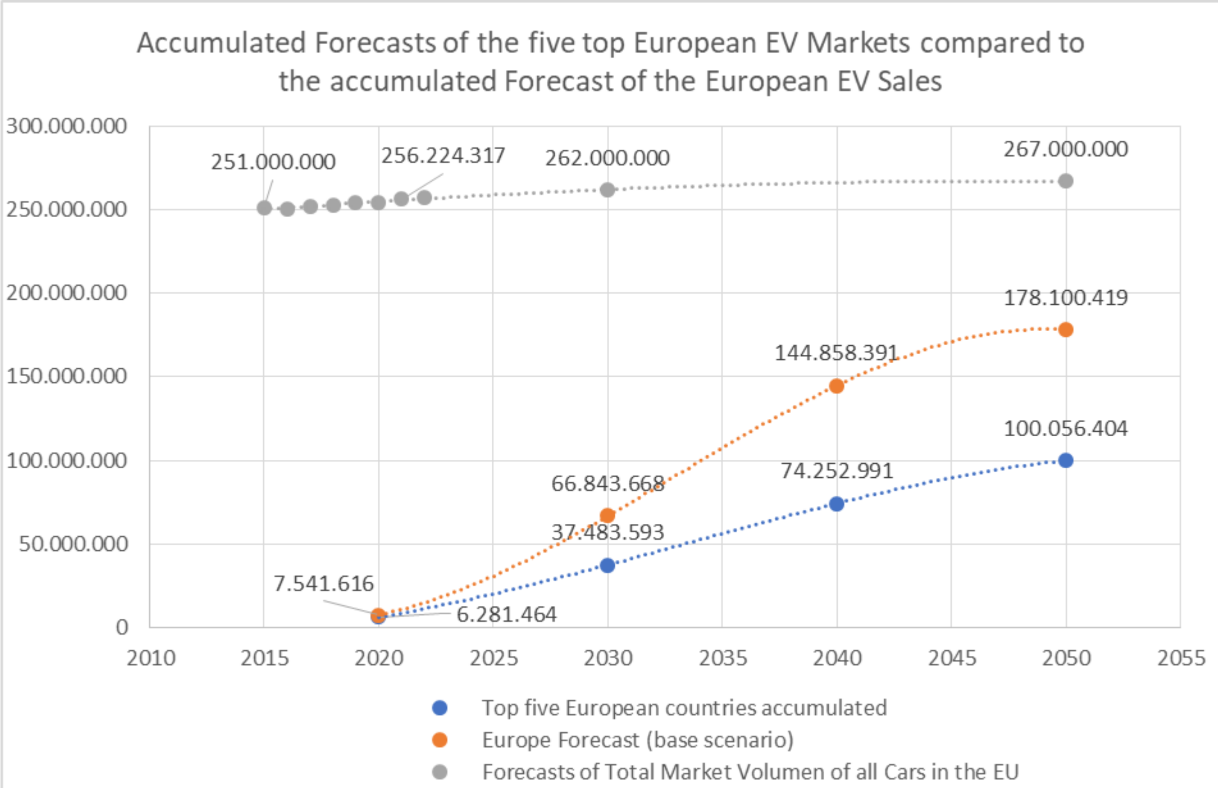


Figure 38: Accumulated Stock forecasts of the 5 top European EV Markets versus forecast of the European EV Stock in base scenario (own calculation)

The Graph above shows that the forecasts for the European top five markets combined predict a big amount of the high penetration scenarios from the EU forecasts in the base scenario. What does not seem to be sufficient accounted for is the development of the EV market in the other 35 European countries. For that reason, we will estimate a stock curve higher than the one reflected in the chart above which represent the most reasonable forecast of the available roadmaps established to date. We will call the new curve the FABRIC forecast (depicted in table 31).

Therefore, the question is to what kind of development all this will lead. A good orientation is the mobile phone example given in the introduction to this report or the example of HD-Flat-Screen TVs in comparison to traditional colour TVs and how they entered the market. Given all the market indicators, we cannot find a good reason why electric cars should not enter the market in a disruptive way.

Since we cannot foresee the political actions that will be taken per country, we will not consider hard measures as the ban of any car type that burns fossil fuels. However, just considering the other factors and above all the already reached price parity in comparison to many ICE cars, our estimation will be that the European EV market will grow at least 10% faster than the base scenario and for 2050 even 30% stronger than the base scenario. This assumption is aligned with the most optimistic, and more recent forecast conducted by Carbon Trackers.

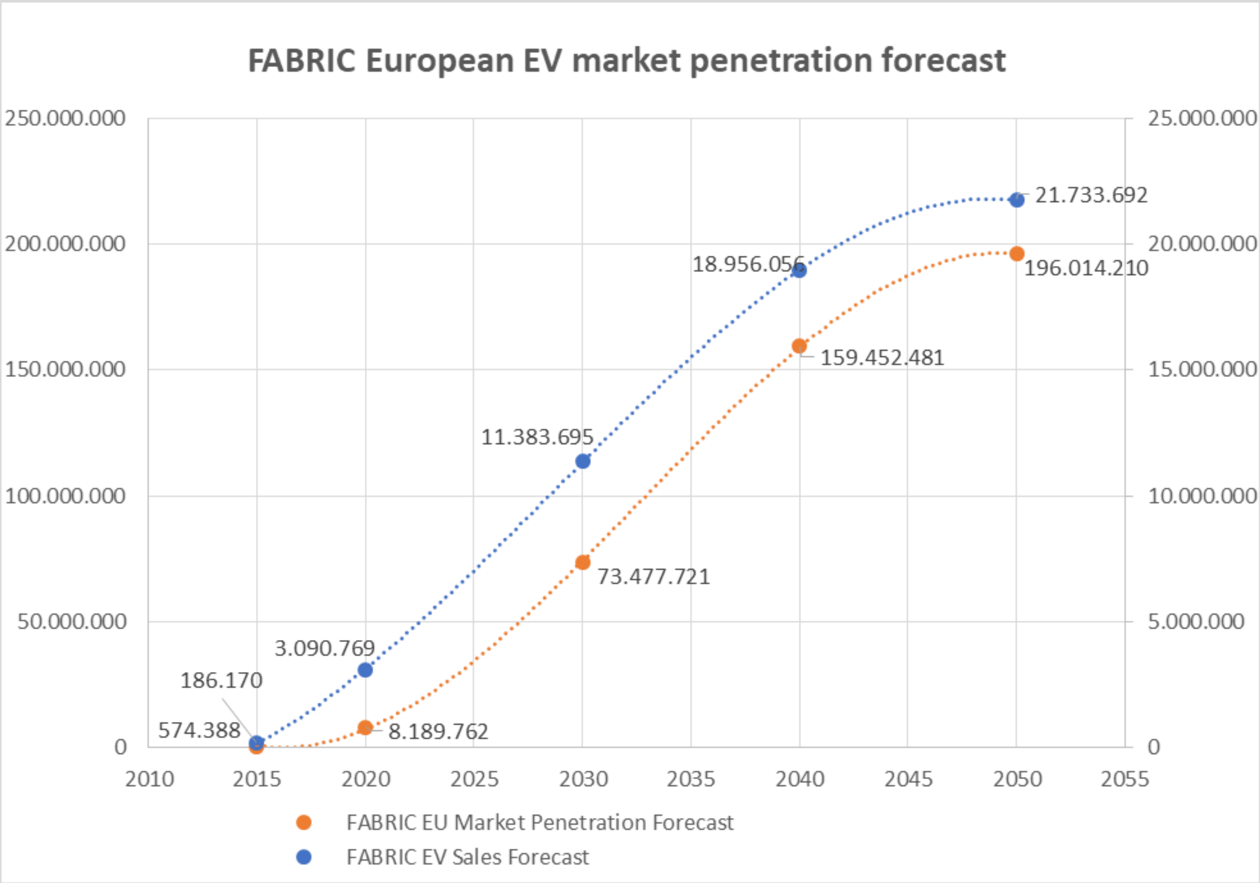


Figure 39: FABRIC European EV most likely market penetration forecast (optimistic scenario)

Total Passenger Cars: 263.932.000
Highway: 43.150 km
EV Stock 2015: 355.540
EV market share in 2015: 0,13%

In short, 196 Million EVs over 264 Million vehicles in 2050 represent 74% of all cars in Europe and EV sales in Europe are expected to peak at around 20 million EVs per year.

3.2.6 Definition of business models; Light EV in trips among cities and HV in short distance trips

The definition of the business models is the matter of other tasks within FABRIC which converge in task 5.5.2. First analysis started in WP52 (Task 5.2.4.) and then some relevant information has been progressively added to end in the mentioned task. To estimate the initial demand for the e-corridors, we have selected from those models, two scenarios which could be

suitable as first entry points. One is oriented toward light EV and e-vans and the second to HDV and in-city as well as intercity buses (heavy vehicles scenario).

- In the heavy vehicles scenario, the e-corridors will provide extra capacity to allow the reduction in the size of the battery of heavy vehicles, enabling a new class of vehicles to compete with the conventional heavy vehicles. This scenario will be likely the first entry point. First urban buses and later duty heavy trucks from surroundings to city centres and inter-city buses.
- Later, in the light vehicle scenario, the e-corridors will be used as range extenders to increase the autonomy of the battery allowing travels between close cities.

So, both strategies are different according to the specific market niche.

3.2.6.1 Heavy vehicle scenario (electric trucks and buses)

Several companies in US, EU and China are investing in these types of vehicles, due to the clear environmental advantages (75% less emissions on average to the equivalent diesel or natural gas). Although these vehicles are currently very expensive, there will be opportunities to make them competitive in the near future. Some announcements identify 300 to 350 km autonomies[14] for the premium heavy vehicles as already possible. E-corridors could reduce the size of the battery allowing more storage capacity.
The most promising business cases for this sector could be urban buses, intercity buses or neighbourhood heavy traffic. In this niche, we also consider the conductive charging with a pantograph or with an on-road conductive line.

[14] http://www.emoss.biz/electric-truck/; http://eforce.ch/

Figure 40: Scania G 360 4×2 with pantograph, electrically powered truck at the Siemens eHighway. Gross Dölln, Germany

Our estimation is that an average battery autonomy for affordable heavy vehicles will be in the range between 100 to 200 km in 2030 when an inductive or conductive system is installed on-board.

3.2.6.2 Light vehicle scenario

If we check the previous analysis, we identify 2030 in certain countries as the year when the ramp up of the EV is evident and consequently, there is enough EVs on the road to justify the investment on an e-corridor under certain circumstances.

We will analyze these special circumstances later, but as a first decision, it is important to figure out the average autonomy of the EV at that moment. The very recent estimations presented by Dr . Gereon Meyer (EPoSS office) under the frame of the European Electrification Roadmap (7th March 2017) are shown below.

Table 11: Hypothesis of batteries ramp up

Case considered	EV 2016	EV 2020		EV 2030	
Hypothesis	Existing	User friendly affordable	High performances premium	User friendly affordable	High performances premium
Electric grid consumption (Wh/km)[22]	140	130	135	115	120
Range (km)[21]	250	250	500	250	700
Retail extra cost (€)[23]	> 7000	> 4000	> 7000	Comparable	> 7000
Battery total energy (kWh)	28	26	55	27	70
Battery cell gravimetric energy density (Wh/kg)	160	> 180	300	> 330	500[24]
Battery cell cost[25] (€/kWh)	180	100	140	80	120

The expected range for the average autonomy of batteries in 2030 is marked with 250 km for the user friendly and affordable units (most common) and 700 km for the high-performance premium.

However, these figures look rather low if the announcement from Tesla becomes reality. Their Tesla Model 3 with a market price of 35.000 € (and 500.000 expected orders per year, 250.000 pre-orders in 2016) to be launched in 2017 and available in Europe in 2018, has promised an autonomy of 400 km.
In parallel Tesla and others are working on graphene batteries with expected autonomy of 800 km. This leads us to believe that the average autonomy for the affordable 2030 EVs will be around 400 km or even more, than in the range from 200 km to 300 km. As it can be seen in the next figure, 320 km (Tesla Model with the lowest range) autonomy is more or less the state of the art in 2016 although those vehicles are not affordable for the common consumers.

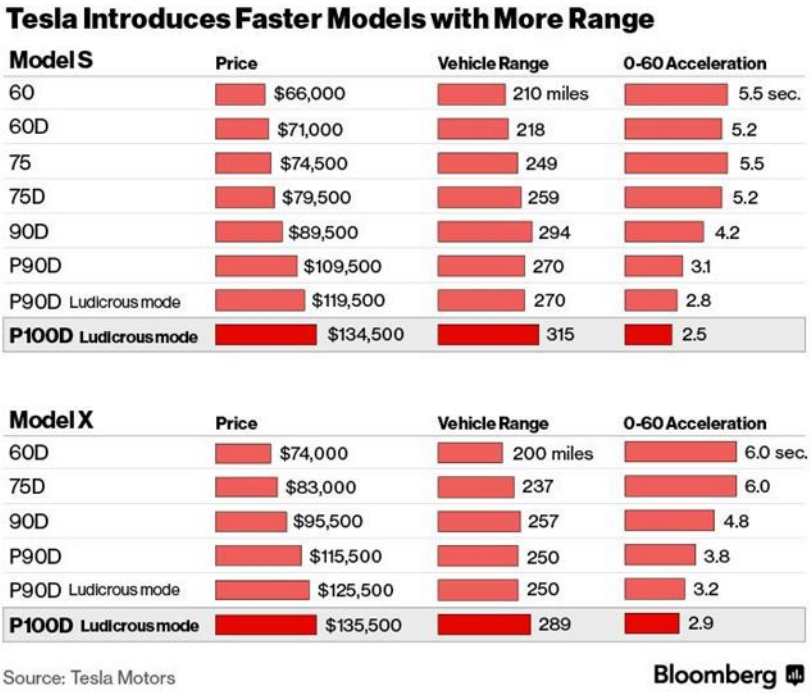


Figure 41: Tesla models characteristics and battery autonomy

In conclusion, cities at a distance between 400 to 600 km could be appropriate for e-corridors, providing a range extension of 20% of the EV autonomy.

3.2.7 Location of widest and most congested motorways between cities at distance 400-600 km

Twenty-four European countries are part of the CEDR (Conference of European Directors of Roads) which has mapped the TEN-T (Trans-European Network – Transport) roads. This network represents the most important roads in Europe (more than 103.000 km). More than two billion vehicle kilometres are driven on this network every day. 60% of the network consists of motorways (this proportion is gradually increasing) and 17% is made up of roads with more than 4 lanes. Investment in the TEN-T network is continuing, with planned capacity improvements identified at nearly 25% of the network.

The network is also very heavily used. More than 40% of the network carries more than 20,000 vehicles per day while 6% carries more than 80,000 vehicles per day, traffic density exceeds 12,000 vehicles per lane per day on 15% of the network, and HGVs comprise more than 20% of all traffic on nearly 20% of the network. The traffic flow for both all vehicles and HGVs specifically is increasing, particularly on motorways.

The second generation of the work plans of the 11 European Coordinators was approved in December 2016 with specific measure to increase the number of lanes in some motorways or even greening the TENT-T network. The Central European Green Corridors project is a good example approved in 2013 with the aim of creating a multi-modal, cross-border network along TEN-T corridors by demonstrating high power recharging points for EVs to enable long distance driving.

This is exactly the approach of the FABRIC project to identifying the entry points for the motorways e-corridors deployment. We believe that such green corridors in the TEN-T network's most congested motorways, will be a perfect demo case to introduce the e-corridors to the market. We depict below the nine key corridors of the core TEN-T road network.

Figure 42: Core TEN-T Corridors in Europe

We made a revision of the busiest and widest motorways in Europe, identifying also cities at an average distance of 400-600 km with daily dense traffic.

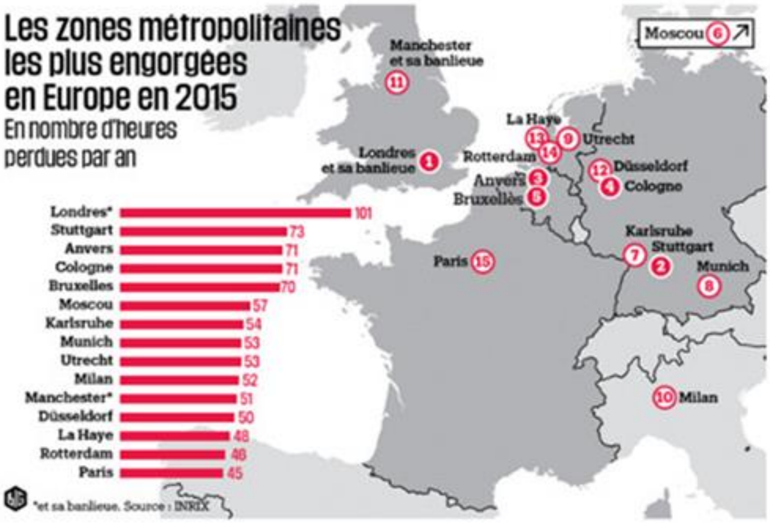


Figure 43: More congested cities in Europe. Source INRIX

Our vision of the market opportunity for the e-corridors in 2030 which is also aligned with the analysis made in the next pages, has been as follows:

1. Selection of the most active countries promoting electromobility; Netherlands, Norway, France, UK, Germany and, to a smaller extent, Italy and Spain.
2. Identification of more congested metropolitan areas by selected country
3. Identification of congested routes between two busier cities that use a multilane network (more than 3 or 4 lanes) included in the TEN-T network at a distance between 400-600 km
4. Selection of first route as entry point in 2030. Assign two or one e-corridor per direction depending on route length.

This analysis considers that the economic business model is fair and that cost has been adjusted to allow the investments amortisation (please check task 5.5.2).

- **For easier reading of the document, the analysis per country is reported in Annex III**.

