Technology scenarios for e-mobility charging infrastructure planning

By Urban Transports

Deliverable number 4.4.1, 2020/12/22

Work Package: WP4 Transferring

Activity No: 4.4

Activity Title: Investigating technology trends

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Abstract

This scenario analysis is intended to be a support document for mobility planning authorities in the process of urban road transport electrification, highlighting relevant issues and topics together with trends perspectives.

The success of electrification depends strictly on charging modality, but this topic is often ignored. Furthermore, affordable and reliable re-charging has already been identified as one of the most important topics to increase user acceptance of electric vehicles. This includes automotive engineering as well as charging infrastructure, energy and environmental issues and urban planning aspects.

As an increasingly widespread choice for consumers as well as for government and commercial fleets, all-electric and plug-in hybrid electric vehicles (EVs) will become an important part of the transportation landscape. The full extent of EV charging demand is not yet fully determined; however, there is a clear need to develop a consistent, accessible charging network of EV infrastructure (known as electric vehicle supply equipment, or EVSE). Anticipated growth in the EV sector creates a need to facilitate and encourage the development of a consistent and accessible infrastructure network, including at home, on public streets, and in commercial settings. EVs offer clear environmental, economic and energy benefits to communities of all sizes. Encouragement of greater EV usage through a more EV-ready environment can bring a range of important benefits to local communities, including reduction of the consumption of natural resources, reduction of air pollution that can cause cancer and other serious health effects, reduction of greenhouse gas emissions, improvements to soil and water quality and anticipated economic development benefits.

1. Abbreviations and glossary

ABBREVIATIONS

AC: Alternating Current

BEB: Battery Electric Bus

BEV: Battery Electric Vehicle

BMS: Battery Management System

BS: Battery Swapping

BSS: Battery Swapping Station

C.A.E.V.: Connected Autonomous Electric Vehicle

CC: Conductive Charging

DC: Direct Current

ES: Energy Storage

EVSE: Electric Vehicle Supply Equipment

IC: Inductive Charging

OLEV: On-Line Electric Vehicle

RES: Renewable Energy Sources

SOC: State Of Charge

GLOSSARY

Battery capacity: the amount of energy (usually expressed in kWh) that a battery is able to store.

Battery Electric Bus (BEB): a bus which is a Battery Electric Vehicle (BEV).

Battery Electric Vehicle (BEV): a vehicle which is propelled by an electric engine powered by the electricity stored in a battery (accumulator properly).

Battery Management System (BMS): is the system which monitors and controls the charging process of the battery of a vehicle.

Battery swapping (BS): charging operation which consists in substituting the exhausted battery of an electric vehicle with a fully charged one.

Conductive charging (CC): charging operation which is done through a wire or cable connection between the infrastructure and the vehicle.

Electric vehicle supply equipment (EVSE): synonym of electric vehicle charging station.

Energy storage (ES): a system which is able to preserve an amount of energy for future uses. There are several different types of energy storage (e.g. chemical, mechanical, thermal, etc.) and related technologies (e.g. batteries, hydrogen production, hydraulic energy storage, etc.).

Inductive charging (IC): wireless charging system which exploits the induction principles in order to charge the vehicle's battery without a physical connection to the charging infrastructure.

Peak shaving: operation which aims at limiting the power absorption when the demand is high through the shift of some non-priority electric loads to a lower demand period; the optimal result is a more constant power absorption without significant peaks, avoiding the risk of exceed the available power.

Renewable Energy Sources (RES): natural sources which are able to provide energy without being depleted by use since they can regenerate (e.g. sunlight, wind, waves, tides, etc.).

State of charge (SOC): the amount of energy (usually expressed in %) stored in a battery compared to its full capacity.

2. Introduction

Autonomous, electric, digital are technological trends that represents the epitome of the transformative wave revolving not only urban mobility, but our whole society. Recent developments, from carmakers' massive investments in electric vehicles to the advances of artificial intelligence and automation, confirm that this mobility paradigm is at a crossroad. ICT represents the transversal thread allowing interaction between human and machine, adding more comfort and safety to our ways to move.

With a view to the mass market but also to public authorities, in order to reach a user-orientated and integrated overall system, we must include automotive engineering as well as charging infrastructure matters, energy and environmental issues and urban planning aspects all together.

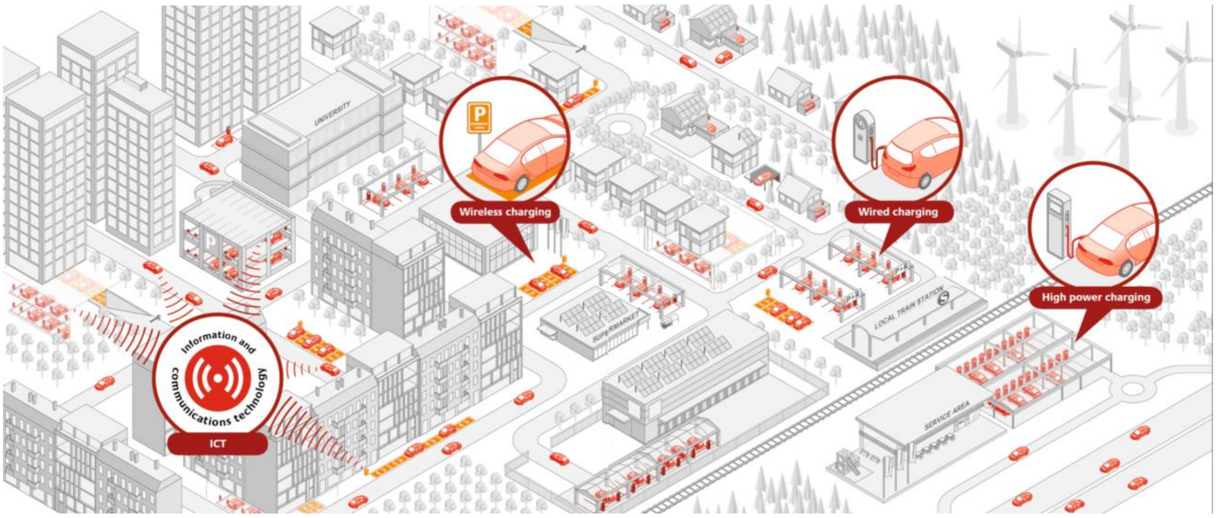


Figure 1 – Smart mobility scenario (source: The German Standardisation Roadmap Electric Mobility 2020 – Nationale Plattform Elektromobilitat)

Area Science Park is investigating on two big thematic areas of high interest for urban transport: automated and connected vehicles and electric mobility charging infrastructure with a specific focus on their impacts on urban spaces and layout. Aim of our ongoing study is to deepen knowledge on nowadays hot topics and give a short-term vision (5 to 10 years) of how these trends are going to develop and impact mobility layout in our cities.

Forecasting based on technical breakthroughs resulting in competitive products and mass production as requested by policy makers from 2020 on may results in market shares up to 70% in 2030. Many different predictions have been found in literature. However, under similar assumptions of technology development the derived market development is within the same range.

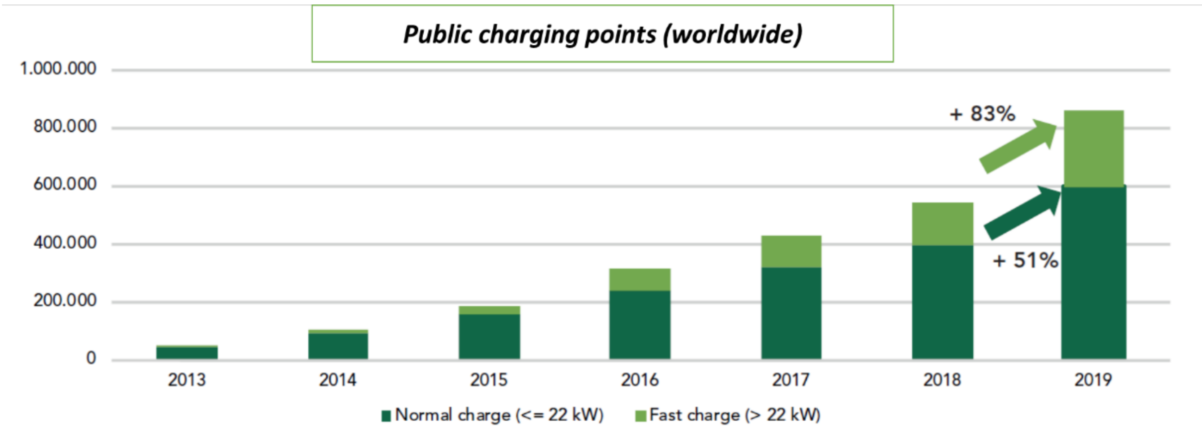


Figure 2 - Public charging points worldwide growth (source: Smart Mobility Report, Energy & Strategy Group, 2020)

The increasing need for public charging infrastructure to support electric vehicle growth can be garnered from historical trends. Global electric vehicle uptake has grown an average of over 60% per year from 2013 to 2018 and public charging infrastructure has also grown an average of over 60% annually over the same time-period. More available public charging increases drivers’ confidence to move to electric vehicles, and additional electric vehicle drivers put more demand on governments, automakers, and property owners to install charging stations.

The "positioning" of European countries at the end of 2019, in terms of the number of public recharging points per 100,000 inhabitants and the number of electric vehicles (BEVs and PHEVs) in circulation per 100,000 inhabitants, is rather heterogeneous. For example, Spain and Italy show the most limited diffusion of electric mobility (in relation to inhabitants) among the analysed countries, with about 15 charging points for every 100,000 inhabitants and 100 electric cars for every 100,000 inhabitants.

Instead, Norway is off the chart in fact it shows a high diffusion of electric mobility, with over 250 charging points for every 100,000 inhabitants and 6,000 electric cars for every 100,000 inhabitants.

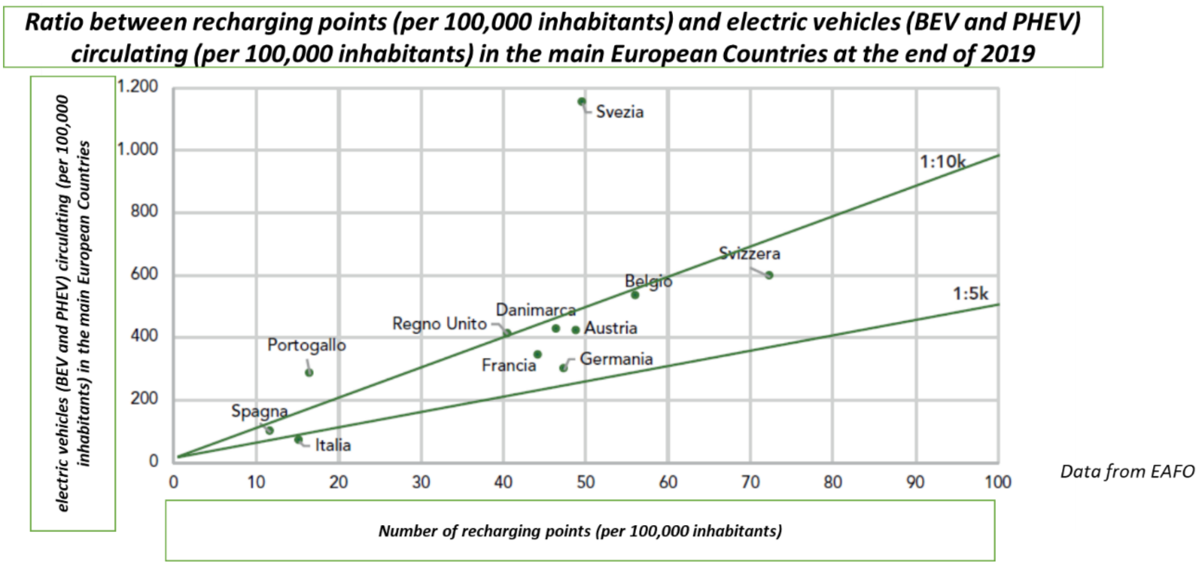


Figure 3 - Ratio between charging points and EVs (source: Smart Mobility Report, Energy & Strategy Group, 2020)

The eight key principles which underpin the Sustainable Urban Mobility Planning approach must include the aspects related to the electrification of transport. E-mobility is a cross-cutting topic covering a wide range of urban road modes and has the potential to support the shift to new sustainable modes. When planning for the electrification of transport, the mobility planning authorities must clearly identify in their long-term vision the main objective(s) that are intended to be reached through corresponding measures. For example, one of the main reasons for implementing e-mobility solutions could be often the improvement of air quality, or noise reduction, or the decrease in greenhouse gas emissions and so on….

- ***Plan for sustainable mobility in the 'functional city'***
- ***Develop a long-term vision and clear implementation plan***
- ***Assess current and future performance***
- ***Develop all transport modes in an integrated manner***
- ***Cooperate across institutional boundaries***
- ***Involve citizens and relevant stakeholders***
- ***Arrange for monitoring and evaluation***
- ***Assure quality***

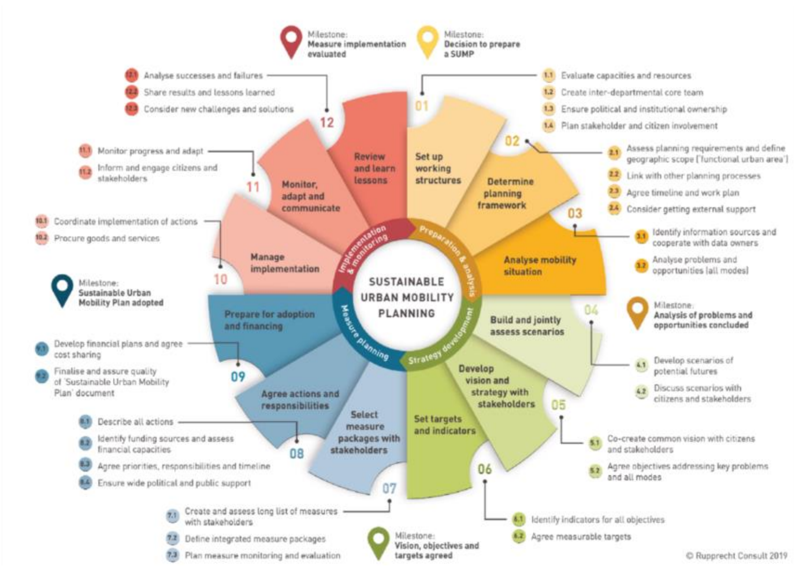


Figure 4 - The SUMP Cycle (from Polis, and Rupprecht Consult - Forschung & Beratung GmbH (eds). 2019. Topic Guide: Electrification- planning for electric road transport in the SUMP context)

As everybody knows, the e-mobility ecosystem stays in between the mobility ecosystem and the energy ecosystem so electromobility puts together many stakeholders and many issues that must be considered in the planning process.

