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Abstract:
This document reports the work performed within WP8 WiseGRID FastV2G and electric transport smart integration. More specifically it analyzes the electric transportation sector and aims on the identification of its characteristics and constraints. The document reports on two different sectors of electric transportation, the electric vehicles sector as well as port and ships sector.

Keywords:
E-mobility, Electric Vehicles, Electric Vehicle Supply Equipment, Electric Vehicle Fleet Management, Electric Vehicle Supply Equipment Management, Shore to ship power supply

Revision History

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V1.0	27.10.2017	Final Version	Dimitrios Lagos (ICCS)

INDEX

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

WiseGRID objectives

The WiseGRID project in its entirety is driven by four core strategic goals, to the achievement of which, the innovative solutions and technologies that will be developed within the Project contribute directly. These goals are in line with the EU (European Union) goals regarding:

- The development and demonstration of **innovative and advanced Demand Response (DR) mechanisms** that will facilitate the active participation, protection and empowerment of the European consumers and prosumers (households and businesses) in the energy grid and market, through flexible RES (Renewable Energy Sources) generation, self-consumption and storage, or through intermediary parties such as aggregators and suppliers on behalf of the former.
- The **smartening of the distribution grid**, in order to achieve smooth operation of the grid through advanced techniques while actively integrating new assets such as VPPs (Virtual Power Plants) and microgrids.
- The **integration of renewable energy storage systems in the network**, such as batteries or heat accumulators, the management of which will ensure the optimal operation of the network.
- The development of tools for planning and the deployment of **electric mobility services**, as well as the management of charge and discharge of these vehicles – including the possible use of their batteries as storage systems or VPPs.

Methodology

This document contributes in the direction of achieving the final of the aforementioned goals. Specifically, this contribution lies on the analysis of the electric transportation sector focusing on its constraints and its characteristics. This analysis is crucial because it will be used later for the planning and implementation of **electric mobility services** in order to identify their key characteristics.

The document is structured according to the transportation sector considered in the WiseGRID project. It reports on e-mobility as well as on ports and ships with special focus on shore to ship power supply.

e-mobility

The e-mobility consists of:

- The potential and challenges of electrification of transport sector;
- e-mobility technologies and standards;
- e-mobility management schemes.

The first two focus on the impact of e-mobility on various fields (social, business and electric grid perspective) and the current state of e-mobility as well as its technical characteristics in the domain of Electric Vehicles (EV), storage and batteries techniques and charging stations.

The latter focusses on EVs and Electric Vehicle Supply Equipment (EVSE) management describing their characteristics and limitations and recommending functionalities that are in the direction of achieving a more ideal management.

Potential and challenges of electrification of transport sector

The strategy of EU is to be more resource efficient, with a greener and more competitive economy by 2020 and it is promoted by policies of EU which, in turn, have led to the promotion of Electric Vehicles (EV). In addition, different incentives have been adopted by EU countries in promoting e-mobility which lead to different market share of electric vehicles among these countries.

In addition, business models of EVs and charging infrastructures can provide business opportunities such as car as a platform, mobility as a service and the electrification of a fleet of EVs.

The electric grid perspective is mainly concerned by the electricity demand increase, due to an extensive roll-out of EVs, which could be introduced on the electric grid. The factors that contribute on this demand rise are the EV deployment level, the charging station technologies, the availability of charging stations as well as the driving profile and EV connectivity.

The issue that emerges from this demand rise is distribution network congestions which might require network upgrade in order to be dealt with. In addition, study of the relevant literature indicates that the worst case scenario occurs when the charging of EVs is not controlled and that a ‘’smart’’ charging of EVs could result in more efficient management of the electrical demand of EVs.

The social perspective of e-mobility has both direct (e.g. emission reduction as well as the noise reduction produced by conventional combustion engine cars) and indirect (new job opportunities, oil dependency reduction) social effects. It has also possible correlation with novel businesses like car sharing.

e-mobility technologies and standards

Different technologies are used in e-mobility. Firstly, the EVs have three different categories, the Battery Electric Vehicle, the Extended Range Electric Vehicle and the Plug in Hybrid Electric Vehicle.

The major benefits of the EVs versus the conventional combustion engine vehicles are –among others– the simplification of the vehicle maintenance processes, the noise reduction of the vehicle, the higher efficiency of the electric motors compared to the combustion engines. On the other hand, some of the drawbacks involve the low autonomy of an electric vehicle compared to the autonomy of an internal combustion engine (ICE) vehicle, the long duration of the recharge and the limited recharge infrastructure.

In addition, there are different technologies of batteries and storage utilized in EVs, a main factor that greatly affects the autonomy of an EV. The main battery technologies are mainly the Lead-Acid, Nickel-metal hydride and Lithium-ion among others.

Lithium-ion technology is the most extensively used storage technology in EVs. The drawbacks of this technology are the average life span, the limited number of charges, the price, that they can be overheated to a point that can lead to explosions, bad performance in worst cold working capability conditions and that they are limited on maximum charge current. However, different models of Lithium-ion batteries have different characteristics in the domain of life span, safety, cost, performance and specific power.

Furthermore, emerging technologies on batteries are air-metal batteries, solid-state lithium-ion as well as other types of storage like supercapacitors and semi-solid flow cell, to mention only a few.

The EV charging stations are categorized according to three different criteria:

- The electric power that the device is able to deliver, (dividing the stations according to the amount of power and current that they can supply and the required time they need to charge the batteries of the EVs).
- Connector types used by the charging stations, categorized according to the standard which refers to them, the charging time as well as the power that they are able to supply.
- Information flow between the vehicle and the charging station (based on communications or information flow criteria between the electric car and the charging station as defined by the IEC 61851-1:2010 standard).

EVs is novel technology and its standardization is still in development. The main standards that exist today pertaining to EVs are:

- IEC 62196 – “Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles”
- IEC 61851 – “Electric vehicle conductive charging system”
- IEC 15118 – “Road Vehicles – Vehicle to grid communication interface”

Apart from these, there are also other standards which are not directly related to e-mobility but they have to do with wireless power transfer or communication networks for power utility automation. Some of these standards are IEC 61980 – “Electric vehicle wireless power transfer (WPT)”, IEC 61850 – “Communication networks and systems for power utility automation”, IEC 61140 – “Protection against electric shock - Common aspects for installation and equipment”, IEC 62040 – “Uninterruptible power systems (UPS)”.

Finally, the OCPP (Open Charge Point Protocol) protocol is an open and standardized protocol for communicating between charging points and a central management system from different vendors.

e-mobility management schemes

The e-mobility management schemes are separated in the EV fleet management and EVSE management.

The EV fleet management is divided in public and private transportation. For the public transportation sector there is an example of a public bus operator in Madrid which uses 100% electric buses. The objectives of an operator of a public transportation fleet are punctuality and regularity of services as well as real time information of the operator and the drivers. There are also requirements in the software and hardware of this system, such as inductive charging points infrastructure installed at bus line terminal stops, inductive charging technology installed at the buses and monitoring system of both of road-side infrastructure and of buses at any time.

The BUS-FMS-Standard, which is an open standard, is recommended for the information exchange. It is adopted by major manufacturers (MAN, Scania, Volvo among others), with the objective of defining the information exchange between vehicle and Fleet Management Systems (FMS).

There are also some functionalities that a public fleet management system should have for an optimal operation. The recommended functionalities should include information for:

- driver assistance (visualization of battery status and ongoing charging session, real-time forecast of range distance of the bus, KPI (Key Performance Indicator) on driving efficiency, estimation of minimum time required for the next opportunistic charge);
- public transport operator assistance (real-time monitoring of all parameters of the electric buses, status of charging points and collection of the minimum required times for the next opportunistic charges).

For the management of an EV fleet in the private transport sector, there are different requirements such as availability according to the schedule, charging times and required SoC (State of Charge) which need to be carefully synchronized with the tasks required by the company.

In addition, two different approaches are recommended for these requirements to be met:

- optimizing the routes (properly rearranging the tasks that a member of the organization has to perform in order to reduce the distance that needs to be covered) or
- optimizing the charge sessions (taking into account the vehicles that are used for allocating particular tasks within the organization, optimally select the proper charge order of the vehicles of the fleet, optimize the charging sessions in order to minimize the energy-associated costs).

The monitoring of such a private fleet can be achieved by the FMS standard for heavy duty vehicles and by OBD (on board diagnostics)-II standard for light duty vehicles and passenger cars.

Furthermore, the characteristics and functionalities of the EVSE management there are also important. Firstly, the EVSE managers must able to offer their services – installation, maintenance and exploitation of charge point – according to the location of the station (private, public).

The tariffs of EVSE usually consider a base price and a price per supplied kWh, including extra charges for additional terms such as location of the charge point (private or public premises) or additional offered services (booking or longer collection times once the charge is complete).

The metering of an EVSE is also fundamental to the operation of the EVSE managers, since it is the basis for the billing of the service. There are two different cases of metering according to the ability of the EVSE to provide the metering to a central system.

In addition, interoperability between different EVSE managers is also quite important. In the direction of resolving this issue, NEMA (National Electrical Manufacturers Association) reports on the gaps in EVSE management interoperability as well as Hubject platform whose objective is the management of interoperability through different functionalities.

The use of OCPP is recommended for communication between the EVSE and the management station. It has several advantages that emerge in its usage for EVSE from the perspective of:

- vendors: allowing the EVSE management platform to communicate with devices independently of their vendor avoiding vendor lock in, encouraging competition among EVSE providers and facilitating scalability of the EVSE network;
- communications: in order to monitor and control the EVSEs through a management platform, the EVSE manager has to invest in the appropriate communication infrastructure. The OCPP protocol contemplates the EVSE registration process in the control platform, which is initiated from the EVSE side. This facilitates enormously the task of maintaining the EVSE communication details from the perspective of the EVSE management platform;
- booking: book a charge point in advance (first defined in OCPP v1.5).

Lastly, as it was previously mentioned, EVs will soon impose a high demand on the current energy distribution grids. It is, therefore, necessary to move towards the paradigm of smart charging which basically implies the capability of the EVSE to modulate the power that is supplied to the electric vehicle along the duration of the charging session, even with the capability to reverse the flow of energy and make the electric vehicle operate as an energy production resource – concept known as Vehicle-to-Grid (V2G) or Vehicle-to-home (V2H).

Depending on the location and owner of the charge point, this V2G or V2H capability can provide many benefits. Therefore some very interesting options are available:

- An agreement between EVSE operator and Distribution System Operator (DSO) which includes a limit on the peak power that can be supplied to the EVSE operator. Smart charging can, in such cases, modulate the power supplied to each of the vehicles of the hub in an optimized way in order to achieve the DSO objectives and, at the same time, take into account the EV customer's demand.
- Reduced economic costs associated with energy when EVSE manager is exposed to dynamic prices according to external context parameters.
- Reduced environmental impact of the EVSE manager by promoting green energy consumption, since supply curves can be optimized to prioritize supply of energy at those moments when production of green energy is higher.
- Explore new business models by providing ancillary services to third parties: EVSE manager is in position of controlling a significant amount of batteries – as much as vehicles connected to its network. Capability to modulate demand and even reverse the power flow and provide energy back to the grid (V2G) can be very beneficial to support DSOs.

Finally, the OCPP is again recommended for smart charging applications, since OCPP 1.6 supports three use cases of smart charging:

- **Load balancing:** Internal load balancing within the Charge Point. The Charge Point controls the charging schedule per connector. The Charge Point is configured with a fixed limit, for example the maximum current of the connection to the grid. Internal balancing of a charge point is achieved with several connectors.
- **Central smart charging:** This charging allows the EVSE manager to perform optimization over the complete set of EVSEs according to the organization optimization objective. With Central smart charging the constraints on the charging schedule, per transaction, are determined by the Central System. The Central System uses these schedules to stay within limits imposed by any external system. The Central System directly controls the limits on the connectors of the Charge Points. Central smart charging assumes that charge limits are controlled by the Central System. The Central System receives a capacity forecast from the grid operator (DSO) or another source and calculates charging schedules for some or all charging transactions.
- **Local smart charging**: Optimization over the operation of a set of charge points operated by a local controller in a more hierarchical control architecture. The Local Smart Charging enables Charge Points that have charging limits to be controlled locally by a Local Controller, not the Central System. The use case for local smart charging is about limiting the amount of power that can be used by a group of Charge Points, to a certain maximum.

Port and Ships Electrification Characteristics

As it was previously mentioned, a special focus is given also on port and ships electrification characteristics. The International Maritime Organization (IMO) has imposed some regulations for emission reduction in port areas (Emission Control Areas) by setting limits on the sulphur emissions of vessels. Even though different strategies can be applied in order to reduce emissions in the port area, the ship to shore power supply or 'cold ironing' is mainly considered here.

The cold ironing concept describes a ship covering its electricity demand by connecting to the mainland grid when docked in a port, instead of using its auxiliary engines. There are several implementations that already exist worldwide, e.g. in Hamburg and Gothenburg port. The social impact of cold ironing mainly lies in emission and noise reduction in the port area. In addition, special focus must be given in the design of a cold ironing system since the electrical characteristics of different ships might differ in the nominal values of frequency, voltage and electricity demand.

The cold ironing concept is quite novel. However, the recently published IEC/ISO/IEEE 80005 standard describes the issue of High Voltage (or Low Voltage) Shore Connection as well as the communication between the ship and the shore.

Another important issue is the increase in electricity demand in port areas due to cold ironing. In order to assess the demand increase in port areas, the ship traffic in port must be taken into account. A ship is berthed at specific places of a port (according to financial or technical reasons). In addition, there are tools, such as the AIS (Automatic Identification System), which can provide real time information as well as historical data of port traffic and can be used in order to produce an estimation on the port electricity consumption increase due to cold ironing.

However, this increase in demand might lead to issues in the electrical grid such us voltage drops, power congestion, current harmonics issues as well as power system stability issues in small islanded systems. In addition, there could be also a possible synergy of shore to ship power supply with smart grids. The port can exploit smart grid technologies since it could contain smart grid equipment such as distributed energy sources, smart loads, controllers and smart meters aggregated in the premises of the port. Thus, this aggregation could lead to a significant cost reduction in IT (Information Technology) and communication equipment compared to a typical smart grid implementation. Finally, smart grid applications, such as demand response and power demand smoothing of the port by energy storage, could be utilized in order to address the issue of the high energy demand in ports.

Finally, there have been reported suggestions for smart grid applications in port. For example, a multi agent system utilizes a decentralized demand response method that eventually turns a port comprising numerous flexible loads and power generation from renewable energy sources to a prosumer Microgrid. Alternatively, a harbor area smart grid could be designed with one of its main objectives to be the supply of power to the vessels. Those systems could also be used in order to adjust the demand of the port to constraints provided by the DSO or provide financial benefits to the port authorities.

Conclusions

The work within this report has produced a significant amount of material that serves as a basis for WiseGRID WP8 future work of WiseGRID. Addressing the challenges and potentials that e-mobility will impose on the future distribution grid has led to the identification and recommendation of the characteristics of e-mobility management techniques. This analysis will be further utilized in the following steps of WP8 for the specification of the advanced modules that will be implemented within by this WP.

1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

WP8 under SP4 aims at the analysis of the technical characteristics of the electric transportation sector in order to optimize its integration process into the distribution grid. This WP will take into consideration multi-diverse parameters and criteria of the WiseGRID FastV2G charging station and the WiseGRID Electric Vehicle Platform (WiseEVP). This document aims through close cooperation of the participating partners to serve as input for the following tasks of WP8 where innovative and advanced electric transport solutions will be implemented. Consequently, and in view of the multidisciplinary nature of the project, the current document reports systematically the high quality, knowledge-intensive output produced during the previous months concerning existing electric transportation technologies covering issues of both EVs and ports/ships.

1.2 SCOPE OF THE DOCUMENT

This document records the accumulated collective knowledge produced through the cooperation of the partners within WP8 –each one contributing with his respective expertise – in order to analyze the technical characteristics of electric transportation sector considered in the WiseGRID project.

Following the task break-down a have been defined (T8.1) which divides the document according to the electric transportation sector, to Electric Vehicles (Subtask 8.1.1) and Port and Ships (Subtask 8.1.2).

The goal of the first subtask is to analyze the Electric Vehicle domain. Specifically it analyzes the current state of e-mobility on Electric Vehicles (EVs) and Electric Vehicle Supply Equipment (EVSE) in order to identify the key characteristics of their management. This analysis will lead to the identification of the modules' characteristics of WiseGRID electric mobility tools to be later implemented.

The second subtask aims to analyze the needs of power for ships while they are in port. The means of estimating the port traffic are also analyzed which are required for the estimation of the power increase in ports. Finally, means to manage this consumption are also described.

1.3 STRUCTURE OF THE DOCUMENT

The rest of the document is organized as follows. Section 2 reports the current state of e-mobility in EU (European Union) as well as their market/business, the electric grid and the social perspective. Section 3 describes the e-mobility technologies focussing on different models of EVs and their different storage techniques and batteries. In addition, it reports the charging station characteristics and their classification as well as the standards that refer to them. Section 4 focuses on EV fleet management (public and private transport sector as well as monitoring of the fleet) and EVSE management and their characteristics. Section 5 reports on the ship to shore power supply, provides insight on its potential and challenges from the electric grid and social perspective and reports on its standards and possible correlation between ship to shore power supply and smart grids. Finally, section 6 gives an account of the conclusions of this analysis and the recommendations for the next steps of WP8.

2 POTENTIAL AND CHALLENGES OF THE ELECTRIFICATION OF TRANSPORT SECTOR

2.1 E-MOBILITY IN EU

2.1.1 Strategy and actions in the last decade

In 2010, a strategic memo from the European Commission (EC) sets the goal for Europe to be more resource efficient, with a greener and more competitive economy in 2020 [1]. Every day, the EU imports for about 500 million euro crude oil [2]. In the last decade, an estimated 84% of the crude oil was burnt to provide our societies with energy [3]. To lower the EU dependency on crude oil, which could result in avoiding costs, decreasing the related to health consequences and avoiding for geopolitical instability, the EU wants to promote novel cleaner energy production. Part of the solution to decarbonize our society is to promote 'zero emission vehicles' for transport. The goals and approach to achieve this are written down in the Clean Power for Transport package [4].

Investigating the approaches set forth by the EU, we discern two clear approaches pursued by the EU at the same time. The first is promoting clean and energy efficient vehicles, still based on conventional internal combustion engines (ICEs). The 2020 target is 95 g/km for those type of passenger cars [5]. The second approach is facilitating the deployment of breakthrough technologies in ultra-low-carbon vehicles, which include battery-electric vehicles (BEVs).

The EU is promoting action on different parallel levels, ranging from the production side by setting rules on vehicles requirements [6], over fiscal stimuli (purchase financial incentives, energy taxation directives, vehicle taxation) [7], extensive monitoring of the EV market [8] and labeling and consumer understanding and guidance [9]. A special emphasis always is made on preventing market-distorting rules when implementing measures.

The very first actions to promote electric vehicles are limited to 'electric and crash safety requirements'. These aspects and their importance are repeated in later communications (e.g. Memo 12/419 [10]). In this early strategic memo, emphasis is also put on charging infrastructure and smart charging. However, a lot of uncertainties had - and to a lesser extent still have - to be dealt with respect to help reaching the Clean Power for Transport package its goals and to validate the assumed environmental friendliness of BEV, causing first researching efforts mainly on extensive researching life cycle assessments of EVs and batteries (e.g. [11]).

In the meanwhile, in a vision for the automotive industry in 2020, dating from 2012, the EU confirms the focus on promoting classic internal combustion technologies as the way forward [10]. We read, "A portfolio of propulsion technologies, dominated by the advanced combustion engine technology, although increasingly electrified" is a key characteristic of a strong and competitive automotive industry". The vision shows a hesitation in choosing fully for development of 'alternative fuels', as a big emphasis is repeatedly made on changing the status quo of vehicle production very slowly and gradually. This might be a result of a conservative attitude of the established automotive sector in redefining the tempo of the uptake of new technology.

In these early days, interesting thoughts are already being set forward about the charging of EVs, such as the 'recognition that charging of electric vehicles is expected to be performed mainly at home/work'. Nevertheless, the EU goal confirms in another recent directive to provide one public charging station for every 10 EVs [12]. The EU members are transforming these directives into locally applied action plans and legislation. [12]

2.1.2 Market evolutions and the steering of it by of EU policies

Usually the appearance of new technologies, such as electric propulsion for cars, offers opportunities for new players to enter the market. We should expect new EV manufacturers appearing in this transition to e-mobility. In Europe this has not yet happened on a large scale.

A part of the answer lies in the high regulatory boundaries for new automotive players that want to bring new vehicles to market. These rules are mostly set by the current industry players and enforced by EU legislation. The automotive sector is the largest industrial sector in the EU. Twenty four percent of all cars produced in the world are built in Europe. 16,5 million passenger cars were made in the EU in 2016 [13]. Another part of the answer to the question of the lack of new automotive players might lie in the fact that current industry players receive large financial support for investigating new technologies. The current industry players remark repeatedly in position papers that “anticipation of change should be holistic and respect all factors influencing the competitiveness and the long-term perspective of companies” [14].

The EU car manufacturers claim to be a key driver of knowledge and innovation. In 2016, R&D (Research and Development) investments in the EU were biggest in the automotive sector, leading with at least 25% more budget compared to other sectors. Moreover, no region in the world invested more in R&D into automotive than Europe, but it is not easy to find out which part goes to investment in electric vehicles [14]. Automotive R&D is currently mainly driven by stricter standards set by authorities on vehicle emissions and fuel consumption. Electro-mobility and further improving internal combustion engines will be key technology areas in which R&D in automotive is directed in the coming years [14].

As a result, more vehicle manufacturers will launch new EV models in the near future. It is to be expected that the launch of these new EV models increases EV market share, a goal of the Clean Power for Transport directive. In addition, the European Clean Power for Transport directive recommends that there should be one public available charging point for every 10 electric cars by 2020 [12]. It is to be expected that more countries will roll out public charging infrastructure projects, which will – together with the novel EV models – will also have a high impact on stimulating the uptake of EVs.

Besides the necessary market offerings, regarding EV models and charging infrastructure, public authorities set also forth financial and fiscal stimuli to increase the purchase and the use of cleaner vehicles. These stimuli are based on general desired performance criteria of cars set by the EU, such as threshold levels of CO_2 emissions [7]. Such stimulating measures need to be technology neutral, and avoid focus on one peculiar type of vehicle, such as electric mobility. In addition, EU is weary that financial incentives indirectly subsidy the manufacturing of the cleaner vehicles, so the financial incentives should not be bigger than the difference with the status-quo vehicles. [7]

Since the possible financial incentives proposed by the EU can be implemented in many ways by member states, we see a lot of different stimuli in different EU countries which are presented in Table 1 [15]. A common measure applied by nearly all countries are registration tax benefits and ownership tax benefits. [7]

As an example, we take the Clean Power for Transport (CPT) program implemented by the Flemish authorities in Flanders [16]. The actions from this program consist of a) a subsidy program to stimulate purchase of EVs for natural persons, which receive a grant in cash upon purchasing an EV, b) the exemption of taxes for purchasing new EVs, c) a yearly project call for investigating implementation of EVs in society on which diverse stakeholders can apply (in 2017 with a budget of 1M€ and maximal 150 k€ per project) and, d) by the roll out of charging infrastructure over Flanders with the goal to provide 2500 charging stations with each 2 connecting points by the end of 2020. The result of these actions should be a market share of 7,5% in 2020, and a number of charging stations that amounts to 10% of the BEV fleet.

Do these efforts to stimulate EV bear fruits? When examining battery electric vehicles, in 2012, the market expectations were 225.000 EVs to be sold in Europe in 2012, and 700.000 in 2015 [17]. But the reality shows lower numbers. Overall, the current sales figures are 3 times less, with approximately 200.000 sold EVs in 2015 in Europe, as is represented in Figure 1. The too optimistic forecast did apparently not take into account the only slowly growing political support of EVs in the EU by most of the member states, which is in stark contrast to some countries outside the EU, such as Norway.

Indeed, Norway has a market share of EVs for new vehicles of 19% nowadays. The EU countries in which EV have the largest share of all newly registered vehicles in 2017, are Austria and The Netherlands, both around 1,4%. In the ranking they are followed by France and Sweden, both around 1,1% market share. The remaining EU countries have similar market shares, averaging 0,4% of market share [18] presented in Figure 2.

The EV growth in Norway is supported by an extensive number of stimuli. Should the members of the EU have imposed all incentives as Norway has done starting in the ‘90s, the EU might have reached or even exceeded the estimates [19]. Even though, in this scenario it is still the question whether the production capacities of the EV suppliers and manufacturers could have met the forecast goals.

Looking at the sales figures of EV, we see a remarkable stagnation in 2016, but in 2017 EVs are again heading toward 0,6% of newly registered vehicles across the EU. The sales of EV are again speeding up during 2017 in the EU [20]. On average for the whole of the EU, sales of EV went up with 39% between 2016 and 2017, when comparing the totals for the same period for those years. Sales of EV do not show a steady increase however, and are still influenced heavily by political decisions. For example, Denmark is a specific case because it has an average market share of BEV of 0,6%, but EV sales dropped in 2017 by 40% [20]. This slowing down in Denmark was due to a change in tax policy for EV owners since 2017, a change which got a lot of media attention [21].

We can safely conclude that a very broad package of incentives and support, both fiscal, financial and structural and accompanying investments, was and is still clearly needed for reaching that initial forecast of 2012, even today in 2017.

Finally, we want to remark that the nature of the car market is slowly changing. Personal car use per person per year in several key European countries is in decline and there is some evidence that younger generations are less interested in car ownership and more open to alternative mobility solutions [22], such as car sharing or mobility-as-a-service. In addition, electric vehicles are perfectly suited for autonomous driving cars, one of the new paradigm shifts in mobility to be expected, which is expected to ‘disrupt’ the market in the next decade to come. Many new business models are therefore emerging in the coming years.