3.2.8 Other entry points for the e-corridors

We have identified in figure 43 the busiest cities in Europe. Some of these cities are strong logistic poles and could be potential applicants for the e-HDV, urban buses and/or intercity buses as first entry points. We consider the HDV Scenario to be the first entry point for dynamic wireless charging, because the regular routes of buses and trucks can be easily known. If there is a combined effort to convert all buses and trucks using a certain route to an electric powertrain which can be recharged on the go, this could justify the investments through assured heavy use and big savings for all the users as well as biggest possible impact on the environment. It is still not clear for us due to the lack of data, if these technologies (wireless and conductive) could be feasible. Cities with existing (conductive) trolleybus systems could be other early adopters, as those which have recently installed overhead (pantograph) could be rapid charge points for buses (e.g. Geneva, Lausanne, Berne, Lyon, St Etienne, Limoges, Bratislava, Salzburg, Budapest, Rome, Milan, Hamburg, Luxembourg, Namur). We will consider some deployment scenarios for these types of vehicles later on.

3.2.9 Revision of TEN-T plans to enlarge some congested motorways adding a green corridor

The trans-European Road Network, TEN-T (Roads), 2015 Performance Report[15] published in December 2016 provides interesting information about the main road distribution network in 28 European countries. Statistics also clarify the most traffic-jammed areas in Europe and

[15] http://www.cedr.eu/download/Publications/2016/CEDR2016-4_N1_TEN-T-Performance-Report.pdf

provide key performance indicators which we have used to figure out the e-corridor future scenarios. In the next tables, some of these indicators are described.

Table 12: Statistics road distribution and traffic in Europe.

Country	National Statistics		TEN-T (Roads) Network Length (km)					TEN-T (Roads) Network Use (Average)		
	Population (1000's)	Total Area (km^2)	Comprehensive Network	Core Network	Motorway	Non-Motorway	No Data	Traffic Flow (AADT)	Traffic Density (AADT/Lane)	Proportion HGV (%)
Austria	8,355	83,872	1,689	1,072	1,689	-	-	54,705	10,943	10.9
Denmark	5,511	43,098	1,554	749	1,113	441	-	30,626	7,117	12.5
Estonia	1,340	45,228	1,350	480	-	1,350	-	10,800	4,126	13.4
Finland	5,326	338,424	5,229	1,094	799	4,430	-	13,927	4,275	10.1
Germany	82,002	357,021	10,700	6,365	10,341	359	-	55,127	11,199	15.2
Greece	11,260	131,990	4,831	1,780	1,695	3,136	-	18,698	4,500	16.1
Iceland	319	103,001	1,803	53	3	1,800	-	11,913	3,319	7.1
Ireland	4,450	70,280	2,258	499	907	1,350	-	27,125	7,688	6.5
Italy	60,045	301,338	8,809	4,259	6,832	1,977	-	28,161	12,045	15.5
Lithuania	3,350	65,200	1,652	597	320	1,332	-	9,568	3,071	19.2
Luxembourg	494	2,586	90	90	90	-	-	43,097	10,703	16.4
Malta	414	364	109	23	-	109	-	21,058	6,526	0.0
Netherlands	16,486	41,543	1,886	643	1,886	-	-	77,556	14,898	14.1
Norway	5,166	385,252	4,928	242	552	4,376	-	14,849	4,562	14.4
Slovenia	2,032	20,273	593	467	537	56	-	29,252	7,322	13.3
Spain	45,828	504,030	12,311	5,976	10,636	1,675	-	28,483	6,127	13.4
Sweden	9,256	449,964	6,391	2,972	1,952	4,439	-	19,208	5,017	14.4
Switzerland	7,702	41,290	1,325	300	1,123	202	-	53,895	15,680	6.1
UK	60,631	223,010	6,926	2,060	2,674	1,694	2,558	78,703	13,951	11.6
Total/Average	**329,969**	**3,207,764**	**74,434**	**29,721**	**43,150**	**28,727**	**2,558**	**32,987**	**8,056**	**12.1**

- The ADDT is the length-weighted Average Annual Daily Traffic (AADT) along a Logical Section, in both directions, rounded to the nearest integer. This includes all vehicle types.
- The Traffic Flow should be calculated as the length-weighted AADT in one direction plus the length-weighted AADT in the other direction.
- The traffic density is measured dividing the AADT by each lane
- The HGV proportion is the proportion of annual average daily traffic along a Logical Section that comprises Heavy Goods Vehicles (HGVs)

In the same report, the number of lanes per motorway which has been used to identify the potential e-corridors is included.

Table 13: Number of lanes in the TEN-T network

		Number of Lanes									
		2 lanes or less		More than 2, up to 4 lanes		More than 4, up to 6 lanes		More than 6 lanes		No data	
Country	Total length	Length (km)	%	Length (km)	%	Length (km)	%	Length (km)	%	Length (km)	%
Austria	1,689	16	0.9	802	47.5	821	48.6	50	3.0	-	0.0
Denmark	1,554	164	10.6	1,090	70.1	250	16.1	50	3.2	-	0.0
Estonia	1,350	1,212	89.7	138	10.3	-	0.0	-	0.0	-	0.0
Finland	5,229	2,694	51.5	2,459	47.0	76	1.5	-	0.0	-	0.0
Germany	10,700	36	0.3	5,521	51.6	4,907	45.9	236	2.2	-	0.0
Greece	4,831	2,776	57.5	1,606	33.2	429	8.9	20	0.4	-	0.0
Iceland	1,803	1,699	94.2	95	5.3	9	0.5	-	0.0	-	0.0
Ireland	2,258	1,285	56.9	885	39.2	87	3.9	-	0.0	-	0.0
Italy	8,809	6,965	79.1	1,793	20.4	-	0.0	-	0.0	51	0.6
Lithuania	1,652	975	59.0	607	36.7	-	0.0	-	0.0	70	4.2
Luxembourg	90	-	0.0	88	97.3	2	2.7	-	0.0	-	0.0
Malta	109	43	39.4	63	57.6	1	0.7	2	2.2	-	0.0
Netherlands	1,886	-	0.0	722	38.3	994	52.7	171	9.0	-	0.0
Norway	4,928	3,329	67.6	1,500	30.4	89	1.8	10	0.2	-	0.0
Slovenia	593	41	6.9	384	64.8	168	28.3	-	0.0	-	0.0
Spain	12,311	1,804	14.7	8,990	73.0	1,210	9.8	226	1.8	79	0.6
Sweden	6,391	3,275	51.2	2,964	46.4	149	2.3	3	0.0	-	0.0
Switzerland	1,325	279	21.1	1,044	78.8	2	0.2	-	0.0	-	0.0
UK	6,926	-	0.0	1,524	22.0	2,086	30.1	758	10.9	2,558	36.9
Total (all data)	**74,434**	**26,594**	**35.7**	**32,275**	**43.4**	**11,280**	**15.2**	**1,527**	**2.1**	**2,758**	**3.7**
Total (ex No data)	**71,676**	**26,594**	**37.1**	**32,275**	**45.0**	**11,280**	**15.7**	**1,527**	**2.1**	**-**	**-**

The next tables provide information on the length of roads according to the ADDT, giving a clear picture of the busiest roads in Europe.

Table 14: Annual average traffic flow

		Annual Average Daily Traffic Flow (AADT)													
		Less than 5,000		5,000–20,000		20,000–40,000		40,000–80,000		80,000–100,000		More than 100,000		No data	
Country	Total length (km)	Length (km)	%	Length (km)	%	Length (km)	%	Length (km)	%	Length (km)	%	Length (km)	%	Length (km)	%
Austria	1,689		0.0	111	6.6	878	52.0	607	35.9	53	3.1	33	2.0	7	0.4
Denmark	1,554	125	8.0	651	41.9	414	26.6	323	20.8	36	2.3	5	0.3	-	0.0
Estonia	1,350	242	17.9	1,059	78.5	49	3.6	-	0.0	-	0.0	-	0.0	-	0.0
Finland	5,229	2,242	42.9	2,532	48.4	371	7.1	84	1.6	-	0.0	-	0.0	-	0.0
Germany	10,700	-	0.0	1,256	11.7	3,591	33.6	4,725	44.2	697	6.5	431	4.0	-	0.0
Greece	4,831	205	4.2	1,624	33.6	284	5.9	56	1.2	65	1.3	9	0.2	2,588	53.6
Iceland	1,803	1,651	91.6	117	6.5	19	1.1	16	0.9	-	0.0	-	0.0	-	0.0
Ireland	2,258	52	2.3	1,820	80.6	224	9.9	137	6.1	8	0.4	18	0.8	-	0.0
Italy	8,809	192	2.2	960	10.9	272	3.1	60	0.7	8	0.1	20	0.2	7,297	82.8
Lithuania	1,652	602	36.4	869	52.6	146	8.8	13	0.8	-	0.0	-	0.0	22	1.3
Luxembourg	90	-	0.0	11	12.7	26	29.2	52	58.1	-	0.0	-	0.0	-	0.0
Malta	109	4	3.3	68	63.0	31	28.1	4	3.7	2	1.8	-	0.0	-	0.0
Netherlands	1,886	-	0.0	24	1.3	264	14.0	1,079	57.2	238	12.6	281	14.9	-	0.0
Norway	4,928	3,174	64.4	1,340	27.2	269	5.5	132	2.7	13	0.3	-	0.0	-	0.0
Slovenia	593	21	3.5	203	34.2	265	44.7	104	17.5	-	0.0	-	0.0	-	0.0
Spain	12,311	1,475	12.0	6,904	56.1	2,690	21.9	935	7.6	71	0.6	160	1.3	76	0.6
Sweden	6,391	2,605	40.8	2,633	41.2	906	14.2	175	2.7	33	0.5	39	0.6	-	0.0
Switzerland	1,325	20	1.5	136	10.3	400	30.2	423	31.9	53	4.0	64	4.8	229	17.3
UK	6,926	-	0.0	304	4.4	789	11.4	1,632	23.6	655	9.5	988	14.3	2,558	36.9
Total (all data)	**74,434**	**12,610**	**16.9**	**22,623**	**30.4**	**11,888**	**16.0**	**10,557**	**14.2**	**1,931**	**2.6**	**2,048**	**2.8**	**12,777**	**17.2**
Total (ex No data)	**61,657**	**12,610**	**20.5**	**22,623**	**36.7**	**11,888**	**19.3**	**10,557**	**17.1**	**1,931**	**3.1**	**2,048**	**3.3**	**-**	**-**

Table 15: Traffic Density (AADT/lane)

		Traffic Density (AADT / lane)											
		Less than 3,000		3,000–6,000		6,000–12,000		12,000–18,000		More than 18,000		No data	
Country	Total length (km)	Length (km)	%	Length (km)	%	Length (km)	%	Length (km)	%	Length (km)	%	Length (km)	%
Austria	1,689	21	1.2	547	32.4	844	50.0	234	13.9	36	2.1	7	0.4
Denmark	1,554	196	12.6	687	44.2	585	37.6	86	5.5	-	0.0	-	0.0
Estonia	1,350	575	42.6	529	39.2	247	18.3	-	0.0	-	0.0	-	0.0
Finland	5,229	3,229	61.8	1,553	29.7	420	8.0	27	0.5	-	0.0	-	0.0
Germany	10,700	279	2.6	1,643	15.4	5,619	52.5	2,840	26.5	319	3.0	-	0.0
Greece	4,831	1,190	24.6	639	13.2	335	6.9	14	0.3	65	1.3	2,588	53.6
Iceland	1,803	1,709	94.8	57	3.2	34	1.9	3	0.2	-	0.0	-	0.0
Ireland	2,258	322	14.2	1,240	54.9	591	26.2	79	3.5	26	1.2	-	0.0
Italy	8,809	50	0.6	667	7.6	435	4.9	323	3.7	37	0.4	7,297	82.8
Lithuania	1,652	1,058	64.0	448	27.1	71	4.3	-	0.0	-	0.0	75	4.5
Luxembourg	90	-	0.0	25	27.7	33	36.8	32	35.5	-	0.0	-	0.0
Malta	109	10	8.8	53	48.4	42	38.2	3	2.8	2	1.8	-	0.0
Netherlands	1,886	-	0.0	88	4.7	476	25.2	941	49.9	382	20.2	-	0.0
Norway	4,928	3,511	71.2	877	17.8	451	9.2	89	1.8	-	0.0	-	0.0
Slovenia	593	62	10.5	236	39.8	258	43.5	37	6.2	-	0.0	-	0.0
Spain	12,311	4,790	38.9	4,740	38.5	2,052	16.7	460	3.7	115	0.9	155	1.3
Sweden	6,391	3,481	54.5	1,972	30.9	843	13.2	95	1.5	-	0.0	-	0.0
Switzerland	1,325	20	1.5	157	11.8	426	32.2	275	20.8	218	16.5	229	17.3
UK	6,926	-	0.0	592	8.5	1,368	19.8	1,753	25.3	655	9.5	2,558	36.9
Total (all data)	**74,434**	**20,502**	**27.5**	**16,749**	**22.5**	**15,129**	**20.3**	**7,291**	**9.8**	**1,854**	**2.5**	**12,909**	**17.3**
Total (ex No data)	**61,525**	**20,502**	**33.3**	**16,749**	**27.2**	**15,129**	**24.6**	**7,291**	**11.8**	**1,854**	**3.0**	**-**	**-**

The final parameter which has been used to estimate the e-corridors demand is related to the traffic density compared with the area and population. Those countries with more stress (bigger traffic density in less area and large population) will be more open to clean vehicles and green corridors to improve the air quality in the territory and the travelling speed. This can be the case of countries as the Netherlands or UK.

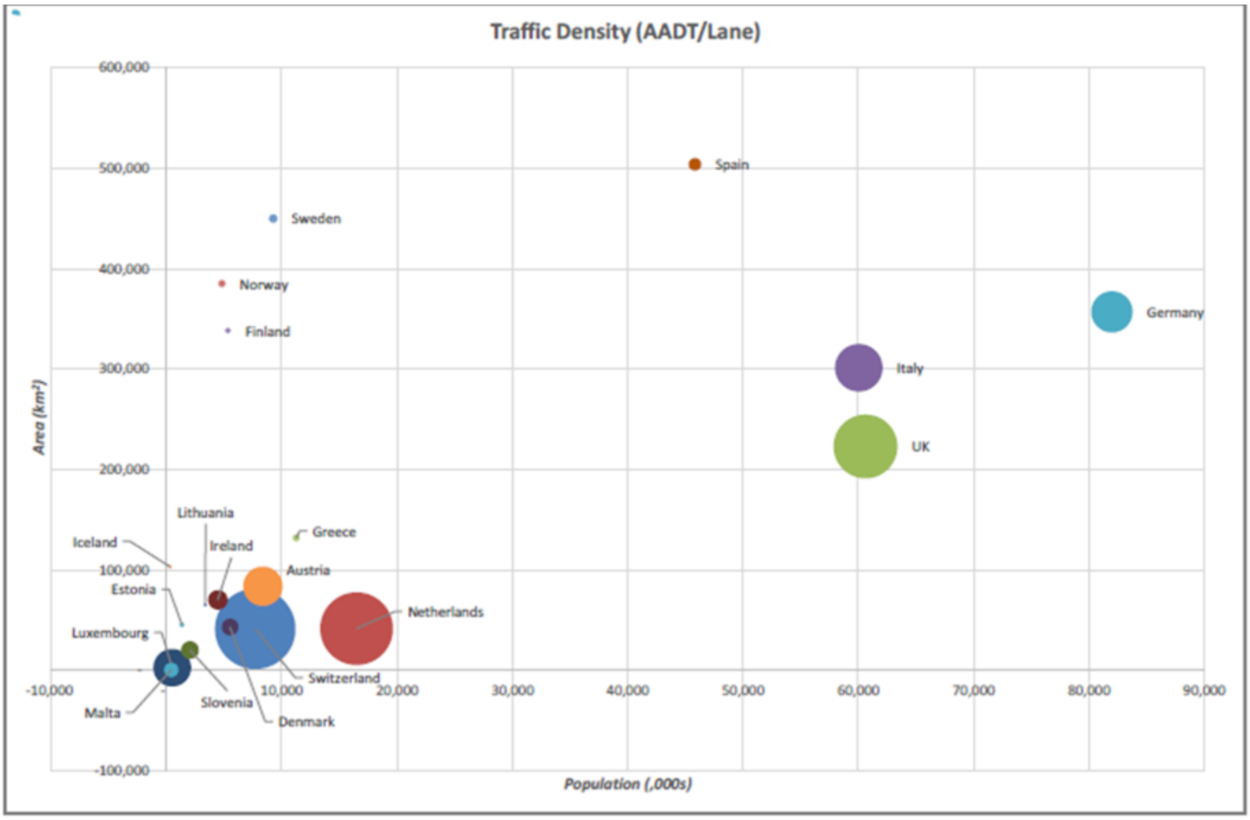


Figure 44: Traffic density in relation to country area and population

3.2.10 Preliminary identified Roadmaps for the initial penetration of dynamic charging.

The final roadmap for the e-corridors has been calculated as follows:

1. The heavy-vehicles market uptake will be likely the first entry point for this technology beginning in some dense cities with HDV traffic along the closest motorways from the neighbourhood to the city centre or between close cities/towns. Urban buses will be likely the first option for dynamic wireless charging followed by the intercity buses and Duty heavy traffic. Between 2025-2030 first fleet of wireless buses will be in operation.
2. For the light vehicles scenario, sufficient market uptake will start in 2030-2040 in the more active countries promoting electromobility. E-corridors will be placed as mentioned in most congested motorways with at least 3 lanes per direction (2 for conventional cars and one green corridor) and more traffic stress (higher traffic density in smaller area and more population). These motorways are included in the TEN-T strategy. The Green corridors planned within the TEN-T upgrade process will

be a great opportunity for the first market experiences probably with initial high incentives.

3.2.10.1 Heavy Duty Vehicle e-corridors

As stated at the round table discussion in Versailles, HDV could be ideally charged by four receiving dynamic wireless charging pads of 50KW each and thereby reaching a total power transfer of 200kW. It is difficult to estimate the penetration of the e-trucks and e-buses in the market to a sufficient extend that a dynamic charging station shall be justified, as there are little commercially available electric trucks or busses yet. In any case, as indicated before, the business model suggested for this category, considers first the use of urban fleet of buses recharged static and dynamic wireless and then movements of intercity buses or HDV in the surroundings of large cities, between the external commercial and distribution belt and the city centre at a distance of 200 to 300 km or between cities or towns at same distance. Cities with high logistic requirements could be the first demo places or cities with trolleybus system in place.