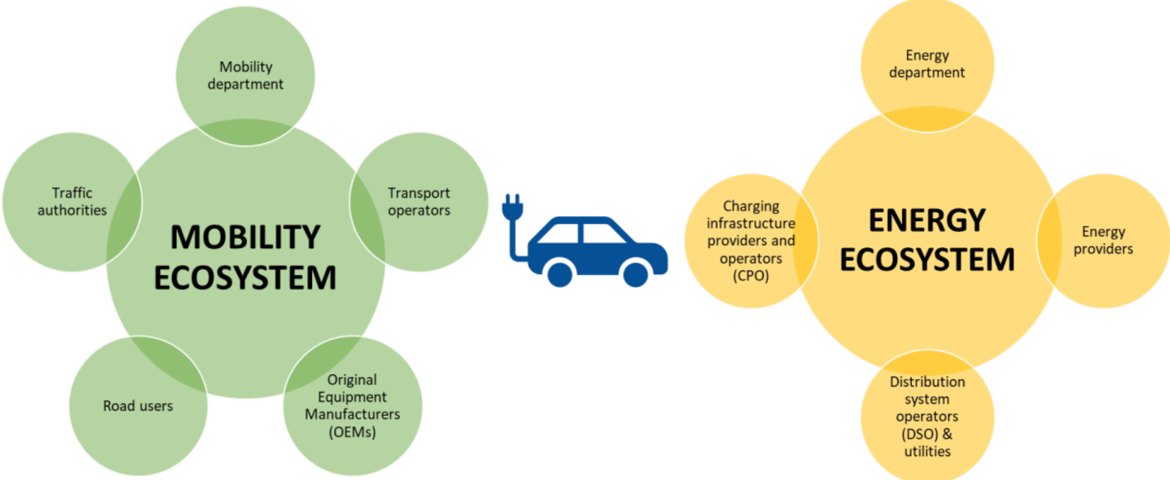


Figure 5 - The e-mobility ecosystem

In different countries a question is arising: could the actual electric grid support the EVs revolution? The vehicle-to-grid paradigm (V2G) should be a solution.

In the energy area two significant progresses will concern electric mobility: the development of renewable energy technologies (but especially their acceptance by the consumer) and the emergence of smart grid systems, in which the energy flow is bidirectional. The irregular availability of most renewable energies requires the storage of electricity, usually made with dedicated batteries. With the assistance of advanced smart grid based electricity management systems, batteries can be employed in the storage of electric energy and aid as an energy reserve, when the peaks of demand occur if the BEVs are inactive.

In the context of systems integration, European researchers have been exploring the potential of driverless electric vehicles for urban transport since 2010. Vehicle-to-grid (V2G) connectivity of electric vehicles (EVs) is tested to assess the potential for the fleet operators to provide ancillary services to the city's electrical system.

3. EVs Charging Infrastructures: a review on key aspects

EVs offer clear environmental, economic and energy benefits to communities of all sizes. As it is known, action to encourage greater EV usage through a more EV-ready environment can bring the following benefits:

- Reduction of petroleum consumption.
- Reduction of air pollution that can have relevant health impacts.
- Reduction of greenhouse gas emissions that contribute to global warming and exacerbate the heat island effect in support of local, regional and national goals.
- Improvements to soil and water quality through the reduction of pollutants in acid rain and stormwater run-off.
- Anticipated economic development benefits in the form of business and job growth in the EV and transportation equipment industries, reduced losses associated with carbon emissions, and potential property value increases due to air quality improvements and noise minimization.
- Improvements to the status of national energy independence and fuel cost savings to individuals and jurisdictions.

While the full extent of EV charging demand is not yet fully determined, there is a clear need for infrastructure. The development of a consistent, accessible charging network would enable EV owners and communities to:

- Charge at home, at work and in commercial and public locations.
- Extend vehicle range.
- Better integrate EVs into regional transportation networks.
- Encourage more widespread EV adoption.

Pure electric vehicles will be competitive with ICE (internal combustion engines) one-on-one vehicles, but with the right dimension of recharging comfort and with the right mix of infrastructure, both private and public. For example, daily e-charging would mean that drivers never have to stop at filling stations in the future; charging would be done daily at home or at work or at public or commercial parking areas (shops, motorway rest areas, etc.). From the point of view of hybrid vehicles, charging comfort will generally drive their use into the right way in order to take benefits from the electric-mode drive in urban areas as much as possible, but overwhelming the range anxiety issue in case of longer distances or less served areas.

E-mobility should not be realized as the simple electrification of the propulsion system and a "stand-alone" solution. Instead, it represents individual components of key transport solutions (both in passenger and freight transport) and must be fitted into an all-inclusive concept of transport and energy. Electromobility should therefore always be recognized as part of a larger systemic design process. Charging solutions, energy production and supply systems and infrastructures should always be integrated into a comprehensive planning process.

On a general level, the range of uses, locations and geographical areas where electromobility can be implemented is extremely heterogeneous. A first challenge is to provide adequate charging resources to city centre inhabitants which need overnight street parking and have limited garage spaces in high-density populated city areas. The long-term tendence of municipalities is about the reduction of the number of vehicles in the cities and not about the general electrification of a high number of parking spaces (with huge or unpleasant charging stations which are not harmonized in the townscape). These users will have to depend on quick-charge infrastructure or charging during the day at work facilities. Moreover, this last option, with right incentives, would promote this mean of charging due to the potential usage in vehicle-to-grid applications.

The aim is put in place adequate, reliable and convenient charging facilities that electric vehicles can use on an everyday basis as appropriate to their mileage and travel radius. Consequently, the further development of the charging infrastructure should be needs-based.

3.1. Overview of the location types of charging infrastructure

There is a first distinction that must be made and this is between rural and urban usages of electromobility.

In rural areas the transport infrastructure is often less developed than in urban areas and public transport services are less widespread or sometimes do not exist at all. Moreover, the distances to be covered are longer (medium to long distances), and users often have to transport heavy loads. The challenge here lies in the creation of more affordable and environmentally friendly mobility services and a basic infrastructure, while environmental impacts related to local pollution play a relatively small role.

In urban areas urban and suburban transport are expected to be the major application for the pure battery electric vehicle, at least within the short and medium term, and the possibilities of electric two/three wheelers for transport of goods and people are relevant. Metropolitan areas generally offer a well-developed road infrastructure and in many cases a range of public transport services. The distances travelled are often shorter than in rural areas while the transport density and emissions levels are generally high. The key topic in urban areas lies in dealing with increasing traffic volume and poor air quality.

Secondly, there must be a differentiation between places with highly developed and less developed infrastructures. This affects in particular to the scope, quality and stability of the transport, electricity and data networks. The central challenge in the integration of e-mobility is the development of basic energy and transport infrastructures, which then shape the basis for subsequent development. On one hand, less developed infrastructures are characterised by intermittent supply and a high exposure to transport troubles, together with data and energy networks disruption. On the other hand, well developed transport, energy and data networks are characterised by a high degree of strength and stability. A wide range of interfaces and interconnection points ensures a variety of mobility, energy and communications services which electromobility can build upon. The central issue in the integration of e-mobility consists of connecting the existing transport systems, managing the following complexity (such as power load management) as well as ensuring data protection.

The combination of these two criteria produces four scenarios which must be examined.

	Urban Area *High traffic density* *Air pollution* *Short transport distances*	**Rural Area** *Low traffic density* *Low air pollution* *Long transport distances*
Advanced infrastructure ✓ *High-capacity power network* ✓ *Efficient data network needed*	• e-carsharing • e-car rental • inductive e-busses	• e-car rental • electric load carriers • e-busses
… basic infrastructure ✓ *Low load capacity of power network* ✓ *poor data network (or lack of connectivity)*	• e-busses • LEVs	• utility vehicles with battery swapping system • LEVs • e-load carriers

At First, feasible operating and business models must be developed for individual components, and administrative and political boundaries must be created or adapted. Regarding supported charging standards, particular attention must also be given to the matter of compatibility with local electricity networks and load capacity, since fast charging technology (for example) can place high demands on network capacity and stability.

Not least, the successful implementation of solutions must also take account of societal factors. This involves the availability of affordable products and services for users, and the image and symbolic value of the vehicles for consumers. Considering the range of possible applications for e-mobility, and the heterogeneity of the specific topics, development stages and framework conditions found in different countries and cities, only general recommendations can be given for each cluster.

Areas with low population density and a rudimentary infrastructure offer only limited possibilities for an immediate and comprehensive implementation of electromobility. In most cases the energy and transport networks are not developed enough to allow a reliable and comprehensive infrastructure for electromobility solutions to be built up. If shares of renewable energy generation in the electricity mix are low, electromobility applications provide little environmental benefit. That is why it is essential to initially promote the development of a decentralised electricity supply based on renewable energy sources — for example through photovoltaic systems — in order to create the infrastructure foundation for an electromobility that is ecologically sustainable. The use of all-electric vehicles is restricted to small-scale applications and, in that context, the connection of a household photovoltaic system with an electric vehicle also provides stability for the household power supply. Otherwise, the hybrid vehicle, with its compatibility with conventional supply infrastructures, offers the range necessary to reach surrounding cities and supply centres. Under these circumstances, charging stations should first be built at decentralised power generation facilities in order to avoid putting a further strain on the already unreliable electricity grid.

Unlike regions with less developed infrastructures, it is areas with a low population density and a well-developed infrastructure — tourist developments for example — which exhibit the necessary prerequisites for the effective use of electromobility. The electricity grids here normally have a higher capacity and reliability, thus enabling fast charging with higher loads, for example. Here too, the environmental benefit of electromobility depends on the share of electricity that comes from renewable energy sources. The development of a charging infrastructure in this case is relatively inexpensive since the individual charging stations do not require large-scale stationary batteries for the storage of decentralised generated power. The promotion of electromobility could take the form of a purchase of a fleet of electric vehicles by city government and the first installation of public charging stations. Beyond support measures to promote the use of electric vehicles at municipal level, there are other electromobility applications to be considered: a programme to promote the use of electric shuttles, rental cars and delivery vehicles in tourism or in local hotels and restaurants is another possible application.

Individual motorised transport, in particular the use of passenger cars, is quickly reaching its limits, alone due to the space it requires in high-density areas with underdeveloped infrastructure. However, while the use of electric vehicles can help mitigate air pollution, it will not solve the problems of congestion and shortage of parking space completely on its own. The promotion of private electric cars does not appear to be useful in this respect, unlike restrictive parking management does. Carsharing models will tend to be successful in more affluent cities with higher security standards, as the vehicles in use can otherwise be the target of theft and vandalism.

High-density areas with highly developed transport, data and energy infrastructures represent an ideal field for integrated transport systems adoption. Long-term spatial and transport planning is complemented by an efficient system of traffic management. An optimal presentation of intermodal real-time information, possibly supplemented by price systems based on load and pollution levels, could already create a steering effect which is favourable to electromobility. The integration of electromobility solutions can be carried out in a first step through the introduction of electric buses in the public transport system, which would provide an initial reduction of pollution levels. This could be followed by other publicly available services such as e-taxis, e-carsharing, e-scooter sharing, e-bike sharing, etc. However, these steps must be taken in parallel with the expansion of electricity generation from renewable energy sources, if climate protection targets are to be met. The introduction of electrically powered taxis, and to an even greater degree of e-carsharing models, will provide the impetus for building and developing a public charging infrastructure that can later be used for private transport as well. Moreover, publicly available services also allow broad sections of the population to test new modes of transport based on electromobility. Any possible isolated economic disadvantages arising from the operation of electric transport systems must be seen in the context of broader societal benefits. Particularly worthy of support measures are resource-efficient and space-saving solutions in high-density metropolitan areas. If the societal benefits outweigh the drawbacks, then funding measures and/or restrictions and price increases for less desirable conventional alternatives are appropriate. Precisely what kind of electromobility applications should be actively promoted today, and what specific mix of measures local governments should implement is a matter for national policymakers to determine.

Countries that already have high shares of environmentally friendly electricity generation and that are continuing to expand the use of regenerative energy should promote the study, testing and operation of combined, systemic solutions. This could benefit a variety of different industries (automobile industry, vehicle manufacturing sector, and also the electronics and energy and recycling industries).

The framework conditions should be designed in such a way that private sector actors are able to easily implement necessary business models.

However, a permanent, purely supply-side subsidy system should be regarded critically, as in the long run this would put a strain on state budgets and could reduce the incentive for implementing self-sustaining business models.

Communication protocols must be standardised, while V2G charging stations and control systems have to be interoperable.

	Privately owned cars	Shared mobility	Public transport	Two-wheelers	Prevailing type of charging
Low-income, dense metropolitan areas			⊕⊕	⊕⊕	Public charging, hubs for buses
High-income suburban sprawl	⊕⊕	⊕	⊕		Home charging
High-income, dense metropolitan areas	⊕	⊕⊕			Charging hubs, more fast charging

Figure 6 - Charging needs according to city type (IRENA (2019), Innovation outlook: Smart charging for electric vehicle. International Renewable Energy Agency, Abu Dhabi.

3.2. Key Findings for creating EV-ready towns and cities

Zoning is a necessary part of EV-readiness but has inherent limitations. Defining EVs as a permissible use in zoning regulations is a first step upon which decision makers can build future regulations. By setting development standards through zoning ordinances, municipalities can use this tool to shape the scope of EV supply equipment (EVSE) deployment. Incentivizing zoning, such as the exchange of development bonuses for the inclusion of EVSE pre-wiring or infrastructure in new development, is a potential method to increase EVSE deployment, but remains largely untested.

Regulation of EVSE through parking ordinances can set the scope and enforcement requirements for parking with state or local laws. Because parking ordinances apply to the public realm, parking tools can be effective in encouraging EVSE in a wide range of installation scenarios including public and private space as well as new and existing construction. Parking ordinances work hand-in-hand with parking management (whether public or private) to enforce regulations on the use of parking spaces, including EV charging-only spots.

The delivery of a vehicle charging network and electric vehicle supply equipment (EVSE) required by the growing number of electric vehicles (EVs) will need to be supported at a planning level from the public sector, often in collaboration with the private sector.

EV-readiness in policy and regulation will involve incentivizing or requiring EVSE infrastructure deployment, eliminating procedural barriers, considering potential for financial incentives or mandating pre-wiring for EVSE installation.

A key strategy for capturing the many benefits of EVs will be the development of policies and programs that aim to deploy EVSE infrastructure to meet today's charging needs and prepare cities, towns and regional corridors for growing EV use. Simply put, EV-readiness can be achieved through: zoning that requires EVSE parking in the private realm; parking ordinances that enable EVSE in the public realm; building or electrical codes that require wiring in parking and set new standards for safety; and permitting that streamlines the administrative process.

Despite differences across the region, there are a handful of factors that need to be in place to successfully advance policy, legislation and ordinances relevant to EV infrastructure. EV-ready planning includes creating and implementing solutions to one or more of the following barrier-reducing actions:

- Ensuring that new construction is EVSE-ready;
- Clearing administrative pathways for residential service upgrades and EVSE retrofit;
- Providing safe, consistent and accessible EVSE installations and implementing good site planning and design;
- Ensuring that new construction can support higher electricity demand, with the potential of adding future vehicle battery charging capacity and eventually energy storage devices;
- Enabling dedicated parking spaces for EVs in both public and private realms:
    - with clear protocols for the usage and operation of the spaces and EVSE,
    - with the indication of the requirements to pre-wire (lay conduit) for a certain percentage or number of parking stalls in new construction for future EVSE installation;
    - reserving space in the electrical closet for future electrical service capacity;
    - providing regulations that do not inhibit voluntary installation.
- Aligning EVSE deployment with policy and environmental mandates to achieve emissions reductions, air quality improvements, transportation technology advances and energy independence.

There is no one-size-fits-all policy approach to increasing EV-readiness. Each national or local jurisdiction needs to evaluate the objectives behind any potential new policy, code revision or other change and follow a path that best suits the available and appropriate menu of options for the jurisdiction.

4. Opportunity roadmaps

4.1. General information about the technology roadmap and the context scenario

A technology roadmap is a flexible planning technique to support strategic and long-range planning, by matching short-term and long-term goals with specific technology solutions. It is a plan that applies to a new product or process and may include using technology forecasting or technology scouting to identify suitable emerging technologies.

Developing a roadmap has three major functions:

a) it helps reach a consensus about a set of needs and the technologies required to satisfy those needs,
b) it provides a mechanism to help forecast technology developments,
c) and it provides a framework to help plan and coordinate technology developments. It may also be used as an analysis tool to map the development and emergence from new markets.

On a general level, the development of the technology roadmap consists of several steps, including:

- identify the "technology" that is the focus of the roadmap,
- identify the critical system requirements and their targets,
- specify the major technology areas,
- specify the technology drivers and their targets,
- identify technology alternatives and their timelines,
- recommend the technology alternatives that should be pursued.