Country	Registration Tax Benefits Applied:21 times	Ownership Tax Benefits Applied:21 times	Purchase Subsidies Applied:16 times	Company Tax Benefits Applied:13 times	Local Incentives Applied:13 times	Infrastructure Incentives Applied:7 times	Financial Benefits Applied:3 times	VAT Benefits Applied:1 times	Number of applied measures
Austria	1	1	1	1	1			1	6
Ireland	1	1	1	1	1	1			6
Malta	1	1	1	1	1	1			6
Spain	1	1	1		1	1	1		6
United Kingo	1	1	1	1	1	1			6
Denmark	1		1	1	1	1			5
France	1	1	1	1	1				5
Germany		1	1	1	1		1		5
Portugal	1	1	1	1	1				5
Belgium	1	1	1	1					4
Hungary	1	1		1	1				4
Romania	1	1	1			1			4
Greece	1	1					1		3
Italy		1	1			1			3
Latvia	1	1			1				3
Luxembourg		1	1	1					3
Netherlands	1	1		1					3
Slovakia	1		1		1				3
Slovenia	1	1	1						3
Sweden		1	1	1					3
Cyprus	1	1							2
Czech Repub	1	1							2
Finland	1	1							2
Lithuania	1				1				2
Croatia	1								1
Bulgaria									0
Estonia									0
Poland									0

Table 1 – Overview of incentives implemented by the EU member states to promote EV uptake. [15]

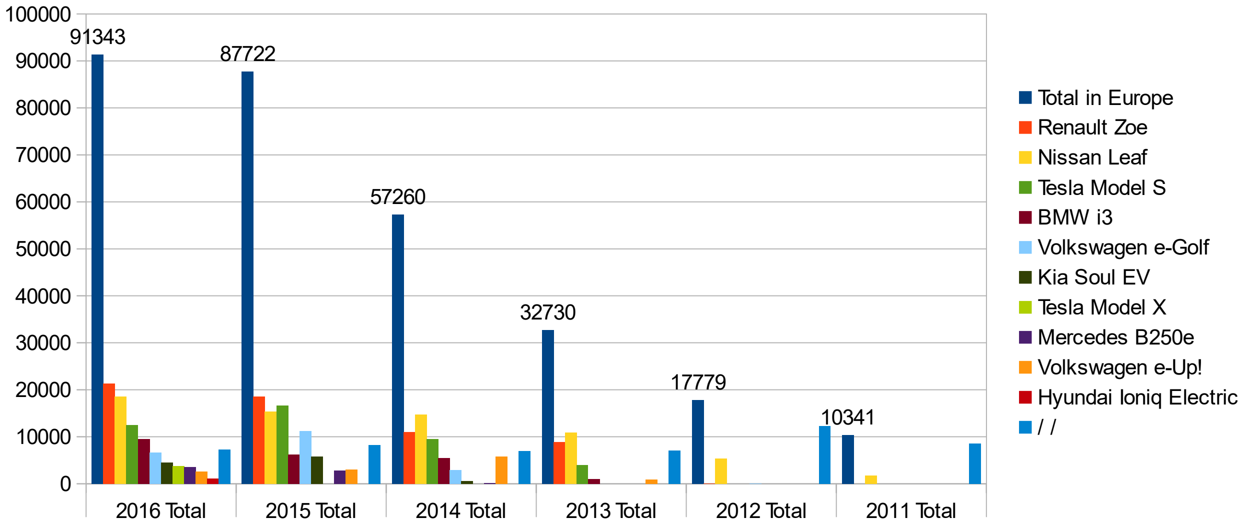

Figure 1 – Total sales numbers of EV in Europe, subdivided by EV make and model. [17]

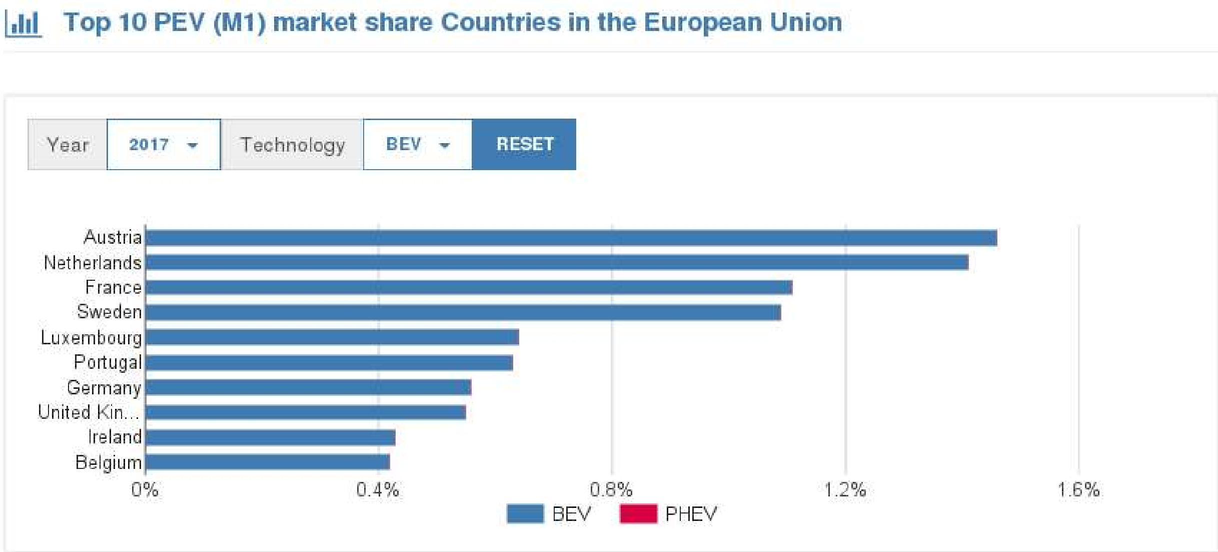

Figure 2 – Overview of the EU countries with the highest market share in EV. [18]

2.2 MARKET AND BUSINESS PERSPECTIVE

2.2.1 Existing bussiness models

Most important business model today is the sales of BEV to natural persons, a model that has been promoted indirectly by many government (financial and fiscal) support mechanisms [23]. Batteries, consisting of around 30% of the cost of the EV, have a substantial value and are usually purchased together with the vehicle. A battery capacity guarantee for a certain number of years or mileage is usually offered with the purchase. As an alternative, for different EV models offer the batteries can be used for rented with the vehicle – instead of having them to purchased - with the manufacturer's guarantee that the battery will be replaced when the capacity gets below a certain value (e.g. 70% capacity for the model Renault Zoé). Overall, the EV without the battery has the same value as the battery of the EV, which opens up perspectives for new business models. Usually, in some cases, the battery is separately insured from the car. This opens new market for insurance companies that specialize on insuring the growing market of high capacity batteries. Overall, the

EV without the battery has the same value as the battery of the EV, which opens up perspectives for new models.

The high value of the battery has made many manufactures search for parallel uses of end-of-life batteries [24]. Currently, there is a research project in China aiming to provide 14MW grid support by means of the use of second-life lithium ion batteries [25]. No viable business models are currently running from second hand car batteries, but it is generally assumed to be one of the key solutions for lucrative business models for the owner of the second hand batteries, for scenarios in which battery capacity is not crucial – unlike their use in EVs – such as for local storage of renewable energy.

2.2.2 Charging infrastructure

Currently, only about 10% of the charging sessions happens at public charging stations, 20% happens at the work places, but the vast majority (70%) of the charging sessions currently happen at home [12]. Therefore some EV manufacturers provide also a home charging installation together with the purchase of the EV. It can come as a reduction when buying a charging station from few selected providers, or, which comes as a reduction on the invoice of the EV for a certain fixed amount, covering installation costs of the home charger (Renault).

Most charging happens at home currently [12]. However, not all owners of an EV can benefit from this. Especially owners living in cities, which do not own a parking space themselves. They typically depend on publicly available charging points for their charging needs.

Some manufacturers roll out a charging station network themselves (e.g. Tesla), or are partners in rolling out (e.g. Nissan with Eneco in Belgium) a charger network to which EV owners have access. EV owners are provided with a subscription to that charger network. In this way, the EV manufacturer complements its activities of merely selling an EV with live long EV services to the customer.

As an answer to the ‘range anxiety’ – this is a doubt of the customers whether the early EV models with small battery capacity would be capable of bringing them to their desired destination – some manufactures offered access to an internal combustion engine for some trips, if the owner of an EV needed one, e.g. for a long trip during holiday (e.g. BMW).

Since EVs consume electricity, and electricity can be locally produced by renewable energy sources (RES) production installations, an interesting novel business case exists, where a charging station installation at a private premise is co-installed with RES production (e.g. solar panels). The RES can be over dimensioned, since at peak production, energy could be stored locally, in the EV or at fixed battery installations. In this way, 1) the owner of the premise has access to cheap energy, 2) the EV drives on cheap locally produced energy, 3) the excess energy of the RES installation can be stored to be locally consumed by the EV later on. A tight technical integration between RES installation, charging infrastructure and possible storage solutions is needed here. A charging station might hence be an additional asset to be installed together with a solar RES installation. This project WiseGRID aims, amongst others, at validating the tools necessary to achieve this powerful combination.

In summary, these are approaches to bind the customer to the brand, by providing services around the car. It is a first step to Mobility as a Service.

2.2.3 Mobility as a Service

As stated before, the nature of the car market is changing.

Although a lot of people like the experience of driving electric cars according to user surveys, the high cost as compared to Internal Combustion Engine (ICE) cars, lowers the intention to purchase to a great extent [26]. Many car manufactures, and also leasing companies, rental companies, and citizens’ cooperative enterprises, are looking into subscription models to provide access to EVs for their customers, rather than selling EVs. Also experiments with smaller electric vehicles for one driver are being performed [27].

Car sharing builds on a business model in which access to cars to provide mobility, is offered to customers, rather than ownership of cars. Typically, the customer takes a subscription of have access to a fleet of vehicles. Doing so offers a couple of advantages for the customer, such as removing many of the unknown investment risks of buying an EV (e.g. doubts about the battery life time, doubts of the resale value of the EV) and providing the necessary additional services (e.g. access to public charging infrastructure, access to a parking spot with charging infrastructure, road assistance, etc.) [28]. In addition, the customers can always choose a car that is fully charged, while other cars of the fleet are charging, avoiding having to wait which can happen with private EVs. A fraction of cars of the car sharing fleet is always left unused – since the need for car capacity to serve the mobility needs of clients - optimally integrating that unused fraction with the charging needs and the customers' needs is a key competitive advantage in the car sharing sector.

The promise of car sharing is to achieve a decrease of privately owned vehicles, freeing up space in the public area. This means that the sales numbers of cars will go down, as with a single car many different customers can be served. Hence, instead of evaluating the market of vehicles, it might become increasingly important to look to 'car mobility access' of citizens, rather than 'vehicle ownership', especially in urban areas, to measure the progress of the automotive industry [29].

Car sharing however is an inherently slow growing market, due to the many lock out customers face for making use of car sharing [26], [30]. The biggest lock-out to the car sharing service for customer is owning a car, or having access to a car as a benefit offered by the employer. In addition, customers doubt that the current offering of car sharing can deliver a reliable mobility solution for their needs. Therefore, many car sharing companies target also companies and other organizations, to speed up the growth of car sharing services. Especially small companies – still 99% of all the companies in the EU have 50 or less employees [30] – are a fruitful segment for selling subscriptions to car services.

As an additional business model, EV car sharing companies are also in a good position to benefit from the bulk intake of electrical energy needed to charge the batteries of the EVs. The car sharing companies can valorize the flexibility they have in purchasing electricity from the grid – and later on delivery back to the grid [31]. This requires extending the scope of car sharing companies to manage EVSE (electric vehicle supply equipment).

2.2.4 Car as a platform

The EV has sometimes been described as 'a tablet with wheels', pointing to the fact that an EV is simple set of interconnected components (an engine, breaks, charging of a battery, user interface, etc.), controlled by a set of algorithms. An example of this paradigm shift, is the possibility to extend the range of an EV, simply by updating the software that runs the vehicle [32]. These continuously connected car offers opportunities for extended services and related business models, such as smartphone apps to control the car and receive continuous updates, trip calculation with taking charging stations into account, content streaming to the car during charging times, gamification of driving statistics (e.g. personal record for more sustainable and ecological driving, etc.), updates of the car software [33]. Companies have just begun to explore the possibilities. The big internet companies are also involved by developing their own car operating system (CarPlay by Apple [34], Android Auto by Google [35]) with the goal to seamlessly integrate the EV with the home and other devices of the customer.

2.2.5 Electrification of fleets

Experiments with the electrification of big fleets are ongoing, such as taxi fleets. The taxi sector has already large experience with plugin hybrid electric vehicles (PHEV), especially in big cities, usually due to clean air directives of the local authorities (example London) [36]. This implementation of PHEV is the first step to a fully electric fleet. Complete electrification of taxi or bus fleets requires an estimated 30% increase of the fleet with current technology, due to the charging times that remain long, especially in the light of still fast growing battery capacities. This extra capacity needs to be valorized in some way, with Vehicle-to-Grid services being a possible model. For small city distribution, fleets electric vans are being increasingly applied. Due to the limited range and power of electric trucks, electrification of trucks has been lagging behind. Replacement of ICE trucks and vans have a bigger impact on reduction of emissions however, which make it a good target to reach the environmental goals faster.[37]

2.3 ELECTRIC GRID PERSPECTIVE

Electric vehicle, as a new type of energy resource, has dual representation as it can have either static or dynamic behavior. In the static representation, electric vehicles are considered as mere loads adhering to the "plug-n-play" concept and their operation is similar to the one of conventional loads. In this case, the charging process of the EV battery starts as soon as the EV plugs into the grid. As far as the dynamic behavior is concerned, electric vehicles can be considered as manageable loads whose demand is flexible and it can be allocated among the non-commuting hours in respect to different business objectives. In a more ambitious scenario, electric vehicles can be considered as distributed storage units which are, additionally, capable of injecting energy back to the electricity grid (Vehicle-to-Grid services, V2G) in order to support grid operation and enhance its operational efficiency.

Irrespectively of the EV representation, the integration of electric vehicles into electricity grids poses an additional load to the system which modifies the system load curve. This demand must be served at any point of the grid, where an EV may be connected, similarly to the conventional one without any discrimination. There are several parameters defining the additional EV demand which can be separated into two categories as follows:

- Constant parameters
    - *EV deployment level:* the size of the EV fleet that is connected to the electricity grid
    - *Charging station technologies*: the nominal charging power of the charging stations varies according to the technology from 3.2kW up to 300kW.
    - *Availability of charging stations*: the placement of the charging stations, i.e. home, work-place, public places, highways etc., affects significantly the demand profile of the charging
- Probabilistic parameters
    - *Driving profile*: the energy consumption of the EV battery which fulfils the mobility needs of electric vehicles depends on the travel distance and the driving conditions (economic or dynamic driving, use of auxiliary loads such as air-condition etc.)
    - *EV connectivity:* electric vehicles are not available for charging unless they are connected to the electricity grid (either via charging cable or contactless). The start and the available duration of the charging process are defined by the arrival and departure time of EV user to and from the charging station.

The aforementioned parameters defines the additional charging demand that fulfills the e-mobility needs of an EV fleet. The way this demand will be imposed on the electricity network load curve depends on the implemented charging policy (dumb charging, multi-tariff charging, smart charging). An extended analysis on the impact of EV demand on the system load curve considering different charging policies has been performed in [38].

Based on this analysis, the dumb charging policy can lead to "worst case" scenarios. When EV charging remains completely uncontrolled, the profile of the charging demand is highly dependent on the time of return from the last journey of the day. Since home arrival normally coincides with increased residential consumption, the EV demand can be synchronized with the system peak load. Thus, dumb charging might result in local distribution network congestions and a higher share of EVs, might require premature grid investments [38]. The Figure 3 shows the impact of the "dumb charging" in the system daily demand in different European countries and for various EV penetration scenarios. The worst-case scenario in a typical winter day is presented.

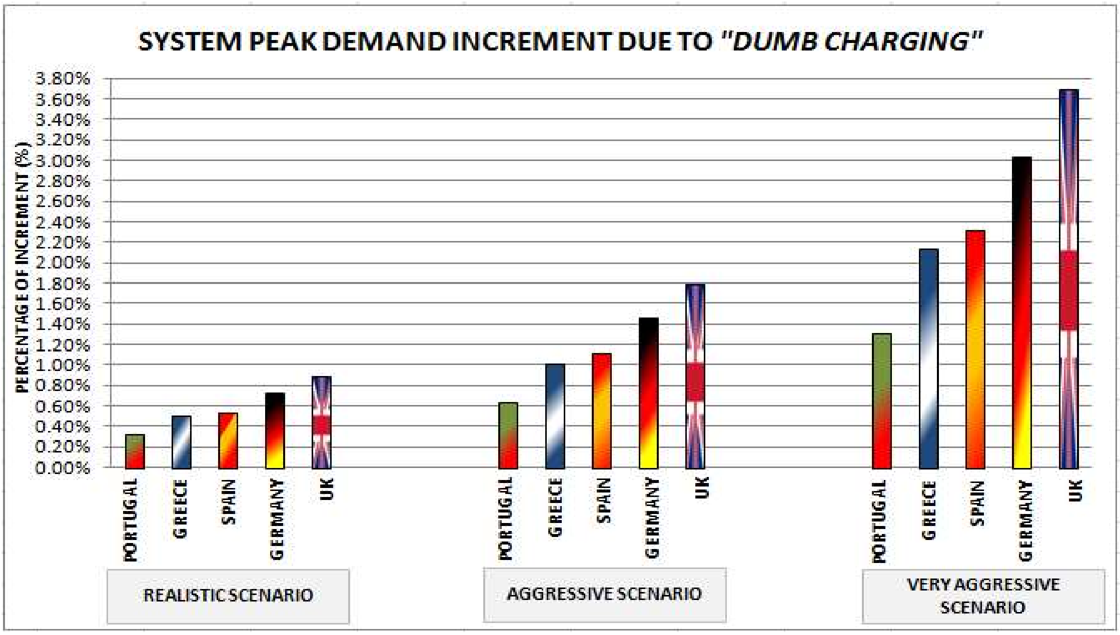

Figure 3 – The increase in system peak demand in different European countries due to "dumb charging" for the three penetration scenarios. [38]

The grid impacts of home charging can be limited by developing charging infrastructures at workplaces. In this case, part of the daily EV charging needs compensating the battery consumption for driving from home to work, can be fulfilled during morning hours at workplace, when the system demand is still relatively low.

Concerning the work charging, it was concluded that the demand peak of the home charging is reduced since the daily mobility energy requirements are partially fulfilled during morning hours. Moreover, in case of hybrid EVs the daily driving autonomy using the battery can be extended if intermediate charging sessions are occurred. However, the conclusion for this analysis is not to develop workplace charging infrastructure in order to reduce the peak demand of home charging but wherever workplace charging infrastructure exists it can be utilized for intermediate charging sessions which can consequently reduce home charging demand peak. As the number of EVs charging at workplaces increases, the additional system peak demand due to EV "dumb charging" reduces.

Dual-tariff charging is more effective than dumb charging, since it enables the shifting of the EV demand from high loading hours to off-peak hours. However, this is likely to result in a sharp increase of EV demand at the beginning of the low energy price period which might affect the network operation.

Smart charging avoids high peak loads by allocating the EV demand during off-peak hours. The figure below (Figure 4) illustrates the effect of this load allocation to the system load factor. In smart charging, EV demand is managed in a way that reduces the system load variation between off-peak hours and high load hours. Smart charging is the most effective charging strategy, however its implementation is not straightforward and for a large number of vehicles it requires advanced control and management techniques.

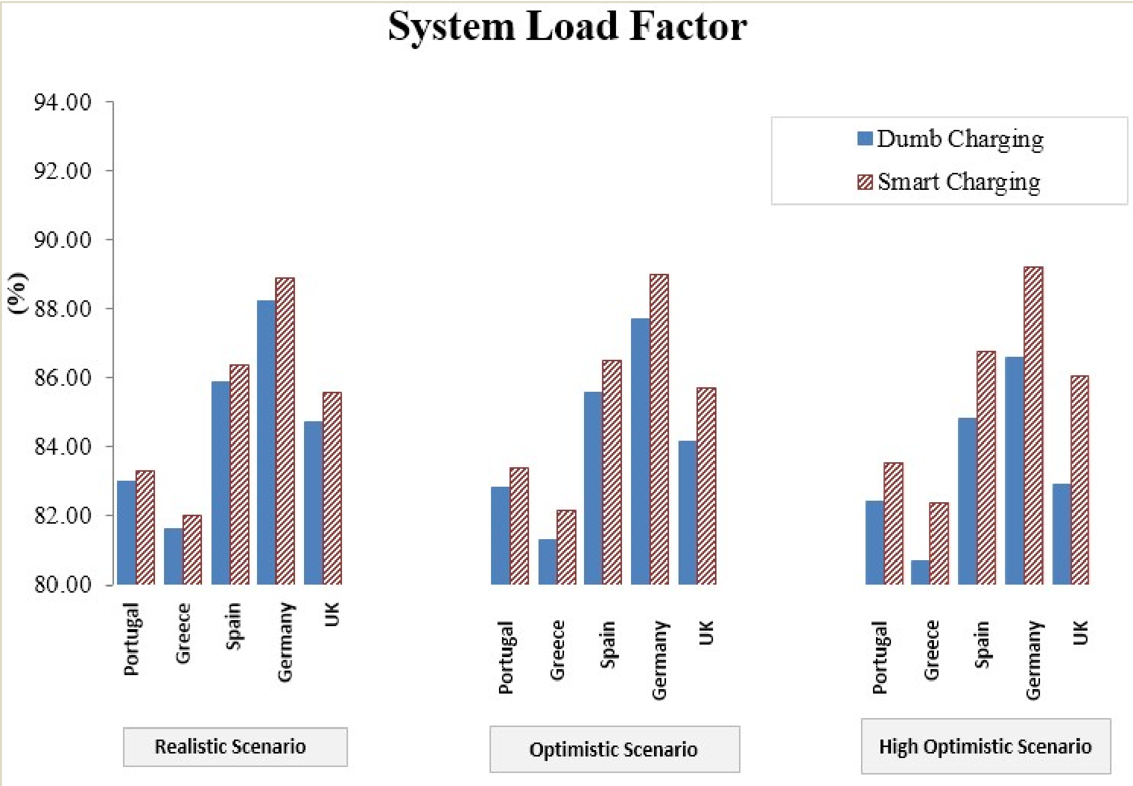

Figure 4 – The increase of system load factor comparing "dumb charging" with "smart charging" [39]

The additional demand of electric vehicles is expected to affect the operation of distribution networks depending on the EV penetration level as well as the adopted charging strategy. The integration of electric vehicles into electricity grids may provoke operational issues at local grid level, i.e. distribution network. Each distribution network can host a maximum number of electric vehicles without violating any network operational constraint [40], [41]. The maximum EV penetration level is called *EV hosting capacity* and it is defined based on the technical and operational characteristics of the respective distribution network. More specifically, MV urban distribution networks are densely populated and the network equipment loading is usually high. Thus, EV deployment is expected to further burden network equipment. On the contrary, MV (Medium Voltage) rural networks comprise long lines provoking high voltage drops, while the network loading is relatively low. Consequently, the EV hosting capacity can be defined either based on the network loading or the voltage profile. The EV hosting capacity of a network can be increased by implementing advanced EV coordination mechanisms enabling more efficient exploitation of the grid capacity and local resources.

Finally, the charging equipment when connected to the local grid can also deliver grid services (V2G) for example, respond to a demand of the grid operator. Possible scenario's in which connected electric cars could favor grid stability by adjusting the charging power of the car, or deliver energy back from the car to grid. The EVs can be connected to grid via a private network (house or building) and also provide services there (Vehicle to Home/Building – V2H/B) such as energy cost reduction.

2.4 SOCIAL PERSPECTIVE

In this section the benefits that e-mobility has versus conventional oil-driven mobility from a social perspective are reviewed.

2.4.1 Direct effects of e-mobility on a societal level

Replacing the current internal combustion engine (ICE) cars with EVs has beneficial effects on society and especially on the overall public health, directly affecting citizens. We describe those direct effects here. The lack of emissions is the most important direct effect. Direct emissions are non-existent (tail-pipe emissions) or greatly reduced (breaks and tires) in BEVs as compared to internal combustion engine cars [42]. The largest fraction of on road emissions for EVs are the wearing of the tires, which are still 25% lower than conventional cars [42]. This big reduction of on-road pollution is a very big local health advantage for the society deploying BEV.

Indirect emissions, related to the production of the energy, are higher than direct emissions, for all types of vehicles. The highest reduction in indirect emissions are recorded with BEV driving on renewable energy. A reduction of a factor 10 is achieved [42]. In addition, indirect emissions can be dealt at the source which leads to a lower impact on society, compared to direct emissions, which are very diffusely spread over a society.

The silent operation of an electric engine is another feature of BEV that positively impacts society. In the EU, about 56 million people living in areas with more than 250.000 inhabitants are exposed to road traffic noise of more than average 55 dB per year, which is thought to be risky to health [43]. The silent electromotor of BEV causes a noise reduction as compared to internal combustion engines. The effect is the greatest at slow and changing speeds, which happen typically in urban settings [44]. Reduced traffic noise might be beneficiary for diseases which are related to noise-induced stress [45]. At higher speeds, the effect of deploying EVs on noise reduction is lower. [43]

The EV's lack of noise is often cited as a possible negative effect on society because it might collaborate to an increase in road accidents. However, no proof has been found for this negative effect [42]. The explanation lies in the fact that at low speed EVs make no noise which might not alert a pedestrian or a cyclist that a vehicle is approaching. At a higher speed, the tires of the EV provide sufficient noise to warn pedestrians and cyclists.

The direct effects described above are mostly beneficial to inhabitants of cities, since they suffer from air pollution and noise hindrance more, as compared to less densely populated areas. However, we note that especially in cities, a complex interplay exists that negatively effects the uptake of EVs. City residents depend on public charging stations to recharge their vehicles, as they don't typically own but rent parking lots. Also individual solar panel installations, which might produce cheap electricity to power an EV, cannot usually be easily acquired by city residents as they do not own the necessary amount of roof area.

2.4.2 Indirect effects on society of using EV

The rise of the new sector of e-mobility comes with many entrepreneurial opportunities, creating much needed jobs and specific expertise. The deployment of EVs in society requires charging infrastructure, battery suppliers and recycling activities, electricity networks capable of charging EVs, parking lots and mobility hubs (since charging is an activity that takes long additional activities might be offered to EV drivers). This causes for additional job creation due to the EV sector. In addition, an increase of EV might boost renewable energy production in society, since more electricity is needed, which can be profitably and locally produced with renewable sources in the cheapest and least environmentally damaging way.

EVs cause also negative indirect effects on society, which are less visible because the resulting costs are usually externalized. As of today, mines which deliver minerals for batteries of BEV are often severely impacting environment in a negative way [46], [47]. Also the labor conditions at mining sites are often questionable or even intolerable [48], [49]. Those excesses are partly due to the high – and increasing – demand for batteries worldwide, causing big competition. Binding regulations on an international level seem the only way to solve this extractive economy, especially in pursue of a growing EV market in the EU and the values we hold.

On the other side, batteries are increasingly recyclable [50]. Before entering the recycle process, they can be used in secondary uses when the capacity for use in BEV is too low [24]. It is important to notice that the research in battery technology is peaking. Novel technologies, which are still a decade from reaching production, promise a doubling of efficiency [51]. A big industry on recycling of batteries (part of the upcoming circular economy) is expected to emerge, providing jobs for societies deploying EVs.