Deliverable D5.4.1 Report on effect of up scaling to vehicle fleet and energy grids, provides interesting conclusions on business scenario for buses. In Table 16 below, three power levels for wireless power transfer for buses were analysed. The most noteworthy conclusion is that with increased power transfer levels, dynamic power transfer is rendered unnecessary. Also, at lower power levels of 50 kW, where a continuous DWPT track is required, still 6 kWh of on-board storage is needed, as power transfer levels are well below the driving demand peaks of up to 200 kW.

In this exercise, with increased transfer power, required DWPT infrastructure has been reduced. Another possibility would have been to minimise on-board storage. Anyway, resulting storage requirements of below 10 kWh are very small, considering that the daily energy consumption of an urban bus is estimated at 650 kWh (equivalent to 325 km autonomy at 2 kWh/km). An important conclusion here is that probably supercapacitors are more suitable for these vehicles than batteries, due to the high power and relatively low energy storage requirement.

Table 16: Summary of urban bus scenario for different power levels of WPT.

Route type	Urban buses
Number of buses	400
Number of routes	40
Driving cycle	SORT 1-1-2-2-3-3
Average Daily route (km)	9
Number of stops per route	27
Total number of stops	1080
Time for one route (round trip)	0.5 h (1 h)
Service time (h) = nº of round trips	18
Energy required (one round trip)	

Per route / bus (kWh)	36.0		
Fleet (MWh)	14.4		
Energy required per day (18 h service)			
One bus (kWh)	648		
Fleet (MWh)	259.2		
Dynamic and static Power transfer (kW)	50	100	150
Total POWER required by fleet (MW)	8	16	24
Charging mode	Continuous	25 m at stop	10 m at stop
km of e-corridor	360	27	11
Required on-board energy storage (kWh)	6	7.5	9
Required average charging time per stop (s)	48	24	16
Required charging time per bus and route (min)	21.6	10,8	7,2
Number of coils per route (2.5m/coil)	3600	270	81
Total number of coils	144,000	10,800	3,240
Number of LV transformers per route	4.5		
Total number of MV/LV transformers	180x 315 kVA	180x 630 kVA	270x 630 kVA
Total number of HV/MV transformers	1x 8 MVA	1x 16 MVA	1x 24 MVA

For our calculations, we will consider the intermediate scenario for buses; let say 100 kW power transfer. In this case for a city with the size of London (40 routes of 27 bus stops each) and dynamic short e-corridors of 25m after the bus stops, the total length of dynamic charging (excluded stationary charging) should be
27 km but if consider some sharing of buses stops among bus lines, we can simplify considering 25 km of e-corridors inside one city (the same figure used for one motorway e-corridor).

We will also assume that e-corridors for trucks and intercity buses between points at a distance of 200 to 300 km will be also 25 km length although this will not be necessarily the case, in areas close to the cities due to space restrictions, but we will accept this figure as first estimation.

Without being exhaustive in the calculation of this e-HDV and e-buses demand (a deep analysis will be presented in the final deliverable D5.5.4 Analysis of deployment scenarios, standardisation and harmonisation), and considering that the number of variables can be enormous, it is evident that the electric corridors within cities and in the proximity (peri-urban areas and intercity buses), as first entry points for the technology, will represent the most significant number compared with the e-corridors in the TEN-T motorways.
The estimation done for the e-corridors deployed in urban and peri-urban areas in Europe, is based in the following assumptions:

- The market uptake will affect to the most crowded cities in Europe with best budgetary conditions and most environmental problems (air polluted)

- A percentage of the bus lines will be electrified and adapted to static/stationary and dynamic charging. We have considered on average a 40% of total fleet from 2030 to 2060.
- We consider that in those pioneering cities where dynamic charging will be in place in urban buses, it will easier to introduce also dynamic charging in the surroundings for intercity buses connections or HDVs short distance trips. The number of peri-urban e-corridors will be also adapted to the size of the city.

The preliminary demand estimation is depicted below.

Table 17: Estimations HDVs and buses in EU cities (urban and peri-urban areas)

Rank	City	Country	Population	Estimations					
				Aproximate Bus lines	% Fleet electrified	No. E-corr. Urban bus 25km	Nº. E-corr Periurban 25 km	Total km E-corr. URBAN	Total Km E-corr. PERIURBAN
1	LONDON	UK	12.496.800	40	40%	0,40	36	10,00	900
2	PARIS	France	11.800.687	38	40%	0,38	34	9,44	850
3	MADRID	Spain	6.529.700	21	40%	0,21	20	5,23	500
4	RUHRGEBIET	Germany	5.045.784	16	40%	0,16	20	4,04	500
5	BERLIN	Germany	5.005.216	16	40%	0,16	20	4,01	500
6	BARCELONA	Spain	4.891.249	16	40%	0,16	18	3,91	450
7	ROME	Italy	4.370.538	14	40%	0,14	16	3,50	400
8	MILANO	Italy	4.252.246	14	40%	0,14	16	3,40	400
9	NAPOLI	Italy	3.627.021	12	40%	0,12	12	2,90	300
10	HAMBURG	Germany	3.173.871	10	40%	0,10	12	2,54	300
11	WEST MIDLANDS	UK	2.909.300	9	40%	0,09	10	2,33	250
12	MANCHESTER	UK	2.815.100	9	40%	0,09	8	2,25	203
13	LISBOA	Portugal	2.810.668	9	40%	0,09	8	2,25	202
14	MÜNCHEN	Germany	2.768.488	9	40%	0,09	8	2,22	199
15	STUTTGART	Germany	2.668.439	9	40%	0,09	8	2,14	192
16	BRUSSELS	Belgium	2.607.961	8	40%	0,08	8	2,09	188
17	FRANKFURT AM MAIN	Germany	2.573.745	8	40%	0,08	8	2	200
83	OTHER EU CITIES	>500.000	<2.500.000	6	35%	4,36	332	108,94	8.300
TOTAL LENGTH E-CORRIDOR URBAN AND PERIURBAN AREAS						6,93	593	173,23	14.834
Data. Eurostars largest cities in Europe 2016						TOTAL E-corridors	600		15.008

Table 18: Penetration of E-corridors in urban and peri-urban areas

Europe SCENARIO CITY BUSES / INTERCITY BUSES / DUTY HEAVY TRAFFIC	Cities > 500K inhabitants	Nº of e-corridors	2030-40	2040-50	2050-60
Nº of e-corridors	100	600	120	180	300
% Penetration e-corridors			20%	30%	50%

The reason to select those cities is that we need a critical mass of buses or heavy vehicles to justify the investment on e-corridors. If the number of buses is low, the static wireless technology at the headquarters could easily substitute the need of dynamic charging, but if the fleet of buses is big, charging in motion will be an option, especially if adapting the static wireless technology to the dynamic within the vehicles is not expensive. In summary, about 600 e-corridors representing 15.008 km will be deployed from 2030 to 2060.

3.2.10.2 Light Vehicle Scenario

In the next table, we include the FABRIC forecast for the key countries identified as the most active in the EV promotion. Then, we add a column with the total length of the motorways included in the TEN-T report, another column with the motorways with more than 4 lanes (those selected who might include a green corridor for the circulation of electric and fuel cell vehicles) and also in parallel the dynamic charging e-corridors. The final column describes the number of km of motorway with an average daily traffic of more than 12.000 vehicles.

Table 19: Forecast EV in key countries, 4 lanes motorways and AADT/lane over 12000 EV

FORECAST 5 KEY COUNTRIES	Forecast Stock light EVs (BEV & PHEV)) (in thousand units)			(in km)	MOTORWAY (in km)	AADT/lane (in km) [1]
Year	2030	2040	2050	Motorway	>4lanes	> 12.000 veh
European Union (20 countries+France)	**73.477.721**	**159.452.481**	**196.014.210**	**54.877**	**15.125**	**9.145**
Germany	6.116.644	25.777.272	37.858.179	10.341	5.143	3.159
Norway	1.600.000	2.040.000	2.400.000	552	99	89
United Kingdown	15.850.000	18.236.710	23.435.941	2.674	2.844	2.408
France	12.752.233	25.815.928	29.790.413	11.727	2.318	nd
Netherlands	1.164.716	2.383.081	4.443.984	1.886	1.165	1.323
TOTAL (FIVE KEY COUNTRIES)	**37.483.593**	**74.252.991**	**97.928.517**	**27.180**	**11.569**	**6.979**
REST OF COUNTRIES	**35.994.128**	**85.199.490**	**98.085.693**	**27.697**	**3.556**	**2.166**

The next table has been prepared to identify if the number of AADT/lane is over 1.000 vehicles. This number has been assumed as the breakeven for the economic viability of the e-corridors. Although this approach will be extensively explained and analysed in the D5.5.4, we include here the main assumptions for that calculation:

- Maximum speed within the e-corridor: 25 m/s (100 km/h)
- Minimum distance between vehicles 60 m
- Added Toll (in addition to the energy fee): 10 €/vehicle (pending confirmation in the Business model report)
- Average depreciation period for the e-corridor: 20 years.
- Yearly incomes: 3,650,000€
- Cost e-corridor /km: around 2,000,000 €/km (target price).

Another preliminary assumption made is that by 2030, most EVs will be prepared for stationary wireless charging and the 60% could also charge dynamic. It can also be argued that it is much easier to convince car makers to make their static WPT systems "dynamic-ready", without the need of providing already the whole dynamic charging infrastructure. According to FABRIC experts the alteration of a static/stationary wireless charging module to dynamic would only cost an additional 600€. Those 60% will be also prepared for autonomous driving. This percentage has been discussed with the car manufacturers during the dedicated FABRIC

workshops organised in coincidence with the Strasbourg General Assembly meeting ITS Conference in June 2017. The next table provides the percentage of EVs in the different scenarios over the total number of passenger cars.

Table 20: Stock of light EV over all vehicles in use in %

% of EV/all light vehicles	2015	2030	2040	2050
Germany	0,11%	13,95%	58,78%	86,33%
Norway	2,83%	64,00%	81,60%	96,00%
United Kingdom	0,17%	55,61%	63,99%	82,23%
France	0,17%	39,55%	80,06%	92,39%
Netherlands	1,09%	14,56%	29,79%	55,55%
Europe (23)	0,13%	27,84%	60,41%	74,27%
Europe (23) (% WPT-EV)		60,00%	75,00%	100,00%

The next table demonstrates in the right columns that, according to the forecasts, the main five countries selected will have the appropriate number of vehicles in the most jammed motorways, in case the same percentage of electric vehicles in use over the total is kept in such motorways.

Table 21: Average daily number of EVs per lane in the most crowded motorways in the key countries

AADT EVs IN MOTORWAYS IN 5 SELECTED COUNTRIES	FABRIC Forecast Stock light EVs No. EVs in busiest roads (>12.000 cars/lane)			FABRIC Forecast Stock light EVs No. EVs in busiest roads with WPT		
Year	2030	2040	2050	2030	2040	2050
European Union (20 countries+France)				60%	75%	100%
Germany	1.674	7.054	10.360	1.004	5.291	10.360
Norway	7.680	9.792	11.520	4.608	7.344	11.520
United Kingdown	6.674	7.679	9.868	4.004	5.759	9.868
France	4.746	9.608	11.087	2.848	7.206	11.087
Netherlands	1.747	3.575	6.666	1.048	2.681	6.666
AVERAGE (FIVE KEY COUNTRIES)	3.341	7.250	8.912	1.336	5.437	8.912

We have considered that 60% of the EVs will mount the DWPT system in 2030, 75% in 2040 and 100% in 2050.

Table 22: Forecast e-corridors for light vehicles

FORECAST 5 KEY COUNTRIES Year	AADT/lane (in km) [1] > 12.000 veh	Maximum e-corridors /500 km	2030-40	2040-50	2050-60
European Union (20 countries+France)	**12.727**	**32**	**10**	**10**	**12**
Germany	3.159	6	2	2	2
Norway	89	2	0	0	2
United Kingdown	2.408	6	2	2	2
France	3.582	8	2	2	4
Netherlands	1.323	4	2	2	0
TOTAL (FIVE KEY COUNTRIES)	**10.561**	**26**	**8**	**8**	**10**
REST OF COUNTRIES	**2.166**	**6**	**2**	**2**	**2**

[1] In the case of France with no data, an estimation of the ADDT/lane has been done
[2] In the case of Norway, the length of the motorways network is reduced but one road has been identified within TEN-T
[3] Some slight adjutaments have been done to provide an even number of e-corridors
[4] The e-corridors are not acummulative

Table 22 reflects the potential number of e-corridors assuming that the widest and most jammed motorways within the TEN-T network will be prepared to incorporate progressively e-corridors in both directions every 500 km. The calculation was made dividing the length of the TEN-T motorways (with more than 12.000 vehicles/lane of daily traffic) by 500 km (distance identified as most appropriate to require a dynamic charging facility). Then, some adjustments have been made to consider an even number as the e-corridors must be constructed in both directions. Norway has a very reduced number of wider motorways (more than four lanes) and busiest roads, but a single road has been selected as some expansion works are in process. The preliminary information we have about TEN-T roads is; most dense roads and widest (more than 4 lanes, both directions), but we don't have the combination of both concepts at the same time. We can figure out that these roads will exist close to the largest and busiest cities, maybe connecting close cities. It is those motorways where the green corridors equipped with e-corridors make sense in case the EVs market penetration might be as expected (stock of 28% of EVs in 2030, 60% in 2040 and 74% in 2050).

3.2.11 The effects of the e-corridors in the EVs market

The effect of e-corridors on motorways, due to their small initial number and their progressive introduction, will probably not affect significantly the sales of electric vehicles, which has its own logic as has been seen, but probably, they will increase the percentage of those vehicles in the motorways. In short, the EVs initially purchased for urban and proximity movements, will begin to increase their displacements through the motorways contributing to greening them.

To what extend this effect will impact is difficult to estimate. This dynamic charging technology will probably compete with the ultra-fast static or plug-in chargers in intermediate filling stations, but both technologies definitively, will increase the traffic of EVs on motorways.

3.2.12 Estimation of total number of EV-DWPT charging in Europe

The final missed calculation relevant for the demand estimation can be found in the conclusions of deliverable D5.3.4 Final LCC/LCA. An assumption was made to estimate the number of vehicles equipped with the DWPT system crossing the e-corridors in urban and peri-urban areas for light and heavy traffic. In the table below the most relevant assumptions are depicted.

Table 23: Forecast EV-DWPT charging at the European E-corridors

		FABRIC SCENARIO (with e-corridors)					
	LIGHT VEHICLES IN MOTORWAYS	**2.030**		**2.040**		**2.050**	
1	Percentage of fleet that it is electric	28	%	60	%	75	%
	Light EVs	13.306	units	28.512	units	35.640	units
2	Nº electric vehicles that use motorways	70	%	80	%	100	%
	Light EVs in motorways	9.314	units	22.810	units	35.640	units
3.	No. Of light EVs equiped with WPT (dynamic charging)	60	%	75	%	100	%
	Light EVs-WPT in motorways	5.588	units	17.107	units	35.640	units
3	Users that recharge in motorway superchargers	20	%	30	%	40	%
	Light EVs charging in supercharger in motorways	1.863	units	6.843	units	14.256	units
4	Users that recharge in motorway e-corridors	10	%	20	%	30	%
	Light Evs-WPT charging in e-corridors in motorways	931	units	4.562	units	10.692	units
	% of users charging in e-corridors/EVs equiped with WPT	17	%	27	%	30	%
	HEAVY VEHICLES IN MOTORWAYS	**2.030**		**2.040**		**2.050**	
5	Percentage of fleet that it is electric	28	%	60	%	75	%
	e-HDVs	1.814	units	3.888	units	4.860	units
6	Nº electric heavy vehicles that use motorways	30	%	60	%	100	%
	e-HDVs in motorways	544	units	2.333	units	4.860	units
7	No. Of e-HDV equiped with WPT (dynamic charging)	60	%	75	%	100	%
	e-HDVs-WPT in motorways	327	units	1.750	units	4.860	units
8	Users that recharge in motorway superchargers	20	%	30	%	40	%
	e-HDV charging in supercharger in motorways	109	units	700	units	1.944	units
9	Users that recharge in motorway e-corridors	10	%	20	%	30	%
	e-HDV charging in e-corridors in motorways	54	units	467	units	1.458	units
	% of users charging in e-corridors/EVs equiped with WPT	17	%	27	%	30	%
10	Nº of e-corridors in motorways	10	units	10	units	12	units
	URBAN AND PERIURBAN LIGHT VEHICLES	**2.030**		**2.040**		**2.050**	
11	Percentage of fleet that it is electric	28	%	60	%	75	%
	Light EVs	13.306	units	28.512	units	35.640	units
12	Nº EVs that moves in urban and periurban areas	100	%	100	%	100	%
	Light EVs in urban and periurban areas	13.306	units	28.512	units	35.640	units
13	No. Of light EVs equiped with WPT (dynamic charging)	60	%	75	%	100	%
	Light EVs-WPT in urban and periurban areas	7.983	units	21.384	units	35.640	units
14	Users of light Evs that recharge in home chargers or urban chargers	100	%	100	%	100	%
	Light EVs charging in home chargers or urban static chargers	13.306	units	28.512	units	35.640	units
15	Users of Evs that recharge in urban e-corridors	2	%	3	%	10	%
	Light EVs-WPT charging in e-corridors in urban or periurban areas	266	units	855	units	3.564	units
	% of users charging in e-corridors/light EVs equiped with WPT	3	%	4	%	10	%
	URBAN AND PERIURBAN HEAVY VEHICLES	**2.030**		**2.040**		**2.050**	
16	Percentage of fleet that it is electric	28	%	60	%	75	%
	e-HDVs	1.814	units	3.888	units	4.860	units
17	Nº e-HDV that moves in urban and periurban areas	100	%	100	%	100	%
	e-HDVs in urban and periurban areas	1.814	units	3.888	units	4.860	units
18	No. Of light EVs equiped with WPT (dynamic charging)	60	%	75	%	100	%
	e-HDVs-WPT in urban and periurban areas	1.089	units	2.916	units	4.860	units
19	e-HDV Users that recharge in headquarters chargers or urban static chargers	100	%	100	%	100	%
	e-HDV charging in supercharger in headquarters or urban static	1.814	units	3.888	units	4.860	units
20	e-HDVs users that recharge in urban e-corridors	50	%	62	%	83	%
	e-HDV charging in e-corridors in urban and periurban	907	units	2.411	units	4.034	units
	% of users charging in e-corridors/e-HDV equiped with WPT	83	%	83	%	83	%
21	Nº of e-corridors in urban and periurban areas	120	units	180	units	300	units
22	TOTAL FORECAST OF E-CORRIDORS	130	units	190	units	312	units

These figures must be understood from an initial assumption of traffic density and distribution of light and heavy traffic in urban, peri-urban and TEN-T motorways.