We put all that information in datasheets, and for each topic you can find:

- general description of its market opportunity,
- identified issues/problems, emerging needs, objectives, achievable benefits, disadvantages, etc,
- emerging technologies within the medium timeframe (3-5 years) and future technologies (<10 years),
- e description of individual technologies to be structured,
- the field of application,
- some commercial development parameters,
- the key success factors,
- the enablers and the barriers,
- some business considerations.

4.2. Electromobility classification

In this study the electric urban mobility clusters are classified as in the following diagram[1].

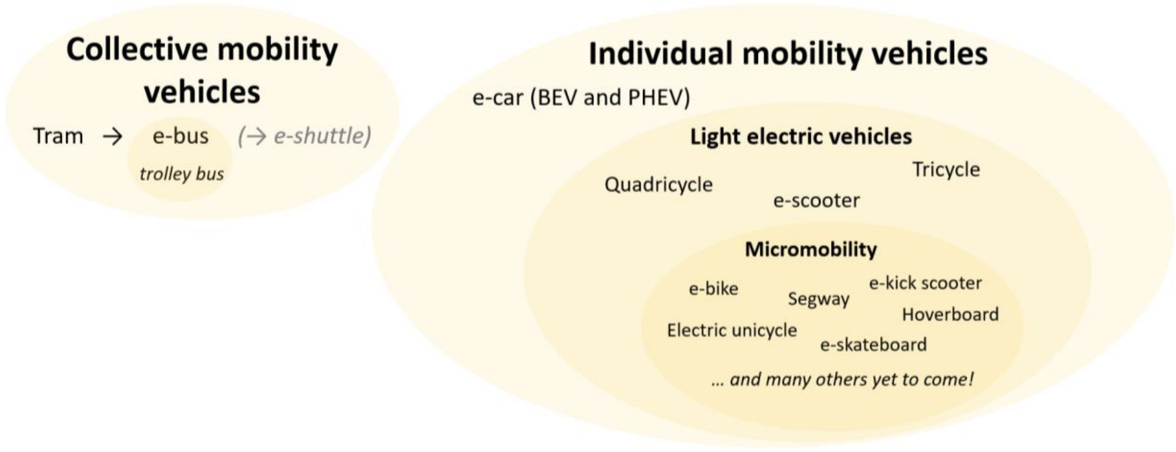
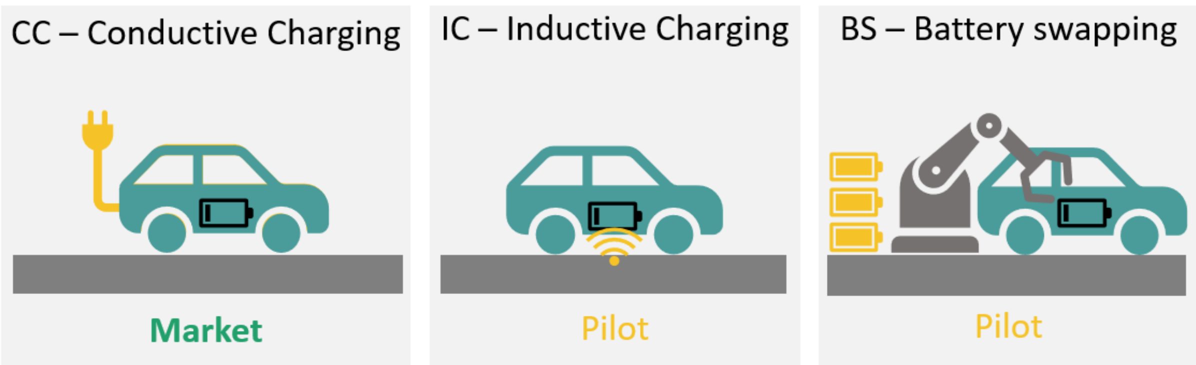


Figure 7 - Electric urban vehicles

For the purpose of this technology scenario, a particular attention is focused on urban collective transport vehicles and the relating technologies for actual and future recharging. In order to the limitations of battery capacities and charging times of this cluster of vehicles, the technical literature of the sector foresees the evolution of collective mobility vehicles into a future hybrid between an electric tram and an e-bus (a sort of trackless tram, maybe rail-less and with tyres): it's called ART – Autonomous rail rapid transit and it will need a reserved lane. In the next future, intelligent systems with high level of automation can suggest to the driver an alternative route to skip the congested road in case of traffic jams, but in this scenario the driver will be still needed. Instead, in a more distant future we could see autonomous driving e-shuttles within a scenario of full automation.

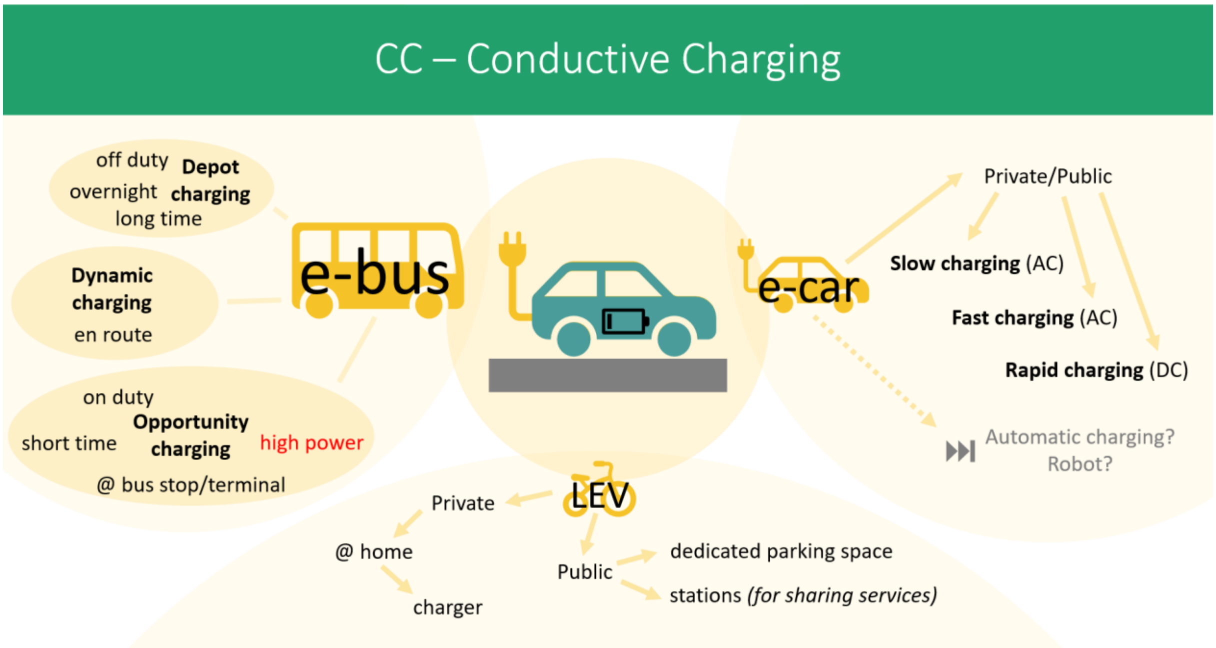
4.3. E-mobility infrastructures technology trends

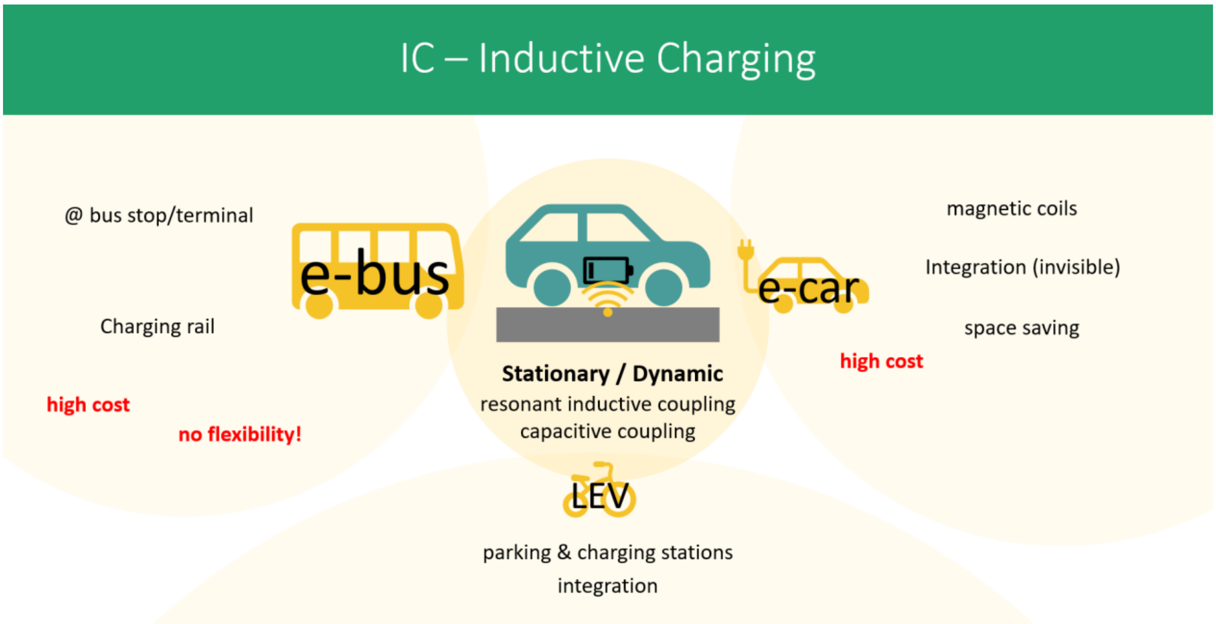
In our analysis we identified three main technology scenarios for EVs re-charging which are summarized in the picture below.

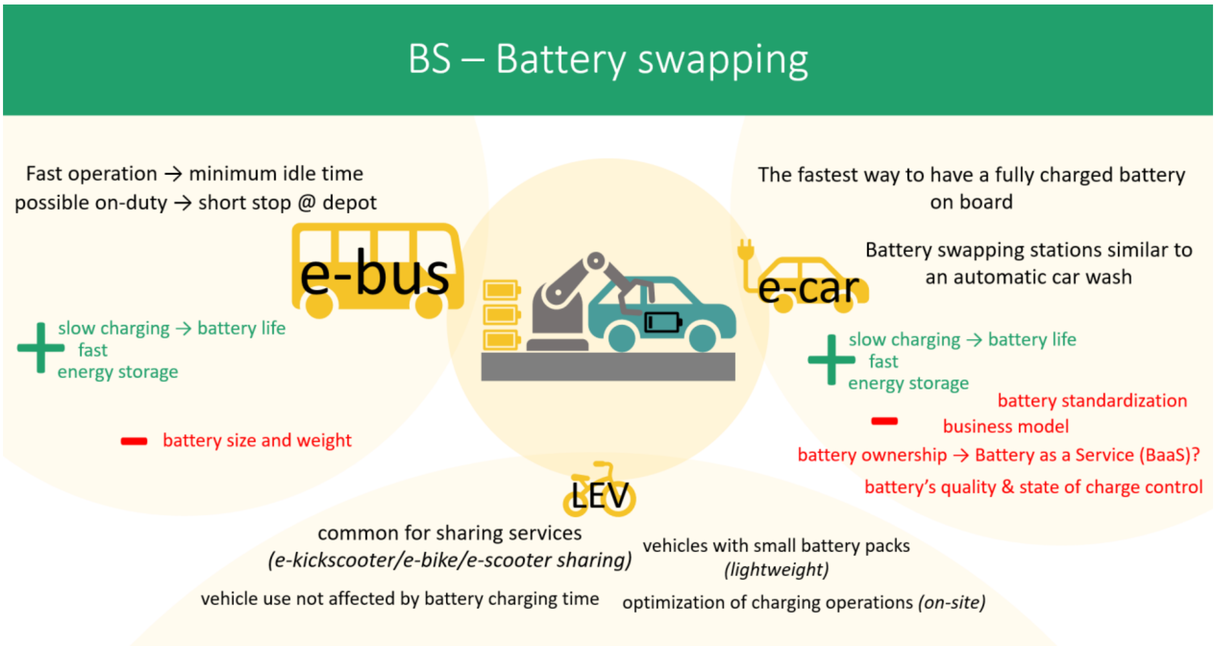


[1] e-shuttle: a self driving (electric) vehicle, often referred to as pod or shuttle as well. Some prototypes of this kind of vehicles have already been tested in the framework of FABULOS project (https://fabulos.eu/).

For each technology scenario, the main and promising technology trends are reported.