2.4.3 Effects of EV stimulation programs

To analyze societal impact of EVs, an understanding of the EV buyer is necessary, since their decisions drive and steer the direction the market is going. There seems not to be a single clear profile of the EV-buyer. Studies on influencing socio-economic and demographic variables including gender, age, income, education level and household composition show no effects in some studies, but effects in opposing directions in others [52]. Unfortunately, no recent studies investigate 'residential location' as a key factor. It is clear that EV adoption is related to environmentally friendly behavior of the buyer, but the concern about value of the EV, battery and technological risks still contribute negatively to the probability of choosing an EV [52] The purchase cost of an EV is higher than a conventional vehicle (although the EV ownership costs are currently lower than conventional vehicles ones [53]). In these early years of EV market penetration, this might lead to an EV representing a certain social status. The support of authorities to stimulate EV adoption need to be checked against a possible Matthew effect [54]. In Belgium for example, the financial incentives for purchasing EVs are lower for high end EVs and higher for more affordable EVs [55]. Because the e-mobility transition requires big investments of the society as a whole – RES (Renewable Energy Sources) production infrastructure, charging infrastructure, manufacturing infrastructure and electric grid investments virtually all levels of public authorities provide large support measures to reach the transition. It is worth noting that nearly all of these investments will be paid by tax payer's money, due to large support measures by virtually all political levels. Hence, for social stability and good acceptation of EVs, it is important that every sociographic stratum of society benefits one way or the other of the transition to EVs. The financial and fiscal stimuli need to be devised accordingly.

2.4.4 Increased oil independancy

Adopting EV lowers oil dependency for a society and can cause for a more secure mobility system, more resilient to change on the global oil market. On a global scale, reducing the burning of fossil fuels leads to lower CO_2 emissions, in an attempt to temper global climate change. Those two effects are indirect positive societal effects. These can be merely effected by individual customer choices, and are almost completely decided on national and EU political levels [56].

2.4.5 Novel bussiness models with EV

Car sharing, in which access to EVs is offered, removes the need to buy an EV. In this way more citizens might benefit from the adoption of EVs in society. By coupling from the start the adoption of EVs to car sharing schemes, another big societal advantage is the reduction of number of parking spots. One shared car replaces 5 to 12 privately owned cars, depending on the reference consulted [57]. Up to one third of available city's area is occupied by cars or roads [58]. But approximately 95% of available car capacity is unused at any given moment. This is a huge waste of resources on a societal level. Car sharing is more efficient with parking spots. Providing shared cars, a lot of space can be freed up in cities. Most crowded neighborhoods in cities can be benefited most of this reduction.

Car sharing with EVs can also lead to more efficiently used charging stations. Charging stations rotate more frequently with car sharing.

The city has to develop rigorous rules for adopting car sharing in society. Car sharing for EVs has big competition from conventional cars. Conventional car sharing can reach break-even in most cities, as shown by the pioneers. This offers opportunities for new players to the market, since excess production of conventional cars can be up valued simply by putting these cars in the streets of cities in a car sharing scheme. This leads often to unfair competition with novel EV car sharing. It seems also not desirable that car sharing grows by offering the service (cars), with the aim to create demand. Some projects of multinational companies seems to do just this, deploying hundreds of cars at once in one city. For example, in 2017, in Brussels, ZipCar (AVIS), DriveNow (BMW), Cambio car sharing, ZenCar are available to customers. Idle shared cars can have a bad negative perception of car sharing in cities, which are scarce in parking spots. It is also not in the interest of a city that car mobility would dominated by one party. EV car sharing is still in development, both technologically, e.g. on charging the EVs efficiently, in the marketing and communication, and in the support of cities e.g. to place charging stations on public domain. No economically viable EV car sharing service exists of today, but reports show that 2017 or 2018 might be the year that break-even might be reached [28], [26].

3 E-MOBILITY TECHNOLOGIES AND STANDARDS

3.1 ELECTRIC VEHICLES

According to [59], the electric vehicle is defined as: "a means of transport driven by traction system consisting of one or more electric energy storage devices, one or more electric power conditioning devices and one or more electric machines that convert stored electric energy to mechanical energy delivered at the wheels for propulsion of the vehicle." According to this definition, we can find three types of electric vehicles which can be connected to the mains in order to charge their batteries:

- *Battery Electric Vehicle (BEV*). Is the simplest electric vehicle model. It is equipped with one or more electric motors powered by batteries, which allow the car to move. The batteries are connected to the mains to be recharged, but they can also be recharged using regenerative braking, which nowadays is pretty common in every kind of electric vehicle.
- *Extended Range Electric Vehicle (EREV*). It is an electric vehicle which includes a traditional combustion engine, whose sole function is to power an electrical generator when the batteries are low. This kind of vehicle is propelled only with electric motors, so they are classified as electric vehicles, instead of being classified as hybrid vehicles.
- *Plug in Hybrid Electric Vehicle (PHEV*). These vehicles are equipped with both electrical motors and a traditional combustion engine, so they can be propelled with any of the two systems. The combustion engine is able to recharge the batteries, but also is able to propel the vehicle by itself or parallel to the electric motors. This kind of vehicle can be connected to the mains, too. Regenerative braking in PHEV can also recharge the batteries, while saving the breaks. This kind of vehicle can be connected to the mains, too, hence the name 'plug in'.

To date, the autonomy of electric vehicles which are only equipped with an electric traction system is one of their most important weak points; nevertheless, this is only a secondary issue for a hybrid vehicle.

It is not easy to give an accurate estimation of the autonomy of electric vehicles, because it changes depending on the type of path (i.e.: driving through the city consumes less energy than compared to driving on the highway), the auxiliary device usages such as air conditioning usage, the driving style of the user, the weather conditions (wind, rain, etc.), or the use of regenerative braking. Apart from these factors, electric vehicles ensure a minimum autonomy based on their batteries capacity.

For the Battery Electric Vehicles, a real autonomy of 135 km is ensured for vehicles equipped with 24kWh batteries, and 170 km for vehicles equipped with 30 kWh batteries and 230 km for vehicles equipped with 41 kWh batteries. Moreover, hybrid vehicles electric autonomy ranges from 5 to 80 km[1], meaning the autonomy of the vehicle considering only the electric batteries.

At the same time, the electric vehicle is an opening up to new horizons in the automobile industry. An increasing number of manufactures are incorporating little by little electric vehicles to their catalogue. For this industry, this is a market niche that is still to explore, and now we can see the innovation capacity of this industry.

Comparing an electric vehicle to a traditional one, it is possible to appreciate the next advantages:

- Significant decrease of vibrations level produced by the propulsion system.
- Simplicity of construction of electric motors in comparison with traditional combustion engines.
- Simplicity of the necessary ancillary systems for the propulsion system.

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[1] The autonomy data has been elaborated by ITE with the information provided by the electric vehicle manufacturers, following the recommendations given by IDAE in their document "El vehículo eléctrico para flotas" (04/10/2012).

- Decrease almost entirely of the noise inside of the vehicle.
- Simplicity of the vehicle maintenance processes.
- Reduced operational costs (i.e. price of electricity compared to price of fuel, reduced taxes, etc.)
- Power delivery is faster and more efficient in an electric motor (instantaneous torque), compared to a traditional engine with the same features.
- Absence of direct emissions (including CO_2, NOX, particles and CO) in BEV vehicles, and decrease of emissions in EREV and PHEV vehicles.
- Emerging business opportunities by exploiting the battery capacity of electric vehicles (V2H, V2G, V2V (Vehicle to Vehicle), etc.).
- The EVs are sweetest to drive due to they run as an automatic car and because of their higher stability (the batteries are usually placed at the bottom of the car so the gravity center is located lower and that improves the equilibrium).
- Higher efficiency of the electric motors compared to the combustion engines.
- Incentives offered for promoting e-mobility (i.e. free parking spaces, free use of toll-controlled areas, etc.).
- More easy to operate for drivers, due to the lack of gears.

On the contrary, these are the main disadvantages that nowadays the electric vehicle has:

- The autonomy of an electric vehicle is lower compared to the autonomy of conventional vehicle.
- The duration of the recharge is still high, ranging from 20 minutes to several hours for a full recharge.
- Low availability of information concerning to the relation of batteries aging with their storage capacity.
- Limited recharge infrastructure.
- Higher purchase price comparing to a conventional vehicle of the same segment.
- Bigger weight, which might cause some increase wearing of tyres and cause longer breaking distances.

Despite these disadvantages, for the vehicle manufactures, having electric vehicles in their catalogue is an element of distinction, either of they be it 100% electric, or hybrid. Remarkable brands such as Audi, BMW, Citroën, Ford, Nissan, Renault and Kia, are a little sample of the huge number of the vehicle manufacturers which are incorporating little by little electric vehicles of every kind to their catalogues, and consequently, widening the electric vehicle offer wider.

Nowadays it is possible to find electric vehicles in almost all of the segments, ranging from two-wheel vehicles, such as mopeds and motorcycles, to four-wheel standard vehicles like compact cars or SUVs (Sport Utility Vehicles), or bigger vehicles such as vans and buses. These are some examples of electric vehicles available on the market for each segment:

- Compact: Renault Zoé, Ford Focus electric, Nissan Leaf.
- Sedan: Opel Ampera (hybrid), Hyundai Ioniq, Tesla S.
- Van: Nissan e-NV200, Citroën Berlingo electric, Renault Kangoo Z.E.
- Motorcycle: BMW C Evolution, Bultaco Rapitan, Brammo Empulse.
- Moped: Yamaha EC-03, KTM Freeride, Emocycles Spirit 2000.
- Buses: Irizar i2e, BYD e-bus.

3.2 EV ENERGY STORAGE TECHNIQUES AND BATTERIES

As mentioned before, the autonomy of the electric vehicle depends on various factors, but the most important one is the capacity of the battery which powers the electric traction system. The energy storage capacity varies with the battery technology.

3.2.1 Types of batteries

It is possible to find a large variety of batteries in the market:

- **Lead-acid batteries**: traditionally used in vehicle industry as energy source to kick start the combustion engine. They are so popular due to their low cost, their capacity to start the engine, and their aptitude to give support in electrical tasks and lighting, this makes them to be a suitable option for small vehicles; but their excessive weight and their really long charging time does not allow these batteries being a suitable choice for electric vehicles.
- **Ni-Cd batteries (NiCd)**: the cost is way too high, and they have another problem: the memory the cost of this type of battery is too high to be used as a traction battery, and they suffer from the memory effect[2]. Because of this reason, the Ni-Cd batteries are not the preferred option in the electric vehicle industry, and their use is practically restricted to planes, helicopters and military vehicles.
- **Nickel-metal hydride batteries (Ni-MH):** the chemical reaction at the positive electrode is similar to that of the nickel–cadmium cell (NiCd), with both using nickel oxide hydroxide (NiOOH). However, the negative electrodes use a hydrogen-absorbing alloy instead of cadmium. A NiMH battery can have two to three times the capacity of an equivalently sized NiCd battery, and its energy density can approach that of a lithium-ion battery. Nickel–metal hydride batteries have a lower specific energy than lithium-ion batteries (see further) have a higher specific energy than nickel–metal hydride batteries [60], but they are significantly more cheaper [61]. They also produce a higher voltage (3,2 – 3,7 V nominal), and are thus not a drop-in replacement for alkaline batteries without circuitry to reduce voltage. They have another advantage respect the Ni-Cd batteries: less prone to memory effect than NiCd, they can be rejuvenated [62].
- **Lithium-ion batteries (Li-ion)**: the most extended storage technology in electric vehicles is the lithium-ion one. The lithium-ion batteries were put on the market in year 1991, and their use was expanded from year 2000. The most common in EV are composed of a lithium salt electrolyte and lithium-manganese-oxide electrodes. The absence of memory effect, their high efficiency and lack of maintenance on this battery, in addition to their higher charge density (it doubles the charge density of the Ni-Cd batteries, and reduces the volume (twice the charge density of the Ni-Cd batteries, and one third reduction of the volume one third in comparison to the Ni-Cd batteries with the same charge density), makes this technology the most proper for the electric vehicle. The fact that these batteries are still in development phase, gives them a large room for improvement.

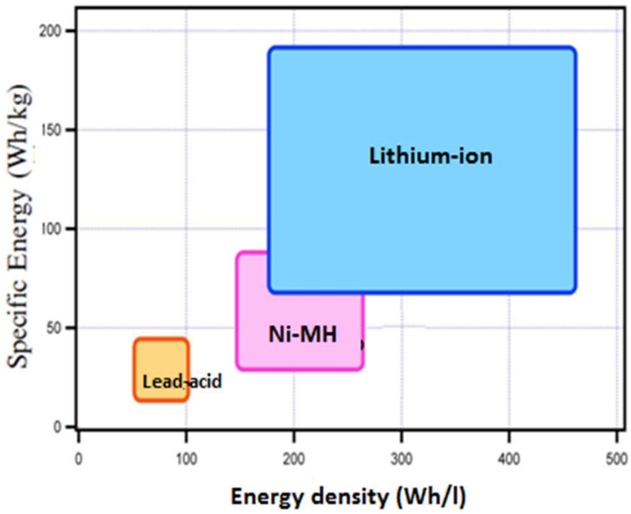

Figure 5 – Energetic characteristics of the three types of batteries most used in EVs [63]

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2 Memory effect: Capacity loss which suffers the battery due to a recharge without being almost fully discharged before.

- **Disadvantages**:
  - **Average lifespan**: depends on the amount of load they store, regardless of their use. They have a lifespan of about 3 years or more if they are stored with 40% of their maximum load.
  - **Limited number of charges**: between 300 and 1000, less than a battery of Ni-Cd and the same as those of Ni-MH, so they are starting to be considered in the consumables category.
  - **Price:** their manufacture is more expensive than Ni-Cd and Ni-MH, although the price is currently down rapidly due to its high penetration in the market.
  - **They can be overheated to the point of exploding**: they are made of flammable materials that make them prone to detonation or fire, so it is necessary to equip them with electronic circuits that control their temperature at all times.
  - **Reduction of performance in cold weather**: delivers lower performance than Ni-Cd or Ni-MH batteries at low temperatures, reducing their life span by up to 25%.

Depending on the material, there are many types of Li-ion batteries:

Material	Specific Capacity (mAh/g)	Voltage vs. L^+ / Li, V	Characteristics
$LiCoO_2$	160	3,7	Most commonly used in consumer product, good capacity and cycle life but expensive and unsafe upon fast charge
$LiMn_2O_4$	130	4	Most commonly used in automobile, low cost, acceptable rate capability, poor cycle and calendar life
$LiFePO_4$	140	3,3	Low cost, improved abuse tolerance, good cycle and power capability but low capacity calendar life
NMC	180	4,2	Lowest cost, high capacity, life is less than NCA
NCA	185	4,2	Highest capacity, low cost but safety concerns
Graphite	372	0 – 0,1	Most commonly used in all applications, low cost
LTO	168	1–2	Highest cycle and calendar life, but costly and low in energy density
Silicon	3.700	0,5 – 1	Still in research stage, high energy but large volume expansion during charging needed to be solved
Silicon	3.700	0,5 – 1	Still in research stage, high energy but large volume expansion during charging needed to be solved

Table 2 – Li-ion battery cathode and anode material comparison [61]

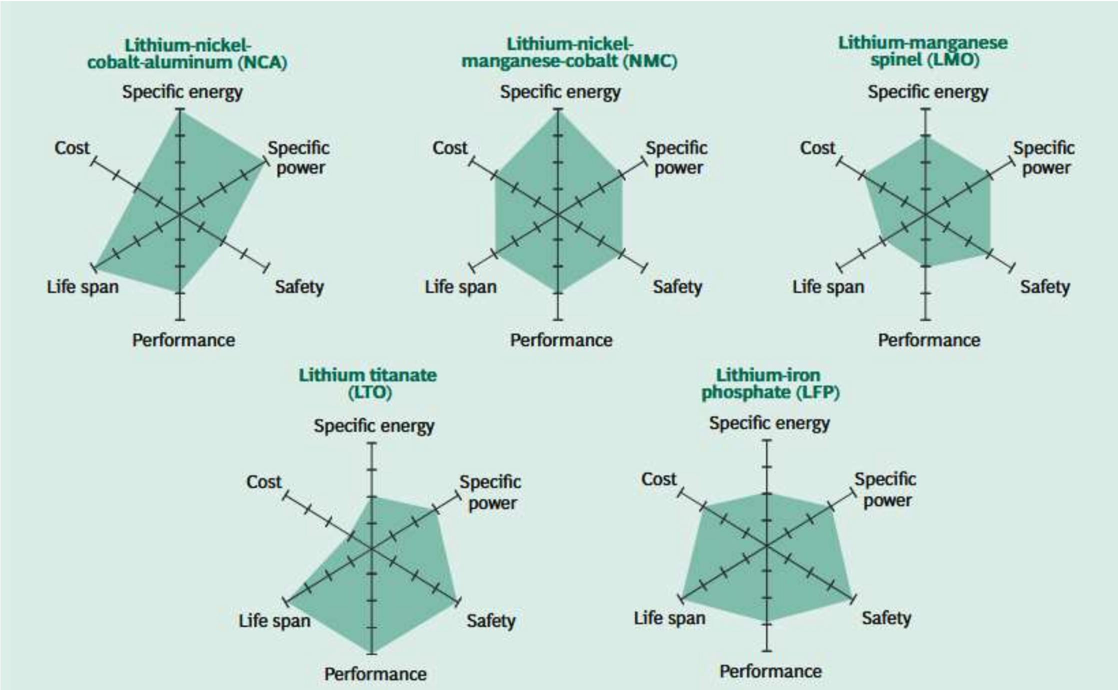


Figure 6 – Tradeoffs among the five principal Lithium-Ion Battery Technologies [64]

It is also important to mention the control needed to avoid fully discharging in order to increase the life expectancy of the lithium-ion batteries.

A partial discharge reduces stress and prolongs battery life, so it is recommended to do partial charges. Elevated temperature and high currents also affect cycle life.

Table 3 estimates the number of discharge/charge cycles Li-ion can deliver at various DoD (Depth of Discharge) levels before the battery capacity drops to 70 percent. DoD constitutes a full charge followed by a discharge to the indicated state-of-charge (SoC) level.

Depth of Discharge	Discharge cycles ($NMC/ LiPO_4$)
100% DoD	~ 300/600
80% DoD	~ 400/900
60% DoD	~ 600/1500
40% DoD	~ 1500/3000
20% DoD	~ 1500/9000
10% DoD	~ 10000/15000

Table 3 – Cycle life as a function of depth of discharge [65].

Another drawback of the Li-ion batteries is the maximum charge current they can accept. It is governed by cell design, not by the cathode material.

A well-designed ultra-fast charger evaluates the condition of the "chemical battery" and makes adjustments according to the ability to receive charge. The charger should also include temperature compensations and other safety features to lower the charge current when certain conditions exist and halt the charge if the battery is under undue stress.

Nowadays, most of the batteries of electric cars are not well prepared to ultra-fast recharge (more than 120 kW). Moreover, if battery uses fast recharge (50 kW) it fills only 70-80 % of the battery. It is because fast-charging creates a lag between voltage and state-of-charge that increases the faster the battery is being charged. The ultra-fast charge forces the voltage to the 4,20 V/cell ceiling quickly while the battery is only partially charged. Full charge will occur at a slower pace as part of saturation.

In terms of longevity, the optimal charge voltage is 3,92 V/cell [65]. Battery experts believe that this threshold eliminates all voltage-related stresses; going lower may not gain further benefits but induce other symptoms. Table 4 summarizes the capacity as a function of charge levels.

Charge Level (V/cell)	Discharge cycles (NMC/ $LiPO_4$)	Available Stored Energy
4,30	150 – 250	110 – 115%
4,25	200 – 350	105 – 110 %
4,20	**300 – 500**	**100%**
4,15	400 – 700	90 – 95 %
4,10	600 – 1000	85 – 90 %
4,05	850 – 1500	80 – 85 %
4,00	1200 – 2000	70 – 75 %
3,90	2400 – 4000	60 – 65 %
3,80	See note	35 – 40%
3,70	See note	30% and less

Table 4 – Discharge cycles and capacity as a function of charge voltage limit [65]

Losses in the charging process of Li-ion batteries exist. It is mainly dependent on the State of Charge (SOC) and the AC current applied to the batteries. Elpiniki Apostolaki-Iosifidou, Paul Codani and Willett Kempton [66] say that total one-way losses (losses occurring by charging or discharging from a certain State of SOC to another SOC) vary from 12% to 36%. The losses occur predominantly in the power electronics used for AC-DC (Alternating Current– Direct Current) conversion, mostly in the car for AC charging and in the EVSE for DC charging. The charging efficiency is lowest at low power transfer and low state-of-charge, and is lower during discharging than charging.

In opposite, battery losses increase significantly with the current. The battery losses during charging are independent from SOC. In Table 5, we can see the round-trip losses of all EV components (conversion and battery losses) as a function of the SOC and the AC current.

		SOC			
		20%	40%	60%	80%
AC Current	10A	24,49	20,30	26,89	19,08
	30A	18,33	16,15	18,41	15,77
	50A	18,96	18,36	17,83	17.40
	70A	22,08	22,45	22,19	20,07

Table 5 – Round-trip losses of all EV components as a function of the SOC and the AC current (in %) [66]

In general, higher charge power produces greater losses. As we can see in the next figure:

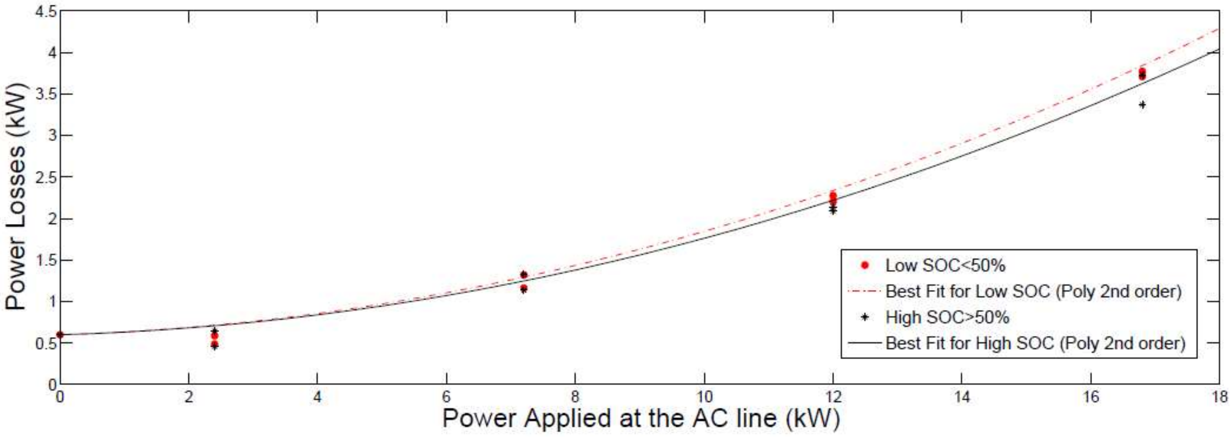


Figure 7 – Round-trip EV losses against AC power applied, both expressed in absolute kW [66]

3.2.2 Upcoming battery technologies

- **Air-metal batteries:** despite the lithium-ion batteries are the most extended in the electric vehicle industry, experts say that air-metal batteries are going to be the best candidates to replace the lithium-ion batteries in electric vehicles use [67]. These batteries, which are still in test phase, offer a high energetic potential, they are reliable and they have three times more capacity than ion-lithium-ion batteries for the same volume and, in addition, their cost is halved.
- **Solid-state lithium-ion batteries:** these batteries replace the liquid with a solid electrolyte. Some designs also eliminate binders and separators. Solid-state designs do not overheat or catch fire, because the solid electrolyte prevents dendrites from creating short circuits. They offer long cycle life, as well as higher volumetric energy densities than current Li-ion designs. They also can be packaged more efficiently, as the cell design can allow in-series stacking and bi-polar structures, and could be safer, as there is no risk of leakage of a liquid electrolyte, and the inflammable and inorganic solid electrolytes have high thermal stability. Acceptance of solid state electrolytes has been limited by the poor conductance of such materials. In March 2017, researchers announced a solid-state battery called a [68] which has a glass electrolyte doped with lithium, oxygen and chlorine ions; and with 3 times the energy density of conventional lithium-ion batteries. An extended life of more than 1.200 cycles was demonstrated. This new solid state glass battery does away with the lithium extraction, as detailed in the University of Texas article announcing the invention.

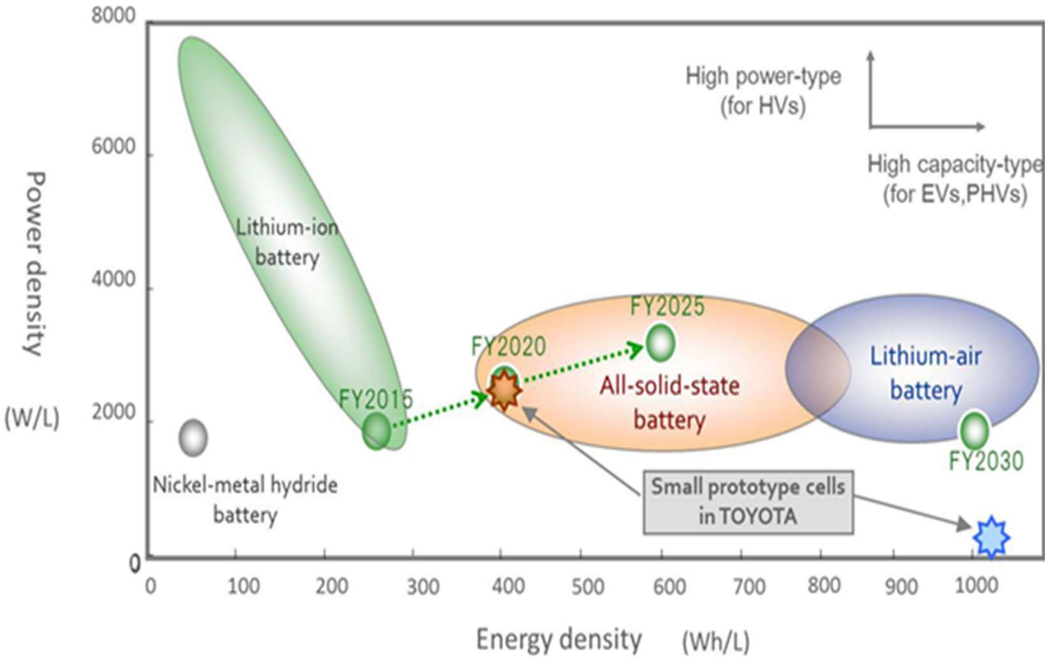


Figure 8 – Ragone plots for various battery systems [69]

- **Other type of batteries:**
  - **Semi-solid flow cell:** the solid particles are suspended in a carrier liquid and pumped through the system. In this design, the battery's active components — the positive and negative electrodes, or cathodes and anodes — are composed of particles suspended in a liquid electrolyte. These two different suspensions are pumped through systems separated by a filter, such as a thin porous membrane. The new design should make it possible to reduce the size and the cost of a complete battery system, including all of its structural support and connectors, to about half the current levels. Another potential advantage is that in vehicle applications, such a system would permit the possibility of simply "refueling" the battery by pumping out the liquid slurry and pumping in a fresh, fully charged replacement, or by swapping out the tanks like tires at a pit stop, while still preserving the option of simply recharging the existing material when time permits. The problem with this is that it needs the existence of an electrolyte refueling infrastructure is needed for this process (not to be emptied in this case), and the car itself carries two tanks of 159 liters each [70], which means adding enough weight to the vehicle.
  - **Supercapacitors:** capacitors are electrical devices capable of storing electrical energy during charging thanks to an electric field, and then returning it to the circuit when the load ceases. Their advantage is that they can be charged and discharged very quickly, in just seconds, and have a really long useful life, but the drawback is that the capacity (its specific energy or energy density) is lower than in the Li-ion batteries.