Table 24: Assumptions for traffic density (ADDT) and number of daily vehicles in TEN-T motorways

ASSUMPTIONS FOR THE LCC AND LCA	No.	Unit
Length e-corridors	25	km
Daily Traffic per lane in selected motorways (ADDT)	18.000	units
Number of lanes	3	units
Total number of daily traffic	54.000	units
Light vehicles	88	%
Total number of daily light vehicles	47.520	units
Total number of daily light vehicles/lane	15.840	units
Heavy vehicles	12	%
Total number of daily heavy vehicles	6.480	units
Total number of daily heavy vehicles/lane	2.160	units

With this information from Table 23, it is now easy to calculate the yearly number of vehicles that charge at the European e-corridors within the referenced years (2030, 2040 and 2050). These figures are the base to prepare the business model to be explained at deliverable D5.5.4.

Table 25: Number of EV-DWPT vehicles charging at the European E-corridors.

Vehicles	2.030	2.040	2.050
MOTORWAYS			
Light Vehicles	9.314	45.619	128.304
Heavy vehicles	544	4.666	17.496
	9.858	**50.285**	**145.800**
URBAN/PERIURBAN			
Light Vehicles	31.933	153.965	1.069.200
Heavy vehicles	108.864	433.901	1.210.140
	140.797	**587.866**	**2.279.340**
TOTAL VEHICLES	**150.656**	**638.150**	**2.425.140**

E-corridors	2.030	2.040	2.050
MOTORWAYS	10	10	12
URBAN/PERIURBAN	120	180	300
TOTAL	**130**	**190**	**312**

According to the previous analysis, a rough estimation of e-corridors in Europe in three decades will account for nearly 632. Assuming a 25km length per e-corridor (even though most of them

are the shorter (peri-)urban ones in the analysis), 15800 e-road kilometers could be expected in Europe by 2050.

4 Scarcity of resources and possible manufacturing delays

4.1 Wireless dynamic charging systems

Depending on their operating power level, the future dynamic electric roads will span for several hundred kilometers per lane probably on intercity highways in order to extend the range of future EVs. This study will focus on wireless dynamic charging which is the main development objective of FABRIC. Specifically, the POLITO system will be used as a reference system due to the availability of information regarding the manufacturing materials. It should be noted that the system produced by Qualcomm was delivered as “black box” to FABRIC partner VEDECOM for installation and testing at the FABRIC test site in Satory, France due to IPR constraints according to the Project Grant Agreement so the provision of specifications for materials and manufacturing processes is inadequate for this study.

Copper is the material that is used mostly for the manufacturing of wireless dynamic charging systems. It is used for the coil windings (in the road and on the EV), the cabling, and for the construction of the power transformers that connect the system to the grid. Due to the above, the materials scarcity study will focus on the estimation of potential Cu scarcity due to large scale deployment of e-roads.

Other issues were explored via a supplier questionnaire which received five responses. The questionnaire (reproduced in Annex I) asked what component(s) were produced, what is the current level of production, how the supplier sees this evolving and any issues or problems foreseen in meeting future demand. It was sent to suppliers of the POLITO (Politecnico di Torino) solution in Italy, to Qualcomm (the supplier of the French FABRIC solution), to members of the FABRIC ERG and to supplier sector partners of ERTICO. The level of response was understandably low, as the suppliers do not currently produce components for wireless infrastructure on an industrial scale (e.g. most of the Italian suppliers to POLITO were SMEs which produced bespoke one-off components for FABRIC, while other components were off-the-shelf and already produced in large quantities for other applications). Hence most potential respondents were unable to predict the likely demand and level competition, or their capacity to respond to it.

4.1.1 Copper demand and scarcity

4.1.1.1 Calculation of copper demand per e-road km

According to FABRIC D3.6.2[16] the dimensions of the primary coils embedded on the road are 1.5m long and 0.5m wide, while there is a 0.5m spacing between the coils. So one coil is installed every 2m of e-road. In order to construct a 100km e-road 50000 coils will be needed. According to POLITO, each primary coil contains 7.1kg of copper, meaning that for 100km of e-road 355tonnes of copper will be needed for the primary coils.

Besides the coils, there is a feeder cable that runs along the highway. The copper used by this cable for the implementation of POLITO contains 120 kg/km of copper. So for a 100km e-road additional 12tonnes of copper will be needed.

[16] FABRIC Deliverable D3.6.2 ” Prototype on-road charging solution 2 and 3”

To the numbers above one should add the cabling for the connection of the feeder cable to the electrical components for the current modulation and from there to the coils, which is estimated to around 100kg/km.

Finally the cabling to connect the feeder cable to the road converter stations transformers and the latter to the substations that are connected to the grid needs to be included, however this depends largely on the in-situ implementation and the site's custom parameters (distance from the grid, restrictions in land usage, ground morphology etc.). In the present report, this cabling is arbitrarily approximated as a 20% overhead of the previous sum.

From the above the needs in copper are roughly calculated as:

$$CuDem_{100km} = (CuC_{100km}+CuF_{100km}+CuO_{100km})*1.2 = (355 + 12 + 10)*1.2 = 452.4 \text{ tonnes} \quad (1)$$

Where CuDem is the overall demand for copper per 100km of e-road in tonnes, CuC is the copper demand for the primary coils, CuF is the copper demand for the feeder cable and CuO is the copper demand for peripheral cabling.

4.1.1.2 Copper demand per EV in general and BEVs capable of dynamic wireless charging

According to a very recent study by IDTechX which was commissioned by the International Copper Association (ICA), the growing EV market is expected to greatly impact the demand for copper over the next decade. The most recent statistics in large markets seem to indicate that the growth may even exceed even the most optimistic forecasts, which will have analogous effect on the copper demand.

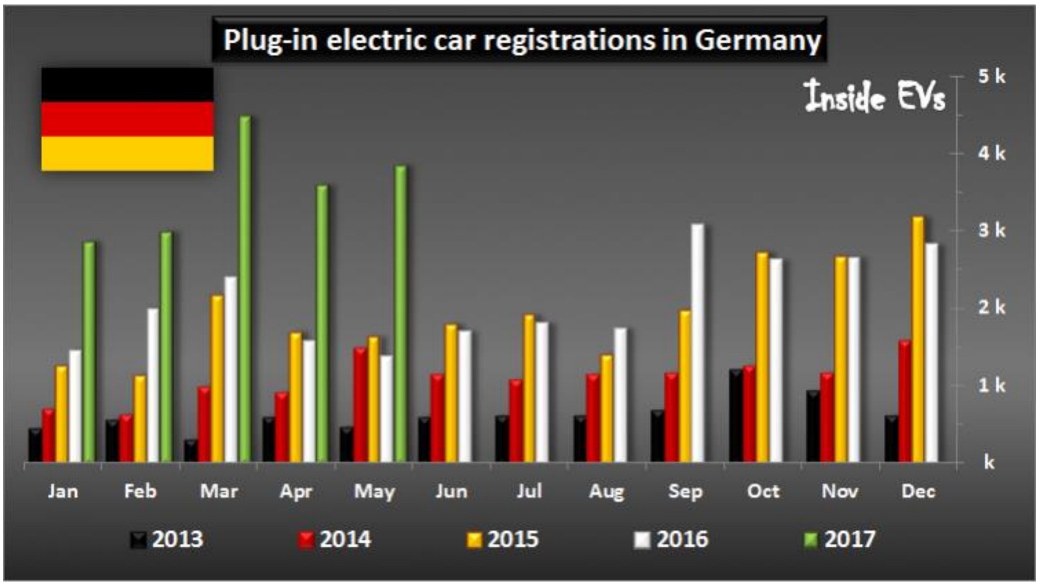


Figure 45: German Plug-In Electric Vehicle Market Almost Triples In May to 3,843 Sales[17]

Specifically, according to IDTechX study[18] electric vehicles use a substantial amount of copper in their batteries, and in the windings and copper rotors used in electric motors. A single car can have up to six kilometers of copper wiring. The metal is also required for busbars, used to connect modules and cells in battery packs, and in charging infrastructure. Whilst most cars use internal combustion engines that require up to 23 kg of copper, the IDTechEX research found that a hybrid electric vehicle uses 40 kg of copper, a plug-in hybrid electric vehicle uses 60 kg, a battery electric vehicle 83 kg, and a hybrid electric bus 89 kg. A battery-powered electric bus can use 224–369 kg of copper, depending on the size of battery used. **Wireless dynamic charging will increase this number for a Light Duty Vehicle by at least 4 kg based on POLITO's secondary coil characteristics, excluding the additional wiring needed. Based on the above a BEV with wireless charging capability will use 87-90kg of copper. However due to a possible reduction of the battery size and related materials, the copper demand may decrease in the end comparing to the current BEVs. However since this depends on future developments and implementations that may differ from OEM to OEM, the worst case scenario is assumed where no savings are achieved due to smaller batteries.**

According to the study, copper demand for electric cars and buses will increase from 185,000 tonnes in 2017 to 1.74 million tonnes in 2027 which is a nine-fold increase. On top of this, each electric vehicle charger will add 0.7 kg of copper and if they are fast chargers, they can add up to 8 kg of copper each. The figures below show the increase in charging stations at the USA over the recent years, while a similar path is followed in several western European countries.

[17] http://insideevs.com/german-ev-sales-may-2017

[18] http://copperalliance.org/wordpress/wp-content/uploads/2017/05/How_Important_are_EVs_Electromobility.pdf

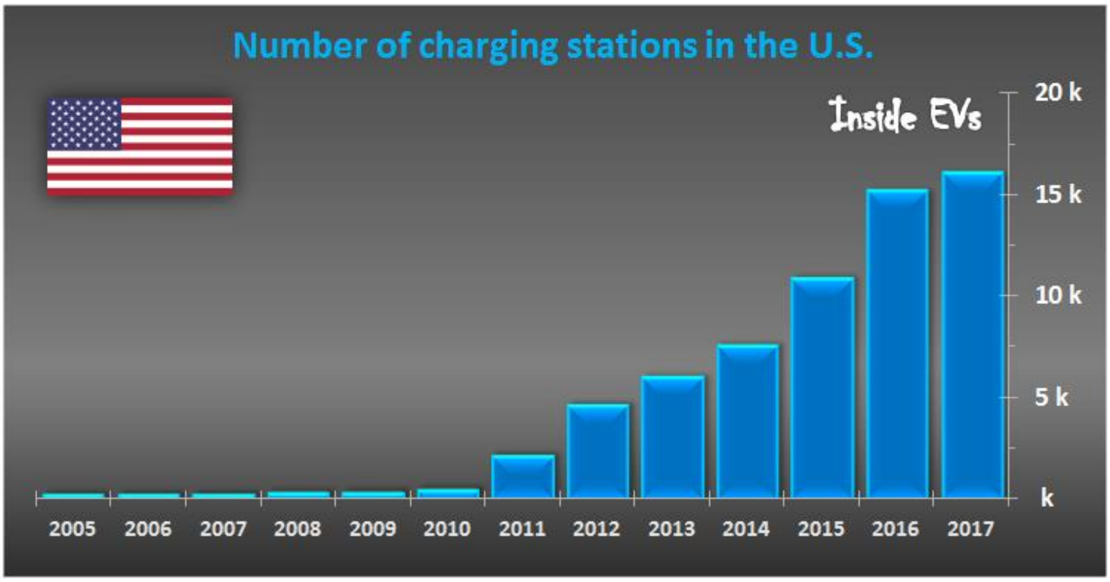


Figure 46: Progression of charging station installations in the US over the last decade[19]

Additionally, increased copper demand is expected due to battery-based large-scale storage and solar energy generation projects.

4.1.1.3 Assessment of copper scarcity due to large-scale dynamic wireless charging deployment

According to a recent report[20] by the International Copper Study Group (ICSG) the refined copper production in 2017 will be around 24 million tonnes.

If we were to equip the whole TEN-T[21] network in EU spanning around 136,000km (x2 for both lanes) with dynamic wireless charging capabilities, the demand for copper would be:

$$CuDem_{TEN\text{-}T} = 2*1360 * CuDem_{100km} = 2*615{,}264 tonnes = 1{,}230{,}528 tonnes \qquad (2)$$

So the copper demand for the whole TEN-T network would be roughly 5% (5.13%) of the annual global copper production.

In case we consider the core TEN-T network which spans 34,401km the needed copper would be around 1.3% of the annual global production.

Regarding the BEVs, equipping a BEV with wireless charging capability would need roughly 5-6kg more copper so for a million BEVs the copper demand would increase by 6,000tonnes which is a negligible amount comparing to the global production.

[19] http://insideevs.com/u-s-now-has-16000-charging-stations/

[20] http://www.icsg.org/index.php/component/jdownloads/finish/113/2252

[21] https://ec.europa.eu/transport/themes/infrastructure/ten-t-guidelines/maps_en

The total Cu demand for a passenger BEV with wireless charging capability is 90kg so 90,000tonnes per million BEVs or 0.38% of the current global Cu production.

4.1.1.4 Conclusion

From the above calculations, the authors see no significant bottlenecks deriving from copper shortages due to increased demand from large-scale dynamic wireless charging deployment in Europe in the immediate future. However, since copper is increasingly used for large storage solutions and other energy related systems there can be a significant price hike for this material in the future, which in turn may hinder the further deployment of e-roads based using copper. This is apparent in the following figure showing the copper prices the past years[22]. In the figure below depreciation of currency (USD) should be taken into account to estimate the real value of the metal.

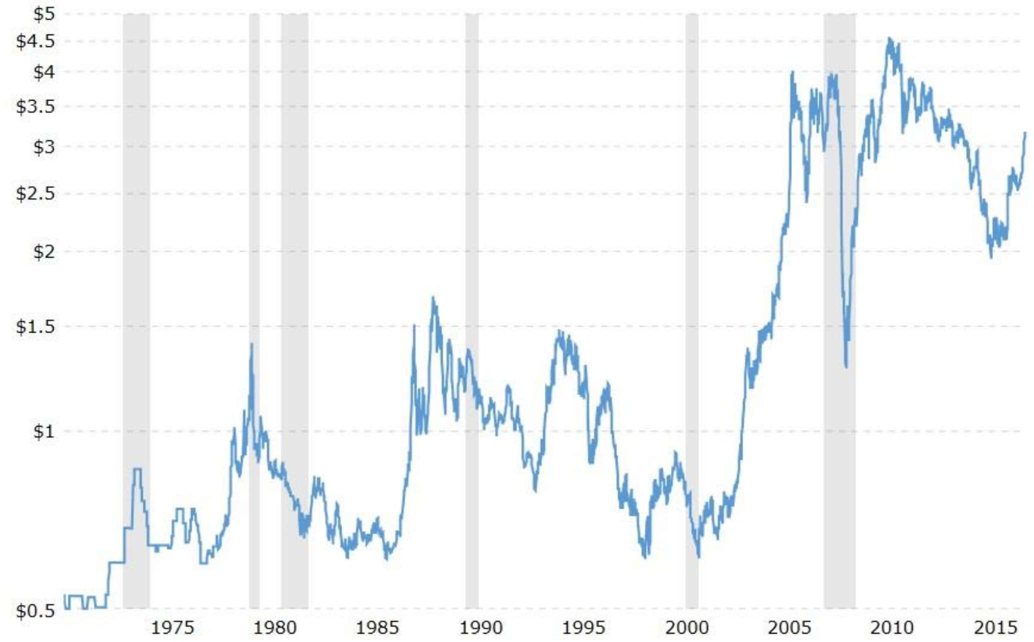


Figure 47: Chart of historical daily COMEX copper prices back to 1971. The price shown is in U.S. Dollars per pound. The current price of copper as of June 13, 2017 is $2.5965 per pound.[23]

On the other hand, in case copper becomes too expensive, other materials may be used instead such as aluminium.

In the optimistic case foreseen in this document where between 2030 and 2050 we could expect the production of 14 million EVs/year in Europe the copper demand (around 1.3 million tonnes/year) could be covered due to the copper reserves worldwide. Specifically the current (2015) reserves are around

[22] http://www.macrotrends.net/1476/copper-prices-historical-chart-data

[23] http://www.macrotrends.net/1476/copper-prices-historical-chart-data

700 million tonnes but an equally significant fact is that the reserves have more than doubled within the last 20 years. Finally, copper is highly recyclable and existing used copper may be repurposed if necessary for e-road usage. A possible bottleneck could appear, depending on the production rate of EVs. In case the vehicle manufacturers decide to mass-produce EVs and shift en masse towards electromobility, perhaps the existing mines will not be able to adapt their capacity and supply chains fast enough to meet the new demand, which may cause copper price surges. In any case, these possible supply-chain and material supply issues are mostly related to the EV production in general and not specifically to the dynamic charging technology which adds a relatively small overhead in copper demand (i.e. ~7% of the EV copper demand).