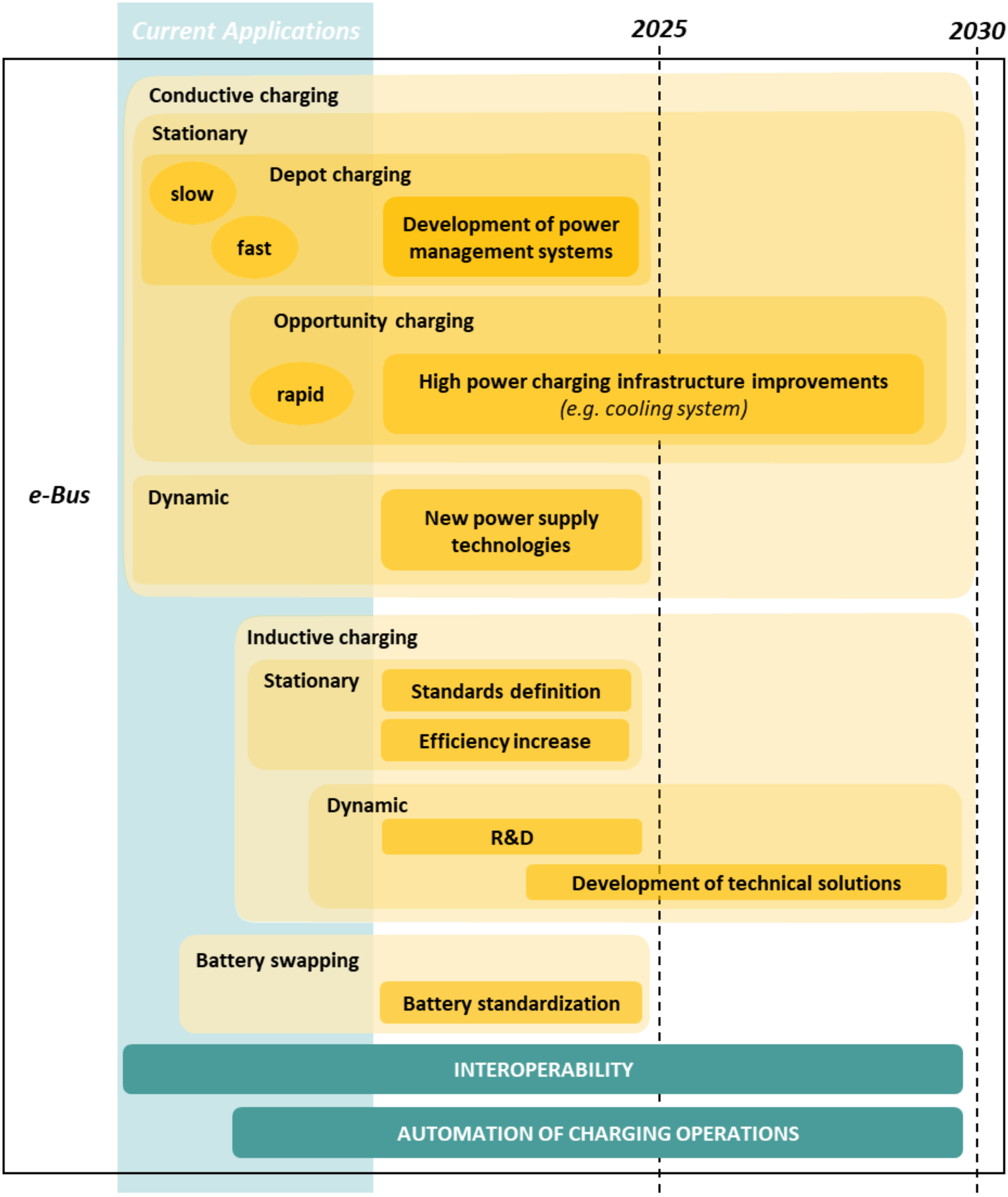


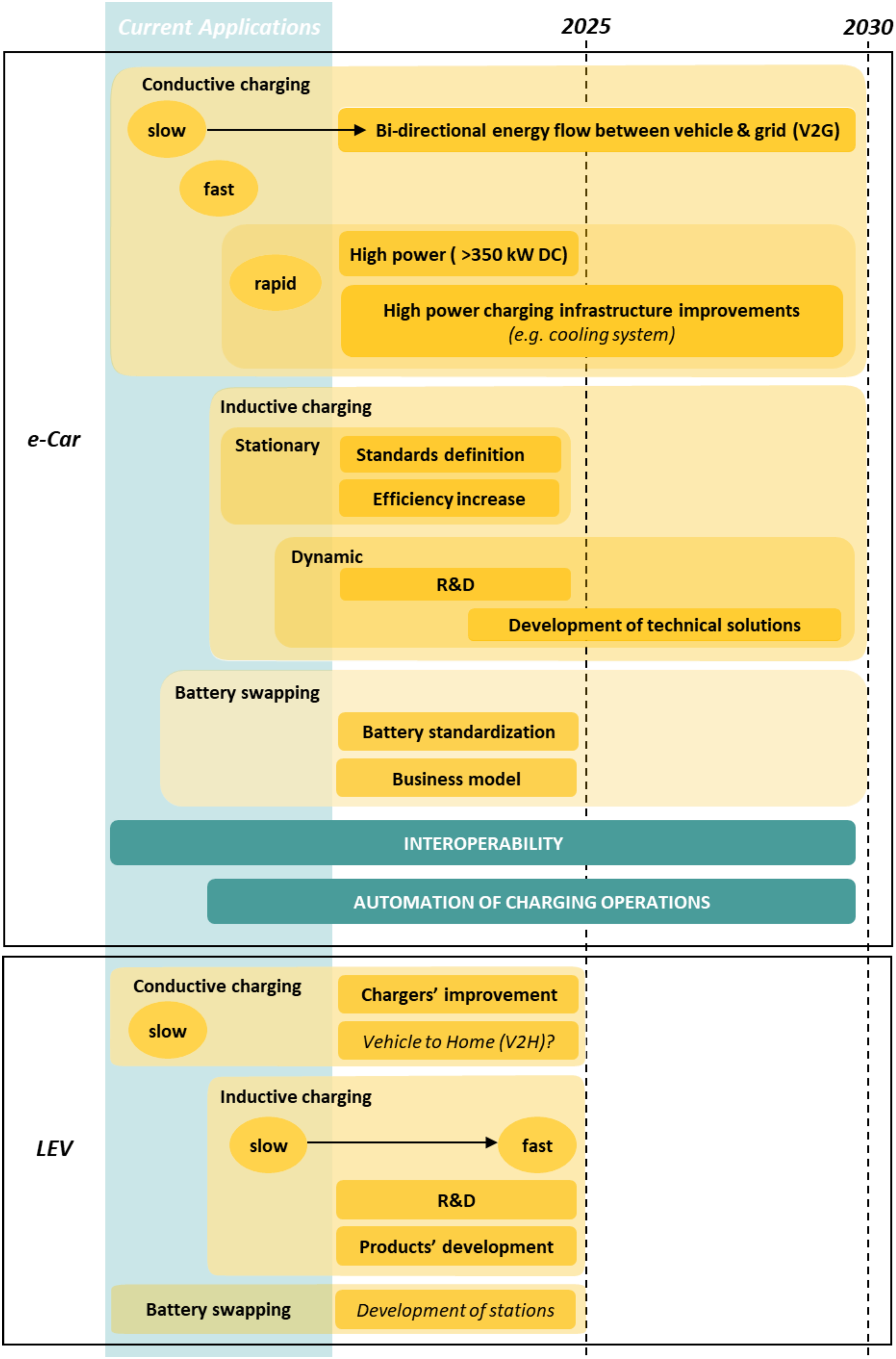




In the following pages the technology roadmaps for the cluster of EVs are shown. We classified some current application (the so-called technologies at the state of the art) and some promising future technology trends.

Chapter 5 reports the analytic fact sheets for all the identified technologies.


Current Applications
2025
2030
e-Bus
Conductive charging
Stationary
Depot charging
slow
fast
Development of power management systems
Opportunity charging
rapid
High power charging infrastructure improvements (e.g. cooling system)
Dynamic
New power supply technologies
Inductive charging
Stationary
Standards definition
Efficiency increase
Dynamic
R&D
Development of technical solutions
Battery swapping
Battery standardization
INTEROPERABILITY
AUTOMATION OF CHARGING OPERATIONS


Current Applications
2025
2030
e-Car
Conductive charging
slow
Bi-directional energy flow between vehicle & grid (V2G)
fast
rapid
High power (>350 kW DC)
High power charging infrastructure improvements
(e.g. cooling system)
Inductive charging
Stationary
Standards definition
Efficiency increase
Dynamic
R&D
Development of technical solutions
Battery swapping
Battery standardization
Business model
INTEROPERABILITY
AUTOMATION OF CHARGING OPERATIONS
LEV
Conductive charging
slow
Chargers' improvement
Vehicle to Home (V2H)?
Inductive charging
slow
fast
R&D
Products' development
Battery swapping
Development of stations

5. Technical factsheets

B_BS

5.1. e-Bus Battery Swapping

Maturity level:

R&D	Testing	**Market**

Description:

The e-bus battery swapping technology consists in changing vehicles’ exhausted batteries and replacing them with others fully charged at a swapping station or battery storage facility. A large number of batteries are stored at the swapping station where they can charge slowly. This is the fastest way to get a fully charged battery reducing at a minimum the bus technical idle time for ‘charging’ operations. The swapping operation is fully automated and requires about 10 minutes.
This solution is already in use in China, but there are no documented applications in Europe yet.

source: https://www.youtube.com/watch?v=RpVZjq7i-gk

Technical features:

- Battery swapping station (BSS) charges vehicles’ batteries off-board
- BSS power requirements depends on the battery storage size (according to the number of stored batteries and bus fleet size) and can vary from hundreds of kWs to some MWs.
- Management system to monitor batteries’ state of charge (SOC) and charging process
- Swapping time: 3 ÷ 8 minutes

SWOT analysis:

Strengths	Weaknesses
• Fast operations • Charging time does not affect bus service • Slow charging of batteries preserves their life	• The number of batteries is higher than that of busses → higher costs
Opportunities	**Threats**
• E-bus battery storage could serve as energy storage for the grid as well • Storage for RES: energy produced by renewable sources during peak hours can be stored even if all the busses are in service	

Urban impacts:

- There are no urban impacts since no charging infrastructure is needed in urban centres. The lack of rapid charging need reduces the power demand at the depot which could even provide energy storage to the grid, contributing to stabilizing it.

Case studies:

CS_7 - Xuejiadao Station (Qingdao, Shandong Province, China)

- The world's largest and most advanced battery swapping station for battery electric busses
- 7 MW energy storage facility for charging electric buses and cars and stabilizing the grid
- The battery swapping station serves 6 battery electric busses' routes since July 2011
- Battery swapping time: 6 ÷ 8 minutes (540 battery swaps/day are possible)

Tips:

- Such a complex infrastructure needs **real time monitoring** of the state of charge (SOC) of the stored batteries and their charging process. Moreover, **swapping operation planning** could contribute to optimize it, reducing busses waiting times and their idle times consequently.
- Small battery swapping stations could be located at some bus terminals as well in order to change batteries when they stop, avoiding the need to go back to the depot for battery change and providing a seamless service.
- The optimal solution (centralized battery swapping station at depot or more smaller BSSs at bus stops/terminals) is still investigated in literature and depends on specific situations. The starting point is the analysis of the swapping and charging demand according to the scheduling timetable and the distance between bus terminals and swapping station(s).
- Batteries' capacity and charging power (i.e. charging speed) affects the number of batteries needed by the system.

<u>Warning</u>!

Remember that the **<u>transition to the electric public transportation</u>** does not imply only the change of vehicles' drivetrain, but the setup of a **<u>completely new complex system</u>** made of:

- **vehicles**
- **charging infrastructures**
- **trained staff**
- **management**
- **operations**

Project co-financed by the European Regional Development Fund
https://urban-transports.interreg-med.eu

B_d-CC

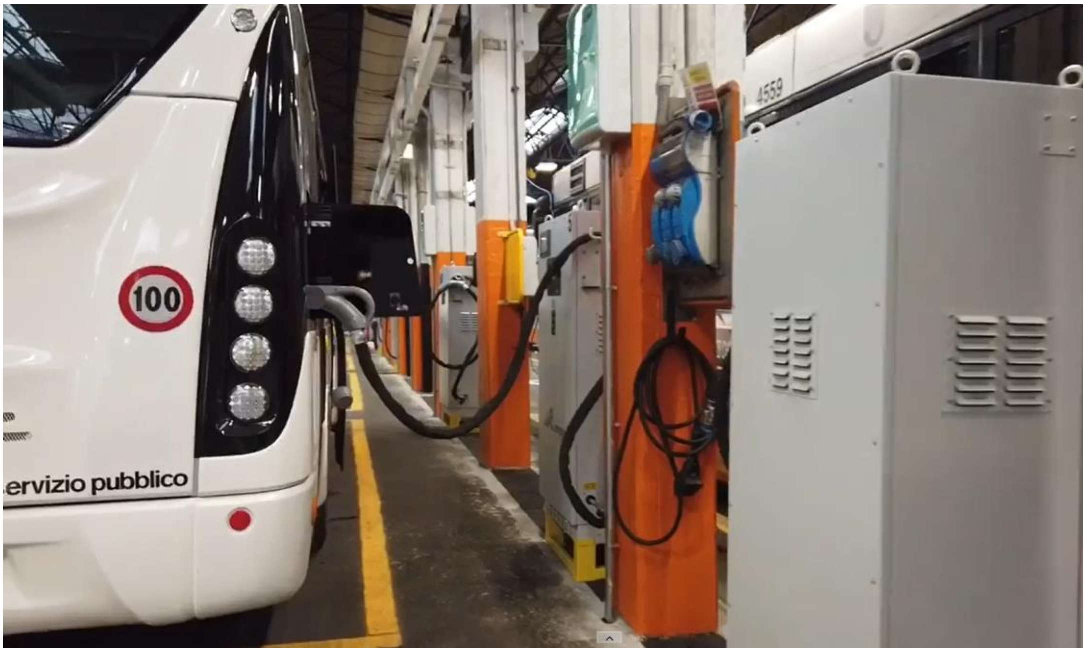
5.2. e-Bus depot Conductive Charging

Maturity level:

R&D	Testing	**Market**

Description:

The e-bus depot conductive charging consists in charging vehicles’ batteries in the depot before and after service, mainly at night. Usually the slow charging is performed through plug-in or pantograph systems. The battery capacity (typically > 200 kWh) must allow the bus to complete the service and go back to the depot (200 km is nowadays an average 12 m e-bus range). When a safety limit of the battery state of charge is reached (e.g. 20%) busses must go back to depot. Service timetable and routes must be planned carefully considering charging times, vehicles’ technical features and performances (especially range).



source: https://www.genova24.it/2019/11/amt-la-rivoluzione-continua-nel-2020-bus-elettrici-anche-in-centro-e-nel-ponente-226032/

Technical features:

- Medium voltage grid connection needed: > 10 MW
- Maximum depot bus capacity suggested: approx. 150 busses *(overnight slow charging)*
- Charging point power range: 30 ÷ 150 kW DC
- Optimal busses to charging point ratio: 1:1
- Depot load and charging management system
- Charging time: 1 ÷ 8 h *(depends on several variables: battery state of charge, charging power, …)*

Grid connection > Transformer > (Energy storage) > Distribution > Bus charging

SWOT analysis:

Strengths	**Weaknesses**
• Concentration of charging infrastructures in one or a limited number of places - urban space saving: potentially no need for charging infrastructure around the city • Slow charging for long times, taking advantage of idle periods, requires less power and preserves battery life • Less sensitive to traffic related delays during service	• High total charge power needed due to the concentration of a large number of vehicles in a single place • Demand peak at night • Long charging times • Limitations in operations • Need for large batteries on board
Opportunities	**Threats**
• Depots' multifunctionality: they could be equipped with energy storage systems that can provide services to the distribution grid when power is not needed for vehicles' charging	• Possible service disruptions if the charging infrastructure system does not work properly or as the fleet ages and consequently the vehicles' battery capacity (and range) decreases

Urban impacts:

- Large depots needed *(usually located on the outskirts)*
- High power availability at depot needed:
  - Upgrade of electricity transmission system
  - Need for new electricity transformer substation(s)

Case studies:

CS_1 – Amsterdam e-bus system

- World's largest recharge depot
- Overnight charging (30 kW DC chargers)
- Total charge power: 13 MW

Tips:

- Provide **energy storage (ES)** at depots *(especially where the distribution system is not able to deliver the amount of power needed)*
- **Hybrid system: depot charging + opportunity charging** *(rapid charging at some bus stops)*
- Such a complex infrastructure needs **real time monitoring** of chargers' proper operation (*error reporting*), charging process and bus batteries' state of charging. Moreover, **charge planning** could contribute to ***peak shaving***.

Warning!

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- **vehicles**
- **charging infrastructures**
- **trained staff**
- **management**
- **operations**

B_o-CC

5.3. e-Bus opportunity Conductive Charging

Maturity level:

R&D	Testing	**Market**

Description:

The e-bus opportunity conductive charging consists in charging vehicles’ batteries partially at some stops or terminals during service, nonetheless vehicles must be charged completely at depot. Since time available for opportunity charging varies between a few seconds to some minutes, this kind of charging is rapid and requires very high voltage and power. It is performed through pantograph systems usually. The bus battery capacity can be medium-sized (typically 50 ÷ 150 kWh) since charging occurs several times during service. This technology is ideal for bus lines with long service time and little idle time, but traffic congestion can cause service disruptions due to the impossibility of charging according to planning and the reduction of time at stops or terminals in order to follow the timetable.

source: https://commons.wikimedia.org/wiki/File:Bertrange,_Volvo_Electric_Hybrid_AVL_(2).jpg

Technical features:

- Charging point power range: 150 ÷ 600 kW DC
  - *- 150 ÷ 500 kW at bus terminals for minutes during longer stops*
  - *- up to 600 kW at bus stops for about 30 seconds while passengers board/disembark*
- Charging time: 20 sec ÷ 10 min *(seconds at stops along the line, minutes at terminals)*
- Busses to charging point ratio: 5:1 ÷ 7:1

Grid connection > Transformer > (Energy storage) > Bus charging

SWOT analysis:

Strengths	**Weaknesses**
• Long service time allowed *(no need for long idle periods)* • Short charging time at stops or terminals • Need for small battery on board *(higher passenger capacity)*	• Large infrastructures needed in existing urban environment • High power needed • Frequent partial recharges needed • Limited range with a single charge • Very sensitive to traffic related delays during service
Opportunities	**Threats**
• Creation of energy storage at the bus stop/terminal and integration of charging infrastructure in a smart grid or microgrid	• Risk of service interruption if only one charging infrastructure is out of order or timetable is not met

Urban impacts:

- Large infrastructures must be fitted in already dense city centres
- High power and voltage needed in a crowded living environment:
  - Upgrade of the electricity transmission system
  - Need for new electricity transformer substations *(and adequate space to build them!)*

Case studies:

CS_1 - Amsterdam e-bus system

- Hybrid system: depot charging + 23 opportunity chargers at 4 strategic points along the line
- Opportunity chargers: 450 kW DC
- Charging time: 2 ÷ 4 minutes

Tips:

- Provide **energy storage (ES)** at opportunity chargers *(especially where the distribution system is not able to deliver the amount of power needed)*
- **Hybrid system: opportunity charging** *(partial recharge)* **+ depot charging** *(full charging during idle time/at night)*
- Choose bus stops/terminals/mobility hubs shared by more bus lines in order to optimize the system and shift the timetables so that more busses can charge at the same infrastructure
- Such a complex infrastructure needs **real time monitoring** of chargers' proper operation (*error reporting*).