    To improve the capacity is used supercapacitors. Supercapacitors are capacitors with increased capacity. Nowadays they already exist, but their specific energy, around 20 Wh/kg [71] is not, does not get to be as high as with the chemical batteries. They are used for example in some urban electric buses that recharge very quickly in the stops.

    To further increase its capacity, graphene supercapacitors are being investigated, which can reach, for example, 64 Wh/kg of specific energy [72].

    Trying to combine the best of both worlds, there are also wells, also known as hybrid supercapacitors or LIC (Lithium Ion Capacitor), because it is a combination of capacitor and Li-ion battery. For now they have been used in hybrid racing cars only, but we will see where their evolution comesthey hold promise for the future.

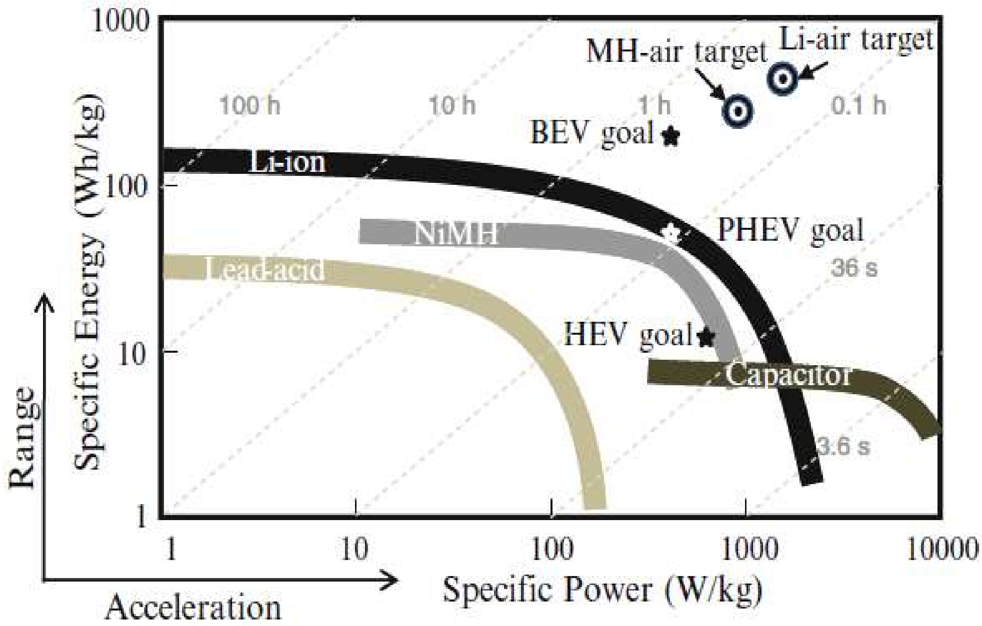


Figure 9 – Ragone plot of a few electrochemical energy storage devices used in the propulsion applications [73]

3.3 CHARGING STATIONS

The charge the batteries of electric vehicles, there exists a large variety of devices or charging stations. A charging station could be defined as a group of elements necessary to couple the electric vehicle to a fixed electric network in order to charge its batteries. Such EVSE can have one or multiple charging points.

The charging stations can be classified according to different criteria:

- The electric power that the device is able to deliver, and consequently, necessary spent charging time.
- Connector type used by the charging station.
- Information flow among the vehicle and the charging station.

3.3.1 Charging station classification according to electrical properties

According to the delivered power and charging time criterion, charging stations are classified in ultra-fast, fast, semi-fast, slow, and super-slow, as it is shown in Table 6. These criteria are an adaptation of the four charging modes, which are defined in the UNE-EN 61851 – 1:2012 standard, distinguishing them by the voltage and the current by which the charging process is performed.

The four charging modes defined in [74] are the ones shown below:

- **MODE 1**: This charging mode allows charging intensities up to 16 A, and there is no communication between the vehicle and the station.
- **MODE 2**: Like in charging mode 1, no communication between the vehicle and the station is taking place. But the current limit is limited to 32 A of alternating current (single-phase or three-phase).

- **MODE 3**: This charging mode has two differenced sub-modes. In one of them, the intensity limit is set on 32 A of alternating current, differing on the mode 2 in the use of seven control pins instead of four control pins in mode 2. The other sub-mode allows up to 250 A of charging current of alternating current.
- **MODE 4**: The fourth charging mode allows a charging current of 400 A, but in this mode, direct current is the only option.

Based on these four modes of charging EVs, the following classification of battery charging has colloquially extended, based on the time needed to charge the batteries of the electric vehicle.

- The **ultra-fast charging** devices are considered experimental and their use is not very common. Due to the really high power supplied by these chargers (> 50 kW) the batteries can be charged up in 5 or 10 minutes. For example, charging at 150 kW we could charge a battery of 22 kWh in 15 minutes. This charge method is being developed to charge large batteries of trucks and buses, to reduce charging times of their batteries, which need to be designed to be able to withstand the high amounts of supplied power.
- **Fast charging** devices must be able to supply 44 to 50 kW of electric power. Because of this, these devices are able to charge the battery of an electric vehicle (22 kWh, e.g.) up to the 80% in just half an hour.
- The **semi-fast chargin**g is done at 22 kW of electric power; this allows for fully charging up a 22 kWh battery in just one hour and a quarter to one hour and a half.
- The **slow charging** is performed at a maximum current rate of 16 A, which makes this power station to supply only 3,6 kW of maximum power. For this type of charger, the charging time of a default 22 kWh battery is about 6 to 8 hours.
- The **super-slow charging** is performed in a maximum intensity no higher than 10 A; and as consequence, it takes for the charging station to completely charge up a 22 kWh battery about 10 or 12 hours.

Charging method	Power (kW)	Intensity (A)	Time	Final charge level	AC/DC
Ultra-fast	>50	>110	5 -10 minutes	100%	DC or AC
Fast	44 – 50	63	0,5 hours	80%	AC
Semi-fast	22	32	1 – 1,25 hours	100%	AC
Slow	3,6	16	6 – 8 hours	100%	AC
Super-slow	2,3	10	10 -12 hours	100%	AC

Table 6 – Summary of different charging devices features

3.3.2 Charging station classification according to the connector type

The connector criteria are still in development phase, since at an international level there are diverse standardization criteria. The standards to be followed for connector designing phase are UNE-EN 61851-1:2012 and IEC 62196. Both standards do not define connector physical dimensions. Absence of general agreement in the standardization of connector physical dimensions is clearly evidenced by the current variety of connectors available on the market.

- First of all, type Schuko connector (Figure 10) is the one which supports less intensity, and is the most common in the household equipment. This connector follows the CEE7/4 type F standard, supports a maximum current of 16 A, and it has got two terminals and a grounding.

Figure 10 – Schuko connector [75]

- The North-American standards established their own connector type for EVs: the SAE J1772, also known as Yazaki, which is a connector used only by electric vehicles (Figure 11). It has got 5 pins two of them are used to supply the electric power, another one of them is used as grounding, and the remaining two pins have complementary functions (proximity detection and communications with electric grid). Within this type of connector there exist two sub-groups: level 1 supports up to 16A and it is only suitable for slow charging, and level 2, which supports up to 80A and is used for fast-charging.

Figure 11 – SAE J1772 connector [76]

- Another connector that is very common and follows the standard VDE-AR-E 2623-2-2, is Mennekes (Figure 12). This German-designed connector was originally created for industrial purposes, but now is used also to charge electric vehicles. With a diameter of 55 mm, it counts seven pins, four of them are used to supply three-phase current, one is for the grounding, and the other two are used for communications. This connector can supply power in single-phase alternating current with a maximum current of 16 A (slow charging), or it can supply up to 63 A in three-phase current (fast charging).

Figure 12 – Mennekes connector [77]

- Trying to establish common criteria, North-American and German manufacturers have proposed a standardized solution, the combined connector, known as CCS (Combined Charging System) (Figure 13). This connector has got five pins, which are used for power supply, grounding and communications. This connector allows both fast and slow charging.

Figure 13 – CCS connector [78]

- Another design proposed by French manufacturers is the Scame connector, also known as EV Plug-in Alliance (Figure 14). It is equipped with five pins, which are used to supply current (three-phase or single-phase), grounding and communications. Its intensity limit is 32 A, making it suitable for semi-fast charging.

Figure 14 – Scame connector [79]

- Finally, the standard created by the Japanese manufacturers is called CHAdeMO (Figure 15). It is designed only to allow fast and ultra-fast charging in direct current only, as shows its maximum current of 200 A. It has ten pins, used for power supply, grounding and communications.

Figure 15 – CHAdeMO connector [79]

The Table 7 and Table 8 summarize the electric and physical features of the main existing connectors nowadays to charge electric vehicles.

Connector	Standard	Charging type	I max. (A)	P max.(kW)	Current type
Schuko	CEE 7/4 Type F	Slow	16	3,7	Alternating
Yazaki	SAE J1772	Slow / Fast	16 (level 1) /80 (level2)	3,7 / 43,8	Alternating
Mennekes	VDE-AR-E 2623-2-2	Slow / Semi-fast	16 1~ / 63 3~	43,8	Alternating
Combo	IEC 62196-2	Slow / Fast	32 ~/ 200	22 / 100	Alternating / Direct
Scame	IEC 62196-2	Semi-fast	16 1~ /32 3~	22	Alternating
CHAdeMO	IEC 62196-1 UL 2551	Fast / Ultra-fast	200	62,5	Direct

Table 7 – Summary of electric features of charging connectors

Connector	Diameter	Connectors	Phases	Grounding	Communications
Schuko	37 mm	3	2	1	0
Yazaki	35 mm	5	2	1	2
Mennekes	55mm	7	4	1	2
Combo	35 mm	5	2	1	2
Scame		5	2	1	2
CHAdeMO	70mm	10	2	1	7

Table 8 – Summary of physical features of charging connectors

3.3.3 Charging station classification according to communications

Regarding to communications or information flow criteria, the classification of charging modes refers to the communication between the electric car and the charging station. This includes actions such as programming the charge, starting the charge or re-starting the charge. Depending on the communication level, the standard IEC 61851-1:2010 establishes four types of charging:

- **Mode 1**. In this mode the communication between the electric car and the mains does not exist. A good example for this mode would be an electric vehicle charging through a conventional power socket with a Schuko connector. In mode 1, the charging is performed in alternating current.
- **Mode 2**. In this case, the communication level is low. The communication consists of verifying the connection between the vehicle and the mains, thanks to an intermediate device located on the charging cable This type of control can be implemented even in Schuko connectors. The charging in mode 2 is performed in alternating current.
- **Mode 3**. This modality implies a high communication level between the vehicle and the mains. For this to happen, the charger is equipped with control and protection devices. Furthermore, the cable is equipped with a communication pilot wire. SAE J1772, Mennekes, CCS or Scame connectors have got this type of technology. For this mode, charging is performed in alternating current.
- **Mode 4**. This mode also implies a high communication level with the mains. This mode is only used in fast charging, and disposes of direct current converter. An example of connector which integrates this technology is CHAdeMO. In mode 4, charge is performed in direct current.

In Figure 16, there is a graphic summary of summarizing the four charging modes defined before.

The main communication protocols are described in section 0. According to the connector types used at the charge stations, we can mark which of them are in the models of the main manufacturers in Figure 16

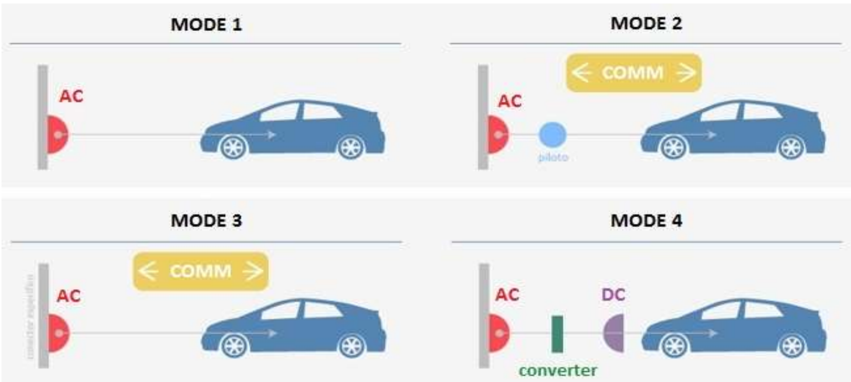


Figure 16 – Communication schemes of the different charge modes

Plug-in electric and hybrid vehicle recharge cables			Charge Point side								EV side	
			Mode 2		Mode 3		Fast charge					
Manufacturer	Model	Technology	Schuko	Cetac	Type 3: Scame	Type 2: Mennekes	CHAdeMO	Mennekes 3-phase	Combo 2	Mennekes DC	Type 1: J1772 (Yakazi)	Type 2: Mennekes
Audi	A3-Sportback e-tron	PHEV	X	X		3,7 kW						X
	Q7 e-tron	PHEV	X	X		7,2 kW						X
BMW	i3	BEV	X			X			X			X
	i3 REX	E-REV	X			X			X			X
	i8	PHEV	X			X						X
	330e	PHEV	X			X						
	X5 eDRIVE40e	PHEV	X			X						X
Citröen	Citröen C-Zero	BEV	X				X				X	
	Citröen Berlingo	BEV	X				X				X	
Ford	Focus Electric	BEV	X			X					X	
KIA	Soul EV	BEV	X			X	X				X	
Mercedes-Benz	S500e	PHEV	X			X						X
	C350e	PHEV	X			X						X
	GLE 500 e4MATIC	PHEV	X			X						X
	B ED	BEV	X			X						X
Mitsubishi	Outlander PHEV 2016	PHEV	X				X				X	
	i-MIEV	BEV	X				X				X	
Nissan	LEAF	BEV	X		X	X	X				X	
	e-nv200	BEV	X		X	X	X				X	
	e-nv200 evalia	BEV	X		X	X	X				X	
Opel	Ampera	E-REV	X								X	
Peugeot	Ion	BEV	X				X				X	
	partner	BEV	X				X				X	
Renault	ZOE R240	BEV	X		X	X						X
	ZOE Q210	BEV	X		X	X		X				X
	Kangoo ZE	BEV	X		X	X						X
	Twizy	BEV	X									
Smart	Fortwo	BEV	X			X						X
Tesla	Model S 70D	BEV	X		X	X				X		X
	Model S 90	BEV	X		X	X				X		X
	Model S 90D	BEV	X		X	X				X		X
	Model S P90D	BEV	X		X	X				X		X
	Model X 70D	BEV	X		X	X				X		X
	Model X 90D	BEV	X		X	X				X		X
	Model X P90D	BEV	X		X	X				X		X
Volkswagen	e-UP	BEV	X		X	3,7 kW			X			X
	e-GOLF	BEV	X		X	3,7 kW			X			X
	Golf GTE	PHEV	X		X	3,7 kW						X
	Passat GTE	PHEV	X		X	3,7 kW						X
Volvo	V60 twin engine	PHEV	X			X						X
	XC90 T8 Twin Engine	PHEV	X			X						X

Figure 17 – Plug-in electric and hybrid recharge cables for models and manufacturers. [80]

Regarding V2G technology, CCS combo and CHAdeMO are the connectors most suited.

CHAdeMO communication is based on IEC 61851-1/23 Annex A. It uses communication via CAN bus. The current version is CHAdeMO v0.9, but CHAdeMO v1.1 is under development.

On the other hand, CCS combo is based on IEC 61851-1/23 Annex C.

Finally, the advantages and disadvantages of these connectors for V2G technology are presented in Table 9.

	Advantages	**Disadvantages**
CCS Combo	Dynamic Charging and V2G during the same charging session	Bidirectional Charging is not part of the related standards (DIN 70121, ISO 15118) Response times can be over 60s
CHAdeMO	Response time: 100ms (1sec error) V2H standard released	Charging or discharging session

Table 9 – V2G advantages and disadvantages for CCS combo and CHAdeMO connectors

3.4 STANDARDS AND PROTOCOLS ON E-MOBILITY

As the EVs is not very integrated in our current car park, standardization is still in development. Standardization regarding e-mobility has the goal to ensure safety in the usage of EVs, approaching safety from two points of view. On the one hand, it concerns safety during usual EV use. On the other hand, it concerns electrical safety related to the EV and related ancillary services and devices.

The main international organisations working on e-mobility standardizations on an international level are ISO (International Standardization Organization), IEC (International Electrotechnical Commission) and ITU (International Telecommunication Union). In Europe, aligned with these international entities, the main associations which are standardizing e-mobility are CEN (European Committee of Standardization), CENELEC (European Committee for Electrotechnical Standardization), ETSI (European Telecommunications Standards Institute).

Efforts made include standardization of charging points, EVs and communications performed in all e-mobility activities. The main parts are focused on regulation of EV and its supply equipment.

Today, in Europe more than 200 standards and protocols exist in Europe related to e-mobility. Some of those standards are generally applied, which will be introduced in the next paragraphs.

IEC 62196 – "Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles" is one of the main standards. This standard defines charge point connectors, but only its technical characteristics, never their physical dimensions. This standard is divided into three parts, which are:

- IEC 62196-1 – "General requirements". This first part defines the general characteristics of the electrical properties of the EV connectors
- IEC 62196-2 – "Dimensional compatibility and interchangeability requirements for AC pin and contact-tube accessories". This standard applies to accessories and connectors used in conductive charging, whose operating voltage do not exceeds AC 480 V, 50 or 60 Hz of rated frequency, and their rated current do no exceed 63 A (three-phase) or 70 A (single-phase)
- IEC 62196-3 – "Dimensional compatibility and interchangeability requirements for DC and AC/DC pin and contact-tube vehicle couplers". This standard applies to accessories and connectors used in conductive charging with control system, whose rated operating voltage is up to 1500 V DC, and rated operating current up to 250 A; or rated operating voltage up to 1000 V AC, and rated operating current up to 250 A

All aspects related to EV conductive charging requirements are defined in the standard IEC 61851 – "Electric vehicle conductive charging system" (as opposed to the still in development 'inductive charging'). This standard is divided into five parts, which are:

- IEC 61851-1 – "General requirements". This standard has as main topic the charging modes definition, and safety issues related to EV charging.
- IEC 61851-21 – "Electric vehicle requirements for conducting connection to an AC/DC supply". This part of the main standard defines both requirements in the electrical transmission and safety during the EV connection to the electric grid; and electric characteristics, and electromagnetic compatibility of EV.
- IEC 61851-22 – "AC electric vehicle charging station". This standard defines guidelines and testing procedures for electrical safety, and dielectric test requirements.
- IEC 61851-23 – "DC electric vehicle charging station". This standard covers the necessary requirements for digital communication between DC EV charging station and EV.
- IEC 61851-24 – "Digital communication between a DC EV charging station and an electric vehicle for control of DC charging". This standard covers the necessary requirements for control of digital communications of DC conductive charging.

This last standard, IEC 61851 and all its parts, defines communications interfaces of the charging process, but not optimizing this process. The standard which is in charge of defining the optimization is IEC 15118 – "Road Vehicles – Vehicle to grid communication interface". This standard covers the gap of high level communication led by IEC 61851, defining the necessary information to exchange between EV and EVSE. There are three parts of this standard that are mainly in importance:

- IEC 15118-1 – "General information and use-case definition". This first part of the standard defines the general aspects and, specifies smart charging aspects such as charge process, payment and load levelling.
- IEC 15118-2 – "Network and application protocol requirements". This defines the messages, data models and data representation necessary during charging communications. In addition this standard describes how data link layer services can be accessed.
- IEC 15118-3 – "Physical and data link layer requirements". This part of the standard covers the overall information exchange between all actors involved in the electrical energy exchange. Only charging modes 3 and 4, with high-level communication module, are covered by this standard.

Another standard, which has been published recently in 2015, is IEC 61980 – "Electric vehicle wireless power transfer (WPT)", and its first part IEC 61980-1 – "General requirements". Wireless charging is an EV charging mode which has been developed recently, and thus, in order to guarantee safety to users, has been standardized. This standard covers and defines all aspects related to this charging mode, defining its necessary equipment, technical requirements and safety tests.

Above mentioned standards relate to connectors, charging stations, charging process and all the communications related to them. Another important aspect is user identification at the charging station. This process enables relates the user to a charging process, and this process is today usually performed through the usage of contact-less cards. This type of identification makes use of RFID (Radio-Frequency IDentification) cards, and it is regulated by the ISO/IEC 14443 – "Identification cards – Contactless integrated circuit cards - Proximity cards". This standard in all its parts defines all properties, processes, and related tests concerning RFID usage.

Moreover, many providers are starting to offer smartphones applications in order to be identified.

One of the most common protocols used for communications among EV with EVSE is OCPP (Open Charge Point Protocol) protocol. This protocol was created to have an open and standardized protocol for communicating between charging points and a central management system from different vendors. Open Charge Alliance (OCA) is the global consortium of public and private EVSE leaders that have come together to promote these open standards [81]. OCA and OCPP are described more detail in paragraph 4.2.5 of this document.

Concerning metering, the same protocol as that has been in use to meter electricity, gas, water and heat, is also mainly used in e-mobility. This protocol is DLMS (Device Language Message Specification)/COSEM (Companion Specification for Energy Metering) protocol. IEC 62056 – "Electricity metering – Data exchange for meter reading, tariff and load control" is a set of standards which defines all specifications and requirements of electricity metering, and is based on the general specifications of the DLMS/COSEM protocol.

The last important standard related to communications is IEC 61850 – "Communication networks and systems for power utility automation". This set of standards defines configuration of all types of automated intelligent electronic devices of electric substations, enabling communication among them. One of the most used standards of this collection is IEC 61850-7-420 – "DER logical nodes", which defines information models to be used in the exchange of information with DER. Thanks to possibility of delivering energy from the EV's battery back to the electricity grid (V2G), EV can be considered as a storage device. This standard and some parts of its family of standards can be applied in e-mobility.

Figure 18 summarizes graphically all the standards which have been listed herein this section.

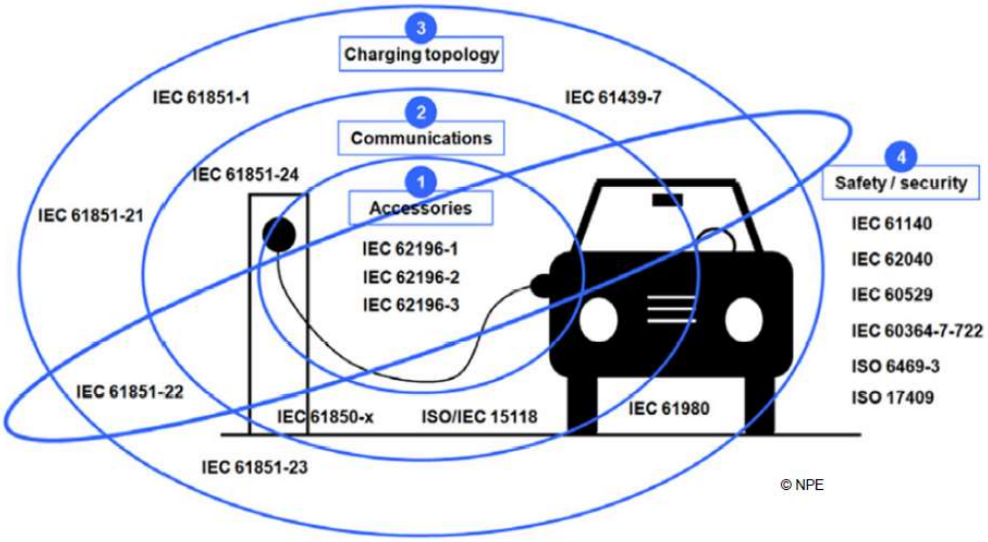


Figure 18 – Standards related to e-mobility grouped by topic [82]

On the right part of Figure 18, an overview of additional standards related to security are shown. In the following paragraphs these are listed and reviewed.

The first standard of concerning security is IEC 61140 – "Protection against electric shock - Common aspects for installation and equipment". This standard applies to the protection of persons and livestock against electric shock. This standard defines essential requirements to be applied in electrical installations, and its ancillary systems, regardless the voltage or current of the installation, but limiting its frequency up to 1000 Hz.

Concerning protection of users against risks of fire, electric shock, thermal, energy and mechanical hazards during EV operation or charging, a set of standards exists, which is IEC 62040 – "Uninterruptible power systems (UPS)". This standard applies to movable, stationary, fixed or built-in UPS for use in low-voltage distribution systems; these systems are intended to be accessible and operated by ordinary users and are able to provide a fixed frequency output in both AC current, not exceeding 1000 V, and DC current, not exceeding 1500 V.

In addition, to prevent users against electrical hazard, there exists a classification of protection level provided by enclosure for electric devices which applies, like in any other case of electric device, to EV and EVSE. This classification is defined by IEC 60529 – "Degrees of protection provided by enclosures (IP Code)".

And complementing these general safety aspects, IEC 60364-7-22 – "Low-voltage electrical installations – Part 7-722: Requirements for special installations or locations – Supplies for electric vehicles", defines all the necessary safety requirements for feeding back electricity from EV into the electric grid, but excluding wireless charging. This standard applies both, to circuits intended to supply energy to EVs, and circuits intended for feeding back electricity from electric vehicles into the supply network.

Finally, we list some standard rules to ensure electrical safety in the usual operation of an EV, such as ISO 6469-3 – "Electrically propelled road vehicles – Safety specifications – Part 3: Protection of persons against electric shock" and ISO 17409 – "Electrically propelled road vehicles – Connection to an external electric power supply – Safety requirements". They define electric safety requirements during the operation of the EV, and electric safety requirements in the EV charging process.

4 E-MOBILITY MANAGEMENT SCHEMES

4.1 EV FLEET MANAGEMENT

This section describes the functionalities and particularities required by different organizations managing an EV fleet of different constellations.

4.1.1 Public transport – electric bus fleet management

This section describes the particularities of a public transport operator using 100% electric buses must handle, when compared to regular operations with traditional internal combustion engine (ICE) buses. Information is based on a pilot project in which ETRA participated, with the objective of setting up a 100% EV-based bus line in the city of Madrid.

The buses of this line are charged at maximum load SoC at depots during the night by means of a wired DC charge. During the daily operation they carry a so called *opportunity charge* through an inductive quick charging system at the bus line termini. This operation optimizes the life of the batteries by keeping them within a charge range that ensures optimal life span, and extends the distance the vehicle can operate without requiring a new complete charge (only available at depot premises).