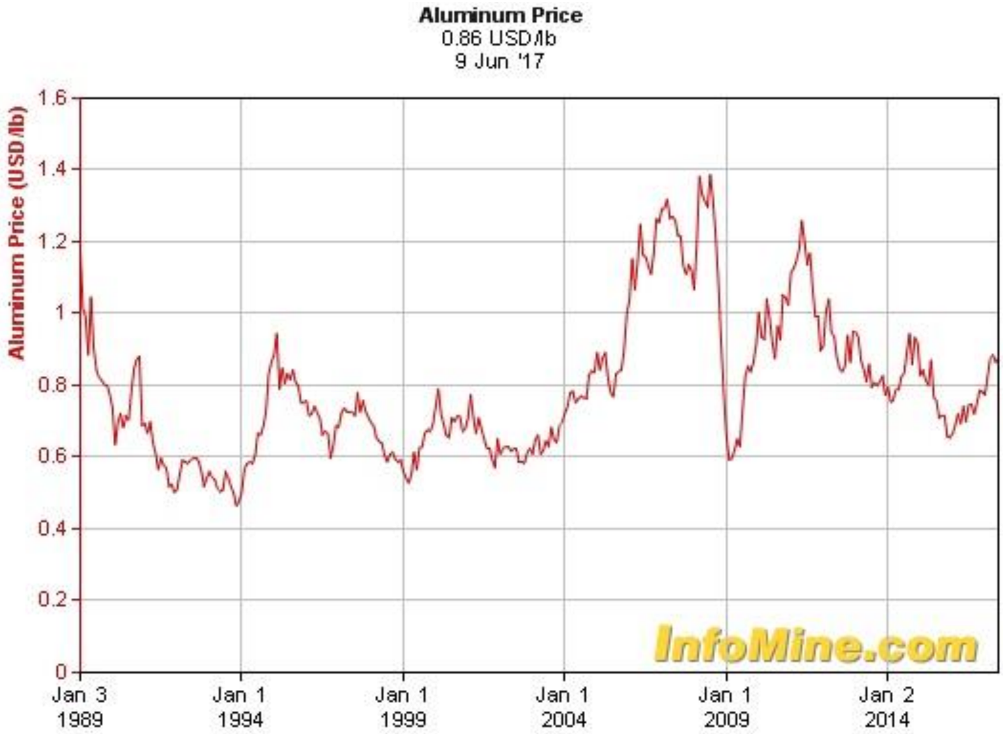


Figure 48: Historical Aluminum Prices and Price Chart. Despite increased demand the price fluctuates within a narrow band. Copper is more preferable for coil manufacturing but Aluminum could be used as well. Aluminum is currently priced at around 30% of the copper price.

4.1.2 Other materials and issues coming from suppliers (Questionnaire feedback)

The questionnaire reproduced in Annex 1 was sent to FABRIC suppliers and other potential suppliers known to the consortium (approximately 30 recipients), but due to the precise nature of the questions and the fact that those contacted were either producing a one-off solution or were producing components mostly used in other sectors, only five responded (plus a few more which stated that they were unable to respond). Responses came from Qualcomm (focusing on intellectual property rather than materials, as its business model is to create IP and license it to Tier 1 suppliers to manufacture),

Fujitsu-TEN Ltd (ERTICO partner and large scale supplier) and three suppliers for the POLITO system: Scanteq (Italian SME), Staubli Italia (Italian subsidiary of a large German company) and Vishay Semiconductor Italiana (medium to large company).

The components produced by respondents were DC Charging Control Electronic Control Units (ECU), Wireless Charging Control ECUs, Wireless Communication Control ECUs, Component boards, Connectors, and Power Electronics (PE) modules (full H-Bridge MOSFETs – metal-oxide semiconductor field-effect transistors and full H-Bridge rectifiers and SCRs – Semiconductor Controlled Rectifiers).

Current output and prices ranged from single-figure output (for bespoke solutions only) for specific components boards (at costs of around €5000 each) to mass produced connectors (millions produced, at around one euro each).

Expected increase in output by 2030 ranged widely from 150% of current production to 1400%, but with no supply chain risks envisaged. All were confident that they could increase capacity by 50-100% by 2020 and by 100-400% by 2030.

The lead time from order to delivery for components ranged from 25 to 90 working days, with the 90-day figure being applicable to the larger components like coils. The number of suppliers used ranged from 5 to 50, and were worldwide. All considered that their transportation services were flexible enough to adapt quickly to changes in demand.

According to the FABRIC manufacturers and suppliers no rare materials are used for the construction of peripheral components needed for the wireless charging systems, so no scarcity of resources is foreseen.

One supplier stated that the main scarcity issue is not raw materials or components, but suitably qualified experts and engineers to design, build and install systems. If a major Europe-wide deployment was to be envisaged, the limit to the number of skilled persons to implement this would be a major constraint, and building human capacity in this domain would only happen if there was a clear market and certainty that such deployment would take place.

In terms of the current and expected future level of competition experienced for the component(s) mentioned, there were differing answers. Current competition was considered low for three respondents, medium for one and high for one. All except one expected competition to increase in the future if there were to be a major increase in demand due to deployment of e-roads.

4.1.3 Delays due to long construction time for power transformers needed for the MV/LV substations

An essential part of the future e-roads will the HV/MV substations for the connection of the charging infrastructure with the grid. Taking into account the most probable deployment scenario for e-roads (intercity highways), the Power Transformers (PT) will be installed in regular intervals. Their number, size and placement depends heavily on the anticipated traffic density (or utilization of the charging lane by EVs equipped with a dynamic charging system) and the charging power level. The Table below provides an estimation of the needed power per km and per 25km in order to estimate the rating of the HV/MV substation.

Table 26: Extra-urban case: power requirement for grid supply assuming values of N_{vpk} of 15 or 30 vehicles per km and different charging power levels.

Charging power (per vehicle) P_{ch} $[kW]$	Grid power per km (Road converter station) P_{km} $[MW]$		Grid power per 25 km (HV/MV substation rating) P_{25km} $[MW]$	
	$N_{vpk} = 15$	$N_{vpk} = 30$	$N_{vpk} = 15$	$N_{vpk} = 30$
20	0.38	0.75	9.4	18.8
50	0.94	1.88	23.4	46.9
100	1.875	3.75	46.9	93.8

The 30EVs/km density is included as it is a boundary condition, as to say, more would probably cause a traffic jam. 30 vehicles per km is considered a critical traffic density for freeways under basic conditions (Daganzo, 1997)[24], as explained in POLITO traffic model in D3.2.1 of FABRIC project[25]. This traffic density is also obtained assuming 50 km/h speed and applying the 2-s distance rule (see also D5.4.1).

The above density assumes that the charging lanes are operating at full capacity. Using the 2 second rule (accepted minimum safety distance in most countries), this is 55.6m between cars at 100km/h. Assuming each car is around 4m long, then we have almost 60m (1 car + safety distance). Then we get 16.7 cars per km at 100km/h. A more realistic scenario is that of 10EVs/km charging at the same time at peak deployment of dynamic charging, while the density will be much lower as well if the e-road is built for HGV (due to longer vehicles and larger safety distance).

Assuming that a FABRIC-like system is deployed, with operating power of 20kW, the power needed is around 9.4MW per 25km for 15EVs/km or 18.8MW for 30EVs/km (25MW in order to have some power transformer capacity reserves). Assuming for simplicity that the power factor is 1 and the power transfer

[24] Daganzo C.F., (1997), "Fundamentals of Transportation and Traffic Operations". ISBN: 978-0-08-042785-0.

[25] FABRIC deliverable D3.2.1 “Architecture definition”.

efficiency is 100%, a power transformer of around 25MVA is needed per 25 km for charging lane utilization at full capacity so:

1. For the extreme case of deploying dynamic charging on the whole TEN-T network (one charging lane in each direction) 273GVA of power is needed: (273,412km/25km)*25MVA
2. For the case of deploying dynamic charging on the core TEN-T network (one charging lane in each direction), 69GVA of power is needed: (68,802km/25km)*25MVA
3. For the realistic case of deploying dynamic charging on 16,000km of TEN-T network, (one charging lane in each direction), 32GVA of power is needed: (32,000km/25km)*25MVA

If the e-roads are used by HGVs much higher charging power is required, however the vehicle density is expected to be lower. Assuming the trucks have a length of ~17m and a 5-second safety margin (at 100km/h the safety distance is 139m) the maximum, safe traffic density is 6,5-7 HGVs per km. Assuming 100kW of charging power, 700kW/km and 17.5MW/25km are needed. This is similar to the above findings for passenger EVs charging at 20kW in high density.

It has to be noted, that 20kW of charging power is barely enough to propel a passenger EV, so using this power level the battery will not be recharged and the e-road will function as a range extender. This will affect the length of the e-road (it needs to span for many km to be useful, for example in the case of a 600km intercity highway, assuming the EV autonomy is (will be) ~400km the 20kW e-road would have to span for at least 250km/direction). A more probable deployment scenario is higher power rates in order to reduce the length of the e-road. In theory each doubling of the power level would half the length of the required e-road, however the size of the HV/MV transformers would also need to double e.g. a 125MVA transformer per 25km for the case of charging 30EVs/km at 100kW/EV.

4.1.4 Power transformer (PT) production capacity

Depending on their size and characteristics, PTs are custom-designed equipment that entail significant capital expenditures and **long lead times** due to an intricate procurement and manufacturing process. Although the costs and pricing vary by manufacturer and by size, a PT can cost millions of dollars and weigh between approximately 100 and 400 tons (or between 100 and 400 tonnes). Procurement and manufacturing of (Large) PTs is a complex process that requires prequalification of manufacturers, a competitive bidding process, the purchase of raw materials, and special modes of transportation due to their size and weight. **The result is the possibility of extended lead times that could stretch beyond 20 months if the manufacturer has difficulty obtaining certain key parts or materials.** Two raw materials—copper and electrical steel—account for over 50 percent of the total cost of a PT. Electrical steel is used for the core of a power transformer and is critical to the efficiency and performance of the equipment; copper is used for the windings. In recent years, the price volatility of these two commodities in the global market has affected the manufacturing conditions and procurement strategy for PTs.[26]

While global procurement has become a common practice for many utilities to meet their growing need for PTs, there are several challenges associated with it. Such challenges include: the potential for

[26] https://energy.gov/sites/prod/files/Large%20Power%20Transformer%20Study%20-%20June%202012_0.pdf

extended lead times due to unexpected global events (e.g., hurricanes) or difficulty in transportation; the fluctuation of currency exchange rates and material prices; and cultural differences and communication barriers. The utility industry is also facing the challenge of maintaining experienced in-house workforce that is able to address procurement and maintenance issues.

In terms of annual production capacity (2011), ABB and Alstom Grid each had approximately 200,000 MVA and 130,000 MVA of annual production capacity, respectively.[27]

Other companies have emerged in recent years and have been extending their offer coverage and geographical reach such as HHI and Hyosung Power and Industrial Systems (**HICO**) of South Korea; **Crompton Greaves** of India; Tebian Electric Apparatus Stock Co., Ltd. (**TBEA**), Baoding Tianwei Baobian Electric Co., Ltd. (**TWBB**), and Xian XD Transformer of China (**XD**). Each of these companies boasts an annual production capacity in the range of 70,000 to 125,000 MVA (2012 figures). The US annual production of LPT (60+ MVA) was around 20,000 MVA (in 2011), however production ramped up since.
It should be noted that the capacity to produce does not necessarily warrant actual production of large power transformers. A number of firms identified constraints in equipment (cranes, ovens, testing, winding, and vapor phase systems) **and the availability of trained personnel set limits to their production capacity**[28].

- Additional demand for power transformers due to e-road construction

From the four scenarios calculated in the beginning of this section, the two extreme scenarios require around 140,000MVA of power transformers while the more realistic deployment scenarios require around 25,000MVA of power transformers (just for the Europe TEN-T network). This is roughly the annual power transformer production of Alstom Grid and 1/5th of it respectively for the extreme and realistic scenarios. However one should take into account that the deployment of e-roads will be gradual, spanning several years, heavily depending on country policies and international agreements.

- Competition for the procurement of LPTs

In addition to the aging of power transformers, key demand drivers for LPTs include: transmission expansion to integrate solar and wind renewable sources; electric reliability improvement; and new capacity addition in thermal and nuclear power generation.

- Raw materials for PTs

Two key raw materials—copper and electrical steel—are vital to LPT manufacturing. However, there are limited supply sources for special grades of electrical steel needed for the PT core, and both steel and copper have experienced wide price fluctuations since 2004. Their price volatility is expected to

[27] ABB: https://library.e.abb.com/public/9ebd14f0eaa245be8174788ee1028486/Power%20Transformers.pdf and http://www.abb.mu/cawp/seitp202/51719ef8b8b364ee48257690001f063a.aspx; Siemens does not disclose its total annual production capacity; however, it has an annual manufacturing capacity of 70,000 MVA in China. See http://www.stcl.com.cn/stcl/en/aboutus.asp.

[28] "Large Power Transformers from Korea," USITC, Preliminary Investigation, September 2011. https://www.usitc.gov/publications/701_731/Pub4256.pdf

continue as the demand for these commodities, especially from developing economies (i.e., China and India), is forecasted to grow in the next several years.

- Procurement delays

PTs require a long lead time and transporting them can be challenging. **The average lead time for an PT is between five and 16 months**; however, the lead time can extend beyond 20 months if there are any supply disruptions or delays with the supplies, raw materials, or key parts. Its large size and weight can further complicate the procurement process, as an LPT requires special arrangements and special rail cars for transport. New LPT concepts such as RecX could reduce transportation and installation times. The prototype transformer delivery and set up was successfully demonstrated in March of 2012 in an exercise that included the transportation, installation, assembly, commissioning and energization of the transformer in less than 1 week[29].

- Conclusion

The connection of the e-roads with the grid requires a large number of HV/MW power transformers which is expected to put pressure on the manufacturing companies. Due to the size and weight of these transformers, transportation can be challenging and expensive, while unforeseen events may cause significant delays. Due to these reasons, European manufacturers and local production should be preferred for the European deployment of e-roads. ABB and Alstom Grid (acquired by GE since 2015), as well as Siemens having long experience, being worldwide leaders and having very mature supply chains will probably be able to cover the additional demand on power transformers especially taking into account that e-road deployment will be gradual. However careful planning should be done due to the long lead time required for the manufacturing of power transformers, which could cause delays in the e-road deployment that could reach months or even years.

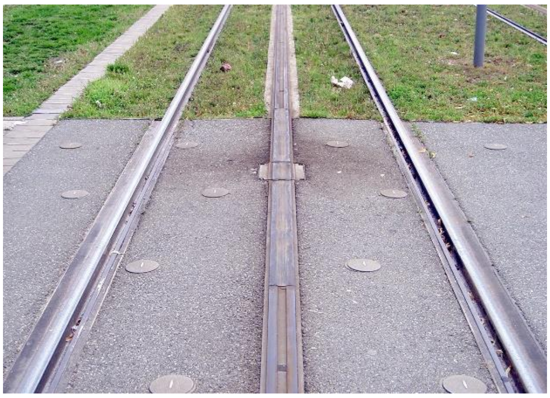
[29] http://www.abb.com/cawp/seitp202/c838625f4d7a38e4c1257a92001e9b8a.aspx

4.2 Conductive dynamic charging systems

Conductive charging is mainly aimed at large vehicles due to space restrictions for the pantograph and allows for high operational power suitable for freight transportation. It is a technology found in trams, trolleys and trains which has been operational for many decades and is now adapted to facilitate the dynamic charging of electric heavy vehicles. There are two main variations of the technology, the ground-level power supply and the overhead line power supply.

4.2.1 Volvo-Alstom APS system

It is an adaptation of the third-rail electrical pick-up for street trams.



(a)

(b)

Figure 49: (a) A section of APS track showing the neutral sections at the end of the powered segments plus one of the insulating joint boxes which mechanically and electrically join the APS rail segments (b) Volvo Slide-in project track

The system has been pioneered by the Bordeaux tramway in France where there are 12 km of APS[30] tramway installed by Alstom. In July 2006, it was announced that two new French tram systems would be using APS over part of their networks.[31] These are located in Angers[32] and Reims, with both systems opening in 2011. A couple of months later, it was announced that Orléans would use APS on a section of its second tram line, which opened in 2012, and that Tours would use APS on sections of its new network which began service in 2013[33].

[30] APS: “Alimentation par le Sol” (feeding from the ground)

[31] "Reims and Angers choose APS". Railway Gazette International. 1 August 2006.

[32] "Angers tram opens". Railway Gazette International. 29 June 2011.

[33] "Tours selects Citadis and APS". Railway Gazette International. 2010-09-14.

The Dubai Tram, which opened in 2014, is fully equipped with APS over its entire passenger length. Other cities that have previously, or are in the process of proposing the use of APS and similar systems (e.g. Bombardier Primove, Ansaldo TramWave) include:

- Nice, France (abandoned in favour of nickel metal hydride batteries)
- TRAMMET, Barcelona, Spain[34]
- Western Suburb Line, Beijing
- Gestione Servizio tramviario (GEST), Florence, Italy
- Tramway de Marseille, Marseille, France
- VLT, Rio de Janeiro, Brazil
- Tranvía Cuatro Ríos de Cuenca, Cuenca, Ecuador
- CBD and South East Light Rail, Sydney, Australia[35]

From the above it can be seen that APS conductive charging is much more mature than inductive charging systems, have been or are planned to be installed in several cities and there are supply chains in place. In case it is decided to move forward with large-scale deployment of conductive charging for electromobility the existing supply chains will expand and new ones will be formed.

4.2.2 Conductive charging with overhead line – Siemens

This system is similar to the ones used for electric trains and trolleys. Both systems use a pantograph to collect energy from the overhead lines, with the difference that rail systems (trains and trams) use one of the rails for the return current, whereas road systems (traditional trolleybuses and the new Siemens system) require twin overhead wires to allow the current return.. The Siemens system has been installed in Sweden (2km) and USA (1.6km) for demonstration purposes. In addition Siemens has been commissioned by the German state of Hesse to build an overhead contact line for electrified freight transport on a ten-kilometer stretch of autobahn .

In Figure 51 the existing network of high-speed railway lines in Europe is shown. In 2006, 240,000 km (25% of total length) of the world rail network was electrified and 50% of all rail transport was carried by electric traction . In 2012 China surpassed Russia making it first place in the world with over 48,000 km electrified railroads . Trailing behind China were Russia 43,300 km, India 30,012 km , Germany 21,000 km, Japan 17,000 km, and France 15,200 km.

It can be assumed that the supply chains and components/materials for gradually deploying a similar network for the dynamic charging of electric HGVs already exist. This is verified also by expert opinions from Volvo, Alstom and Siemens.