Warning!

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- **vehicles**
- **charging infrastructures**
- **trained staff**
- **management**
- **operations**

B_s-IC

5.4. e-Bus stationary Inductive Charging

Maturity level:

R&D	Testing	**Market**

Description:

The e-bus stationary inductive charging system consists in charging vehicles’ batteries in a wireless mode thanks to the electromagnetic induction principle. There are several typologies of electromagnetic induction systems, but the most used ones in the automotive sector are those based on resonant magnetic inductive coupling and on capacitive coupling. Depending on the typology of electromagnetic induction principle adopted by the different systems, a magnetic coil or plate is sunken under the road surface at bus terminals and/or at the depot and another coil or plate is placed on the bottom of the vehicle. In order to increase power transmission efficiency coils or plates must be aligned as much as possible. Charging is automatic and is allowed by a wireless communication system between the infrastructure and the vehicle’s battery management system (BMS). A lot of R&D is still in progress about this very promising charging system whose overall efficiency is about 90% or higher, comparable or slightly higher than the conductive charging one (78÷88%).

source: https://www.youtube.com/watch?v=lqP7acLh34c

Technical features:

- Charging point power range: 50 ÷ 300 kW
- Charging time: 30 ÷ 60 minutes *(on average)*
  Charging time depends on several variables: battery size and state of charge, charging power, efficiency of the system, dimension of coils/plates and air gap between them

Grid connection > (Energy storage) > Power electronics cabinet > Bus charging

SWOT analysis:

Strengths	Weaknesses
• Easy integration in the urbanscape: space-saving multipurpose facility *(bus stop/terminal + charging infrastructure under road surface)* • Automatic charging *(no human intervention needed)* • Safety: no possibility of electric shock • Charging with any weather (rain, snow, ice, …)	• Further development needed: misalignment between coils/plates and the air gap between them affects efficiency negatively • High cost • Lack of flexibility in bus operations *(difficult modifications to bus lines routes and stops)* • Still interoperability and standards issues • Possible maintainability issues
Opportunities	**Threats**
• Since no human intervention is needed, this technology is extremely suitable for Connected Autonomous Electric Vehicles (C.A.E.V.)	• Possible risks for human health *(still unknown) and* interferences with health monitoring devices *(e.g. pacemakers)*

Urban impacts:

- There are no significant impacts on the urbanscape since the charging infrastructure of this technology is located under the road surface except for the power electronics cabinet.
- Possible risks for human health due to electromagnetic fields pollution in densely populated areas

Case studies:

CS_2 – Columbia station, Wenatchee, Washington (US)

- Pilot started in March 2018
- Resonant magnetic inductive charging infrastructure at the Columbia Station bus terminal
- Opportunity charging: 7-10 minutes every hour
- Up to 16-hour service/day maintaining 75% battery state of charge
- Charging power: up to 200 kW

Tips:

- Provide **energy storage (ES)** *(especially where the distribution system is not able to deliver the amount of power needed)*
- Choose terminals/mobility hubs shared by more bus lines in order to optimize the system and shift the timetables so that more busses can charge at the same infrastructure
- Such a complex infrastructure needs **real time monitoring** of chargers' proper operation (*error reporting*), charging process and bus batteries' state of charging.

Warning!

Remember that the **transition to the electric public transportation** does not imply only the change of vehicles' drivetrain, but the setup of a **completely new complex system** made of:

- **vehicles**
- **charging infrastructures**
- **trained staff**
- **management**
- **operations**

B_δ-CC

5.5. e-Bus dynamic Conductive Charging

Maturity level:

R&D	Testing	**Market**

Description:

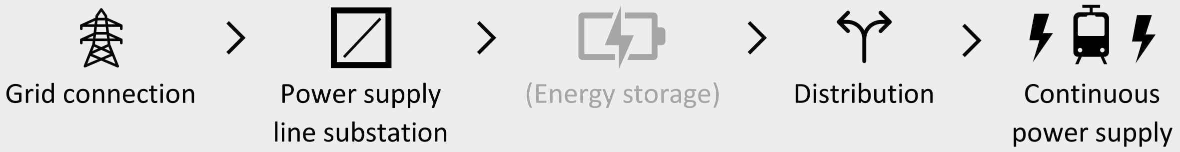
The dynamic conductive charging consists in providing the vehicle with the energy needed to work or recharge its batteries through overhead wires or ground electrified rail constantly. This technology is the oldest charging system for electric vehicles and is adopted by trams and their evolution, trolley busses. Battery assisted trolley busses are equipped with batteries (2÷10 time smaller than BEBs) which allow them to move without direct power supply for a short stretch. Some new trolley busses are equipped with bigger batteries which allow them to recharge their batteries while travelling and operate without direct power supply for longer stretches; a more powerful infrastructure can reduce the length of the power supply infrastructure as well. This technical solution is a hybrid between a tram and a battery electric bus (BEB) that can overcome the range issue, the main barrier to BEBs' wide adoption. Since the power is supplied constantly during service, this kind of vehicles can operate seamlessly without idle time for charging but routes are fixed.

source: https://commons.wikimedia.org/wiki/File:Geneva_Van_Hool_ExquiCity_trolleybus_at_Place_Bel-Air_(2017).jpg

Technical features:

- Voltage supply: 500 ÷ 700 V
- Power supply: up to 500 kW DC
- Trolley bus battery capacity: 20 ÷ 100 kWh
- Trolley bus range without power supply *(battery only)*: 10 ÷ 30 km *(depends on several factors)*

(since trolley busses can have different dimensions, battery capacity and range vary accordingly)



SWOT analysis:

Strengths	Weaknesses
• No need for idle times for charging operations • Seamless service • Smaller batteries → higher passenger capacity	• High costs for the widespread infrastructure • Ground infrastructures interfere with traffic • Limited flexibility: a part of the route is fixed due to power supply infrastructure
Opportunities	**Threats**
• Possible solution to e-bus range issues • Higher route flexibility thanks to higher range (up to tens of kilometres) due to new-generation trolley busses’ higher capacity of batteries: possible partial modifications of the route	• Possible risks due to widespread high-power infrastructure in urban environment

Urban impacts:

- Widespread and continuous power supply system (overhead wires or ground electrified rail) needed along the whole or part of the line routes.

Tips:

- **Energy storage (ES)** could benefit the city by providing services to the grid as well
  (especially where the distribution system is not able to deliver the amount of power needed)
- Such a complex infrastructure needs **real time monitoring through a centralized control room**.

B_δ-IC

5.6. e-Bus dynamic Inductive Charging

Maturity level:

R&D	**Testing**	Market

Description:

The e-bus dynamic inductive charging system consists in charging vehicles' batteries in a wireless mode, thanks to the electromagnetic induction principle, while travelling. Another name of this system is OLEV, On-Line Electric Vehicle. In this system the charging infrastructure is a power track that consists in some purpose designed modules embedded in the road or sunken under its surface. The system works by exploiting the shaped magnetic field in resonance technology (SMFIR); modules activate only when the vehicle passes on each of them. On the bottom of the vehicle there is a secondary coil or receiver which transfer energy to the battery. This technology allows smaller - and lighter consequently - battery packs on board of the vehicles and does not need stops for charging.

source: https://www.youtube.com/watch?v=8Z9FW9ijP3Y

Technical features:

- Charging infrastructure: segmented recharging electrified lane with embedded purpose design modules *(power track length equal to 20% of route length could be enough to operate OLEVs)*
- Air gap between transmitter and receiver: max. 20 cm
- Charging power range: 75 ÷ 200 kW - Voltage: 380 ÷ 440 V AC
- Power transfer efficiency: max. 85%
- Electromagnetic field frequency: 20 kHz

Grid connection > (Energy storage) > Power electronics cabinets and road sensors > Dynamic charging

SWOT analysis:

Strengths	Weaknesses
• Charging while travelling: no need for technical stops or idle time for charging • Easy integration in the urbanscape: space-saving underground infrastructure (no need for additional charging space → circulation space = charging space) • Frequent charging → lower range needed → 3÷5 times smaller (and lighter) battery packs compared to other e-bus charging systems → higher passenger capacity → higher efficiency • Lower power compared to stationary rapid opportunity charging → preserves battery life • Charging with any weather (rain, snow, ice, …) • Safety: no possibility of electric shock	• High construction cost • Lack of flexibility in bus operations *(difficult modifications to bus lines routes and stops)* • *Dynamic systems are traffic sensitive* • *Possible interferences with other existing urban underground utilities (≈ 30 cm clearance)* • Further development of this technology needed: power transmission efficiency increase • Possible maintainability issues
Opportunities	**Threats**
• Less vehicles needed since they do not need to stop in order to charge battery • 24/7 service with Connected Autonomous Electric Vehicles (C.A.E.V.) in the future	• Possible risks for human health *(still unknown) and* interferences with health monitoring devices *(e.g. pacemakers)*

Urban impacts:

- There are no significant impacts on the urbanscape since the charging infrastructure of this technology is located under the road surface except for the power electronics cabinets. Some disruptions can occur during the construction phase.
- Possible risks for human health due to electromagnetic fields pollution in densely populated areas.

Case studies:

CS_6 – The OLEV system developed by KAIST *(see Case study factsheet 6.6)*

6.6.4 - Dubai Silicon Oasis (Dubai, AE)

- Pilot started in 2020
- 60 m long charging lane

Tips:

- **Energy storage (ES)** needed potentially: charging occurs during operation. Present grids are not able to provide the amount of energy needed by the full transition of the whole public transport fleet to this system.
- Such a complex infrastructure needs both **energy and data exchange** and **real time monitoring**.

C_BS

5.7. e-Car Battery Swapping

Maturity level:

R&D	Testing	**Market**

Description:

The e-car battery swapping technology consists in changing vehicles' exhausted batteries and replacing them with others fully charged at a swapping station or battery storage facility. Many batteries are stored at the swapping station where they can charge slowly. This is the fastest way to get a fully charged battery reducing at a minimum the technical idle time for 'charging' operations. The swapping operation is fully automated and requires less than 10 minutes.
Better Place was a startup founded in 2007 that opened some battery swapping stations (BSSs) in Israel but went on bankrupt in 2013, maybe because there were only few electric vehicles at the time. Today this solution is already in use in China where some car manufacturers opened BSS networks both in urban environments and on motorways, but there are no documented applications in Europe yet. Battery swapping is not possible with every car; the vehicle must be designed to allow it.

source: https://www.youtube.com/watch?v=DX1SB1355wc

Technical features:

- Battery swapping stations (BSSs) charge vehicles' batteries off-board
- BSS power requirements depends on the battery storage size, according to the number of stored batteries *(in the order of magnitude of 100 kW generally)*
- Management system to monitor batteries' state of charge (SOC) and charging process
- Swapping time: 3 ÷ 8 minutes (stated switch capacity: 400 swaps/day)
- BSS cost: ≈ USD 500.000

SWOT analysis:

Strengths	Weaknesses
• Fast operation • Suitable for long-range travels • Slow charging of batteries preserves their life • Lower cost of BEV (-20% esteemed by market operators) if battery is not owned → larger diffusion of BEV reducing the cost barrier	• Large investments required to set up a network of battery swapping stations • Interoperability problems: lack of battery and powertrain standardization • Business model needed: battery ownership or some form of rental *(BaaS - Battery as a Service)* • More batteries than vehicles needed
Opportunities	**Threats**
• In the future the fully automated battery swapping process could be used to change the batteries of Connected Autonomous Electric Vehicles (C.A.E.V.) • Battery storages could serve as energy storages for the grid as well • Storage for RES: energy produced by renewable sources during peak hours can be stored even if vehicles are in use	

Urban impacts:

- Battery swapping stations (BSSs) need integration and spaces in the existing urban environment. They could be placed at existing petrol station (and could replace them when all vehicles will be BEV) or inside parking facilities or garages. The lack of rapid charging need reduces the power demand and BSSs could even provide energy storage to the grid, contributing to stabilizing it.

Case studies:

CS_4 - E-car battery swapping station network in China

- The world's largest battery swapping station network
- 452 BSSs in China, mainly in the Eastern coast area and 40% of the total concentrated in Beijing alone (June 2020)
- Battery swapping time: 3 ÷ 8 minutes (up to 400 battery swaps/day are possible at a BSS)
- More than 800.000 swaps completed so far at a Chinese automaker's BSS network, at a rate of 4.000 swaps/day (automaker statement)

Tips:

- Vehicles' efficiency, battery capacity, BSS charging power (i.e. charging speed) and users' travel habits influence the number of batteries and BSSs needed. Nowadays a charge is enough for several days for the urban travels of most BEV users generally. As the battery capacity and vehicles' efficiency grow, the number of charging infrastructure needed will decrease.
- Such a complex infrastructure needs **real time monitoring** of the state of charge (SOC) and charging process of the stored batteries.

C_s-CC

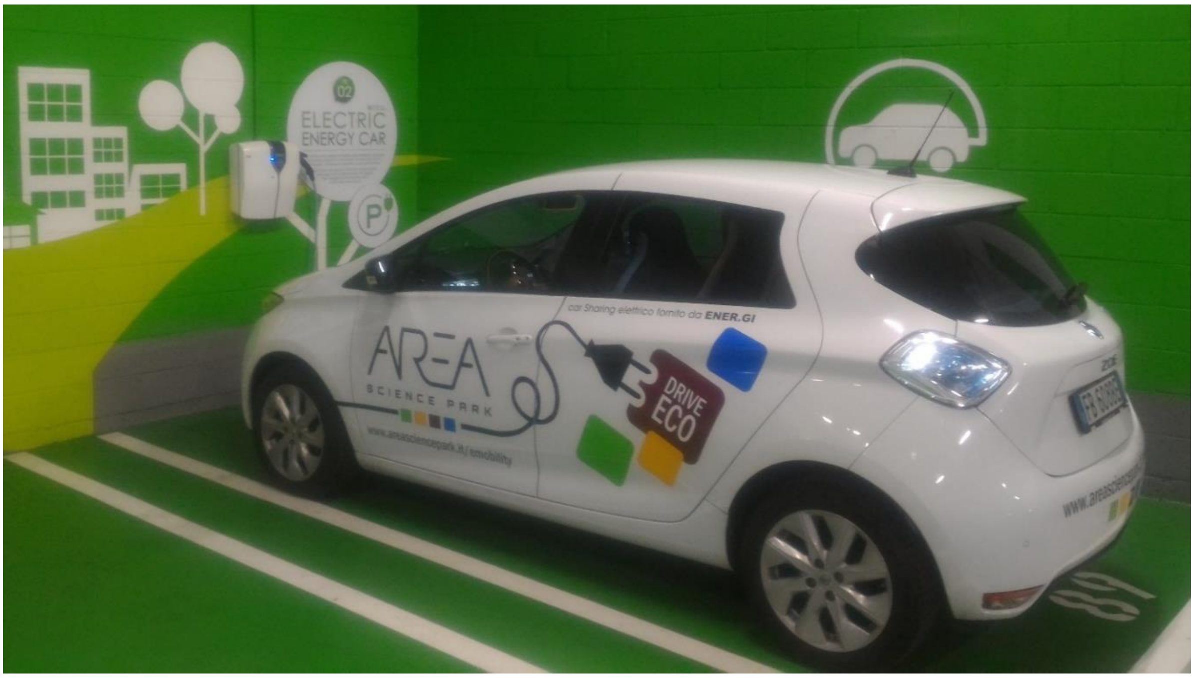
5.8. e-Car stationary Conductive Charging

Maturity level:

R&D	Testing	**Market**

Description:

The e-car stationary conductive charging consists in charging the battery by connecting the vehicle to the charging infrastructure through a cable or another plug-in system. This technology represents the state of the art and is the most widespread on the market. Conductive charging can be divided into 4 modes, but only the last 2 (mode 3 and 4) can be deployed in public space. Mode 3 enables slow and fast charging because it consists in providing the vehicle with AC (up to 22 kW) which is transformed into DC by the on-board converter and the process is controlled by the vehicle’s Battery Management System (BMS). Mode 4, on the other hand, enables rapid charging because the infrastructures provide high-power (> 22 kW) DC to the vehicles.
This technology is used to charge light commercial vehicles as well (e.g. e-taxi and e-vans): it must be highlighted that this kind of vehicles need as little as possible idle times for charging, so accurate planning and dedicated facilities must be foreseen for them.