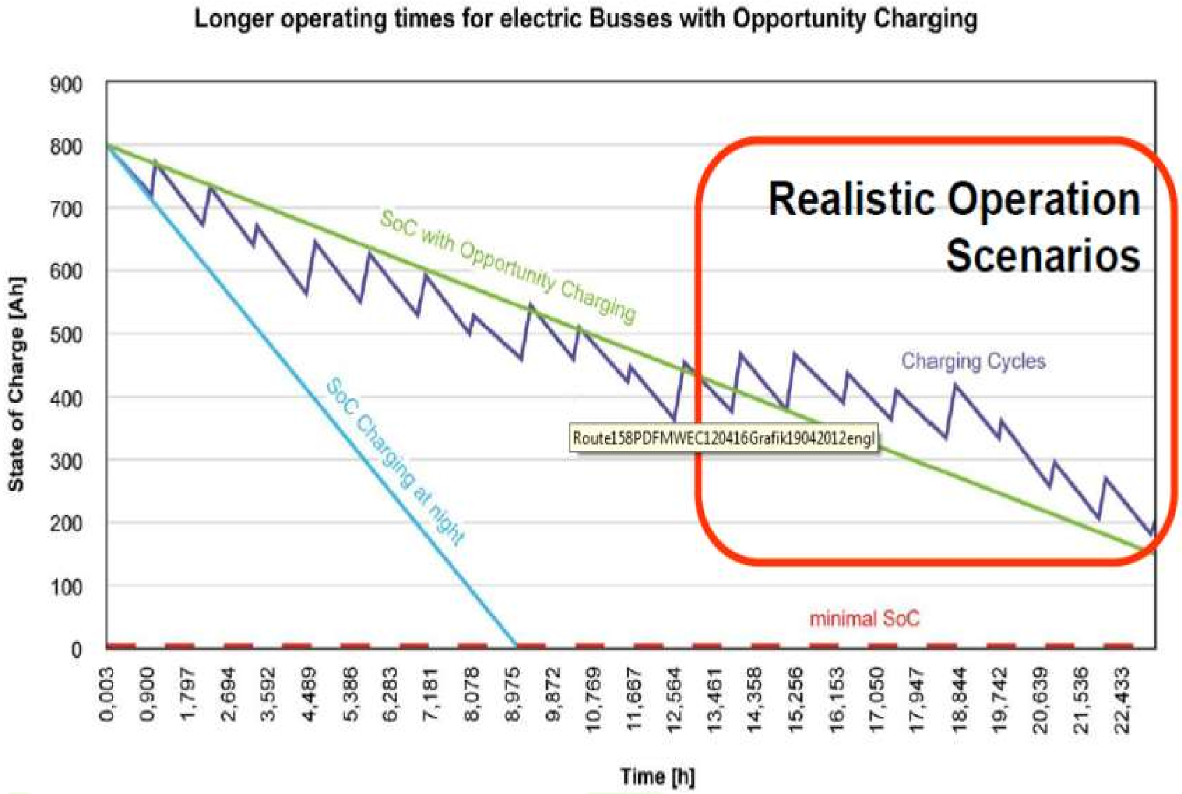


Figure 19 – Electric bus maximum ranges under different charging strategies (nightly charge and opportunistic charge)

The charging time of the batteries at terminus stops is about 8 to 12 minutes. This charging is short enough to respect the frequency of the service and to allow at the same time the maximization of the range of the bus in the daily operation, thus minimizing the need of bringing the buses back to the depot to be connected to DC charge points for a full charge operation.

In this sense, and related to the mode of operation of an electric bus fleet, the primary objectives of the public transport operator are:

- Maintain the **regularity** and **punctuality** of the service while addressing the needs of recharging the electric buses during the hours of service.
- Get **real-time information**, to be reported to operators and drivers, about the operation of the charging sessions and the current autonomy of the buses.

These objectives impose requirements on the hardware and software systems needed in place in order to retrieve and handle this information:

- Inductive charging points infrastructure installed at bus line terminal stops.
- Inductive charging technology installed at the buses.
- Monitoring system, both of road-side infrastructure and of buses at any time.

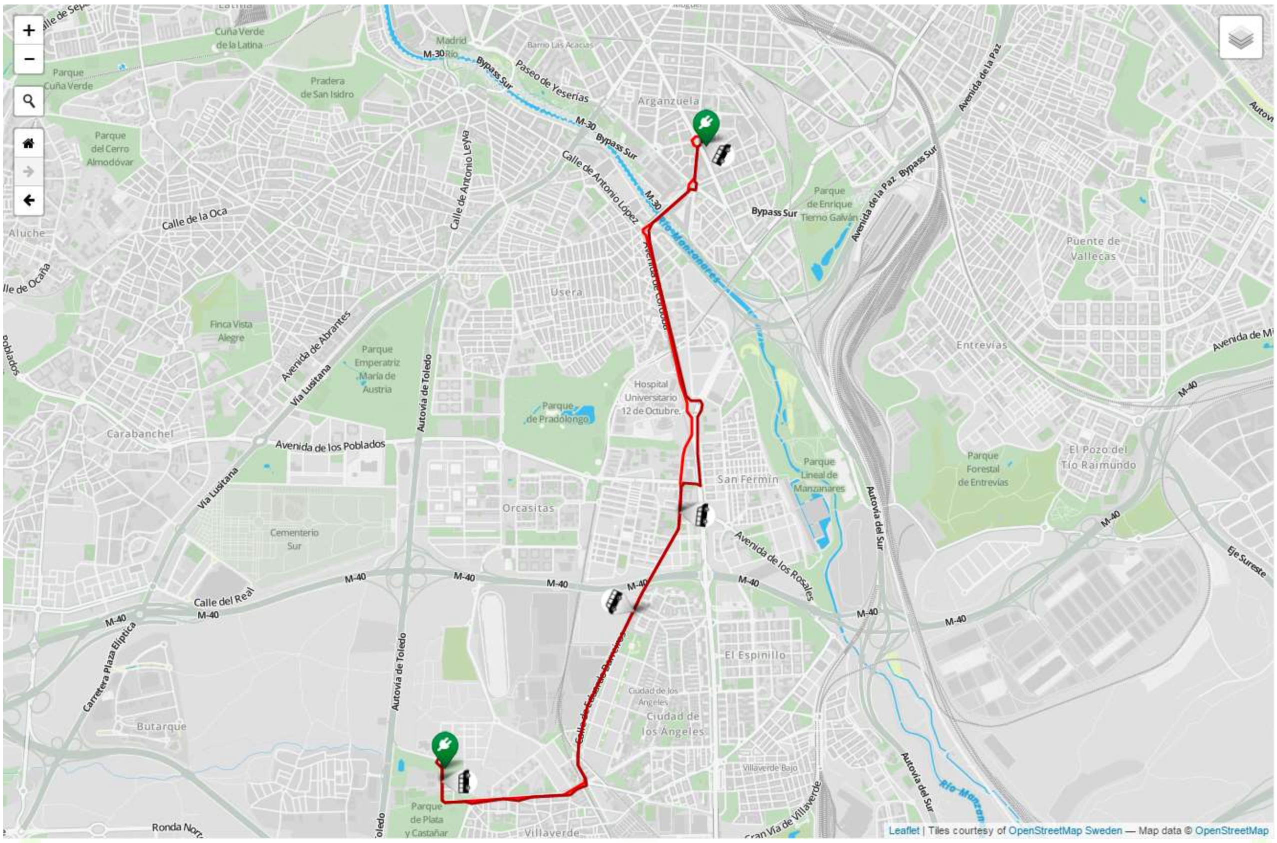


Figure 20 – 100% electric bus line, with inductive charging points at both terminal stops

4.1.1.1 Bus monitoring - Bus-FMS-Standard

The Bus-FMS-Standard interface is an optional interface of different manufacturers of buses and coaches [83]. It defines a common interface as an open standard, adopted by major manufacturers (MAN, Scania, Volvo among others), with the objective of defining the information exchange between vehicle and Fleet Management Systems. The interface is built upon the J1939 norm, which defines the data exchange protocol through CAN bus for heavy-duty vehicles. While Bus-FMS-Standard applies to the management of EV vehicle fleets, it is not particularly addressing those type of vehicles alone, and it does not contemplate EV specific data. This pilot uses a private extension of Bus-FMS-Standard to provide battery details by using extra message codes not defined in the standard.

The content of Bus-FMS-Standard comprises information about the cruise control, vehicle speed, fuel consumption, vehicle identification, engine temperature, door status, time and date, air supply pressure, high resolution vehicle distance, ambient conditions and alternator speed. It also specifies the electronic engine controllers, door control and air suspension control among others.

4.1.1.2 Required functionalities for an optimal electric bus fleet management

Operators of electric bus fleet for public transport do have strict requirements in the quality of the service they provide, considering not only operational constraints that need to be met (schedules, frequency, etc.) but also the comfort of the passengers. Taking this into account, a system managing such an EV fleet needs to provide the following information to the different personnel involved:

- Driver assistance:
    - Visualization of battery status and basic parameters of the ongoing charging session basic parameters.

- Real-time forecast of available range distance of the EV bus, accompanied by to current SoC and historical battery discharge data.
- KPI on driving efficiency, based on measured battery discharge curves (when compared to an optimal discharge pattern for that particular bus line).
- Estimation of minimum time required for the next 'opportunistic' charge at bus line termini.

- Public transport operator assistance:
  - Real-time monitoring of all parameters of the electric buses, including location, SoC, estimated range, required charging times.

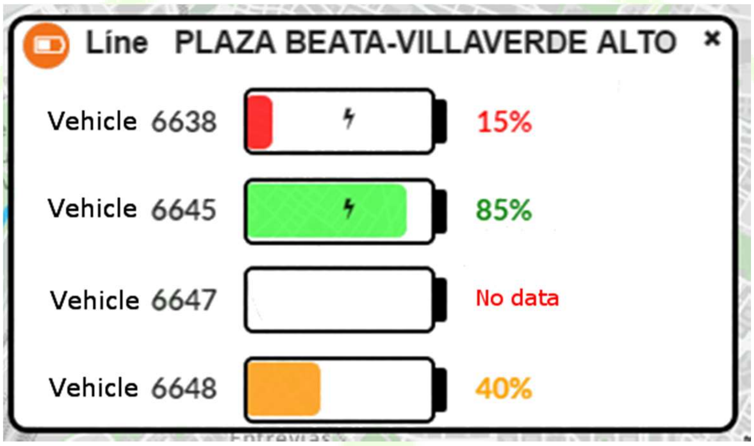
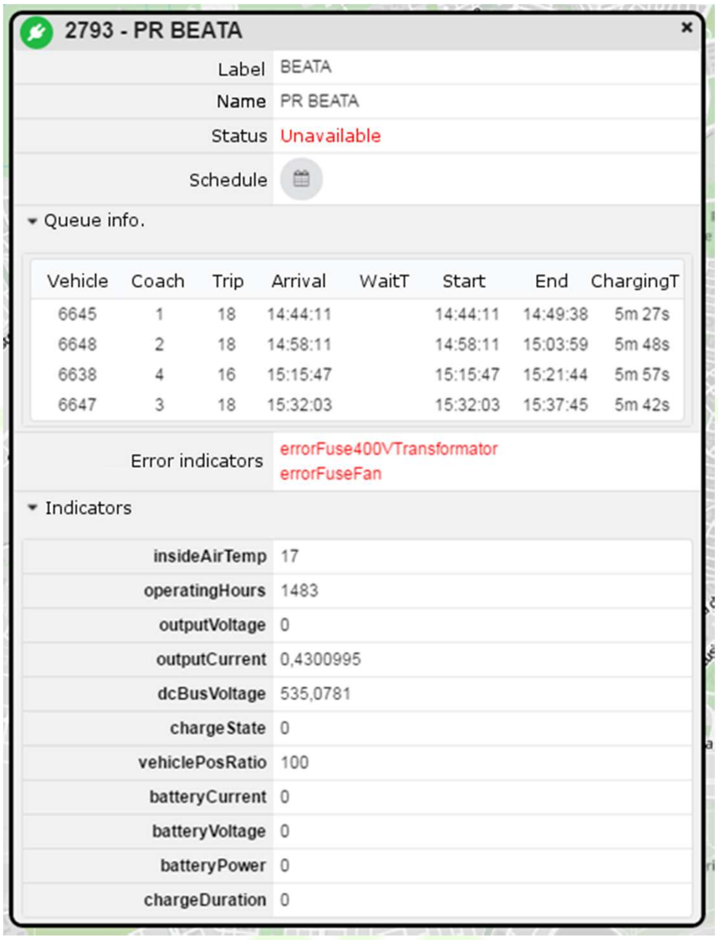


Figure 21 – Real-time SoC of the vehicles of the line

  - Status of charging points, including details of the charging sessions performed at those points.



Vehicle	Coach	Trip	Arrival	WaitT	Start	End	ChargingT
6645	1	18	14:44:11		14:44:11	14:49:38	5m 27s
6648	2	18	14:58:11		14:58:11	15:03:59	5m 48s
6638	4	16	15:15:47		15:15:47	15:21:44	5m 57s
6647	3	18	15:32:03		15:32:03	15:37:45	5m 42s

Figure 22 – Real time information of the charge point

- Summary of the minimum required times for the next opportunistic charges, and guidance to needed to readjust the service plan if needed (e.g. upon significant delay of a vehicle).

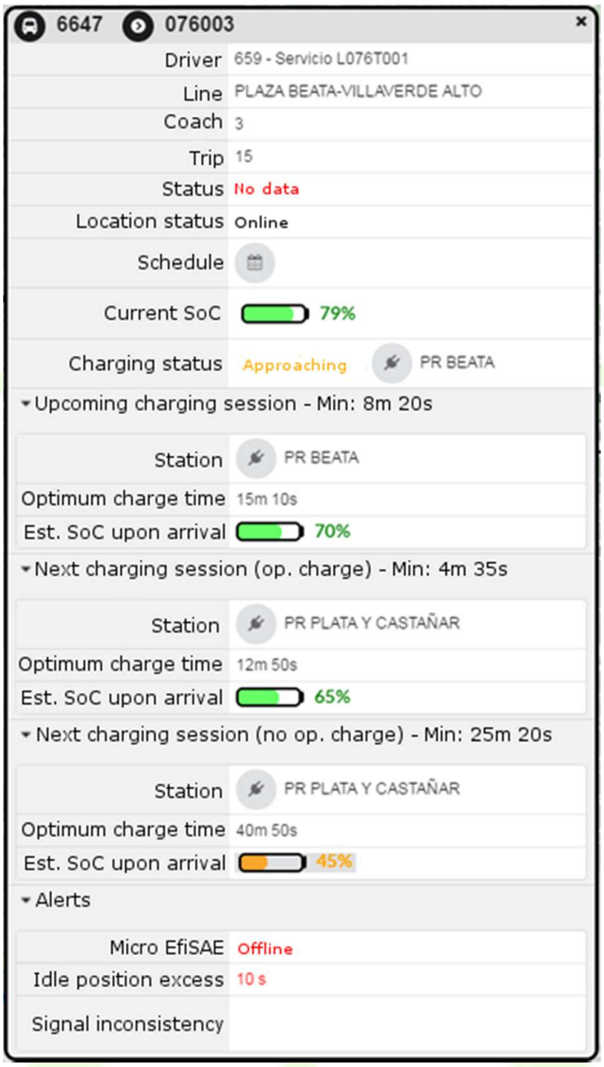


Figure 23 – Real-time information of the electric bus, including forecast of next charging sessions

4.1.2 Private transport – private EV fleet

Companies continuously seek to increase their productivity, which is the ratio between the results obtained and the amount of resources used for to obtain those results. In the transport domain companies, there are factors that critically affect their productivity, such as the number of services performed per day, the costs associated to fuel or electric energy, the number of vehicles used and the optimal itineraries of services.

This kind of companies can benefit from the support of fleet management systems helping them to achieve better control of the activity performed, to reduce fuel and energy consumption and to facilitate vehicle maintenance tasks, among other advantages.

Existence of electric vehicles in the companies' fleet pose extra requirements to these systems, since those vehicles require longer 'refueling' times as compared to those required for fueling internal combustion vehicles. This adds complexity to the management of their availability. Their availability schedule, charging times and required SoC needs to be carefully synchronized with the tasks required by the company - i.e. the vehicle must be ready when required, and have enough charge to allow the required trips. Several approaches can be taken towards this objective:

- Optimizing routes. By properly rearranging the tasks that a member of the organization has to perform, the same amount of work can be achieved with reduced travel distances. That means shorter charging times (higher availability of vehicles and charging points) and less required energy (lower costs). This particular optimization also increments the useful life time of the vehicles.
- Optimizing charging sessions. Scheduling of charge sessions is a core issue that has to be handled in a smart way, since it has implications for the organization:
    - Vehicles are used for performing particular tasks within the organization. The fleet management system must take this into account to make sure that each vehicle is ready when required. I.e. the effect of charging session requirements, such as charging times required, on the regular operation of the business must be minimal
    - Related to the previous point, in such cases where the fleet size is greater than the number of available charging points, optimally selecting the proper charge order of the vehicles of the fleet is critical. Vehicles can be scored accordingly to their required availability – time to use and required charge – thus allowing a proper arrangement of the charging sessions. The objective is having the right vehicles ready at the right moment, even if that implies delaying the availability of vehicles with less priority.
    - Optimizing the charging sessions leads to in order to minimizing the energy-associated costs. The maximum peak power produced by the charging of the fleet is a critical parameter of the charge session scheduling, since it implies extra costs to the company (retailer tariffs define a significant cost associated to the maximum peak power contracted). This peak can be minimized and strictly kept under a threshold by properly scheduling the charging sessions (smart charging).

4.1.2.1 Fleet monitoring

4.1.2.1.1 Passenger cars and light-duty vehicles – OBD-II

On-board diagnostics (OBD) is an automotive term referring to a vehicle's self-diagnostic and reporting capability [84]. Second version of this standard (OBD-II) is currently implemented in most passenger cars and light-duty industrial vehicles manufactured after 1996 – due to its legal requirement in the USA market – , and allows an easy way to access certain real-time information and fault codes of the vehicle.

Figure 24 – OBD-II interface device

Basically, this standard defines the connector, electrical signaling protocols and messaging format to be used by ECUs to communicate a predefined set of data through a vehicle's data bus, which can be accessed by external equipment. The data set includes, among others, speed, RPM, engine temperature, fuel consumption, ambient temperature and emissions.

This information has been used by insurance companies in order to adapt tariffs of their customers by evaluating their driving behavior. This information can also be very beneficial for private organizations in order to monitor the usage of their vehicles and assess the useful life of their fleet and other operational issues, such as ensuring that drivers of the organization respect speed limits or encouraging efficient driving behaviors.

Despite the broad adaption of this system for accessing ECU information, the standard set of data does not include yet references to data specific to the particularities of electric vehicles (state of charge, voltage and current at vehicle's batteries, etc.).

4.1.2.1.2 Heavy-duty vehicles – FMS

The FMS-Standard interface is an optional interface of different truck manufacturers [85], related to the protocol described in paragraph 4.1.1.1. It defines a common interface as an open standard, adopted by major manufacturers (MAN, Scania, IVECO, Volvo among others), with the objective of defining the information exchange between vehicle and Fleet Management Systems. Similarly to the previously defined Bus-FMS-Standard, the interface is built upon the J1939 norm, which defines the data exchange protocol through CAN bus for heavy-duty vehicles. FMS-Standard is broadly used by private fleet operators, but does not contemplate the particularities of electric vehicles.

4.2 EVSE MANAGEMENT

EVSE managers are organizations whose business includes installation and often also exploitation of electric vehicle charging points, as well at private premises as at public areas. In those cases where the organization handles a significant amount of energy, those organizations can adopt the role of retailers as well, thus directly purchasing the required energy for their service from the wholesale market.

This section describes the details of this management and the functionalities required by an EVSE managing organization in order to deal with their business. Relevant protocols and initiatives addressing particular aspects of this business are highlighted in the following sub-sections.

4.2.1 Locations

EVSE managers are able to offer their services – installation, maintenance and exploitation of charging points – at both public and private premises:

- Installation of EVSE at private premises consider both service provision to individual – domestic premises – or to organizations – private or public entities with electric vehicle fleets or seeking to offer charging capabilities at their premises to employees or customers. Those EVSE installations may include a contract for supplying the energy as well, with tariffs especially suited to electric vehicle charge requirements.

- Installation of EVSE at public spaces are always accompanied by the management of customers allowed to charge there. EVSE managers need, therefore, a backend management system to handle the details of their customers and the charge operations they make in the system. The EVSE manager usually provides to its customers with an RFID card they need to identify themselves at the charging point interface, thus correlating the charge operation details to their billing account.

4.2.2 Tariffs and metering

Tariffs formally describe the amount the users of the EVSEs will be charged. Those tariffs usually consider a base price and a price per supplied kWh, including extra charges for additional terms such as location of the charge point (private or public premises) or additional offered services (booking or longer collection times once the charge is complete).

4.2.2.1 Tariffs

Tariffs are linked to individual customers and all cards that can activate charging at EVSEs associated to those customers. There are 3 fundamental aspects in tariffs structure:

- Recurring fee: tariffs may include a recurring (e.g. monthly) fee that is always charged to customers.
- Time of use: price per of kWh may be fixed or variable - depending on the time of use. Periods are usually defined to contain whole hours. There usually exist standard periods according to the area of operation of the EVSE manager. E.g. in the case of Spain, tariffs 3.0 and 2.0DHS define peak, off-peak and base periods.
- kWh pool: tariffs can count with a kWh pool allocated to certain time of use periods (flat-rate).

Alternative pricing schemes are also being developed based on time, rather than kWh, such as paying per time unit that an EV is connected to an EVSE, or charging a parking fee for a certain period of time which includes charging.
Next Table 10 shows an example of a private charging point tariff with 200kWh flat-rate allocated during the night, including discount on usage of public charge points operated by the same EVSE manager:

SINGLE-FAMILY INTEGRAL PLAN with hourly discrimination		
Energy (contracted kWh)	**Flat rate until 200 kWh**	
SCHEDULE		
PERIOD	**Until 200 kWh**	**From 200 kWh**
P1 Peak period (13h to 23h)	**0,111 €/kWh**	**0,19 €/kWh**
P2 Base period (23h to 1h and 7h to 13h)	**0,026 €/kWh**	**0,105 €/kWh**
P3 Off-peak period (1h to 7h)	**0,0 €/kWh**	**0,079 €/kWh**
Included services	**Management center**	
	Maintenance	
	Insurance	
	Mobile communications	

CHARGING SESSIONS ON PUBLIC THOROUGHFARE (MADRID) 10% DISCOUNT OVER PUBLIC TARIFFS INCLUDED		
	0,33471 €/kWh	
	0,74376 €	per reservation
	0,66942 €/fraction	per every 30 minutes excess

Table 10 - Example of private charging point tariff

In the example, the tariff states that first 200kWh are given at a price of 0€ freely only if those are consumed during the night period (1h to 7h), but with an associated cost if those are consumed outside that period.

4.2.2.2 Metering

As already pointed out, energy metering information is fundamental to the operation of the EVSE managers, since it is the basis for the billing of the service. Any platform supporting the EVSE management business needs to facilitate this billing process to the EVSE manager. Usually, the EVSEs provide the capability of metering and are able to send the energy metering information to the management system.

4.2.3 Customers

EVSE managers may handle two different types of customers:

- Customers with a contract: all personal data is handled by the EVSE manager. A monthly bill is produced released with the charge of the corresponding charging sessions. This option is suitable for customers that regularly utilize the service, being even mandatory in some countries, such as Belgium.
- Customers with pre-paid cards: EVSE manager only handles information about how much balance is left in the associated card. This option is suitable for customers making sporadic use of the service. The management of pre-paid cards imposes extra requirements to the EVSE management platform. Upon request of a new charging session, the system needs to check the balance of the card. Depending on the balance, different scenarios may occur:
    - A minimum balance is not met, and the charging operation is therefore rejected;
    - If the minimum balance is met, the charging proceeds. The EVSE management system calculates and communicates to the EVSE the maximum amount of energy that can be delivered. This is a dynamic process, since price of the supplied energy depends on several contextual information, such as location or period of the day;
    - Upon end of the charge session, the EVSE management platform has to recover the details of the session and update the remaining balance of the card accordingly.

4.2.4 Interoperability

EVSE management business case introduces the possibility of allowing customers of a certain EVSE service to make use of EVSEs managed by a different organization – the so called Driver Roaming, or interoperability. Towards this objective, an interoperability mechanism should exist among the different EVSE platforms.

Interoperability is agreed among different EVSE services – let them be A and B -, which apply a single specific tariff to any charge session that is initiated by any customer of the other EVSE services. For example, a customer of EVSE service B charges at EVSE service A. EVSE service A bills EVSE service B with the agreed fixed tariff, as if EVSE service B is a customer, and as it would do with any of its own customers. Afterwards, EVSE service B bills the session to their own customers for the charging sessions they initiated at EVSE service A, by applying the *interoperability tariff* defined for EVSE service A.

The following picture depicts this process:

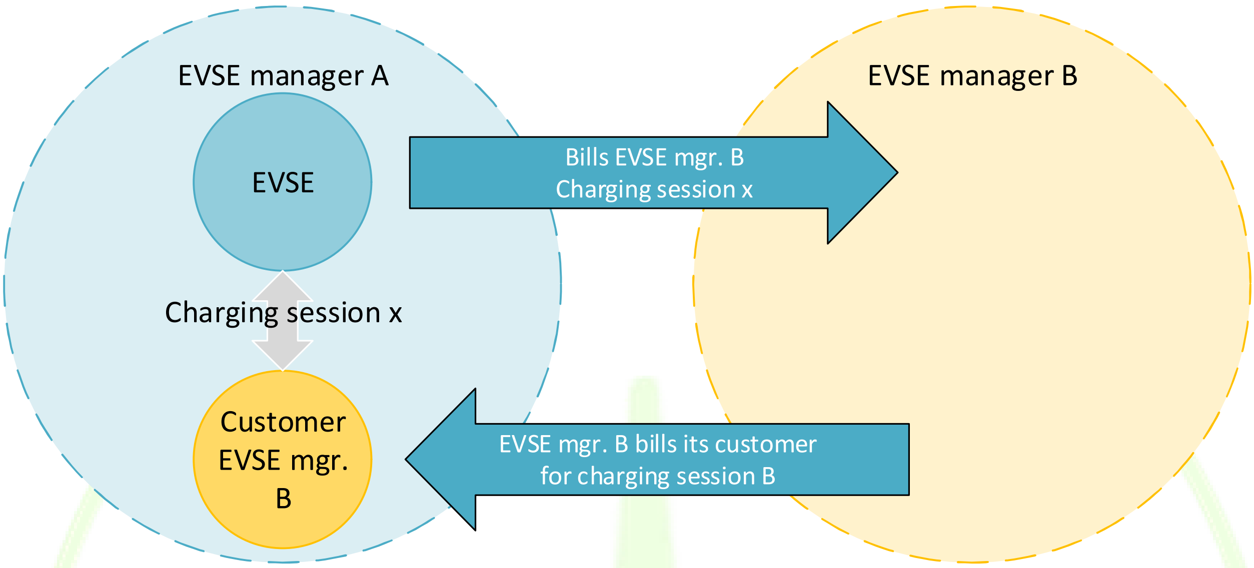


Figure 25 – EVSE manager interoperability principles

Therefore, in order interoperability to work, there must exist an information exchange mechanism used by EVSE management platforms to access up-to-date information on all public EVSEs in the interconnected systems. The updated information on the cards – customers – of each interconnected system must also be maintained. Each of the EVSE management systems themselves are responsible for keeping this information up-to-date.