It can be expected that there will be a stress in the procurement of large power transformers, switches and other components for the connection to the electric grid since HGVs require high operating power for the system to be functional (>200kW), however the magnitude of this stress depends on the

34 "El Consistorio planea un tranvía sin catenaria por la Diagonal". El País. 2008-09-09. Retrieved 2008-10-19.

35 http://www.transport.nsw.gov.au/media-releases/cbd-and-south-east-light-rail-improvements-deliver-better-service-customers

deployment rate of the dynamic charging technology. Depending on the traffic volume, significant upgrades of electric grid infrastructure will be required which could be similar to the requirements for building a new railway for a high-speed train.

(a)

(b)

(c)

Figure 50: (a) Overhead lines for railway electrification; (b) overhead lines for trolleybuses; (c) overhead lines of Siemens eHighway

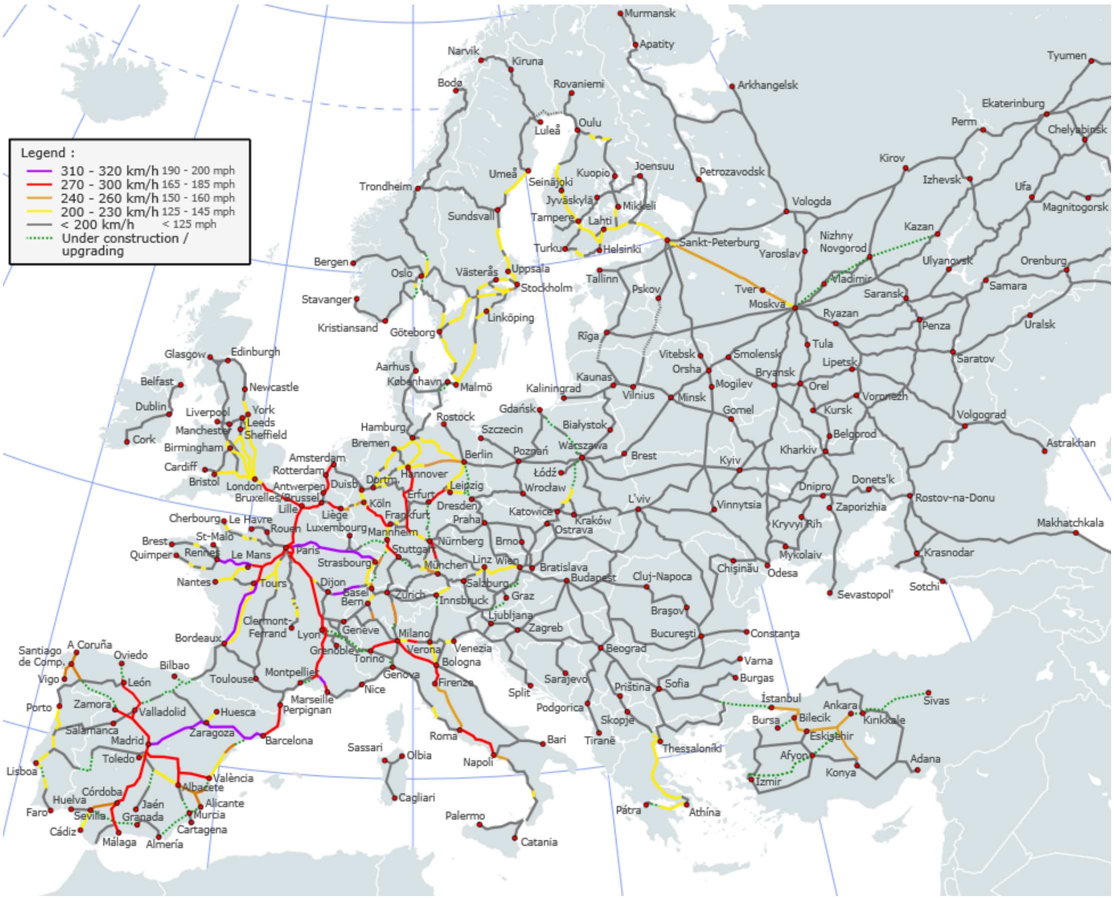


Figure 51: Operational high-speed lines in Europe

Regarding urban trolleybus networks, although many have closed in recent decades, there are still 73 systems in operation in the EU, another 63 in other European countries (excluding Russia), and 85 in Russia. Europe's largest system is in Moscow and the second is in Minsk, while other large systems include Athens-Piraeus (360 trolleybuses), Bucharest (300 trolleybuses) and Riga (264 trolleybuses). Although nearly all systems are urban, there is an 86 km interurban route in Crimea, the longest trolleybus line in the world.

Most networks are old and are mostly situated in Eastern European countries, but not exclusively, e.g. there are 14 networks in Italy and 13 in Switzerland. But while some are in decline and lack investment, others have been recently modernized and a small number of new systems are being constructed. A recently built system is in Castelló de la Plana (the first reopened trolleybus network in Spain, opened in 2008) where the trolleybuses are optically guided.

So, in the countries where systems exist, there are supply chains, materials and expertise for construction, maintenance and renewal of overhead line conductive on-street systems.

5 CONCLUSIONS

Deliverable D5.4.2 aimed to detect and investigate issues that may arise with the supply chain for dynamic charging systems' manufacturing. Furthermore it checked whether limitations on the procurement of raw materials should be expected, whether due to the use of rare resources or resources that could become scarce because of the large demand.

Several issues became apparent during the preparation of this report:

1. For wireless dynamic charging, the technology is currently TRL6 meaning that there are no supply chains in place for this kind of systems. The manufacturing scale for the production of the prototypes is very small, and the study findings that are based on the current FABRIC components supplier interviews cannot be necessarily generalized, representing the future conditions due to the following reasons:
    a. The supply chain processes in FABRIC are non-existent and certainly not optimized for large-scale manufacturing.
    b. The production capability of the suppliers interviewed within the frame of the project is not oriented specifically towards the dynamic charging technology investigated in the project.
    c. It is obvious that the limited production capacity of the interviewed suppliers cannot satisfy the demand for such a system in a country or European level, however since demand is non-existent at the time of writing no efforts have been done to expand the manufacturing capabilities in that direction.
2. The demand for such a system is next to impossible to predict because:
    a. The demand for EVs as a function of time is a variable which is heavily dependent for the time being and the foreseeable future on policies and government incentives.
    b. Even if the future EV market penetration rate was known, the number of EVs that will feature dynamic wireless charging remains an assumption, which affects directly the anticipated demand as a function of time. A large number of studies exist on the subject, but not only do they vary extremely regarding their estimations, but the estimations are revisited frequently due to updated, real-time market observations and new technology trends.
    c. Furthermore, battery technology has been making steady progress as well as significant leaps in the recent years, such as the construction of Tesla Gigafactory 1 (and the very recent plans for the construction of a similar Gigafactory in Germany by Daimler. These large scale efforts bring the battery cost down significantly due to the vertical manufacturing processes (from raw materials to finished product) while bringing the production times down as well, which is also factor for cost reduction. This may mean that larger batteries could become affordable reducing range limitations for future EVs even further. An additional factor that may play significant role in reducing the future demand for dynamic charging is the very likely increase of battery energy density via the use of new chemistries and topologies (packaging).

   d. A factor that may also affect demand for dynamic charging but in a positive way is a future lack of materials and increased international competition for securing resources used in battery manufacturing, especially since lately there has been increasing demand for large-scale energy storage projects to facilitate increased RES penetration and smart grid applications, in addition to electromobility applications (e.g. demand shaping for increased security in grid operation and energy production cost optimization). The lack of resources may push for much smaller batteries, hence increased need for dynamic charging for interstate and intercity travels will emerge.
   e. Finally a factor that will affect future demand and application scenarios is fast and ultra-fast charging. Depending on the time needed to recharge completely and the number (availability) of (ultra-) fast chargers along intercity highways, the demand (need) for dynamic charging may be nullified (or not). The implementation of ultra-fast charging infrastructure in turn depends on several factors such as cost, grid capacity, standardization, EV market share and incentives in order to have a viable business model.
3. Cost is a critical parameter in determining the large-scale deployment potential of a new technology. It has to be (or become via incentives) comparable to competitive technologies that to a degree satisfy the end-user operational requirements (i.e. reach a destination with a comfort and usability level comparable to ICE vehicles). Within SP5 of FABRIC there was an effort to estimate the cost of the investigated technology (wireless dynamic charging), however this cost refers to the prototypic development and it is not representative of future large-scale production cost. In that way, we reach a circular problem in which the cost affects future demand and future demand affects the projected cost. It becomes clear that government incentives will play a major role for early development which will lead to lower production costs. However this factor cannot be predicted and it will differ greatly among the EU countries.

Study outcomes

Due to the above it becomes apparent that no definitive results can be produced, but educated guesses can be made in case that no glaring limitations in the manufacturing process are detected.

EV market growth forecast

One of the main outcomes, although not directly related with the supply chains capacity, was the revised outlook on future EV market growth and hence demand for wireless charging in general. FABRIC study found that with the current data and rate of adoption, the existing forecasts should be revised towards higher EV adoption rates. This is due to most current EV sales numbers (that exceed by large the past forecasts) and large-scale manufacturing projects that are bringing the batteries and EV costs down. Large adoption of EVs with wireless charging capabilities is pre-requisite for the installations of wireless charging corridors due to the high investment cost. In order to check whether there will be material shortages related to dynamic charging, the most optimistic prediction for EV adoption was selected.

Materials scarcity assessment

The second outcome is the decomposition of the system and the results of the interviews with the suppliers, focusing mainly on the use of rare materials that may cause production bottlenecks or increased competition among suppliers, which in turn will increase the materials' prices and as a direct result the system cost.

The interviews revealed that no material shortages are expected, however even if that was the case (scarcity of materials), this would not necessarily be the critical factor that would stop dynamic wireless charging systems' deployment. This is due to the following reasons:

- Only the FABRIC prototypes were investigated. Other (future) implementations may use other topologies and other materials. For instance, even within FABRIC, the SAET coils use much less copper than the POLITO coils. Other implementations may use different materials as well, for example aluminum instead of copper.
- The means and processes for raw material extraction and procurement are evolving and become more efficient with time (and material scarcity) so materials can now be extracted from areas that were not exploitable in the past. This is the reason why metal prices do not skyrocket but rather fluctuate with time even though demand is steadily increasing.

Since no rare materials are used, the next thing to investigate was whether there would be shortages due to the large quantities of material needed for dynamic charging. This includes both infrastructure and EVs. Again a maximalist approach was followed considering that the whole TEN-T European road network will be covered by dynamic charging infrastructure. For wireless charging the result was that the copper demand to cover the whole TEN-T network would be roughly 5% (5.13%) of the annual global copper production. In case we consider the core TEN-T network which spans 34,401km the needed copper would be around 1.3% of the annual global production.

Regarding the BEVs, equipping a BEV with wireless charging capability would require roughly 5-6kg more copper so for a million BEVs the copper demand would increase by 6,000tonnes which is a negligible amount comparing to the global production. The total Cu demand for a passenger BEV with wireless charging capability is 90kg so 90,000tonnes per million BEVs or 0.38% of the current global Cu production.

In the optimistic case foreseen in this document where between 2030 and 2050 we could expect the production of 14 million EVs/year in Europe the copper demand (around 1.3 million tonnes/year) could be covered due to the copper reserves worldwide. Specifically the current (2015) reserves are around 700 million tonnes but an equally significant fact is that the reserves have more than doubled within the last 20 years. Finally, copper is highly recyclable and existing used copper may be repurposed if necessary for e-road usage. A possible bottleneck could appear depending on the production rate of EVs. In case the vehicle manufacturers decide to mass-produce EVs and shift en masse towards electromobility, perhaps the existing mines will not be able to adapt their capacity and supply chains fast enough to meet the new demand, which may cause copper price surges. In any case, these possible supply-chain and material supply issues are mostly related to the EV production in general and not specifically to the dynamic charging technology which adds a relatively small overhead in copper demand (i.e. ~7% of the EV copper demand).

Supply chain restrictions

Wireless dynamic charging

Three main observations and trends drive the assessment of the future issues that may appear regarding the supply chains for wireless dynamic charging systems:

a. Very gradual deployment of the technology
   Deployment of a certain technology depends on many parameters, mainly cost in relation to the degree of urgency for such deployment, meaning how important in peoples' daily life is the gap that this technology is designed to fill. In the present report a detailed analysis on the most possible deployment scenario is included in order to reach an assessment of the expected demand for a full-scale deployment. Based on several assumptions it provides an estimation of which roads are the most probable candidates to feature charging lanes in the future. This is based on one logical criterion: charging lanes will be installed where the distances are longer than the EVs range, which means that normally the EVs would have to stop for recharging mid-trip which with the current normal slow charging would make intercity travels infeasible. This is a pressing problem that would justify investment on charging lanes and it would facilitate the faster adoption of EVs. However the deployment (if it happens) will most likely be (very) gradual and the demand is not expected to be overwhelming due to the following reasons:
   - Dynamic charging is not addressing a critical everyday problem. This is especially true since the EV users may very well rent an ICE vehicle for long intercity and interstate travels during the decades that the transition to electromobility will take place. In this way, deployment is more likely to be gradual, dependent on government incentives, at least in the beginning, in economically robust and environmentally concerned countries that might want to deploy some corridors featuring dynamic wireless charging as a proof-of-concept and large-scale TRL-9 testing prior to even larger-scale investment.
   - Static charging is experiencing evolutionary leaps the (very) recent years, mainly because of disruptive OEMs that push the technology hard towards increased usability aiming to make EVs competitive to ICE cars. The technological revolution in fast charging started with Tesla superchargers at 120kW. This meant that the Tesla EV could gain 273 km of autonomy in just 30 minutes. Even at this charging level a 30-minute stop every 250-300km is something that makes long-range travel with EVs feasible while many ICE drivers make such short stops to rest during long trips. Since 2016 plans for much higher charging power were announced, while Tesla's CEO Elon Musk hinted at deploying superchargers with operating power that largely exceeds 350 kW.

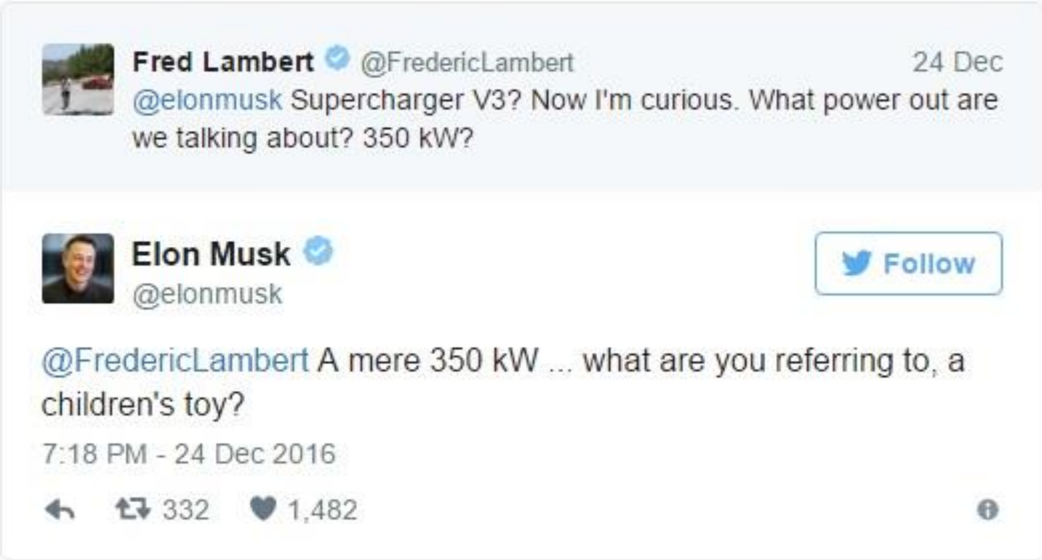


Figure 52: Tesla Motors' CEO Elon Musk reveals plans for ultra-fast charging stations in a tweet at the end of 2016.

In 2017 Porsche and Tritium have unveiled 350kW ultra-fast chargers, capable of providing 300km range in just 15 minutes. Tritium will start installing these chargers in the USA from April 2018.[36]

This comes quite close to the typical ICE refueling times and is most likely acceptable by the vast majority of drivers. This kind of technology could make dynamic charging redundant or at least decrease significantly the pressure for fast, very large-scale deployment and the corresponding formation and optimization of very large supply chains.

- A final factor is as already mentioned the improvement of battery density and the corresponding increase of EV range even for near-future affordable models.

b. No specialized supply chains in place for now but building blocks are in place

Dynamic EV charging pre-requires a large number of EVs with wireless charging capabilities (even static) already on the road. In that way, production of coils and the rest of the necessary components will follow the (gradual) evolution of electromobility, while the corresponding supply chains will be formed, evolve and mature as the gradual demand for EVs with static wireless charging capabilities grows. The first steps towards this supply chain formation are becoming visible this year (2017) with major car manufacturers that introduce to the market several models with wireless charging capabilities (BMW[37], Daimler[38], Toyota). Potential issues

[36] http://insideevs.com/tritium-350-kw-dc-fast-chargers/

[37] http://www.bmwblog.com/2017/04/27/bmw-wireless-charging-530e-2018-inductive-charging/

[38] https://www.daimler.com/innovation/efficiency/emission-free-driving.html

with suppliers and supply chain optimization are expected to be ironed out by the time dynamic charging lanes are to be deployed, since most components are similar or the same between static and dynamic wireless charging.

c. Recent vertical manufacturing trends will likely solve issues that may appear
Tesla Motors has become a disruptive company for the automotive industry. Since 2008 when it first launched its first model, it has been introducing innovations in electromobility and at the moment of writing it has (briefly) surpassed in capital value the giant ICE automakers GM and BMW, becoming the 4th most valuable automaker worldwide[39]. A critical factor for Tesla Motors' success has been the continuous innovation, not only regarding the vehicles but also the manufacturing process. By centralizing production in a vertical manner via the creation of "Gigafactories", Tesla was able to reduce production times, make better deals with raw material suppliers, optimize processes via large-scale automation and robotics and eliminate transportation-related delays from Tier 2, 3…, n suppliers. Similar vertical manufacturing factories are under construction in Europe as well[40]. At least three more Gigafactories are planned by Tesla to feed the increasing demand of EVs. A similar approach, where supply adjusts quickly to meet demand following disruptive avenues, could be expected for the manufacturing of dynamic charging systems in case there is significant demand. This will optimize and consolidate supply chains bringing the cost down and reducing delivery times.