Technical features:
Average battery capacity: 20 ÷ 50 kWh *(and higher in the next future, up to 100 kWh)*

Type of charging:	Slow	Fast	Rapid
Mode:	3 *(in public space)*	3 *(in public space)*	4
Power:	< 7 kW	7 ÷ 22 kW	> 22 kW
Charging time:	up to 20 hours	a couple of hours	< 1 h

SWOT analysis:

Strengths	Weaknesses
• This technology is very suitable for small personal vehicles in urban contexts *(small, lightweight, with little battery and little range requirements)*	• Charging needs time *(more than refilling a fuel tank)* • Limitations in operations for commercial vehicles
Opportunities	**Threats**
• Parking facilities could serve as energy storages thanks to vehicle to grid technology (V2G)	• Possible power problems without a recharge planning or management to avoid peaks

Urban impacts:

- If BEVs spread, more charging infrastructure than today will be necessary in already dense and busy environments such as city centers.

Tips:

- Provide **energy storage (ES)** where the distribution system is not able to deliver the amount of power needed.
- As the number of electric vehicles rises, **real time monitoring** of charging process and **charge planning** for ***peak shaving*** is essential.

C_s-IC

5.9. e-Car stationary Inductive Charging

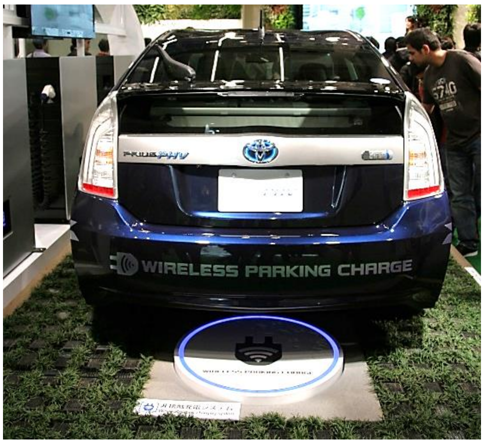
Maturity level:

R&D	**Testing**	Market

Description:

The e-car stationary inductive charging system consists in charging vehicles' batteries in a wireless mode thanks to the electromagnetic induction principle. There are several typologies of electromagnetic induction systems, but the most used ones in the automotive sector are those based on resonant magnetic inductive coupling and on capacitive coupling. Depending on the typology of electromagnetic induction principle adopted by the different systems, a magnetic coil or plate is sunken under the road surface in the charging bay and another coil or plate is placed on the bottom of the vehicle. In order to increase power transmission efficiency coils or plates must be aligned as much as possible. Charging is automatic and is allowed by a wireless communication system between the infrastructure and the vehicle's battery management system (BMS). A lot of R&D is still in progress about this very promising charging system whose efficiency is 90% or higher.

https://www.flickr.com/photos/micsworld/8653274002/



https://en.wikipedia.org/wiki/File:Electric_car_wireless_parking_charge.jpg

Technical features:

- Charging point power range: 3,3 ÷ 50 kW
  - 3 ÷ 11 kW slow charging
  - 11 ÷ 22 kW fast charging
  - 22 ÷ 50 kW rapid charging
  below 20 kW → domestic and at workplaces
  above 12 kW → public/commercial fast charging
- Charging time depends on several variables *(charging power, battery size and state of charge)*
- Efficiency: ≈ 90%
- Air gap between transmitter and receiver: max. 20 cm

Grid connection > (Energy storage) > Power electronics cabinet and sensor > Charging bay

SWOT analysis:

Strengths	Weaknesses
• Easy integration in the urbanscape: space-saving multipurpose facility *(parking bay + charging infrastructure under the road surface)* • Automatic charging *(no human intervention needed)* • Safety: no possibility of electric shock • Charging with any weather (rain, snow, ice, …)	• Further development needed: misalignment and air gap between coils/plates affects efficiency negatively • High cost • Still interoperability and standards issues • Possible maintainability issues
Opportunities	**Threats**
• Since no human intervention is needed, this technology is extremely suitable for Connected Autonomous Electric Vehicles (C.A.E.V.)	• Possible risks for human health *(still unknown) and* interferences with health monitoring devices *(e.g., pacemakers)*

Urban impacts:

- There are no significant impacts on the urbanscape since the charging infrastructure of this technology is located under the road surface except for the power electronics cabinet.
- Possible risks for human health due to electromagnetic fields pollution in densely populated areas

Case studies:

E-taxi opportunity wireless charging pilot in Nottingham (UK)

- Six-month pilot *(started in June 2020)*
- 10 e-taxi owned by the Nottingham City Council free-rented to selected drivers
- 5 charging pads at taxi ranks near the railway station of Nottingham
- £3.4m *(government funding)*

external links:
https://www.bbc.com/news/uk-england-nottinghamshire-51140689
https://www.mdpi.com/2071-1050/12/21/8798

Tips:

- Provide **energy storage (ES)** *(especially where there is a concentration of charging infrastructures and the distribution system is not able to deliver the amount of power needed)*

Warning!
Passenger cannot sit in the vehicle while charging due to the electromagnetic field generated by the charging infrastructure

C_δ-IC

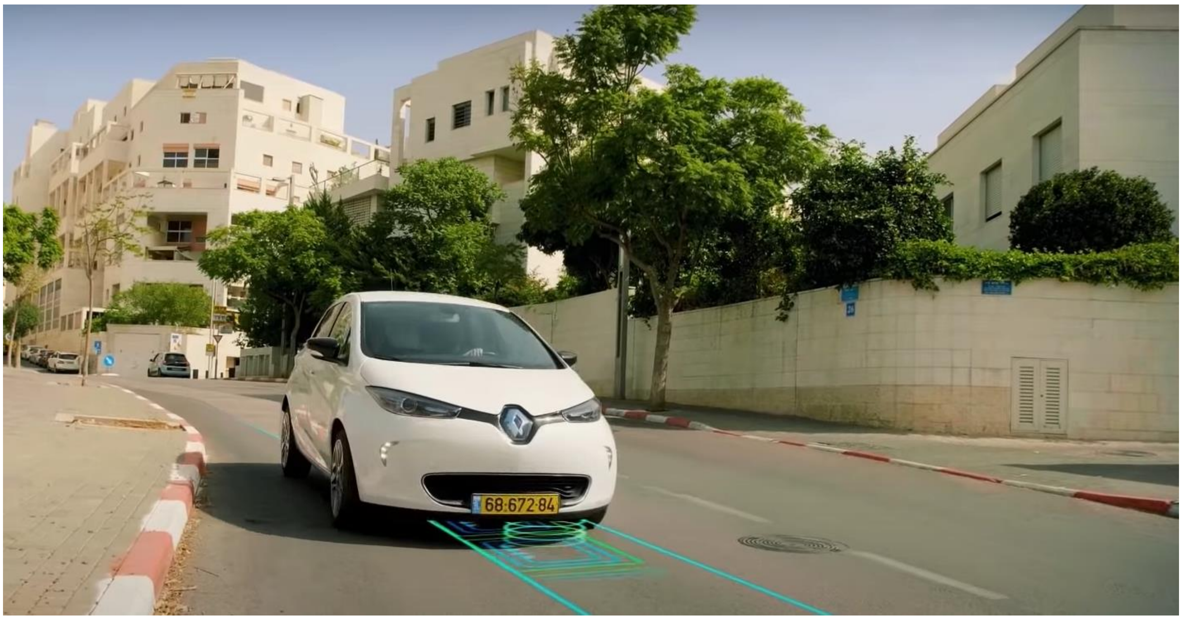
5.10. e-Car dynamic Inductive Charging

Maturity level:

R&D	**Testing**	Market

Description:

The e-car dynamic inductive charging system consists in charging vehicles' batteries in a wireless mode, thanks to the electromagnetic induction principle, while travelling. In this system the charging infrastructure is a power track composed of purpose designed modules embedded in the road or sunken under its surface which activate only when the vehicle passes on each of them. On the bottom of the vehicle (or in its tyres to reduce to a minimum the air gap in some research) there is a secondary coil or receiver which transfers energy to the battery. This technology allows smaller - and lighter consequently - battery packs on board of the vehicles and does not need stops for charging. The most suitable application of this technology is on motorways and in suburban areas for long-range trips, but it can be used in urban contexts as well.



source: https://www.youtube.com/watch?v=04enYJUDpuI

Technical features:

- Charging infrastructure: segmented recharging electrified lane with embedded purpose designed modules
- Air gap between transmitter and receiver: max. 20 cm
- Charging power: up to 20 kW
- Potential maximum power transfer efficiency: > 90% *(not yet achieved)*

Grid connection > (Energy storage) > Power electronics cabinets and road sensors > Dynamic charging

SWOT analysis:

Strengths	Weaknesses
• Charging while travelling: no need for technical stops or idle time for charging • No need for on-board battery potentially or smaller battery required → cheaper vehicles • Lower power for charging → longer battery life • Charging with any weather (rain, snow, ice, …) • Easy integration in the urbanscape: space-saving underground infrastructure (no need for additional charging space → circulation space = charging space) • Safety: no possibility of electric shock	• High investments in infrastructure • Possible interferences with other existing urban underground utilities *(≈ 30 cm clearance)* • Further development of this technology needed: power transmission efficiency increase • Business model needed: measurement and payment system for the energy taken • Possible maintainability issues
Opportunities	**Threats**
• Possibility of using vehicles' batteries for energy storage and grid balancing even when vehicles are in use and moving or producing energy with regenerative braking thanks to V2G technology	• Possible risks for human health *(still unknown) and* interferences with health monitoring devices *(e.g. pacemakers)*

Urban impacts:

- There are no significant impacts on the urbanscape since the charging infrastructure of this technology is located under the road surface except for the power electronics cabinets. Some disruptions can occur during the construction phase.
- Possible risks for human health due to electromagnetic fields pollution in densely populated areas.

Case studies:

CS_3 - Dynamic wireless power transfer test site (Versailles, FR)

- The pilot was set up in the framework of the FABRIC European project
- Testing period: March 2017 - November 2017 *(December 2017 - March 2018: final data collection)*
- 100-metre power track test road *(construction cost: USD 10,1 million)*
- Vehicles used: 2 Renault Kangoo vans, each equipped with 2 receiving pads on the bottom
- Speed: 0 ÷ 120 km/h - both static (up to 7,4 kW) and dynamic (up to 20 kW) charging are possible
- Frequency: 85 kHz *(wireless charging standard frequency → allows compatibility)*
- Possible misalignment: +/- 20 cm *(no significant power transfer losses with less than 12 cm average misalignment)*
- Maximum air gap: +/- 25 cm

Total energy efficiency: up to 70% in best condition *(possible improvements in the future)*

Tips:

- **Energy storage (ES)** needed potentially. Present grids are not able to provide the amount of energy needed by the full transition to this system.
- Such a complex infrastructure needs both **energy and data exchange** and **real time monitoring**.

L_BS

5.11. LEV Battery Swapping

Maturity level:

R&D	Testing	**Market**

Description:

The Light Electric Vehicle (LEV) battery swapping technology consists in changing vehicles' exhausted batteries and replacing them with others fully charged. This is the fastest way to get a fully charged battery reducing at a minimum the technical idle time for charging operations. Since LEVs' batteries are small and light generally, they can be switched manually and this solution is the most convenient on-site 'recharging' operation, ideal for dockless sharing mobility services.
According to different types of vehicle and use modes there are different battery swapping solutions. Private vehicles' batteries can be charged at home or a fully charged battery can be found at a public swapping station if the battery is not owned (i.e. BaaS – Battery as a Service business model). Sharing vehicles' batteries are changed on-site by service operators during redistribution or on purpose operations.

source: https://commons.wikimedia.org/wiki/File:Electric_scooters_in_Finland.jpg

Technical features:

- The vehicle (quadricycle, tricycle, e-scooter, e-bike, e-kickscooter, …) has one or more removeable batteries: the exhausted batteries are removed and substituted with a fully charged ones
- The recharging operation is performed off-board (e.g., at home/garage, at depot or at a battery charging station)
- Average battery capacity: 1 ÷ 8 kWh
- Average battery weight: up to ≈ 10 kg *(sometimes there are 2 battery packs)*
- Average charging time: 3 ÷ 6 h

- If the vehicle must operate during the battery charging time more than one battery per vehicle is needed
- If charging is performed during vehicle's idle time (e.g., overnight for a private vehicle) or while using another battery, slow charging at low power is the best solution

SWOT analysis:

Strengths	Weaknesses
• Fast operation • Convenient solution for sharing services • Slow charging of batteries preserves their life	• More batteries than vehicles needed
Opportunities	**Threats**
• Battery storages could serve as energy storages for the grid as well • Storage for RES: energy produced by renewable sources during peak hours can be stored even if vehicles are in use	

Urban impacts:

- Battery swapping stations (BSSs) for LEVs does not need much space and are rather easy to integrate in the existing urban environment. Since LEV battery capacity is small, the power demand is low if slow charging is performed, but BSSs could provide a little energy storage to a micro or local grid anyway.