Different organizations have addressed the interoperability issue with the objective of formally defining the necessary interfaces among different EVSE managers to address this aspect.

4.2.4.1 NEMA – National Electrical Manufacturers Association

NEMA [86] is the association of electrical equipment and medical imaging manufacturers founded in 1926 in USA. This organization has worked, in collaboration with several EV infrastructure manufacturers (such as Schneider Electric, Siemens, ABB and Fuji Electric among others) in identifying and filling in the gaps for interoperability among different EVSE managers [87]. Main identified gaps are:

- Charging of roaming EVs: need to permit roaming EVs to charge at spots affiliated with a different manager
- Locating and reserving public EVSEs: need for a standardized communication method to allow EV drivers to locate and reserve public charging spots
- Offline access control at EVSEs: standardize offline access control at EVSEs which have lost communication with the corresponding EVSE management system, where a vehicle or driver may be denied access to charging

Towards covering those gaps, several standards are being developed, addressing the different interactions required to achieve a complete interoperable operation of the EVSE managers.

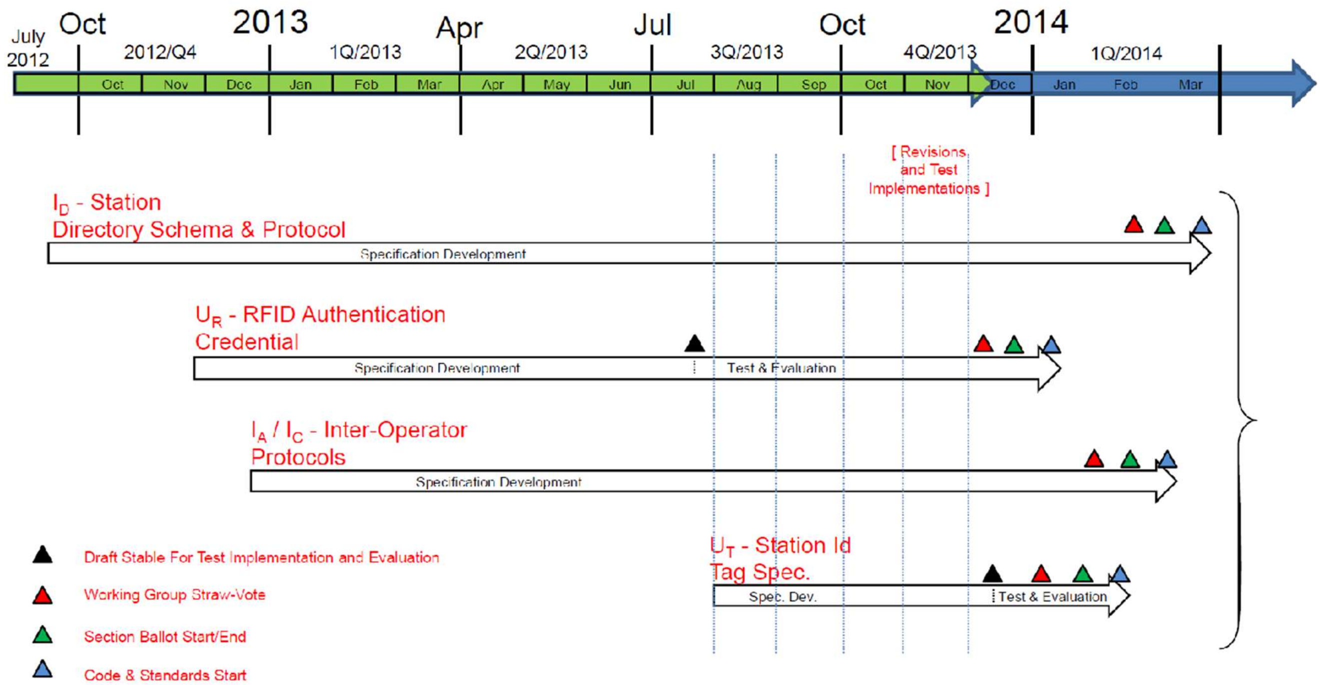


Figure 26 – NEMA standards roadmap

4.2.4.2 Hubject

Hubject [88] is a european eRoaming platform for charging of electric vehicles. Its objective is to provide connection to the different isolated EVSE management platforms, thus offering interoperability to EV drivers for charging in Europe independently of the EVSE manager handling them, and enabling the electric mobility market in Europe.

The enabler functions of the platform include:

- Ensuring the interoperability of the public and semi-public infrastructure through promotion of accepted standards within the network and open business user interfaces to the platform
- Simplification of authentication and authorization procedures through a trustworthy instance as well as safekeeping of sensitive data through the uncoupling of personal data and anonymous user data
- Automation of contract-based business relationships between power suppliers, car manufacturers, infrastructure service providers as well as further mobility business parties
- B2B information services for the realization of advanced services within the areas of energy management, traffic management, vehicle reservations, intelligent charging, car sharing and intermodal mobility

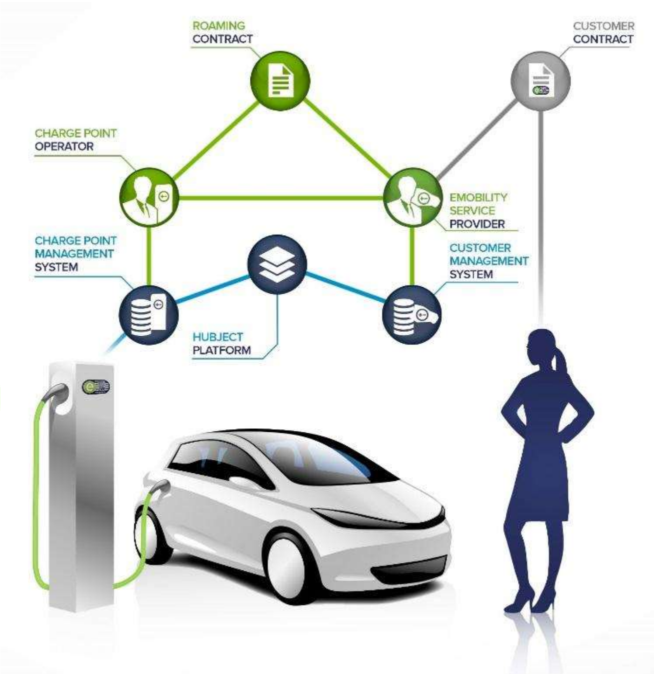


Figure 27 – The Hubject Platform

Towards this objective, Hubject has described 2 open protocols addressed to both public EV fleet and EVSE managers:

- OICP CPO 2.1 - Open InterChange Protocol for Charge Point Operators: protocol that allows customers who have a contract with any EVSE manager to charge their vehicles with the infrastructure of a different EVSE manager via the Hubject eRoaming platform, which functions as an open emobility market place, creating an open synergetic EVSE network. This protocol is based in SOAP web services.
- OICP ESP 2.1 - Open InterChange Protocol for e-mobility Service Providers: protocol that allows public EV fleet managers to offer drivers access to public charging infrastructure across national borders. Drivers are able to use any available charging point of the Hubject network, which have been registered using the OICP CPO 2.1 protocol previously defined. This protocol is based in SOAP web services.

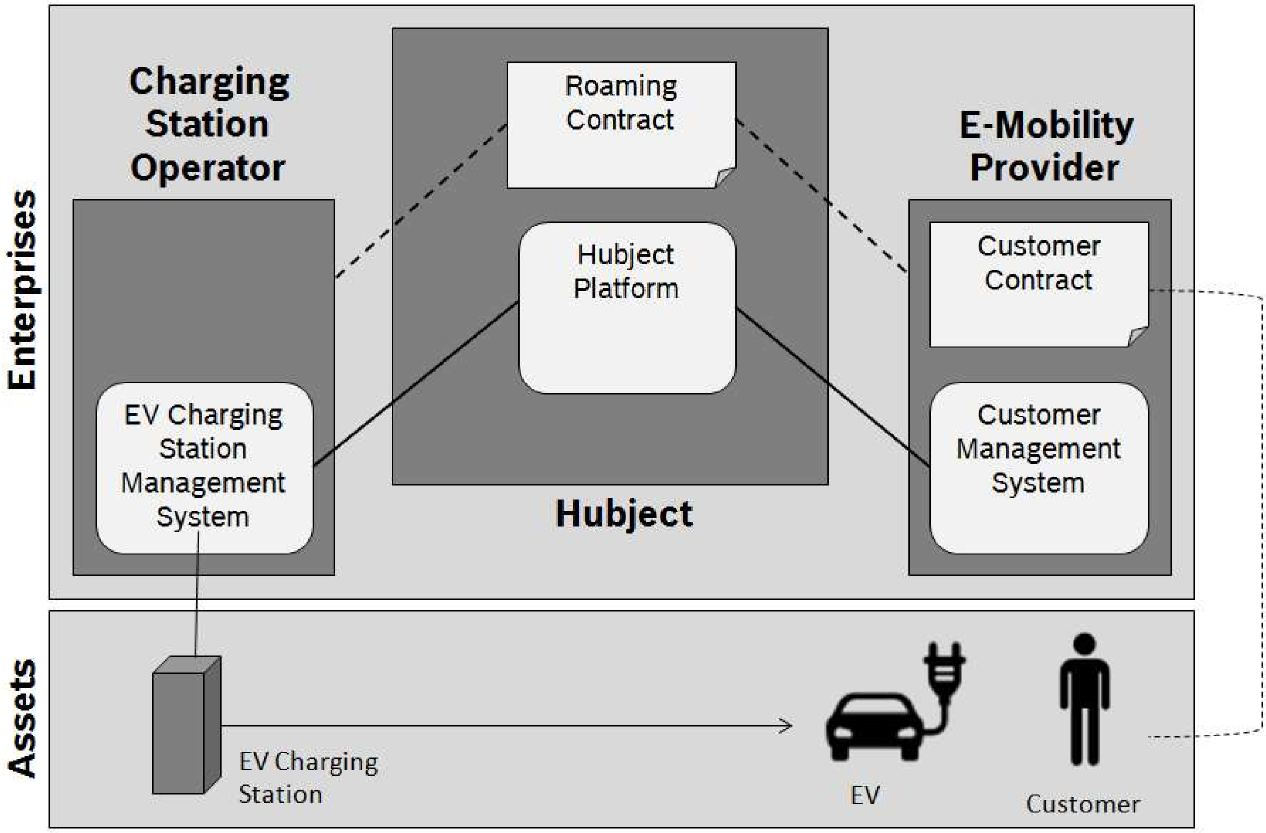


Figure 28 – Hubject simplified architecture. [89]

4.2.5 EVSE vendors and OCPP

Using open standards to communicate with the EVSEs allows the EVSE management platform to communicate with devices independently of their vendor, which gives many advantages to the EVSE manager:

- Avoids vendor lock in
- Encourages competition among EVSE providers, which is an advantage for the EVSE manager
- Facilitates scalability of the EVSE network, since new EVSEs may be added to the system without modifying the EVSE management platform

The OCPP is an open application level protocol promoted by the OCA, for communication between EVSEs and central management systems [90]. OCPP is an open protocol for EVSE management. It is broadly adopted in Europe and Asia, and the Open Charge Alliance provides a Compliance Testing Tool for the latest version of the protocol.

For the last years, OCA has worked intensively to adjust OCPP to better meet the ever-changing market and industry requirements. In line with the last four years, OCA will release OCPP 2.0 independently in the fourth quarter of 2017, providing extra functionalities for e.g. security, smart charging and device management.

In Figure 18, is shown the full roadmap for OCPP:

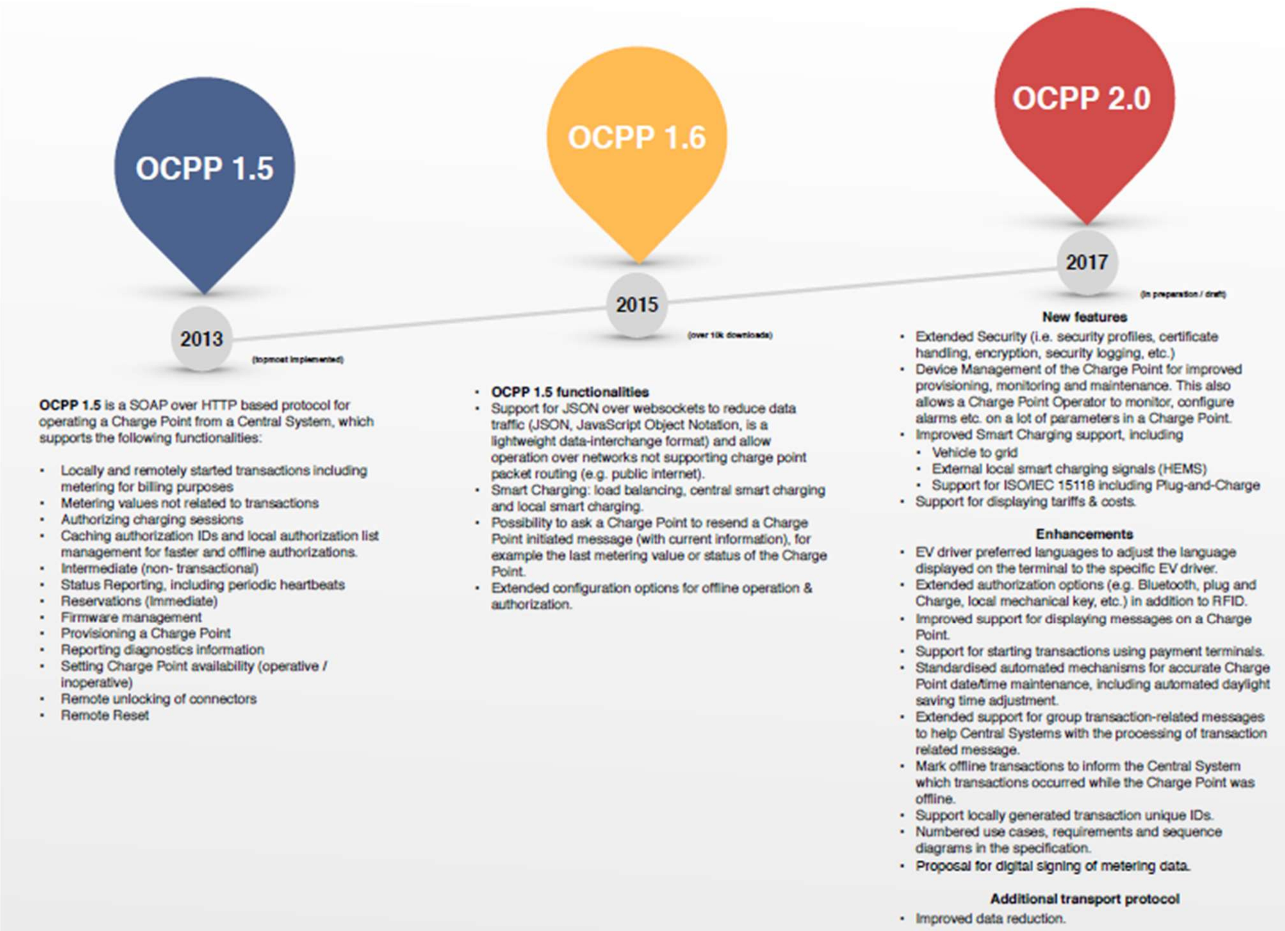


Figure 29 – OCPP roadmap [91]

4.2.6 Communications with EVSE and OCPP

In order to monitor and control the EVSEs from a management platform, the EVSE manager has to invest in the appropriate communication infrastructure. Usually, EVSE manufacturers include a TCP/IP based protocol for monitoring and control. As a reference, OCPP is built upon SOAP web services, thus any communication technology providing TCP/IP connectivity to the EVSEs using this open protocol can be applied.

An additional advantage of OCPP protocol is that it contemplates the EVSE registration process in the control platform, which is initiated from the EVSE side. This facilitates enormously the task of maintaining the EVSE communication details from the perspective of the EVSE management platform, since this responsibility is leveraged and distributed among every individual EVSE.

4.2.7 Booking and OCPP

One worthwhile functionality an EVSE manager has to be able to offer to its customers is the ability to book a charge point in advanced for a particular amount of time. This functionality adds value to the service that is provided to the customers, at the price of adding complexity to the central management system.

Booking procedure is first defined in OCPP v1.5 (released in 2013), which defines a set of messages to be exchanged between the EVSE management platform and the EVSE in order to lock it for a particular customer and up to a defined timestamp. One particularity of the procedure defined so far by this open standard is that reservation happens immediately after the messages are exchanged. That means that the business logic of the reservation remains a responsibility of the central system, thus allowing flexible reservation schemes, such as allowing reservation of any charge point in a particular area – EVSE management system will lock the most appropriate one accordingly to the latest information allowed and redirect the customer to it.

4.2.8 Open data

A key functionality required by the customers of an EVSE manager is having access to important information of the EVSE network, being the status of the EVSEs (i.e. whether it is occupied or not, and its schedule) the most relevant information.

4.2.9 Charge session schedule and smart charging

The proliferation of electric vehicles will soon impose a high demand to the current energy distribution grids, and it is foreseen that those sum up for a significant amount of the demand they have to support - an additional 30% on top of today's peak demand accordingly to [92]. Evaluation of the effect of electric vehicle penetration in the power demand that future smart grids will need to support is a field of extensive study at this moment.

Within this context, there exists the necessity of moving from the most basic charging patterns – charge now and as fast as possible, as implemented by basic charge points – towards the paradigm of smart charging. Smart charging basically implies the capability of the EVSE to modulate the power that is supplied to the electric vehicle along the duration of the charging session, even with the capability to reverse the flow of energy and make the electric vehicle operate as an energy production resource – concept known as Vehicle-to-Grid V2G or Vehicle-to-home V2H.

Depending on the location and owner of the charge point, this capability can provide many benefits and opens up interesting options:

- EVSE hubs with different charge points connected to the same supply point in the distribution grid might be managed efficiently. Agreements between EVSE operator and DSO can contain a limit on the peak power that can be supplied to the hub. This severely affects the way the EVSE management system has to organize the charge sessions that happen simultaneously. Customers' requirements (required state of charge and limit time period) need to be fulfilled while respecting the peak power constraint. Smart charging can, in such cases, modulate the power supplied to each of the vehicles of the hub in an optimized way in order to achieve these objectives
- Smart charging allow to reduce economic costs associated to energy. The capability of modulating the power supplied to a number of vehicles in time allows optimization of these supply curves towards minimizing the energy cost associated to the supplied energy. This scenario is particularly interesting when EVSE manager can benefit from dynamic energy prices that may change hourly accordingly to external context parameters – e.g. type of production units active at that moment.
- Reduce environmental impact of the EVSE manager by promoting green energy consumption. Supply curves can be optimized to prioritize supply of energy at those moments of high green energy production. In this line, green EVSE managers are in position of signing contracts to buy energy of local renewable producers, and bind their supply needs to the existing production as much as possible
- New business models are possible by providing ancillary services to third parties. EVSE manager controls a significant amount of batteries – as much as vehicles connected to its network. Capability to modulate demand and even reverse the power flow and, by doing so, provide energy back to the grid (V2G) can be very beneficial to support DSOs to meet congestion problems. Both reducing demand and enabling production near to the demand can help alleviating congestion problems. In addition, Electric vehicle batteries can in this way be very beneficial to support the intermittency of renewable energy sources.

In order to perform smart charging, the procedures to communicate all necessary information from the EVSE management system to the charge points were defined at version 1.6 of the OCPP protocol, released at 2015. Protocol clearly specifies how the EVSE manager can send a *charging profiles profile* to particular EVSEs in order to modulate the power supplied during a charging session. Those *charging profiles* basically define calendar-based restrictions on the maximum power an EVSE is authorized to supply. OCPP 1.6 [93] defines three different use cases for this functionality:

- **Load balancing:** The Load Balancing use case is about internal load balancing within the Charge Point, the Charge Point controls the charging schedule per connector. The Charge Point is configured with a fixed limit, for example the maximum current of the connection to the grid. – internal balancing of a charge point with several connectors,

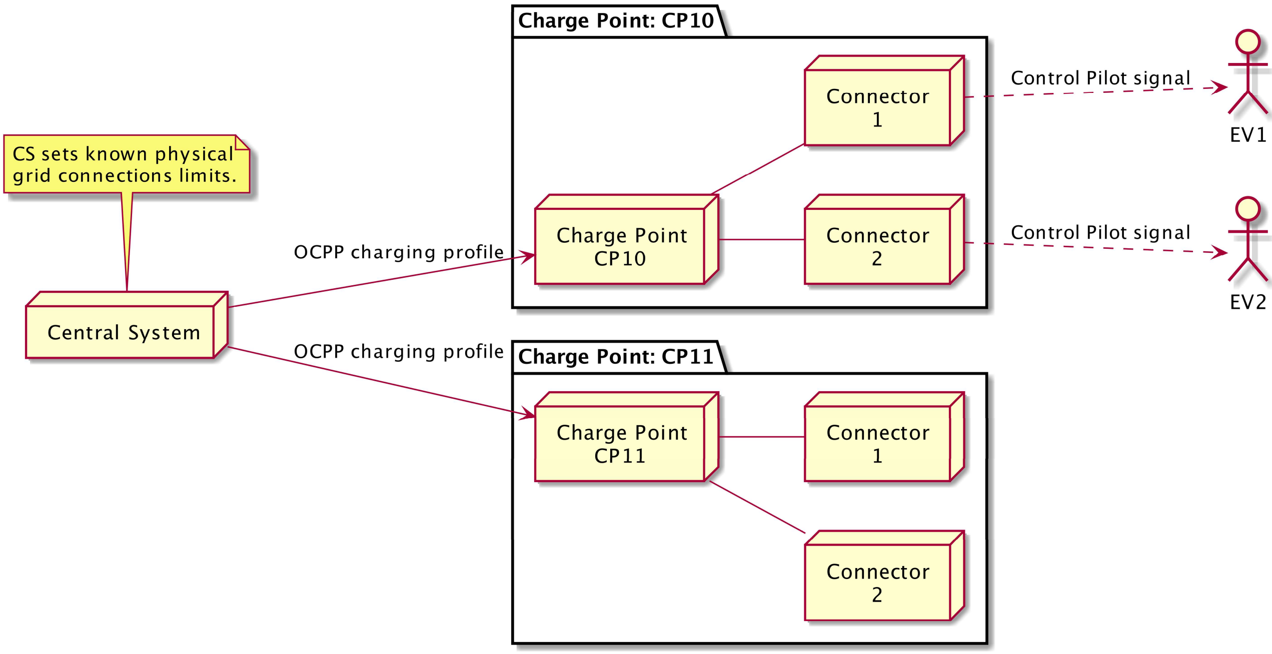


Figure 30 - OCPP 1.6 Load Balancing

- **Central smart charging:** the core of this section, allowing the EVSE manager to perform optimization over the complete set of EVSEs accordingly to the organization optimization objective, and With Central smart charging the constraints on the charging schedule, per transaction, are determined by the Central System. The Central System uses these schedules to stay within limits imposed by any external system. The Central System directly controls the limits on the connectors of the Charge Points. Central smart charging assumes that charge limits are controlled by the Central System. The Central System receives a capacity forecast from the grid operator (DSO) or another source in one form or another and calculates charging schedules for some or all charging transactions

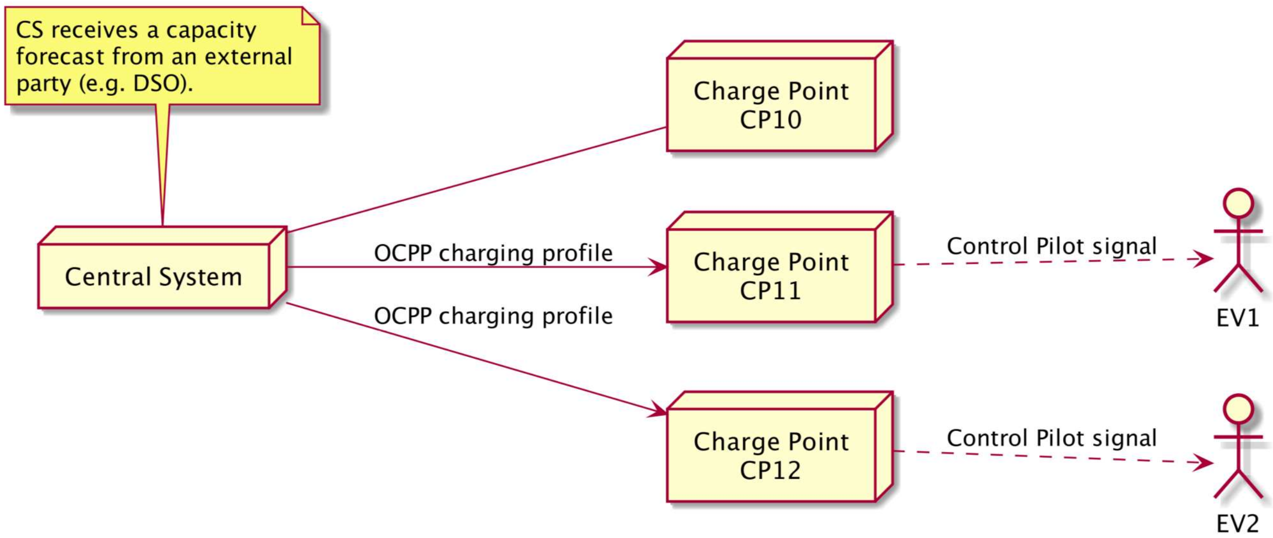


Figure 31 – OCPP 1.6 Central Smart Charging

- **Local smart charging**: optimization over the operation of a set of charge points operated by a local controller in a more hierarchical control architecture. The Local Smart Charging use case describes a use case in which smart charging enabled Charge Points have charging limits controlled locally by a Local Controller, not the Central System. The use case for local smart charging is about limiting the amount of power that can be used by a group of Charge Points, to a certain maximum. A typical use would be a number of Charge Points in a parking garage where the rating of the connection to the grid is less than the sum the ratings of the Charge Points. Another application might be that the Local Controller receives information about the availability of power from a DSO or a local smart grid node.