Conductive dynamic charging

Conductive dynamic charging systems fall into two categories depending on the layout of the current collection system: the overhead lines power supply and the ground-level power supply systems. In both cases the vehicle collects the current using properly constructed pantographs. These systems have been in use for trolleys, trams and trains for several decades. The conductive systems are focused mainly for heavy good vehicles due to vehicle space restrictions and support high-power energy transfers.
Since both systems have been in use for a long time, there are already mature supply chains that need to be slightly adjusted for application on trucks. In addition, the sheer length of existing electrified railway network is an indication that so far there has not been a problem with materials scarcity, which is also verified by expert opinions from Alstom, Volvo and Siemens.

Connection with the Electric Grid

The required power for feeding an e-road has been estimated based on extreme and more realistic traffic scenarios for operating powers of 20kW (FABRIC-like system) up to 100kW. Depending on the traffic density, the charging operating power and the coverage area of TEN-T network with e-roads the required power could range from 32,000MVA to more than 270,000MVA (for 20kW charging power and

39 https://www.bloomberg.com/news/articles/2017-06-09/tesla-passes-bmw-in-market-cap-ranks-no-4-automaker-by-value-j3pxj7gc

40 https://electrek.co/2017/05/22/daimler-battery-gigafactory-electric-vehicles/

maximum traffic density). To put into perspective, in terms of annual production capacity (2011), ABB and Alstom Grid had approximately 200,000 MVA and 130,000 MVA of power transformer annual production capacity, respectively.
Regardless of whether the implementation of dynamic charging is inductive or conductive, It can be expected that there will be a stress in the procurement of power transformers, switches and other components for the connection to the electric grid since HGVs or high-powered charging for passenger EVs require high operating power for the system to be functional (100kW - >200kW), however the magnitude of this stress will depend on the deployment rate of the dynamic charging technology. Depending on the traffic volume, significant upgrades of electric grid infrastructure will be required which could be similar to the requirements for building a new railway for a high-speed train.

Other possible bottlenecks

A possible shortage may appear regarding suitably qualified experts and engineers to design, build and install systems. If a major Europe-wide deployment was to be envisaged, the limit to the number of skilled persons to implement this would be a major constraint, and building human capacity in this domain would only happen if there was a clear market and certainty that such deployment would take place.

REFERENCES

References are provided as footnotes in the document for easier access.

ANNEX I – SURVEY QUESTIONNAIRE

FABRIC questionnaire on supply chain of components and systems for dynamic wireless electric vehicle charging

Thank you for assisting the FABRIC project with this questionnaire.

FABRIC (www.fabric-project.eu) is a European project investigating the feasibility of **dynamic on-road charging for Electric Vehicles (EVs)** using different technologies, with a focus on **Wireless Power Transfer (WPT)**. It includes demonstrations of this technology at sites in Italy (Turin/Susa) and France (Versailles).

This questionnaire is part of a task looking at the maturity, reliability, efficiency and stability of the supply chain of components and systems needed for WPT charging to be implemented on a large scale.

The purpose is to identify potential bottlenecks: components or systems that might not be able to be produced in sufficient quantities in the required timescale due to the availability of materials, production capacity or other factors.

Please respond as to your own opinion in each case (there are no right and wrong answers). You can give an estimate (in fact most answers may be estimates) but if you cannot, or if a question is outside your area of work or competence, please skip it – it is not obligatory to answer every question.

Results of the questionnaire will be included in a public report but they will not be linked to the identity of the respondent or to their company. Therefore your answers will be treated confidentially in that they will be anonymous. Your email address will be kept confidential and not used for other purposes. We will send you an advance copy of the report for comments before it is made public.

Fields to fill in are in red text.

If you have any questions, please contact Andrew Winder (ERTICO), a.winder@mail.ertico.com

1. Respondent/company profile

Company name: Name

Type of company (SME, large international company, etc.): Select a response
Approximate number of staff: Select a response
Location of main manufacturing facility making the components covered in this questionnaire: Town or city
Respondent name: Your name
Email: @

2. Which component(s), related to electric power transfer systems for vehicles, do you manufacture, supply or purchase? What are their average selling prices?

These can be components currently used for wireless or conductive charging, or components that are not yet used for these purposes but which could be in the future.

Please enter at least one component (a) and up to a maximum of 3 (b, c).

In all subsequent questions, (a), (b) and (c) relate to the component(s) you have entered for this question.

	Component name	Wireless (or conductive) power transfer element in which it is used (or could be used in the future)	Average selling price without tax (€ per unit or specify currency if not euro). You can give an approximate range.	If the price is based on selling a certain quantity of units (for example 100 or 1000), please enter how many units.
a)	Component 1	Select a response	€ /unit	units
b)	Component 2 (if applicable)	Select a response (if applicable)	€ /unit	units
c)	Component 3 (if applicable)	Select a response (if applicable)	€ /unit	units

Comment (optional): Comment (e.g. to specify if "Other" is selected above

3. For the above component(s), is your organisation a manufacturer, distributor or buyer of this component? If you manufacture it, are you a Tier 1, Tier 2 or Tier 3 supplier, or the final producer?

Final producer: assembler such as OEM (car maker) or builder of electric charge points or road systems.

Tier 1: you supply directly to the assembler.

Tier 2: you supply to a Tier 1 component producer.

Tier 3: you supply to a Tier 2 component producer.

Component (from Question 2)	Is your organisation a manufacturer, distributor or buyer of this component?	If manufacturer, what type of supplier (Tier 1, 2, 3, final assembler?)
a)	Select a response	Select a response
b)*	Select a response	Select a response
c)*	Select a response	Select a response

Comment (optional): Comment

4. What is your current annual production for this item, how has it evolved in recent years and what evolution do you see in the next few years?

Component	Units manufactured	Approximate %	Expected % change	Do you see any

(from Question 2)	(or sold) per year (latest available figure)	change in production (+ or -) since Select year	in production (+ or -) by the year 2030?	risks in your current supply chain for this item
a)	Number	+ or – x%	+ or – x%	Select a response
b)*	Number	+ or – x%	+ or – x%	Select a response
c)*	Number	+ or – x%	+ or – x%	Select a response

* if applicable (in case of more than one component)

5. What percentage of this production is used in vehicle or road systems and what percentages are used in other industries?

Component (from Question 2)	Current % of production used in automotive industry	Other industries in which this item is used	Current % of production used in each of these other industries
a)	%	Industry/industries	%
b)*	%	Industry/industries	%
c)*	%	Industry/industries	%

6. How long does it take you to produce this component?

Component (from Question 2)	Lead time from order to shipment (working days)	Actual time to manufacture the product (once all needed materials are on the production site) (working days)
a)	days	days
b)*	days	days
c)*	days	days

* if applicable (in case of more than one component)

7. What is your expected future capacity to cope with the following production increases?

Component (from Question 2)	By the year 2020		By the year 2030	
	Possible with in current resources (equipment, availability of raw materials and current staff)	Possible with some planning and increase in capacity and sufficient demand	Realistic capacity with some planning and increase in capacity and sufficient demand	Maximum capacity in the event of high and sustained demand
a)	Approx. output per year (units)	Approx. output per year (units)	Approx. output per year (units)	Approx. output per year (units)
b)*	Approx. output per year (units)	Approx. output per year (units)	Approx. output per year (units)	Approx. output per year (units)
c)*	Approx. output per year (units)	Approx. output per year (units)	Approx. output per year (units)	Approx. output per year (units)

* if applicable (in case of more than one component)

Please state what the main bottleneck, if any, is likely to be (availability of raw materials, investment in new equipment/machines, recruitment of qualified staff, physical space at your premises, other…):
Click here to enter text.

8. How many suppliers do you use for your raw materials (or components) to manufacture the following products?
Where are they located and what are their capacities to respond to changes in demand?

Component (from Question 2)	Number of suppliers	Locations (select all that apply)	Supplier response to changes in demand	Ability for transportation to adapt quickly to changes in demand
a)	Number	☐Local (within 50km) ☐National ☐Other European countries ☐World (other continents)	Select a response	Select a response
b)*	Number	☐Local (within 50km) ☐National ☐Other European countries ☐World (other continents)	Select a response	Select a response
c)*	Number	☐Local (within 50km) ☐National ☐Other European countries ☐World (other continents)	Select a response	Select a response

* if applicable (in case of more than one component)

In each case please use one of the drop-down menu options, explained as follows:
1. Flexible (can adapt quickly to changes, quantity of supply is not an issue)
2. Fairly flexible (e.g. one month delay)
3. Probable need to find additional supplier(s) or transport provider(s) in case of short term capacity increases
4. Difficulties envisaged even in case of longer terms increases in need (e.g. > 1 year) due to availability (please expand/explain if this is the case)

5. Do the components you make use rare earth metals or expensive materials whose price has increased significantly in recent years?

Component (from Question 2)	Uses rare earth elements (see http://en.wikipedia.org/wiki/Rare_earth_element for definitions), other expensive elements, or elements whose price has significantly increased recently.	If yes, please state which ones
a)	Select a response	Name(s) of element(s)
b)*	Select a response	Name(s) of element(s)
c)*	Select a response	Name(s) of element(s)

6. How do you see unit prices evolving in future years?

Component (from Question 2)	By the year 2020		By the year 2030	
	Expected change in price compared to now, assuming 50% increase in production levels	Expected change in price compared to now, assuming doubling of production levels (100% increase)	Expected change in price compared to now, assuming doubling of production levels	Expected change in price compared to now, assuming quadrupling of production levels
a)	%	%	%	%
b)*	%	%	%	%
c)*	%	%	%	%

* if applicable (in case of more than one component)

7. What level of competition do you experience now for the component(s) mentioned? How do you expect it to change in each of the three future scenarios given below?

Component (from Question 2)	Current competition (in 2017)	Expected change in competition by the year 2020		Expected change in competition by the year 2030 with quadruple the current demand
		with 50% additional demand	with double the current demand	
a)	Select a response	Select a response	Select a response	Select a response
b)*	Select a response	Select a response	Select a response	Select a response
c)*	Select a response	Select a response	Select a response	Select a response

* if applicable (in case of more than one component)

In each case please give a score:

Low (only a few suppliers, mostly local markets)
Medium / stable
High
Intense (rapidly changing situation and volatile prices / market)

8. Any other comments or information? (optional): Click here to enter text.

End of questionnaire. Please email this form to a.winder@mail.ertico.com
Thank you for your assistance!

ANNEX II – EUROPEAN COUNTRY INCENTIVES FOR EV ADOPTION

Norway

Total Passenger Cars: 2.500.000
Highway: 194km
EV stock 2015: 70.820
EV market share in 2015: 2,83%

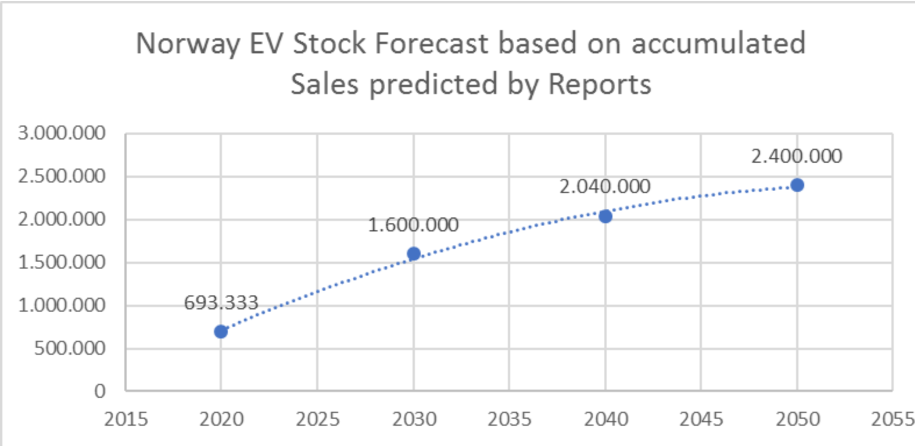


Figure 53: Norway EV Stock Forecast based on accumulated Sales predicted by Reports[41]

Table 27: Norwegian incentives

Incentive category	Description
Registration Tax Benefits	Purchase Tax exemption for BEV's/FCEV's, reduction for PHEV's (Up to 10.000€)
Ownership Tax Benefits	Tax reduction
Company Tax Benefits	Tax reduction
VAT Benefits	No VAT tax (BEV / FCEV)
Other Financial Benefits	No import Tax - Purchase tax/import tax is the same in Norway.
Local Incentives	▪ Urban toll exemption ▪ Highway toll exemption ▪ Free Parking ▪ Bus lane use ▪ Funding in some cities for normal charging stations in shared apartment buildings, shopping centers, parking garages etc.
Infrastructure Incentives	Public funding for fast charging stations every 50 km on main roads.

41 EAFO (2016): Country Profile on Website; *(*http://www.eafo.eu/content/norway*)*
Electrive.net (2016): Norwegen zählt 100.000 reine Elektroautos; *(*https://www.electrive.net/tag/norwegian-ev-association/*)*
Fridstrøm L. et al. (2016): Vehicle fleet forecasts based on stock-flow modelling

United Kingdom

Total Passenger Cars: 28.500.000
Highway: 3.555 km
EV Stock in 2015: 49.670
EV market share in 2017: 0,17%

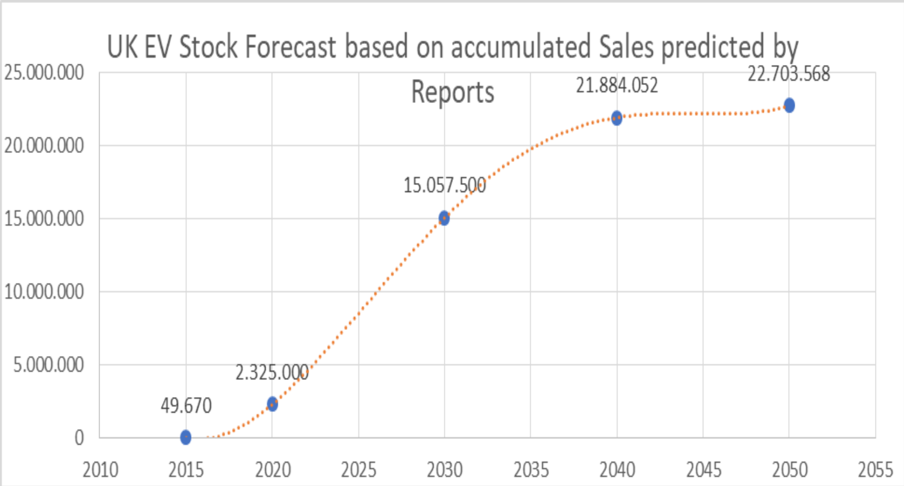


Figure 54: UK EV Stock Forecast based on accumulated Sales predicted by Reports[42]

Table 28: UK incentives

Incentive category	Description
Purchase Subsidies	▪ EVs with CO_2 emissions below 50 g/km and an electric range of 70 miles receive a grant of £4,500. ▪ EVs with CO_2 emissions below 75 g/km and an electric range of at least 10 miles

42 Element Energy Limited, University of Aberdeen, Ecolane (2013): Pathways to high penetration of electric vehicles, *for The Committee on Climate Change*

- myelectricavenue.info (2016): "The growth of electric vehicles" *(*http://myelectricavenue.info/growth-electric-vehicles*)*
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- Element Energy Limited, University of Aberdeen, Ecolane (2013): Pathways to high penetration of electric vehicles, *for The Committee on Climate Change*
- Kay D. et al. (2013): Powering ahead The Future of low-carbon cars and fuels
- Juniper Research (2016): "Hybrid and Electric Vehicle Sales to Exceed 17 million by 2020 as 'Range Anxiety' Lessens"; *(*https://www.juniperresearch.com/press/press-releases/hybrid-and-electric-vehicle-sales-to-exceed-17m*)*
- SMMT (2016): SMMT MOTOR INDUSTRY FACTS 2016; *(*https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-Motor-Industry-Facts-2016_v2-1.pdf*)*

	receive a grant of £2,500, with a price cap for vehicles of £60,000. ▪ Vans with CO_2 emissions below 75g/km and an electric range of 10 miles receive a grant up to £8,000 (N1, N2 or N3). The first 200 N2 or N3 vehicles ordered will receive a grant of up to £20,000. ▪ Motorcycles with CO_2 emissions of 0g/km and an electric range of at least 19 miles receive a grant of up £1,500
Registration Tax Benefits	From April 2017, there is a tax exemption for zero emission vehicles valued £40,000 or less. Low emission vehicles pay reduced tax rates.
Ownership Tax Benefits	From April 2017, zero emission vehicles valued £40,000 or less are exempt from the annual tax.
Company Tax Benefits	EV's pay reduced company car tax rates. Tax benefits for businesses installing charging infrastructure through a 100% first year allowance (FYA) for expenditure incurred on electric vehicle charge point equipment.
Local Incentives	▪ EVs exempt from London congestion zone charge. ▪ Local incentives such as free parking and access to bus lanes are decided at local level.
Infrastructure Incentives	▪ £500 incentive for installing a dedicated home charging station. ▪ £300 per socket towards the installation of a workplace charge point for employee and fleets. ▪ Up to 75% (capped at £7500) towards the cost of installing an on-street residential charge point in areas without off-street parking.