Case studies:

CS_5 – E-scooter Battery Swapping Station network in Taiwan

- The world's largest e-scooter Battery Swapping Station network
- There are 1936 BSSs in service and other 97 under construction (source: map on the company's website, January 2021)
- BSSs are present in the cities of Taipei, New Taipei, Taichung, Taoyuan, Kaohsiung and Tainan, but can be found in less densely populated areas as well (24% in 2020)
- Everywhere in Taiwan one can find a BSS within 1 km distance, even one station every 400 m in some areas: there are more BSSs than gas stations in the 6 metropolitan areas served now
- BSSs are located at or near points of interest (e.g., petrol stations, convenience markets, shopping malls, public buildings, etc.)
- The BSS is an automatic device *(similar to a vending machine)* which does not require the presence of an operator
- Battery swapping time: < 1 minute *(only 6 seconds according to the company's official video commercial)*
- Average number of slots per station: 35
- The biggest BSS can manage up to 120 batteries (able to serve up to 1.000 riders) and has an energy storage capacity of 200 kWh
- Single battery capacity: 1,3 kWh
- Single battery weight: 9 kg
- These BSSs can operate bidirectionally providing energy to the grid if needed

L_s-CC

5.12. LEV stationary Conductive Charging

Maturity level:

R&D	Testing	**Market**

Description:

The Light Electric Vehicle (LEV) stationary conductive charging consists in charging the battery by connecting the vehicle to the charging infrastructure through a cable or another plug-in system. At home and in private spaces charging is performed in mode 1, that consists in connecting the vehicle directly to an electric socket, usually through a charger which transform AC to DC, or mode 2 in which there is a control box on the cable that manages the charging process. In public space different kinds of charging infrastructures can be found according to the type of vehicle: tricycles and quadricycles can be charged at the same e-car slow or fast charging infrastructures (mode 3) because they have an on-board Battery Management System (BMS) and AC/DC transformer usually, while micromobility vehicles (e.g. e-bikes and e-kickscooters) need dedicated infrastructures like docking stations or electrified racks which provide them with DC since they are not equipped with an on-board AC/DC transformer.

source: https://www.stuff.co.nz/environment/climate-news/300010373/ebike-charging-and-locking-stations-coming-to-christchurch

Technical features:

- LEV category is wide including a large variety of vehicles, from quadricycles to hoverboards, therefore providing detailed technical features is difficult
- This kind of infrastructures performs slow charging at low power (up to ≈ 3 kW) generally
- The total power required by these infrastructures depends on the number and typology of vehicles served but it is lower than 100 kW usually
- Average vehicle battery capacity: < 10 kWh

SWOT analysis:

Strengths	Weaknesses
• This technology is very suitable for small personal vehicles in urban contexts *(small, lightweight, with little battery and little range requirements)*	• Charging needs time *(more than refilling a fuel tank)* • Limitations in operations for commercial vehicles
Opportunities	**Threats**
• Parking facilities could serve as energy storages thanks to vehicle to grid technology (V2G)	

Urban impacts:

- If LEVs spread, more charging infrastructure than today will be necessary and existing parking spaces should be electrified in order to provide charging as well as parking at the same place, optimizing the available space.

Case studies:

LEV lockers

- Some municipalities built access-controlled parking or lockers for micromobility vehicles (e-bikes and e-kickscooters mainly)
- These infrastructures allow the users to park and recharge their vehicles in a safe place
- Only registered users can open the lockers or storages by authentication through a card or mobile app and they can be charged for the service

source: https://www.youtube.com/watch?v=chDUqhXk0po&feature=emb_logo

Docking stations for sharing mobility

- One of the main problems of free-floating sharing mobility services is the large number of LEVs abandoned everywhere
- Free-floating services require operators' interventions for vehicle redistribution and charging
- A widespread network of docking stations could be a win-win strategy: it would reduce operations and solve the problem of LEV abandoned everywhere at the same time
- A station base system is ideal for LEV because they can charge when not used without the need of an operator

source: https://commons.wikimedia.org/wiki/File:Swiftmile_charging_station.jpg

L_s-IC

5.13. LEV stationary Inductive Charging

Maturity level:

R&D	Testing	**Market**

Description:

The Light Electric Vehicle (LEV) stationary inductive charging system consists in charging vehicles' batteries in a wireless mode, thanks to the electromagnetic induction principle. There are several typologies of electromagnetic induction systems, but the most used ones are those based on resonant magnetic inductive coupling and on capacitive coupling. The charging infrastructure is composed only by a pad, the transmitter, which can be embedded in the stand or rack or placed under the parking space. The receiver is placed on the vehicle. In order to increase the power transmission efficiency, the transmitter and the receiver must be aligned and close as much as possible. Charging is automatic when the vehicle is near the infrastructure. There are already some products available on the market, but this technology is not much widespread yet. A lot of R&D is still in progress about this very promising charging system whose efficiency is very high.

source: https://www.youtube.com/watch?v=aCpkFT7YkZs

Technical features:

- Charging point power: up to 3,3 kW
- Charging time depends on several variables *(charging power, battery size and state of charge)*
- Efficiency: ≈ 90%
- The air gap is reduced to a minimum and the transmitter and the receiver can even touch in some cases

SWOT analysis:

Strengths	Weaknesses
• Easy integration in the urbanscape: space-saving multipurpose facility *(parking + charging infrastructure)* • Low power needed • Automatic charging and interoperability • Safety: no possibility of electric shock • Charging with any weather (rain, snow, ice, …)	
Opportunities	**Threats**
	• Possible risks for human health *(still unknown)*

Urban impacts:

- There are no significant impacts on the urbanscape since the charging infrastructure of this technology is integrated in LEV parking spaces perfectly.

Warning!

The effects of human body exposure to electromagnetic fields are still unknown. This charging infrastructure does not generate strong electromagnetic fields since power transmission is low, but some risks could arise if this technology spreads and many devices adopt it increasing the number of electromagnetic fields people are exposed to.

ESs

5.14. Energy Storage systems

Description:

Energy storage consists in preserving an amount of energy for a delayed use. It allows to separate the energy generation from its usage time keeping in balance energy demand and production. Energy storage devices are commonly called accumulators. There are several forms of energy and storage systems can exploit the conversion of energy in some forms that are easier – technically or economically - to store. Since this study focuses on electrification, only energy storage forms that are most used and suitable for electricity will be discussed.

Energy storage systems are very important for the decarbonization of the energy sector: renewable energy sources are intermittent and often the production peak is decoupled from the demand peak. Energy storage systems allow the storage of clean energy and its use when needed giving the chance to rely largely – and in the future only - on renewable sources.

There are several different types of storage systems which can be grouped in the following main categories:

- ***Chemical***
  - *power to liquid*
    - *biofuel*
  - *power to gas*
    - *hydrogen*
- ***Electrical***
  - *capacitor*
  - *supercapacitor*
- ***Electrochemical***
  - *flow battery*
  - *rechargeable battery*
  - *fuel cell*
- ***Mechanical***
  - *potential energy accumulator*
    - *pumped hydroelectric storage (PHS)*
    - *solid mass gravitational*
  - *Hydraulic accumulator*
  - *Compressed air energy storage*
  - *Flywheel Energy Storage (FES)*

The most widespread energy storage system is pumped hydroelectric storage (PHS) at present which accounts for more than 99% of storage capacity worldwide (≈ 127.000 MW). PHS efficiency varies between 70 and 87%. Moreover, hydroelectric is very suitable to tackle demand peaks because it is very responsive since turbines have a start-up time on the order of a few minutes.

Another interesting mechanical storage typology - which could be employed where water is not available in large quantity - is the solid mass gravitational system, also called gravity battery since it stores potential energy. This technology consists in lifting a mass (e.g., a block of concrete) to a certain height by using excess energy and let it fall converting potential energy into electricity thanks to a generator when energy is needed.

Electrochemical and electrical systems have not spread much so far due to their higher cost, but a lot of research on energy density and new battery technologies (e.g., solid state batteries) are in progress. Hydrogen could be a promising option in the future, but there are still some issues to be solved before its large-scale deployment.

External references:

videos:

solid mass gravitational

- https://www.youtube.com/watch?v=mmrwdTGZxGk
- https://vimeo.com/335818817
- https://vimeo.com/394206540

hydrogen

- https://www.youtube.com/watch?v=c3YjzpGqQJA
- https://www.youtube.com/watch?v=tGKKHWkrXDA

websites:

solid mass gravitational

- https://energyvault.com/
- https://gravitricity.com/

Rechargeable batteries

- https://cordis.europa.eu/article/id/411622-liquid-battery-allows-fast-recharge-and-double-the-range-of-e-vehicles
- http://www.bettery.eu/

hydrogen

- http://www.fchea.org/
- https://hydrogeneurope.eu/
- https://www.energy.gov/eere/fuelcells/hydrogen-storage
- https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Power-to-Hydrogen_Innovation_2019.pdf?la=en&hash=C166B06F4B4D95AA05C67DAB4DE8E2934C79858D
- https://www.sciencedirect.com/science/article/pii/S2451904919302628
- https://www.researchgate.net/publication/336009310_Renewable_hydrogen_as_an_energy_storage_solution
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- http://www.hystoc.eu

V2G

5.15. V2G: Vehicle-to-Grid

Description:

Vehicle-to-grid (V2G) is a technology that permits energy to be pushed back from the battery of an electric vehicle to the power grid. It is a system that has ability of bi-directional and controllable electrical energy flow among vehicle and electrical grid. Vehicle to grid market perceives substantial growth due to exponentially growing number of EV charging stations across the world.

The bi-directional nature of batteries (i.e. charging and discharging) can prove as biggest flexibility asset on wheels in future. To lower the impact of EVs charging on power system's supply-demand balance, Grid-to-Vehicle or V1G technology has been rolled out. Using Smart Charging, rate of charging could be increased to utilize the maximum VRE (Variable Renewable Energy production). In the event of overgeneration, while lower VRE production, the charging rate, power and duration of charge can be adapted to reduce the load on the grid.

The concept allows V2G vehicles to provide power to help balance loads by "valley filling" (charging at night when demand is low) and "peak shaving" (sending power back to the grid when demand is high, see duck curve). Peak load leveling can enable new ways for utilities to provide regulation services (keeping voltage and frequency stable) and provide spinning reserves (meet sudden demands for power). These services coupled with "smart-meters" would allow V2G vehicles to give power back to the grid and in return, receive monetary benefits based on how much power given back to the grid.

V2G services on the other hand refer to injecting power back into the grid from the vehicle batteries to avoid Loss of Load events. V2G technology could aid turning EVs from an energy consumer into a producer or prosumer helping to shave peak demands and save money by avoiding running costly Peak Power Plants (PPP). It also enables energy to be fed back to the power grid from the battery of an electric car. With V2G technology, a car battery is discharged based on different signals — such as energy production, demand at that moment of time, electricity market prices, etc. (CHAdeMO, 2020).

Meeting peak demands in an electricity system typically requires 15-25% of generation capacity beyond the capacity needed to meet electricity demand for 90% of the hours of lowest demand.

Currently the charging standard that readily supports V2G is CHAdeMO, which has bidirectional capability and was introduced first in Japan. CHAdeMo is now available in all major EV markets including China, Europe, and North America. Until now, only 12 vehicle manufacturers (OEMs) have participated in V2G projects with Renault, Nissan, and Mitsubishi clearly dominant representing more than 50% of V2G projects. However, more standards (CCS, GB/T, etc.) need to get on board for greater adoption of V2G among other OEMs around the globe (CHAdeMO, 2019).

Around 5% of total global EV battery capacity could be available for V2G, unlocking several hundreds of gigawatt-hours to meet peak demand (Global EV Outlook 2020, IEA, 2020). Despite being a very small share of the total EV battery capacity by 2030, the total technically available potential for V2G deployment exceeds the additional generation capacity required to meet peak demand in almost all major EV markets.

Most research claims that a maximum of 60-80% of the nominal battery capacity can be drawn without premature degradation of the battery. However, more research and tests are needed to identify the parameters that influence the degradation of batteries (Global EV Outlook 2020, IEA, 2020).

Case studies/Best practises:

- In Denmark, Nuvve Corporation declared 4 years of successive vehicle to grid operations of electric vehicles in September 2020. The company has been carrying out current frequency regulation service for Energinet, the Danish grid operator, for 4 successive years. The initial fleet of vehicles commenced service in September 2016 at a municipal water and gas Utility Corporation in Denmark named Frederiksberg Foraying. https://nuvve.com/projects/
- The German power utility E. ON is currently working with Nissan on the business model for V2G services, distributed energy generation and renewable energy systems (V2G: Everything You Need to Know, Virta Global, 2020). Similarly, Volkswagen sees an enormous potential in EVs. They project that by 2025, they will have 350 gigawatt hours of energy storage at their disposal through their car fleets thus bringing down the cost of energy storage (Electric Vehicles, Volkswagen, 2020).

External references:

videos:

https://www.youtube.com/watch?v=wHNFYMPFUv4

https://www.youtube.com/watch?v=QCYcsk40FLs (Fullycharged)

https://www.youtube.com/watch?v=b3ZgF4X9BdQ (VIRTA)

websites:

https://www.eba250.com/vehicle-to-grid-energy-storage-on-wheels/

https://sepapower.org/knowledge/the-path-to-a-vehicle-to-grid-future/

https://www.media.fcaemea.com/em-en/e-mobility/press/the-vehicle-to-grid-pilot-project-has-been-inaugurated-at-mirafiori

6. Case studies

CS_1

6.1. Amsterdam e-bus system

Location: Amsterdam, Netherlands
Year: active from March 2018
Description:
The e-bus system of Amsterdam is the world's largest opportunity and depot fast charging network.

source: https://www.youtube.com/watch?v=ruUJly8l5s8

Specifications:
Charging typology: Conductive charging *(via roof-mounted pantograph)*
System type: hybrid (86 depot charging infrastructures + 23 opportunity charging infrastructures)
System structure:
- Depot Amsterdam: 44 depot charging infrastructures – 7 opportunity charging infrastructures
- Depot Amstelveen: 42 depot charging infrastructures – 8 opportunity charging infrastructures
- Schiphol Parking North: 4 opportunity charging infrastructures
- Schiphol Parking P30: 4 opportunity charging infrastructures

Depot power supply: 13 MW
Depot charging infrastructure: 30 kW DC chargers *(overnight charging)*
Opportunity charging infrastructure: 450 kW DC chargers *(2 ÷ 4 minutes charging)*
Fleet size: 100 BEBs
future expansion foreseen: 258 BEBs in 2021 (90% of the fleet → zero emission target by 2025)

Service information:
- 6 routes around the Schiphol airport
- 24/7 service

Depot management: web portal which allows live-monitoring, error reporting, detailed overview and insight into use, charging processes and state of charging infrastructures
Energy: 100% from renewable sources *(mainly wind power + solar panels on depots)*

External references:

videos:

- https://www.youtube.com/watch?v=tlUn3DJDYf8
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websites:

- https://www.electrive.com/2018/03/28/extra-large-13-mw-charge-depot-for-100-e-buses-live-in-amsterdam/
- https://insideevs.com/news/337596/heliox-launches-europes-largest-opportunity-amp-depot-charging-for-buses/
- https://www.transdev.com/en/solutions/environmental-solutions-amsterdam/
- https://www.iamsterdam.com/en/business/news-and-insights/news/2018/amsterdam-first-fleet-of-electric-buses

CS_2

6.2. Columbia station

Location: Wenatchee, Washington (US)
Year: pilot started in March 2018
Description:
Columbia station is a bus terminal where an e-bus wireless opportunity charging infrastructure has been installed. The charging infrastructure consists in a power electronics cabinet and a transmitter pad sunken under the road surface. On the vehicle side there are four 50 kW modules (receiving pads) that transfer the energy to a management module and then to the battery. This charging system does not have moving parts and is fully automated. *The electricity used is clean because it is generated by the nearby Grand Coulee Dam. The pilot started in 2018 with one e-bus and one 200 kW wireless charging infrastructure, but, since the test has been successful, this year the public transport company added 10 more electric busses and is going to install three new 300 kW wireless opportunity chargers soon.*

Specifications:
Charging typology: inductive charging *(transmitter pad sunken under road surface)*
Induction typology: resonant magnetic induction
Maximum charging power: 200 kW
Charging time: 7 ÷ 10 minutes every hour
Bus and service information:
- bus battery size: 266 kWh (BYD K9S)
- bus driving range *(per single charge)*: 145 miles (≈ 233 km)
- service duration: 16 hours/day
- battery state of charge (SOC) during service: ≥ 75%

source: https://vimeo.com/337273961

External references:

videos:
- https://vimeo.com/337273961
- https://insideevs.com/news/377253/byd-electric-bus-wireless-charging/

websites:

- https://momentumdynamics.com/solution/#casestudy
- https://insideevs.com/news/424428/50-mwh-energy-delivered-wirelessly-ev-bus/
- https://insideevs.com/news/430559/link-transit-10-wirelessly-rechargeable-electric-buses/

Wireless charging efficiency:

- https://insideevs.com/news/425972/momentum-dynamics-wireless-charging-efficiency/