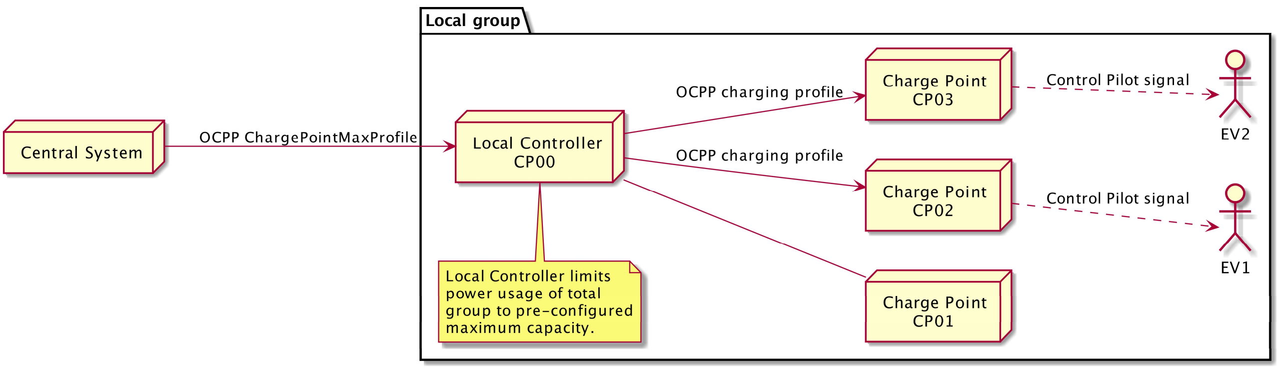


Figure 32 – OCPP 1.6 Local Smart Charging

The capability to reverse the flow of energy and using vehicle's batteries as a production unit (V2G or V2H) is, nowadays, still a novel feature of EVSEs and EVs, since only a minor portion of those implement these. The OCA is currently working in the OCPP 2.0 draft, planned to be published 2018, which defines the messages needed to manage V2G features of the EVSE from the EVSE management system [94].

Model	Category	Input AC power	PV input voltage	Max AC output power	Max AC current	Max DC output power	Max DC current	Output voltage	Input power source	Comm. protocols	Storage capacity
Honda Power Exporter 9000	V2L			9kVA	30A			AC 100V/200V	DC150-450V	V2L protocol DC Version 2.1	
MiEV power BOX	V2L					1500W	15A	DC 100V			
Mitsubishi Electric (6kW)	V2H										
Honda Power Manager	V2H					5.5kW	27.5A	DC 200V		CHAdeMO 1.0	
Endesa (10kW)	V2G									CHAdeMO	
Nichicon (6kW)	V2H									CHAdeMO 1.0	
e8energy (10kW)	V2H	10kVA	DC 150-340V					DC 200-400V		CHAdeMO 1.0	10kWh
Tsubakimoto (5kW)	V2H									CHAdeMO	
Princeton Power Systems (10kW, 30kW)	V2G			10 kW, 30 kW			40A, 120A	500V		CHAdeMO	

Table 11 – Commercially available V2x EVSEs [95]

5 PORTS AND SHIPS ELECTRIFICATION CHARACTERISTICS

5.1 COLD IRONING

Worldwide concern about air quality and global warming has led to emission regulations for the shipping industry. International shipping contributes with approximately 2,4% of global greenhouse gas (GHG) emissions, and its share is expected to increase in the future. GHGs from shipping include mainly carbon dioxide (CO_2), methane (CH_4) and dinitrogen oxide (N_2O), of which CO_2 dominates the global warming potential.

In an attempt to reduce the ship contribution to GHGs, a new regulatory framework has been introduced by the International Maritime Organization (IMO). IMO has been working to reduce harmful impacts of shipping on the environment since the 1960s. Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL Convention) was adopted in 1997, to address air pollution from shipping. The regulations for the Prevention of Air Pollution from Ships (Annex VI) seek to control emissions from ships (SOx, NOx, ODS (Ozone Depleting Substances), VOC (Volatile Organic Compound) shipboard incineration) and their contribution to local and global air pollution, human health issues and environmental problems.

In addition, Annex VI entered into force on May, 19th 2005 and a revised Annex VI with significantly enforced requirements was adopted in October 2008 which entered into force on July, 1st 2010. The regulations to reduce sulphur oxide emissions introduced a global limit for sulphur content of ships' fuel oil, with tighter restrictions in designated emission control areas in order to reduce marine vessels' exhausts that pollute the environment.

In addition, IMO commissioned a review on the availability of low sulphur fuel oil for use by ships, to help member states determine whether a new lower global cap on sulphur emissions from international shipping shall be established on January, 1st 2020 or be deferred until January, 1st 2025. The current global limit for sulphur content of ships' fuel oil is 3,50% m/m (mass by mass). The new global cap will be 0,50% m/m will apply on and after January, 1st 2020 or January, 1st 2025, depending on the outcome of the review. Under the new global cap, ships will have to use fuel oil on board with a sulphur content of no more than 0.50% m/m, against the current limit of 3,50%, which has been in effect since January, 1st 2012. The interpretation of "fuel oil used on board" includes use in main and auxiliary engines and boilers [96].

First results seem to indicate that the 2015 sulphur regulations have brought about substantial emission reductions with reductions sulphur emissions between 40 to 80 %. [97]

This new framework also includes low permissible emission rates in the broader area of ports, often named as Emission Controlled Areas (ECA's). In these areas the limits for the emissions of SOx are even stricter as depicted in Table 12. The current ECA's and possible future ECA's are shown in Figure 36 [96].

Outside an ECA established to limit SOx and particulate matter emissions	Inside an ECA established to limit SOx and particulate matter emissions
4,50% m/m prior to 1 January 2012	1,50% m/m prior to 1 July 2010
3,50% m/m on and after 1 January 2012	1,00% m/m on and after 1 July 2010
0,50% m/m on and after 1 January 2020*	0,10% m/m on and after 1 January 2015

Table 12 – Limits on SOx and particulate matter emissions inside and outside an ECA (Emission Control Area). [96]

Figure 33 – Current and Possible future Emission Control Areas (ECA's). [96]

Several alternative methods are under development in order to achieve these goals. For example, some regions (e.g. California) already require ships to switch to cleaner fuel (e.g. low-sulphur compliant fuel oil), when they are in their local waters. There has been also a focus on slower speed at sea in order to reduce fuel consumption, and there has indeed been a significant reduction in CO_2 emissions per transport work as a consequence of slow steaming. However, the average speed of the world fleet depends foremost on freight rates and on the fuel price. Thus, there is a risk that ships will speed up again and that emissions will increase when freight rates rise in times of prosperity. There has also been a focus on improved ship design, for example the development of the energy efficiency design index (EEDI) at the IMO [98].

One effective way towards the emission reduction in the vicinity of ports is to use “cold ironing”, also known as “alternative marine power system” or “shore to ship power supply”. The actual term comes from the act of turning off all internal combustion engines resulting in ‘’a vessel is going cold’’. Cold ironing is a term initially used by U.S. Navy and refers to the time when all ships had coal fired iron clad steam engines. When a ship would come into port there would be no need to stoke the fire, as a result, the iron clad engines would literally cool down and eventually go completely cold, thus the term cold ironing. Cold ironing supplies the ship power by the land-based grid instead of the on-board diesel engines. The Cold-Ironing concept is illustrated in Figure 34.

Figure 34 – Cold-Ironing concept. [99]

While the ship is berthed at port, its auxiliary engines are used for lighting, heating, hot water, air conditioning etc. These operations consume a large amount of diesel and heavy oil, generating harmful exhaust fumes, noise and vibrations. Moreover, emissions from shipping fuel have a serious impact not only on the environment but also on the health of port workers, on-board personnel, and the inhabitants of port areas. The concept of ‘’plugging in’’ a vessel at port allows completely to shut down all vessel’s diesel generators and practically eliminate pollution coming directly from shipboard emissions as well as noise and vibrations. The power required for the vessels to continue their activities at birth can be provided by a variety of sources: port city’s power grid, in-port power plants or even by renewable energy sources [99].

Cold ironing, nowadays, is often used to describe a new generation of high voltage shore connections with fast plugs and seamless power transfer without blackouts. Considering economic and financial aspects, it is important to underline that cold ironing is most effective and convenient for those vessels that call frequently at the same port and operate on dedicated routes, and for those that consume huge amounts of power and emit high levels of air pollutants when berthed. The vessel typologies include: ferries, cruise ships, containerships, LNG carriers and tankers.

The world's first commercial cold ironing system was installed at the port of Gothenburg in 2000. Since then, the technology has been applied in ports of the Pacific coast of North America as well as in Germany, Sweden, Finland and the Netherlands. In 2010, the organization responsible for the port of Gothenburg decided to install another shore substation, which will supply vessels with an 11kV frequency converter system. By the end of 2010, shore-to-ship power connections have been implemented widely in more than twenty port terminals worldwide, and on over 100 ships ranging from cruise vessels to oil tankers and container ships. Existing cold ironing implementations are listed in Table 13.

Port	Country	Connection Voltage (kV)	Frequency (Hz)
Gothenburg	Sweden	0,4/6,6/10	50
Stockholm	Sweden	0,4/0,69	50
Helsingborg	Sweden	0,4/0,44	50
Pitea	Sweden	6	50
Antwerp	Belgium	6.6	50/60
Zeebrugge	Belgium	6.6	50
Lubeck	Germany	6	50
Hamburg	Germany	6/6,6/10/11	50/60
Oslo	Norway	6,6	50
Bergen	Norway	0,44/0,69	50/60
Rotterdam	Netherlands	6,6	50
Kotka	Finland	6,6	50
Oulu	Finland	6,6	50
Kemi	Finland	6,6	50
Livorno	Italy	6,6/11	50/60
Marseille	France	11	50
Los Angeles	USA	0,44/6,6	60
Long Beach	USA	6,6	60
Seattle	USA	6,6/11	60
San Francisco	USA	6,6/11	60
Pittsburg	USA	0,44	60
Juneau	USA	6,6/11	60
San Diego	USA	6,6/11	60

Table 13 – Existing Shore to Ship Power Supplies Worldwide [100]

The existing cold ironing connection solutions can be split into three main categories [99]:

- For small power exchange requirements (<1 MW), all use manual operations for cable and connector handling, such as in several applications in the Baltic Sea.

- For large cruise ships with large power requirements (<12 MW) mechanized supports and handling of the cable on the connectors up to the vessel power sockets, with manual connection, such as for several US (Alaska) applications.
- For Container Carriers (2 to 12 MW) the Port of Long Beach is actively promoting a solution, called "AMP" (Alternative Maritime Power) based on two on-board mechanized cable reels with manual connection, and this solution is considered by IEC in forming the basis of the relevant standard.

In 2009, NG2, a company based in France, made a world first by releasing on the market the PLUG (Power-Generation during Loading & Unloading) solution, the first fully automated shore power technology which allows connecting ship to shore power supply with a multi MW, High Voltage link in a time estimated to be less than a minute [99]. In January 2011, NG2 had equipped with a 4 MVA, 11kV unit the vessel Color Magic ROPAX and the port of Oslo. All operations will be performed by a single crew member who will control from the ship side the whole PLUG system.

Finally, when compared to running the onboard generators, the use of the cold ironing supply was seen to reduce CO_2 emissions by a sufficient amount, for example by 46% based on the local (Spanish) power generation mix in [101]. There is also an extensive feasibility study about sailboats in Italian harbors [102], where the diesel generators were assumed to be replaced by the Battery Energy Storage Systems (BESS) and RES in the vessels.

5.2 GENERAL REQUIREMENTS AND CONSTRAINTS FOR SHORE TO SHIP SUPPLY

Currently there is insufficient infrastructure in the majority of both ports and existing ships to support cold ironing. The main issue is the vast differentiation in the electrical characteristics of the vessels. For example, primary distribution voltage of a vessel can vary from 440V to 11kV. Load requirement varies from ship to ship and ranges from a few hundred kW up to a few MW. Thus, it is questionable if the inland grid at the port can always cover the demands of cold-ironed ships. Different characteristics of ship's voltage, frequency and power demand are presented in Table 14 for various types of ships.

Type of Ship	Voltage Level	Frequency	Average Power Demand
Cruise Ship	6,6kV/11kV	50/60 Hz	5-10 MVA
Bulk carriers/ tankers	440V/6,6 kV	50/60 Hz	0,5-1 MVA
Container Ships	6,6kV	50/60 Hz	1–2 MVA
Ro/Ro ships	440V/6,6 kV	50/60 Hz	0,5-1 MVA

Table 14 – Electrical characteristics of different ships

In addition, even vessels of the same type could differ as it is presented in Figure 35 where the frequency of the electrical supply of 300 random ships is presented [103].

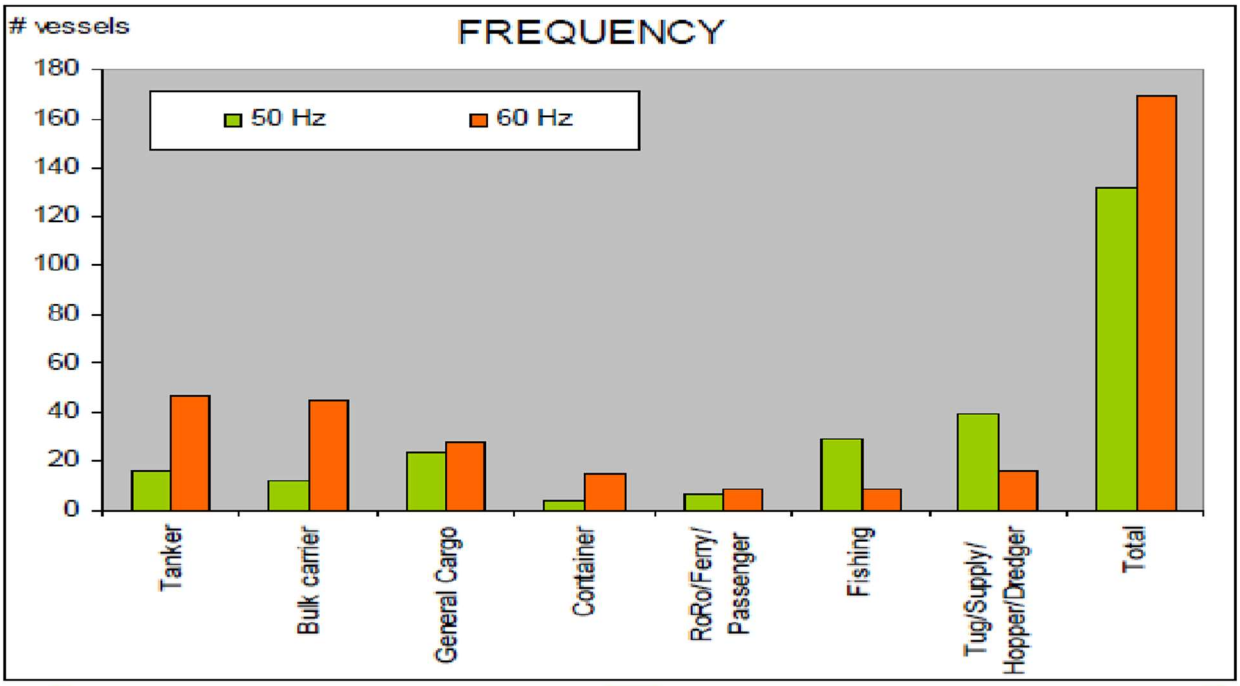


Figure 35 – Frequencies at different types of vessels 300 random vessels. [103]

Therefore, it is required a distribution system in the port which is capable of providing power in every vessel, despite of its characteristics.

Existing Cold Ironing connection types that have been reported in literature can be divided into three main categories [99]:

- **High voltage transformation**: In this connection type the High Voltage grid is transformed to 400V (or the selected Voltage) for each vessel at its berth. Conversion stages are minimal but there is no frequency flexibility when using transformers so –if required– motor-generators are often used.
- **High voltage transformation with frequency converter**: In this connection type, there is also a rectifier and inverter. The constant frequency link is coupled with the variable frequency link to increase the flexibility by converting the frequency of the grid to the appropriate load frequency. With this solution the system gives as output variable frequency (50Hz and 60Hz) depending on the ship's grid. It offers the flexibility to supply power to vessels with 50Hz and 60Hz system frequencies at the same time. Selection of this solution depends on the distribution system and the logistics of the port. A schematic is given in Figure 36.
- **High voltage transformation with DC link**: This connection utilizes a DC grid. After High Voltage transformation, a rectifier converts the voltage form AC to DC. A DC bus link is connecting the station where the converter is placed with DC/AC inverters located at each berth station. These stations supply AC at required voltage and frequency, directly onboard. This type of connection provides the best flexibility, however it is the most costly. The schematic is presented in Figure 37.

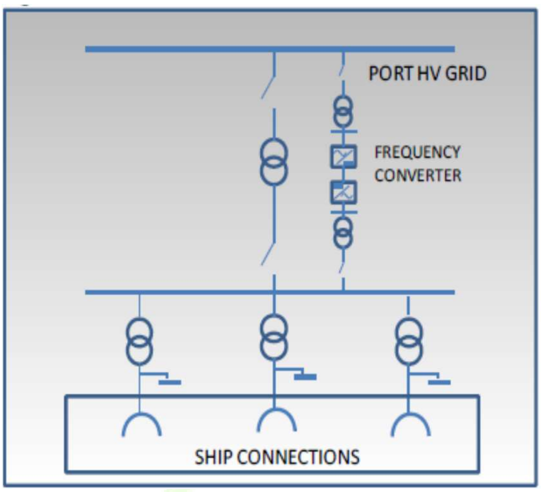


Figure 36 – High voltage transformation with frequency converter. [99]

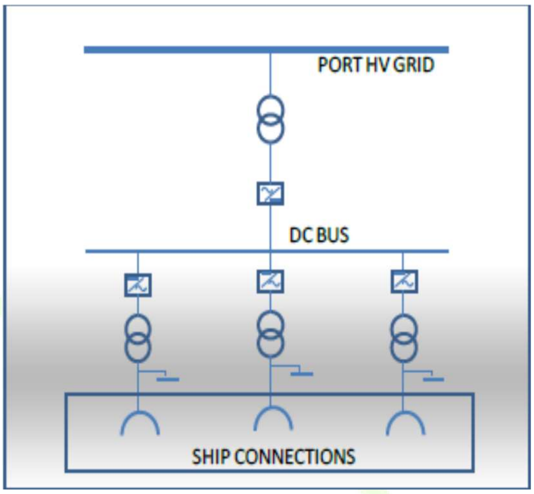


Figure 37 – High voltage transformation with DC link. [99]

However, in most ships, the shore connection is seldom used, due to the following reasons [99]:

- The capacity of the installed shore connection facilities, comprising cabling, switch-gear and plugging components, is limited. It is noted that, in certain cases, voltage matching between shore mains and ship grid is matched via a power transformer with an associated tap changing unit. This transformer assembly is of significant volume and weight and cannot accomplish any frequency matching.
- The connection is not well monitored or controlled via the ship's Power Management System (PMS), but is done manually based on the experience of the personnel (aboard and ashore). Moreover, in most ships no synchronizing facility is integrated. Hence, exclusive power supply from shore mains necessitates a temporary "black ship situation", i.e. shutting the ship generators down, and a subsequent activation of the shore supply. However, while a black-out is of minor importance in most cargo ships, it is very unpleasant in cruise and passenger ships. Still, it is these latter ship types that are proven to have increased pollution rates in ports, primarily due to their hotel luxury electric loads. It is noted that a synchronizing facility can be integrated, monitored and controlled via the ship PMS.
- The local infrastructure of the electrical grid is insufficient to support the ship load (typical of large cruise ships visiting smaller islands).

All the above point out the necessity of an electrical infrastructure located at the port which is able to provide power to vessels at different voltage levels and frequencies. The IEC/IEEE 80005-1,2,3 standards were created in order to address the issues of the high and low voltage shore connections and will be described in section 5.3.

However, these standards do not examine the local grid's infrastructure ability to supply the demanded power to the vessels. While at port, the power demand of the vessels could differ among different types of vessels. In Table 15 some average power demand values are presented according to the type of the vessel as a load factor of its auxiliary's generators which operate when the ship is at the port [104].

Ship Type	Average Auxiliaries Engines Power (kW)	Load Factor in Port	Power Demand in Port (kW)
Auto Carrier	2850	0.24	684
Bulk Carrier	1776	0.22	391
Container Ship	6800	0.17	1156

Ship Type	Average Auxiliaries Engines Power (kW)	Load Factor in Port	Power Demand in Port (kW)
Passenger Ship	11000	0.64	7040
General Cargo	1776	0.22	391
RORO	2850	0.30	855
Reefer	3900	0.34	1326
Tanker	1985	0.67	1330

Table 15 – Average Power Demand according to vessel type [91]

In a port, the vessels usually are berthed to specific places according to their functionality. For example, passenger ships are berthed in different berths compared to cargo ships and tankers. The following two pictures taken by the maritimetraffic.com [105] show the port of Piraeus and the port of Hamburg. With green dots are the cargo vessels, with blue dots the passenger vessels and red dots the tankers.

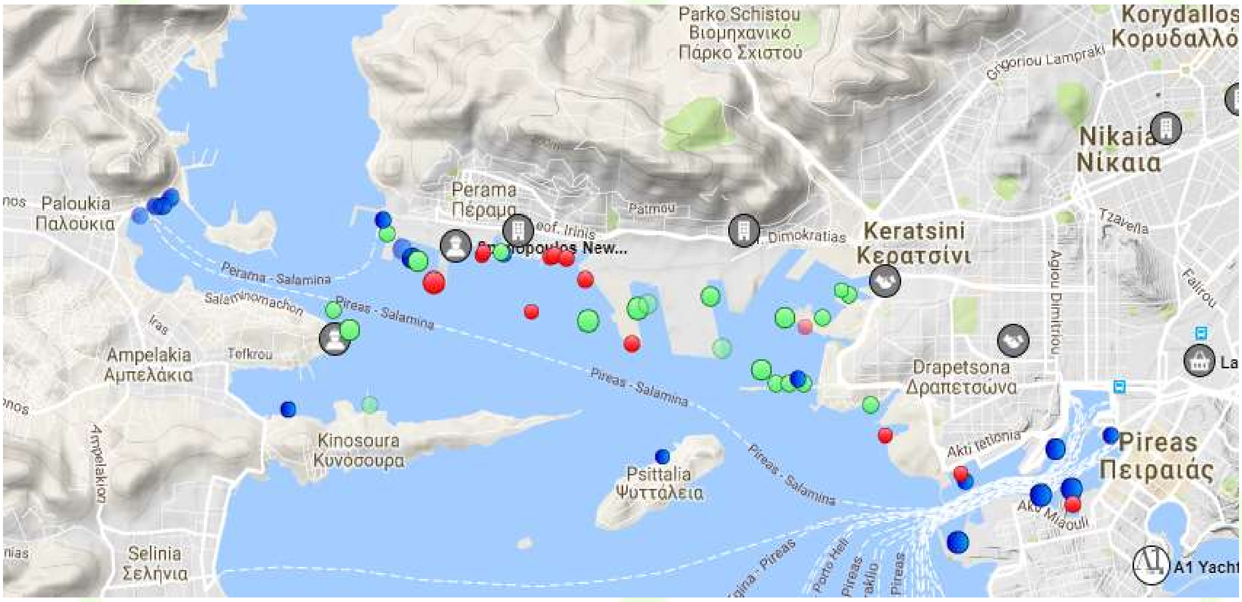


Figure 38 – Different type of Vessels at port of Piraeus. [105]

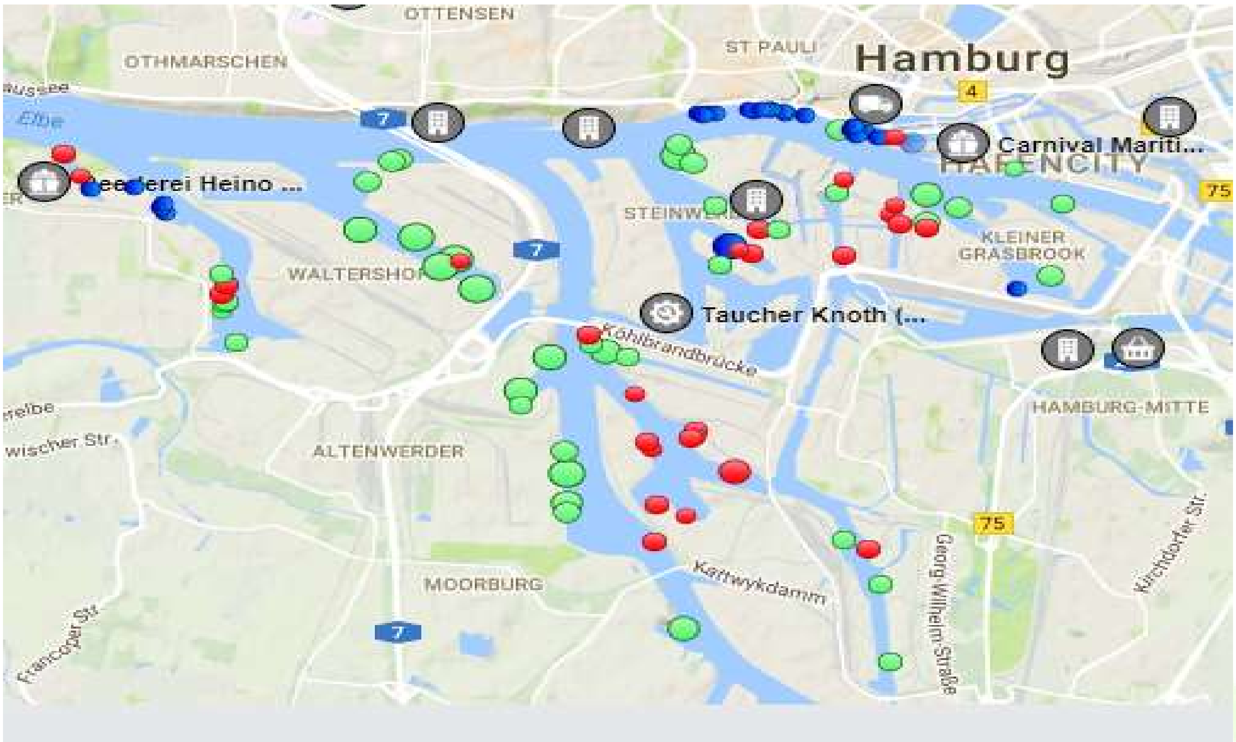


Figure 39 – Different type of Vessels at port of Hamburg. [105]

As we can observe, the vessels are berthed to different places in each port according to their type. Further segregation of the vessel's berths can be based on the length of the vessel or other technical characteristics of the berth. For example, the Port of Gothenburg has 1.140 meters of mooring space at the southern quay and 630 meters of mooring space at the western quay dedicated specifically to container vessels. The general minimum UKC (under keel clearance) is 0,5 meters. The exceptions are berths 610-612 where the minimum UKC is 0,7 meters. Detailed information about the different berths can be found in Table 16. There is one berth at the Port of Gothenburg dedicated to car carriers [106].