France

Total Passenger Cars: 32.244.000
Highway: 11.392 km
EV stock: 54.290
EV market share in 2015: 0,17%

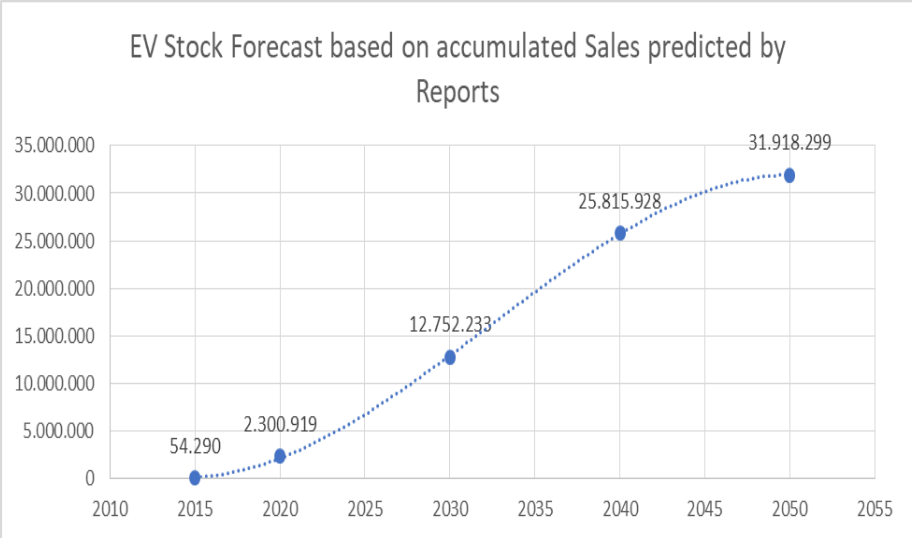

Figure 55: France EV Stock Forecast based on accumulated Sales predicted by Reports[43]

Table 29: French incentives

Incentive category	Description
Purchase Subsidies	▪ Electric and hybrid electric vehicles emitting 20 g/km or less of CO_2 benefit from a premium of € 6,000 under a bonus-malus scheme. ▪ For vehicles emitting between 21 and 60 g/km, the premium is € 1.000. ▪ Diesel Scrappage Scheme: Switching a 11 year or more diesel for a new BEV grants an extra 4.000€ (Or 2.500€ in case it is a PHEV). ▪ The "L" category (Quadricycles, Motorbikes, Scooters...) also has a purchase subsidy (Lead battery vehicles excluded), with €250 per kWh, with a limit of € 1.000 or 27% of purchase prime
Registration Tax Benefits	Road Tax Exemption / Reduction
Ownership Tax Benefits	Road Tax Exemption / Reduction

[43]
- Morganti E. et al. (2016): BEVs and PHEVs in France: Market trends and key drivers of their short-term development
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- Statista (2016): Number of passenger cars sold annually in France from 2009 to 2015; (https://www.statista.com/statistics/418759/passenger-car-sales-in-france/)

Company Tax Benefits	Electric vehicles are exempt from the company car tax. Hybrid vehicles emitting less than 110 g/km are exempt during the first two years after registration.
Local Incentives	Local subsidies

Netherlands

Total Passenger Cars: 8.000.000
Highway: 2.274 km
EV Stock 2015: 87.530
EV market share in 2017: 1,09%

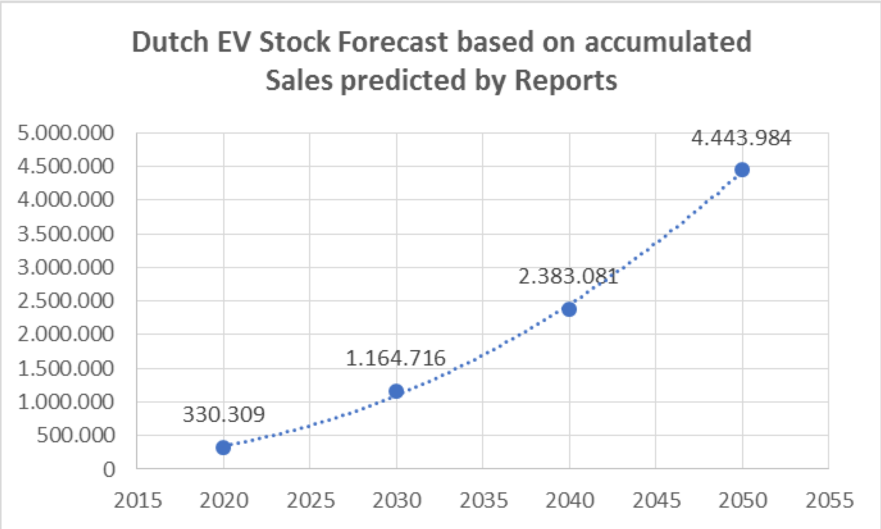

Figure 56: Dutch EV Stock Forecast based on accumulated Sales predicted by Reports[44]

Table 30: Dutch incentives

Incentive category	Description
Registration Tax Benefits	▪ Zero emission cars are exempt from paying registration tax. For other cars, the system is progressive, with 5 levels of CO_2 emissions that pay different amounts of registration tax. ▪ Plug-in hybrid cars go to level 1, 1-79 gr CO_2/km and pay € 6 per gram. For level 2,

44
- Lutsey N. (2015): global climate change mitigation potential from a transition to electric vehicles, *ICCT*
- Rabobank (2016): De elektrische auto: a convenient truth; (https://www.ensoc.nl/uploads/content/ensoc/file/Elektrische%20auto%20rapport%20Rabobank%20kopie.pdf)
- Statista (2016): Number of passenger cars sold in the Netherlands from 2010 to 2015; (https://www.statista.com/statistics/423067/passenger-car-sales-in-the-netherlands/)
- EAFO (2016): Country Profile on Website; (http://www.eafo.eu/content/netherlands)

	80-106 gr CO_2/km the tariff is € 69 per gram CO_2. The final level is € 476 per gram for 174 gr CO_2/km or over.
Ownership Tax Benefits	▪ Road tax: Zero emission cars are exempt from paying road taxes. ▪ Plug-in hybrid cars (< 51 gr CO_2/km) pay 50% of the road tax for a regular car.
Company Tax Benefits	▪ Surcharge on income tax for the private use of company cars: In the Netherlands, income tax must be paid on the private use of a company car. This is done by imposing a surcharge of 4-25% of the catalogue value on the taxable income. For zero emission cars, this percentage is 4%. For most plug-in hybrids the percentage is 15% (< 51 gr CO_2/km), the next level (51 – 106 gr CO_2/km) is 21%. Over that, 25% is imposed. ▪ Tax deductible investments: The Netherlands has a system of facilitating investments in clean technology, by making these investments partially deductible from corporate and income taxes. Zero emission and plug-in hybrid (and not with a diesel engine) cars are on the list of deductible investments, as are the accompanying charging points.

ANNEX III – identification of busiest motorways in EU countries

Netherlands

The A13 in the province of Zuid-Holland is the busiest motorway in the Netherlands. Utrecht is the province with the busiest motorways on average. The second highest traffic intensity is on the A10, the ring around Amsterdam, with an average 4,374 vehicles per hour. The top 5 of busiest motorways in the Netherlands is further completed by the A12, the A16 and the A4. In the next chart the busiest motorways are identified:

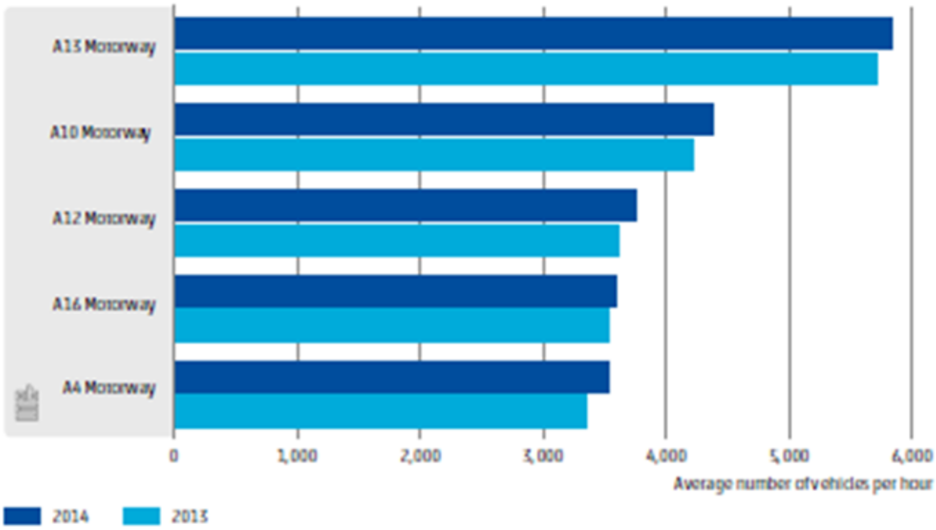

Figure 57: List of main motorways in the Netherlands[45]

Norway

Norway has the lowest population density in Europe after Iceland. However, almost 80 per cent of the population live in urban areas. There are 93 822 km of public roads, from which 10 540 km are national roads. Norway's participation in TEN-T is regulated through the EEA Agreement. The part of the TEN-T network called "The Nordic Triangle" is the most interesting for Norway, as it includes Norwegian infrastructure connections between Norway and abroad. On the Norwegian side, the Nordic Triangle includes the Norwegian rail route from Oslo to Sweden via Kornsjø, the road route E6 from Oslo to Sweden via Svinesund, the Oslofjord connection and railway connection with Sweden via Kongsvingerbanen and the E18 road connection to Sweden. Other parts of Norway's infrastructure are also classified as TEN-T networks, without this having any economic gain or cost for Norway. However, Norway must

[45] Report. A13 National busiest motorway in the Netherlands

adhere to EU requirements for the network, such as the requirements stated in the tunnel directive and Euro Vignette Directive.

Figure 58: E6. Selected motorway in Norway[46]

The selected route in Norway could be the E6 from Oslo (Norway) to Malmo (Sweden) (562 km).

France

According to the most recent report from the European Union Road Association [47], the total length of the road network in France accounts for 1,065,557km at the end of 2012, from which 11,465 km corresponds to motorways. It is not a very dense country (km motorway/area) so EV will be less concentrated.

[46] Norwegian Ministry of Transport and Communications. National Transport Plan 2014–2023

[47] European Union Road Association. Road Statistics Yearbook 2016

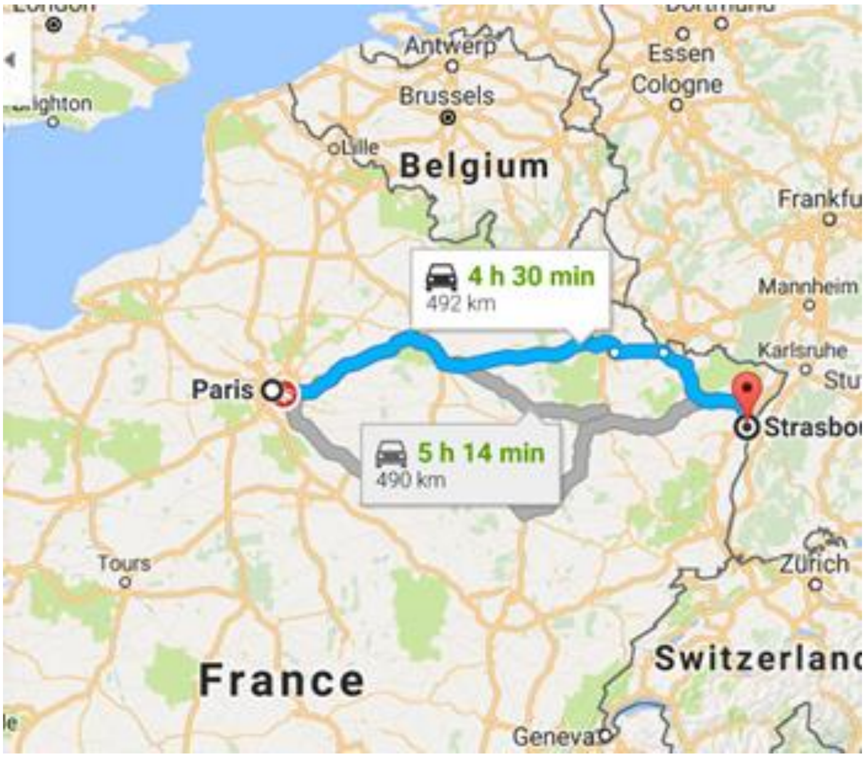

Figure 59: A4 selected motorway in France

United Kingdom

British roads are the most congested in Europe, based on a study of traffic by Inrix consultancy who monitored traffic on every road in 123 cities in Europe. The hotspots in UK were located in:

1. London: M25 northbound between junctions 15 and 16
2. Edinburgh: A720 westbound Edinburgh Bypass at Dreghorn Barracks
3. Glasgow: Eastbound junction of the A8 Glasgow and Edinburgh Road with the M8
4. Birmingham: Northbound junction of the A38 (M) with the M6
5. Manchester: M60 northbound at junction 1 for the A6 Stockport
6. Bristol: M5 southbound at junction 20 for Clevedon
7. Leeds: Westbound M62 junction 26 with M606 junction 1
8. Cardiff: A48 westbound at Riverside Park
9. Bradford: From the A650 in the city centre to the A6038 Otley Road
10. Belfast: A12 eastbound at the junction with the M2 and M3

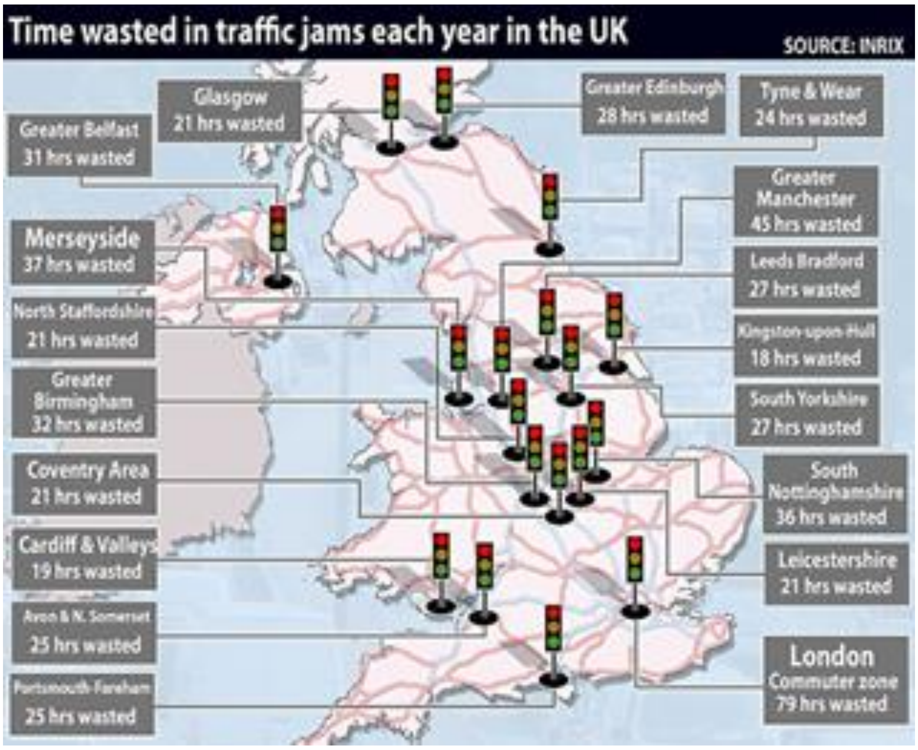

Figure 60: Congestion map in UK[48]

Germany

According to the German Automobile Club ADAC[49] which compiled a study, “the increase in congestion in the past year shows that the motorway network is increasingly reaching its capacity limits. There is immense need for action to eliminate the many bottlenecks, but the expansion of highways lags significantly behind the growth in traffic” This report indicates that the most jammed roads are A3 with about 170 kilometres of traffic jam in the motorway, followed by the A8 (155 km) and A5 (135 km). In particular, the most loaded points were Oberhausen - Cologne on the A3, followed by Stuttgart - Karlsruhe (A8) and Frankfurt - Würzburg (A3).

In the next picture, the most jammed cities/areas in Germany are depicted

[48] Transport Statistics Great Britain, December 2016, Department of Transport

[49] ADAC Staubilanz 2015

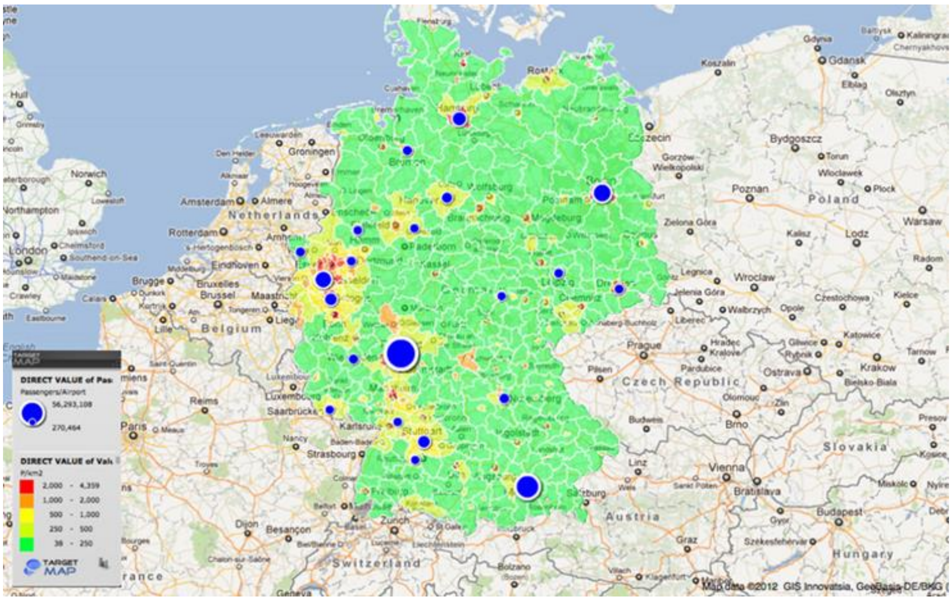

Figure 61: Most congested areas in Germany

Spain and Italy

Spain and Italy are not promoting the introduction of electromobility at the same level as the 5 countries previously mentioned at this time. However, we consider that there will be a drag effect determined by the generation of common community regulations and of the technological imposition of the leading countries that guide the electric vehicles manufacturers, increasing the initiatives also in those countries. At the same time, these two countries have very busy roads around logistic poles in cities as Barcelona or Milan which could serve as a proof of concept for the Heavy-Duty Traffic scenario described in the next point.