CS_3

6.3. Dynamic wireless power transfer test site

Location: Versailles, France
Year: March 2017 – November 2017
Description:
The dynamic wireless power transfer test site in Versailles is a pilot set up in the framework of the FABRIC European project. This wireless power transmission system relies on the electromagnetic induction principle. The charging infrastructure is composed by a segmented electrified track made of modules which activate as the vehicles pass over each of them. On the bottom of the vehicles there is a receiving pad which transfer energy to a system controller which manages the electricity received. The receiving pad is suitable not only for dynamic charging but it works in static mode as well. The charging infrastructure delivers up to 20 kW because at a speed of 100 km/h a typical EV needs between 10 and 13 KW to move and the additional power supplied can be used to charge the battery at the same time. At a lower speed (e.g., 50 km/h) charging is faster since less power is needed to move the vehicle. This technology is suitable not only for motorways but for suburban and urban roads as well. This pilot demonstrated that the technology works but there are still some complexities, like the presence of several cars on the same segment of the electrified track, to be solved before releasing it on the market. The cost to bring the technology on large scale is still to be investigated. Moreover, there are several different players and stakeholders involved in the rolling out of this technology that it will still take several years because roads – some at least - must be equipped with the charging infrastructure. It could take 10 years and the supply grid must be studied as well since megawatts would be needed to supply a motorway segment.

source: https://www.youtube.com/watch?v=2t0E4AcVu6o

Specifications:

- Charging typology: Inductive charging
- Testing period: March 2017 - November 2017 (December 2017 - March 2018: final data collection)
- 100-metre power track test road (construction cost: USD 10,1 million)
- Installation depth: 6 cm underground
- Vehicles used: 2 Renault Kangoo vans, each equipped with 2 receiving pads on the bottom
- Speed: 0 ÷ 120 km/h - both static (up to 7,4 kW) and dynamic (up to 20 kW) charging are possible
- Frequency: 85 kHz *(wireless charging standard frequency → allows compatibility)*
- Possible misalignment: +/- 20 cm (no significant power transfer losses with less than 12 cm average misalignment)
- Maximum air gap: +/- 25 cm
- Total energy efficiency: up to 70% in best condition *(possible improvements in the future)*
- During testing periods intermittent functioning has been registered during heavy rain and hot weather conditions
- EMF requirements satisfied inside and outside the vehicle
- EMC requirements compliant
- Two vehicles travelling in opposite directions can both be charged on the same infrastructure simultaneously

External references:

videos:

- https://www.youtube.com/watch?v=F_kUc3Pf6HY&feature=emb_logo
- https://www.youtube.com/watch?v=2t0E4AcVu6o
- https://www.youtube.com/watch?v=a0UWi8RJDTY&feature=emb_logo

websites:

- http://www.fabric-project.eu/www.fabric-project.eu/indexe7c3.html?option=com_k2&view=itemlist&layout=category&task=category&id=25&Itemid=215
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CS_4

6.4. e-car battery swapping station network in China

Location: China
Year: since 2018
Description:
The Chinese e-car battery swapping station network is the largest in the world. It is not a single interoperable network but four separate ones, since the four bigger Chinese EV makers built their own BSS networks and they keep on offering services to their own clients only, giving them the opportunity to change their e-car battery instead of waiting for it to charge. One automaker offers a Battery as a Service (BaaS) option to its clients too. There are 452 BSSs in China, concentrated in the Eastern coast area mainly and 40% of the total is in Beijing alone. BSSs are located both on the motorways and in urban areas. According to one automaker's statement, more than 800.000 swaps have been completed so far at its 143 BSSs in 64 cities and about 4.000 batteries are currently swapping every day. The daily switch capacity of a BSS is claimed to be 400 swaps (only 70 according to some sources), but at present only 150 ÷ 160 swaps are performed on average; the stated number of daily operations to reach the break-even point as planned is 200. Other business companies outside China tried to offer battery swapping service in the past but they went on bankrupt or preferred developing rapid chargers eventually. China maybe decided to develop battery swapping due to the growing number of BEVs and its cities' density: even adopting rapid charging at very high power there would not be enough space to recharge all the BEVs. Thanks to battery swapping (which takes a few minutes) is possible to 'charge' many more vehicles in the time one rapid charger takes to charge only one (about 1 hour on average). The Chinese government supports EV adoption to phase out ICE vehicles and promotes battery standardization in order to facilitate interoperability and battery swapping which has been included in the 'New infrastructure' campaign, a national project to react to the economic impact of coronavirus pandemic by boosting innovation in industry and economic growth.

source: https://www.youtube.com/watch?v=OBVsPZm5IGU

Specifications:
Charging typology: Battery swapping
Battery swapping time: 3 ÷ 8 minutes (400 battery swaps/day are possible at a BSS)
Fully automated process *(but still an operator is present to assist the process)*
Battery storage capacity: 5 batteries
Power supply: similar to rapid charging infrastructure in order to be able to recharge exhausted batteries as soon as possible
BSS footprint: ≈ 3 parking spaces
BSSs are prefabricated moveable infrastructures similar to automatic car-wash
BSS cost: ≈ USD 500.000

External references:

videos:

- https://www.youtube.com/watch?v=oTXptUuKGrc
- https://technode.com/wp-content/uploads/2020/09/Fifth-cut.mp4
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websites:

- https://www.bloomberg.com/news/articles/2020-01-17/china-embraces-ev-battery-swap-technology-tesla-has-cooled-on
- https://news.cgtn.com/news/2020-08-16/EV-battery-swapping-finds-new-life-in-China-SWZQhFZoEE/index.html

BaaS - Battery as a Service

- https://www.motor1.com/news/439923/nio-battery-as-service-lease/

CS_5

6.5. e-scooter BSS network in Taiwan

Location: Taiwan
Year: active since 2015
Description:

In Taiwan there is the largest e-scooter Battery Swapping Station network in the world: there are 1936 active BSSs and 97 under construction at present (January 2021). E-scooter BSSs are present in the cities of Taipei, New Taipei, Taichung, Taoyuan, Kaohsiung and Tainan, but can be found in less densely populated areas as well: 24% of BSSs were located outside the main cities in 2020. Everywhere in Taiwan one can find a BSS within 1 km distance, even one station every 400 m in some areas: there are more BSSs than gas stations in the 6 metropolitan areas served now. *BSSs are located at or near points of interest (e.g., petrol stations, convenience markets, shopping malls, public buildings, etc.). They are automatic devices, similar to vending machines, which do not require the presence of an operator. The user extract exhausted batteries from the scooter, insert them in some empty slots of the BSS, is identified automatically, energy consumption is calculated and billed on the user’s account and other fully charged batteries are provided. The swapping operation is fast and easy. 200.000 battery swaps are performed daily in Taiwan for a total of 76.000.000 since the service launch in 2015. The company provides an app which allows the users to locate BSSs within a 5-km radius.*
New generation BSSs can keep on operating for up to 46 hours in case of a power interruption and can even operate bidirectionally providing energy to the grid if needed. BSSs rely on Artificial Intelligence (AI) to ensure batteries are always available.
The total energy storage capacity of the BSS system is higher than 1,2 GWh, equal to the average energy consumption of Taipei City for about 40 minutes.

source: https://commons.wikimedia.org/wiki/File:GoStation_Solar-powered.jpg

Specifications:

- Battery swapping time: < 1 minute *(only 6 seconds according to the company's official video commercial)*
- Average number of slots per station: 35
- The biggest BSS can manage up to 120 batteries (able to serve up to 1.000 riders) and has an energy storage capacity of 200 kWh
- Single battery capacity: 1,3 kWh
- Single battery weight: 9 kg

External references:

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- https://electrek.co/2019/09/23/check-out-gogoros-giant-new-battery-swap-stations-for-its-electric-scooters/
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CS_6

6.6. The OLEV system developed by KAIST

The Korea Advanced Institute of Science and Technology (KAIST) developed the On-Line Electric Vehicle (OLEV), an electric vehicle which can be recharged while travelling using the shaped magnetic field in resonance (SMFIR) inductive power transfer technology. The three applications of this technology are described below.

Specifications:
Charging typology: Inductive charging
The charging infrastructure consists in a power track composed by modular elements sunken under the road surface. System modularity contribute to reducing the electromagnetic field (EMF) exposure since modules activate only as the OLEV passes on each of them.
Air gap between power track and receiving pad: ≈ 20 cm
Maximum power transfer efficiency: 85%

6.6.1. Seoul Grand Park trolley

Location: Seoul, South Korea
Year: March 2010
Description:
The Seoul Grand Park diesel trackless train has been replaced by an OLEV as the first demonstration project of the technology developed by KAIST.

Specifications:
Service route length: 2,2 km *(ring circuit)*
Power track length: 372,5 m (≈ 17% of service route length)
Four power track sections: three 122,5m long section + one 5m long section (for stationary charging)
Maximum pick-up capacity: 62 kW
Air gap between power track and receiving pad: 13 cm
Maximum power transfer efficiency: 74%
Battery size: 1/5 the battery size of electric vehicles currently on the market

source: https://www.youtube.com/watch?v=gIdRIJS507Y

6.6.2. KAIST campus shuttle bus system

Location: Daejeon, South Korea
Year: October 2012
Description:
The KAIST campus shuttle bus system represents an application for short-travel distance service with frequent stops in limited areas. It is a demonstration project in a closed environment without traffic congestions and delays. Power track sections are installed at some bus stops and immediately before them, in the calculated braking space; since the energy supplied is proportional to the time the vehicle spends at a power transmitter, installing it where the bus speed decreases approaching a stop and drops to zero when it reaches it is cost efficient.

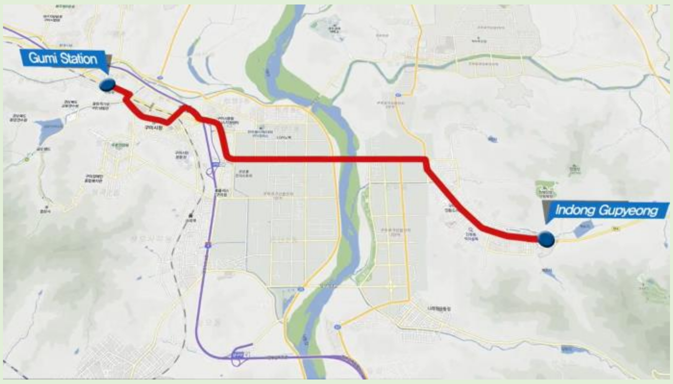
Specifications:
Service route length: 3,374 km *(ring circuit)*
Power track total length: 90 m *(≈ 2,7 % of service route length)*
Four power track sections: 24 m, 25 m, 18 m, 23 m
Number of stops: 8 + 1 *base station where stationary charging is provided (4-minute stop)*
Bus battery capacity: 13 kWh
Number of busses: 2

source: https://www.youtube.com/watch?v=RcnjYyQmRjw

6.6.3. Gumi public transit line

Location: Gumi, South Korea
Year: March 2014
Description:
In Gumi an east-west bus line connects Gumi Train Station to the In-dong district passing through the city center and operating in normal traffic conditions (open environment). It is the first commercial application deployed in city streets. Before the installation of this technology in the streets of Gumi testing was conducted for several months and proved that it meets safety standards for EMFs and does not interfere with medical devices (e.g., pacemakers). It has been calculated that this system allows 54% energy saving compared to diesel busses.

Specifications:
Service route length: ≈ 24 km
Power track total length: ≈ 146 m *(less than 1% of service route length)*
Six power track sections located where the busses reduce their speed or stop (e.g., bus stops, traffic lights, crossroads, slopes). The length of the power track section is proportional to the vehicle speed: the higher the vehicle speed, the longer the power track section must be.
Number of stops: 23 + 1 base station
Pickup capacity: 100 kW
Frequency: 20 kHz
Air gap between power track and receiving pad: 17 cm
Maximum power transfer efficiency: 85%
Battery size: less than 1/5 the battery size of other battery electric busses (BEBs)
Number of busses: 4 *(2 busses at start + 2 more busses from April 2016)*



source: https://www.youtube.com/watch?v=RcnjYyQmRjw

6.6.4. Dubai Silicon Oasis pilot

Location: Dubai, United Arab Emirates
Year: December 2019
Description:
This pilot at the Dubai Silicon Oasis (DSO) in collaboration with the Roads and Transport Authority (RTA) is a test in an "open environment" since a bus and a taxi operate in normal traffic conditions. Two phases are planned: the first one (finished in December 2019) consisted in the construction of a 60 metre power lane and the start of testing; the second (planned for 2020 but delayed due to Covid-19) consists in the implementation of the charging infrastructure at the Dubai Silicon Oasis.

Specifications:
Pickup capacity: 100 kW
Frequency: 20 kHz
First phase:
Power track total length: 60 m
Second phase *(implementation)*:
Service route length: 10 km
Power track total length: 1 km *(10% of service route length)*

source: https://twitter.com/rta_dubai/status/1227577229313527808?lang=gu

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Cost analysis for inductive charging public transportation systems

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CS_7

6.7. Xuejiadao Station

Location: Qingdao, Shandong Province, China
Year: active since July 2011
Description:
Xuejiadao Station is the world’s largest and most advanced battery swapping station (BSS) for battery electric busses (BEBs). The station is not only a BSS but is an energy storage for the distribution grid – it is owned and run by the State Grid Corporation of China (SGCC) – and is able to charge 120 e-busses (BEBs) or 360 e-cars (BEVs). It is located near the Jiaozhou Bay Undersea Tunnel which connects Qingdao and Huangdao because it is designed to serve 6 intercity bus lines. BEBs’ routes length is between 14 and 33 km with service times up to 16 hours a day.
The bus battery swapping operation is fully automated and takes between 6 and 8 minutes; the infrastructure can complete 540 operations during its daily service time.

Specifications:
Storage system power: 7 MW
E-bus battery swapping time: 6 ÷ 8 minutes
Operational level: 540 battery swaps/day

source: https://www.youtube.com/watch?v=RpVZjq7i-gk

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7. Conclusions

The planning and control of energy exchange of EV is the main focus considering EV availability in multiple places during the daytime and in the evening. Indisputably, participating in V2G or V2X affects the state of charge of EV battery, and therefore proper scheduled charge/discharge plan needs to be embraced.

Currently only very few charging stations (both home and public) are smart grid enabled, and very few cars allow for V2G. Rising EV penetration will further increase the need for common standards for charging infrastructure and interoperable solutions between charging stations, distribution networks and the EVs themselves. Interoperability is the key not only to shield from charging infrastructure vendor lock-in but also to allow for cost-effective connectivity of EVs with diverse charging infrastructure and metering.

With automated metering infrastructure communications in houses, smart EV charging stations, and smart building management systems in smart grid-oriented power system, EVs are expected to contribute substantially to overall energy planning and management both in the grid and the customer premises.

With the development of smart grid concept and the availability of bidirectional charging facility, EVs are considered to play a diverse role that can bring several benefits in the smart city power grid. This will provide the opportunity for EV to enact as a power source and exchange energy with the grid for delivering multiple services. V2X is one of the paramount means of improving power systems' stability and reliability, power quality, and maximizing the economic benefit of EV in the present-day and future electric grid.

Within a horizon of 5-10 years, like the timeframe of this report, together with the technology scenarios we proposed in the previous chapters, some policy recommendations can be summed up as following:

- Promote renewable energy to decarbonise power system and promote EVs to decarbonise transports in order to reach CO_2 reduction targets.
- Support charging infrastructure by planning public charging, fast charging and multi-unit dwellings according to zoning principles.
- Choose optimal locations for charging by planning synergies between mobility and the grid.
- Focus on smart charging by implementing it on areas with high shares of renewable energy.
- Complement grid charging with storage at charging points or battery swapping.
- Integrate planning of power and transport sector also by building charging hubs in optimal locations.

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