	Berth 600	**Berth 610-612**
Charted depth (meters)	8,0	11,0
Max. draught (meters)	7,5	10,5
Maximum length of vessel accepted (meters)	170	290

Table 16 – Differences at berths in Gothenburg port. [93]

Another important characteristic for the amount of energy needed for cold ironing implementations is the time that the vessel stays in port. The time that a vessel stays in a port depends on different factors. For example, for a cargo ship loading/unloading time could differ among separate visits to a port according to several factors. In [107] some general observations on correlations between ship loading/unloading time and influence of ship characteristics as well as workers engaged during the loading/unloading process are given. Also, it is created and implemented a methodology of defining correlations between ship loading/unloading time and some parameters from the group of influential factors referred on port machinery (duration of ship loading/unloading time interruptions caused by port machinery failures and port machinery technological adequacy).

In addition, marinetraffic.com [105] could be proven quite useful in order to extract historical data about vessels' time in port. Marinetraffic.com is based on the automatic identification system (AIS) which is an automatic tracking system used for collision avoidance on ships and by vessel traffic services (VTS). When satellites are used to detect AIS signatures, the term Satellite-AIS (S-AIS) is used. AIS information supplements marine radar, which continues to be the primary method of collision avoidance for water transport. Information which AIS equipment provides is –among others– unique identification, position, course, and vessel speed.

Using AIS marinetraffic.com can provide for each port:

- port ID;
- port name;
- vessels identity;
- timestamp;
- arrival time;
- departure time.

Using the above data (average ship power demand, ship time in port) a load profile due to cold ironing could be identified for each berth as well as for the port as a whole. According to the power and current ratings at each berth, sufficient cables can be chosen to transfer the power from the transformer (or frequency converter according to the port infrastructure) to the ship.

In addition, knowing the increase in the port power demand, the port authorities could investigate if the port electrical grid is sufficient. For example, congestion issues could exist at the lines or at the HV/MV transformer of a big port. This could lead to further investments costs for the port authorities for cold ironing implementations in the port area because of new equipment that might be required (transformer, cables).

The DSO (Distribution System Operator)/ TSO (Transmission System Operator) should also investigate the additional stress that could be introduced in the electrical grid due to shore to ship power supply. Therefore congestion issues could also exist in the distribution/transmission network both in lines or HV/MV transformers. Moreover, this extra electrical load in the port could lead to voltage drop issues in the grid.

In ports that are connected in power grids that operate autonomously the ship-to-shore supply could impose stability issues for the whole system, because the local grid might be unable to supply the required power to the ship. An example of this could be a port in a small island that its electrical network isn't interconnected to the mainland. The power generation in an autonomous system of this type might be unable to cover the power demand that a cold ironing implementation could introduce (e.g. a 7MW power demand of a cruise ship).

In order to address these issues, either the demand of the port should be limited, hence the ship-to-shore power supply should be limited, or improvements in the electric grid infrastructure should be made. However, smart grid applications could be also used in order to address the above issues in the port area as well as for financial purposes. The correlation between smart grid and cold ironing is addressed in section 5.4

Finally, the switching equipment, which will be placed in the port area for shore-to-ship supply purposes, will provide both the port electrical infrastructure and the distribution/transmission grid with current harmonics. Sufficient, measures should be taken (e.g. passive/active filters) in order to avoid supplying current with high harmonic content to ships or the electrical grid. The harmonics should be kept below the limits that the national regulatory framework impose for the distribution/transmission grid. For the vessels, the IEC/IEEE 80005 standard described in section 5.3 states the limits in the harmonic distortion for the shore-to-ship power supply.

5.3 PROTOCOLS AND STANDARDS ON SHORE TO SHIP SUPPLY

For the reasons already mentioned (environmental considerations, noise etc.), it could become in the near future an increasingly common requirement for ships to shut down ship generators and to connect to shore power for as long as practicable during stays in port. To this direction IEC/ISO/IEEE 80005-1,2,3 standards were developed in an attempt to address this issue. The following standard was developed jointly by the IEC technical committee 18: Electrical installations of ships and of mobile and fixed offshore units, ISO technical committee 8: Ships and marine technology, subcommittee 3: Piping and machinery, and IEEE IAS PCIC Marine industry subcommittee.

5.3.1 IEC/ISO/IEEE 80005-1: High Voltage Shore Connection (HVSC) Systems – General Requirements

The IEC/ISO/IEEE 80005-1 describes high voltage shore connection (HVSC) systems, on board the ship and on shore, to supply the ship with electrical power from shore. This standard is applicable to the design, installation and testing of HVSC systems and addresses:

- HV shore distribution systems;
- shore-to-ship connection and interface equipment;
- transformers/reactors;
- control, monitoring, interlocking and power management systems;
- semiconductor/rotating convertors;
- ship distribution systems;

The typical HVSC system described in this standard is presented in Figure 40. [108]

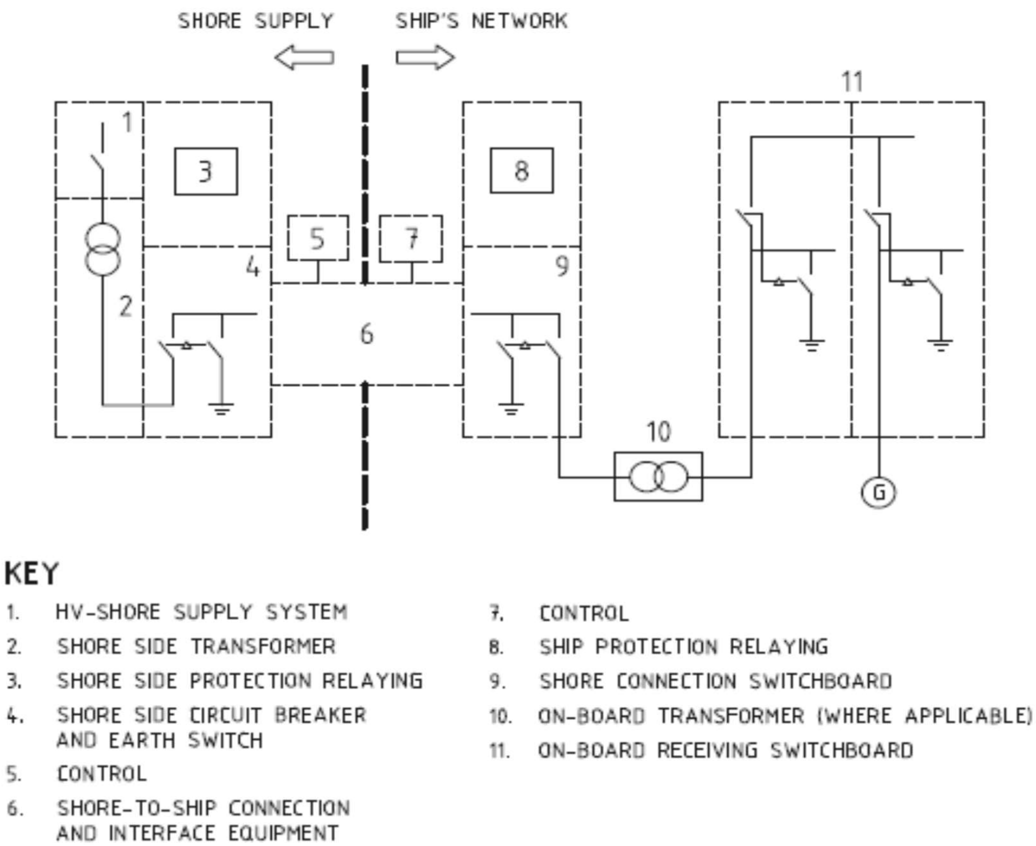


Figure 40 – Typical HVSC system described in 80005-1. [108]

For the shore system design, the standard states that an equipotential bonding between the ship's hull and shore earthing electrode shall be established. It also defines the compatibility assessment that should be performed to verify the possibility to connect a ship to shore HV supply. Compatibility assessment should be performed prior to the first arrival at a terminal and should determine the following [108]:

- compliance with the requirements of this standard and any deviations from the recommendations;
- minimum and maximum prospective short-circuit current;
- nominal ratings of the shore supply, ship to shore connection and ship connection;
- any de-rating for cable coiling or other factors;
- acceptable voltage variations at ship switchboards between no-load and nominal rating;
- steady state and transient ship load demands when connected to a HV shore supply, HV shore supply response to step changes in load;
- system study and calculations;
- verification of ship equipment impulse withstand voltage;
- compatibility of shore and ship side control voltages, where applicable;
- compatibility of communication link;
- distribution system compatibility assessment (shore power transformer neutral earthing);
- functioning of ship earth fault protection, monitoring and alarms when connected to a HVSC supply;
- sufficient cable length;
- compatibility of safety circuits;
- total harmonic distortion (THD);
- consideration of hazardous areas, where applicable;
- utility interconnection requirements for load transfer parallel connection;
- equipotential bond monitoring;
- when a HV supply system is connected, consideration shall be given to provide means to reduce current in-rush and/or inhibit the starting of large loads that would result in failure, overloading or activation of automatic load reduction measure;
- consideration of electrochemical corrosion due to equipotential bonding.

In addition, it mentions that the design and construction shall be integrated and coordinated among the parties responsible for shore and ship HVSC systems. It also states that during the operation of HVSC systems, a person in charge shall be identified at the shore facility and on board the ship for the purposes of communication and that the construction of the HV equipment and operating safety procedures shall provide for the safety of personnel during the establishment of the connection of the ship supply, during all normal operations, in the event of a failure, during disconnection and when not in use.

For the design requirements it states that:

- the protection and safety systems shall be designed based on the failsafe principle;
- effective means shall be provided to prevent accumulation of moisture and condensation;
- HVSC equipment shall be installed in access controlled spaces;
- all HVSC system components type and routine tests shall be performed according to relevant standards.

The location of the equipment is critical to the safety and efficiency of operation of the ship's cargo and mooring systems. When determining the location of the HVSC system, the full range of cargo, bunkering and other utility operations shall be considered, including:

- the cargo handling and mooring equipment in use on the ship and shore, and the areas that must be clear for their operation, along with any movement of the ship along the pier required to accommodate these operations;

- traffic management considerations such that the use of an HVSC system does not interfere with other ships' operations (including mooring) or prevent necessary traffic flow on the pier and to maintain open fire lanes where required;
- personnel safety measures, such as physical barriers to prevent unauthorized personnel access to HVSC equipment or the cable management equipment;
- tidal conditions and ship operations affecting ship’s free board shall be considered;
- characteristics of electrical equipment in areas where flammable gas or vapor and/or combustible dust may be present.

The standard also describes the system study and calculations that should be made in order to design the HVSC system, which are:

- the electrical load during shore connection;
- the short-circuit current calculations (according to IEC 61363-1) shall be performed that take into account the prospective contribution of the shore supply and the ship installations. The following ratings shall be defined and used in these calculations:
    - for shore supply installations, a maximum and minimum prospective short circuit current for visiting ships;
    - for ships, a maximum and minimum prospective short circuit current for visited shore supply installations;
- the calculations may take into account any arrangements that:
    - prevent parallel connection of HV shore supplies with ship sources of electrical power;
    - restrict the number of ship generators operating during parallel connection to transfer load;
    - restrict load to be connected;
- system charging (capacitive) current for shore and ship;
- this system charging current calculation shall consider the shore power system and the expected ship power including the on line generator(s);
- shore power transformer neutral earthing resistor analysis;
- transient overvoltage protection analysis.

The 80005-1 standard defines also the high voltage shore supply characteristics (voltage, frequencies) as well as the quality of the supply. The HV shore connections should provide nominal voltage of 6,6kV AC and/or 11kV AC galvanically separated from the shore distribution system. The operating frequencies (Hz) of the ship and shore electrical systems shall match, otherwise, a frequency convertor may be utilized on shore. Where ships undertake a repeated itinerary at the same ports and their dedicated berths, other IEC voltage nominal values may be considered (according IEC 60092-503). [108]

Ship electrical equipment shall only be connected to shore supplies that will be able to maintain the distribution system voltage, frequency and total harmonic distortion (THD) characteristics given below [108]:

- voltage and frequency tolerances (continuous):
    - the frequency shall not exceed the continuous tolerances $\pm$5% between no-load and nominal rating;
    - for no-load conditions, the voltage at the point of the shore supply connection shall not exceed a voltage increase of 6% of nominal voltage;
    - for rated load conditions, the voltage at the point of the shore supply connection shall not exceed a voltage drop of -3,5% of nominal voltage;
- voltage and frequency transients:
    - the response of the voltage and frequency at the shore connection when subjected to an appropriate range of step changes in load shall be defined and documented for each HV shore supply installation,

- the maximum step change in load expected when connected to a HV shore supply shall be defined and documented for each ship. The part of the system subjected to the largest voltage dip or peak in the event of the maximum step load being connected or disconnected shall be identified;
    - comparison of the above shall be done to verify that the voltage transients limits of voltage +20% and -15% and the frequency transients limits of ±10%, will not be exceeded;
- harmonic distortion:
    - for no-load conditions, voltage harmonic distortion limits shall not exceed 3% for individual harmonic and 5% for total harmonic distortion.

It specifies also the requirements for the shore side equipment (circuit breakers, earthing switch, neutral earthing resistor) as well as the standards that they should be in accordance and their requirements e.g. Dyn winding for the transformer. It also describes the characteristics of the protection system of the shore side equipment which should open all insulated poles in the event of:

- overcurrent including short-circuit,
- over-voltage/ under-voltage, and
- reverse power.

In addition, it describes the HV interlocking and the handling of HV plug/sockets as well as the operating of circuit breakers, disconnectors and earthing switches. Finally, for the shore side equipment it describes the frequency converter characteristics, the standards that it should be in accordance as well as its protection.

It describes also ship to shore connection and interface equipment includes standardized HVSC systems, cables, earthing and communications between ship and shore. The characteristics of the cable management system, the plugs and outlets and their standards are also presented in detail. The cables shall be at least of a flame-retardant type in accordance with the requirements given in IEC 60332-1-2. The outer sheath shall be oil-resistant and resistant to sea air, seawater, solar radiation (UV) and shall be non-hygroscopic. The maximum permissible temperature for the insulation shall be at least 90°C. Control and monitoring cables shall be at least of a flame-retardant type in accordance with the requirements of IEC 60332-1-2.

The standard describes the ship's distribution system protection (short circuit protection, fault monitoring and alarm), the switchboard, the on-board transformer, the instrumentation and protection. There is a section also about the ships power restoration procedure when a fault occurs in the HV shore connection. Ship equipment shall be protected and controlled by the ship's own protection and control systems. If the shore supply fails for any reason, supply by the ship's own generators is permitted, after disconnecting shore supply. Finally, the verification tests are described after the installation as well as the periodic tests and maintenance. In the annexes of the standard, special requirements are describes for specific types of ships (Ro-Ro, cruise ships, container ships and liquefied natural gas carriers (LNGC)). [108]

5.3.2 IEC/ISO/IEEE 80005-2: Data Communication and Control

This part of IEC/IEEE 80005 describes the data interfaces of shore and ships as well as step-by-step procedures for low and high voltage shore connection systems communication for non-emergency functions, where required. It also specifies the interface descriptions, addresses and data type and specifies communication requirements on cruise ships, in Annex A. The general communication diagrammdiagram is presented in Figure 41. [109]

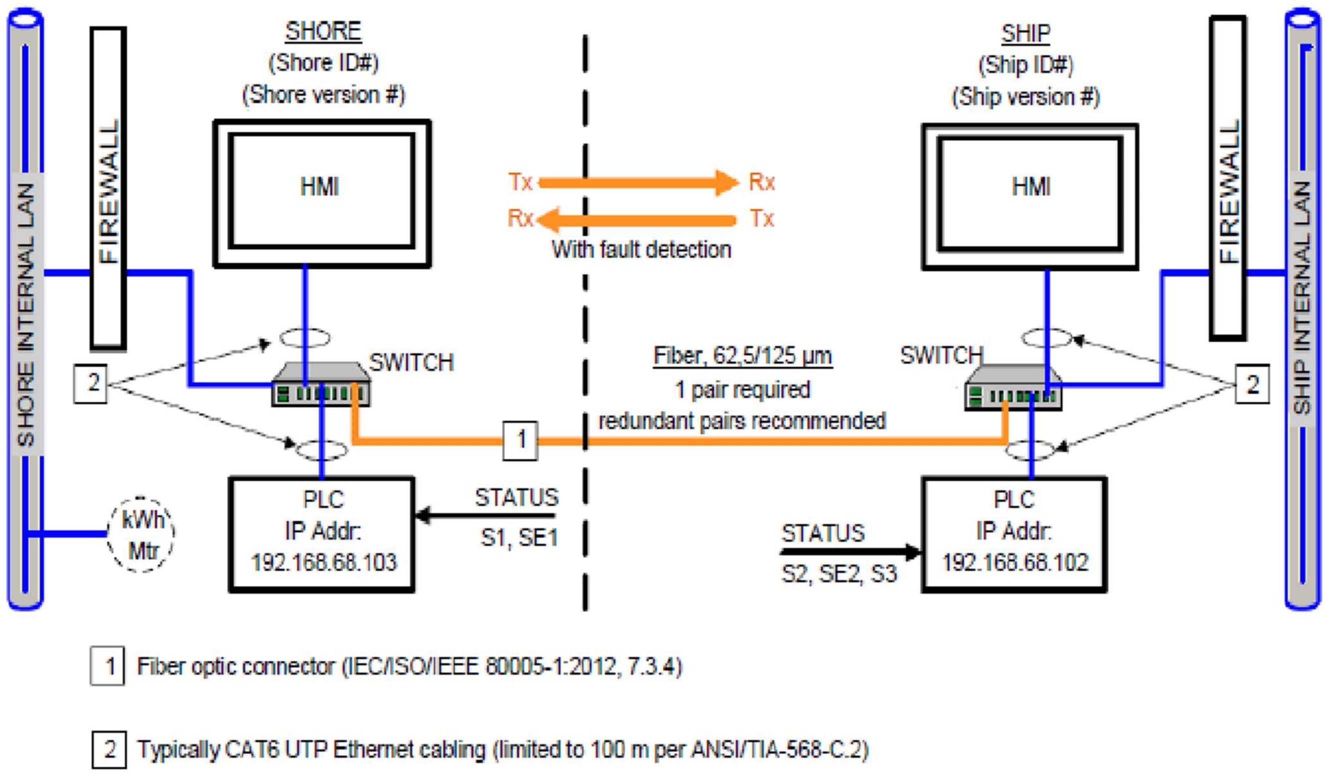


Figure 41 – Data Communication General Diagram. [109]

The ModbusTCP/IP protocol is specified for the communication between shore and ship. The shore side requests from the ship side in every cycle of the communication module (as fast as possible) a single Modbus data packet of 125 registers. The ship side also polls the shore side with every cycle of the communication module (as fast as possible) with a single Modbus data packet request of 125 registers. Both the shore side and the ship side will make the requests with a single Holding Register Block Read utilizing Modbus function code 0x03 with the Modbus Unit ID. It is required that both shore side and ship side have a dedicated and reserved data block to make available information for the other side. This data block starts at the absolute register address 0 and is 125 registers long. It is required that both shore side and ship side have a fixed IP address and port number for the communication via ModbusTCP/IP. In order to avoid any IP address conflict, the communication between shore side and ship side shall be on a dedicated network.

For the shore side interface different registers are proposed by this standard for various information such as [109]:

- the identification of version related to this standard (edition number of the standard), with data quantity and addresses of the data packet for which the running software was designed as well as the version number of the manufacturer-specific shore side software;
- the identification of communication fault;
- basic operation modes (start-up, running, emergency stop, etc.);
- a register for optional operation mode cable test which indicates that the shore connection system is in the procedure to perform a cable test;
- operation modes for synchronization which are presented in Table 17;
- the special fault mode which indicates an overcurrent situation to the ship under different conditions;
- a register for the alarms which indicate a critical condition onshore such as converter leakage, shore circuit-breaker protection overcurrent, etc.;

- warnings for the equipment (converter or transformer high temperature, etc.);
- the status of shore switches;
- shore general status and diagnostic data block includes summary signals and overall signals for the complete system (shore no-fault, ship fault, shore warning: reduce power);
- start up information;
- shore droop values;
- the power consumption with the energy meter values;
- shore start up data.

Register	Bit	Description
3	0	In this mode the ship side is synchronizing to the shore side. Ship starts the synchronizing and after successful synchronizing the on ship circuit breaker is closed and the ship is connected to the shore.
3	1	In this mode the ship side synchronizes the shore by sending commands for voltage and frequency adjustment. This mode may be used, as additional option, when the shore side equipment can be synchronized to the ship and the switching over from ship to shore is controlled by the ships power automation system. Shore ramps up to nominal values (voltage, frequency) and the ship synchronizes shore side by sending step up and down for frequency and voltage to the shore. As soon as shore is synchronous with the ship the circuit breaker on ship side is closed and ship is connected to the shore.
3	2	In this mode the shore side is synchronizing to the ship side. This mode may be used as additional option, when the shore side equipment can be synchronized to the ship. The shore side starts the synchronizing and after successful synchronizing the circuit breaker on shore connecting the ship to the shore supply

Table 17 – Synchronization Operation Modes. [109]

For the ship side interface, the standard proposes registers that provide the following information [109]:

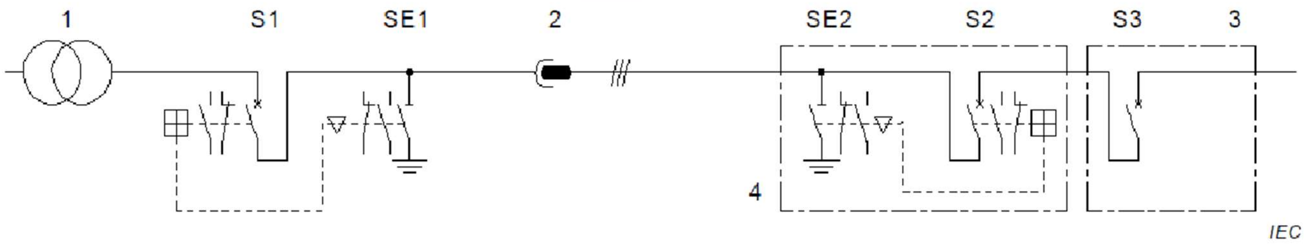
- checking of compatibility with the shore side which identifies the interface version related to this standard (edition number of the standard) with data quantity and addresses of the data packet for which the running software was designed as well as the version of the manufacturer-specific ship side software;
- identification of communication fault;
- ship basic operation modes (Ship Mode Start Up, Ship Mode Emergency Stop, etc.);
- synchronization operation mode;
- ship's alarms;
- ship's warnings;
- status of switches;
- ship commands (Stop Shore Power, Test Cable, etc.);
- general status and diagnostics as described in Table 18;
- ship droop values;
- ship start up data (ship name, ship identification, ship desired energy supplier).

Register	Bit	Description
12	0	**Ship No Fault:** If the system is free of every alarm and warning the signal is set. With appearance of an alarm or warning the signal is reset.
12	1	**Ship Fault:** Ship Fault is the inverted signal of Ship No Fault for safety reasons. Ship Fault is the summary signal for Ship Summary Alarm and Ship Summary Warning from ship side.

Register	Bit	Description
12	2	**Ship Summary Alarm:** The signal is a summary signal for all alarms and in addition for further additional system alarms, which are not listed in the alarm data block. The Ship Summary Alarm is reset as soon as the system is free of every alarm. Ship and shore side will automatically perform an emergency stop.
12	3	**Ship No Summary Alarm:** Ship No Summary Alarm is the inverted signal of Ship Summary Alarm for safety reasons.
12	4	**Ship Summary Warning:** The signal is a summary signal for all warnings and in addition for further additional system warnings, which are not listed in the warning data block. The Ship Summary Warning is reset as soon as the system is free of every warning.
12	6	**Ship Different Interface Version:** This signal is set, if ship identifies different version numbers (Shore Version Number and Ship Version Number) for the interface version between shore and ship.
12	7	**Ship Interface Version Is Compatible:** This signal is set, if the installed software on ship is able to handle the detected interface version of the shore. The signal is only set if a different interface version between ship and shore is detected and shore has a lower version number than ship side.

Table 18 – Ship General Status and Diagnostics Register. [109]

In addition, according to the single line power connection diagram depicted in Figure 42 the 80005-2 standard describes the startup procedure.



Key

1 Shore side transformer

S1 Shore side circuit breaker

SE1 Shore side earthing switch, for HVSC only

2 Cable connection with plugs (single or parallel cables)

SE2 Onboard shore connection switchboard earthing switch, for HVSC only

S2 Onboard shore connection switchboard circuit breaker

S3 Onboard receiving switchboard connection point circuit breaker (synchronizing switch)

3 Onboard receiving switchboard

4 Onboard shore connection switchboard

Figure 42 – Single Line Power Connection. [109]

It states that the following conditions shall be fulfilled to initialize the start-up procedure:

- the communication link is connected and is in operation;
- shore side shall be in Shore Mode Standby;
- shore system has no active alarms or warnings (Shore No Fault);
- ship side shall be in Mode Ship Mode Standby;
- ship system has no active alarms or warnings (Ship No Fault);
- pilot loops are closed;
- circuit breaker S1 is in OPEN position;
- earthing switch SE1 is in CLOSED position;
- circuit breaker S2 is in OPEN position;
- earthing switch SE2 is in CLOSED position;
- circuit breaker S3 is in OPEN position.

When the above conditions are met the choice of the droop values follows if it is possible. After the choice of the droop values (if it is possible) the ship checks if it can connect to the shore and can perform an optional cable test. Finally, the choice of the synchronization mode follows. In addition, the ship may initialize a controlled shutdown of the onshore power supply at any time.

Finally, the standard describes the format of data types (word, string, etc.) and in its annex the requirements for a cruise ship communication system is described as well as the Modbus register list. [109]

5.3.3 IEC/ISO/IEEE 80005-3: LVSC (Low Voltage Shore Connections) Systems – General Requirement

The IEC/ISO/IEEE 80005-3 standard addresses the same issues as 80005-1 standard and is applicable for the design, installation and testing of low voltage shore connection (LVSC) systems. With the support of sufficient planning, cooperation between ship and terminal facilities, and appropriate operating procedures and assessment, compliance with the requirements of this standard is intended to allow different ships to connect to low-voltage shore connection (LVSC) systems at different berths. This provides the benefits of standard, straightforward connection without the need for adaptation and adjustment at different locations that can satisfy the requirement to connect for as long as practicable during stays in port. [110]

This standard is applicable to the design, installation and testing of LVSC systems and addresses:

- LV shore distribution systems;
- shore-to-ship connection and interface equipment;
- transformers/reactors;
- semiconductor/rotating convertors;
- ship distribution systems;
- protection, control, monitoring, interlocking and power management systems.

It is expected that LVSC systems will have practicable applications for ships requiring up to 1MVA while at berth. Low-voltage shore connection systems exceeding 250A, equal or exceeding 400V AC and up to 1000V AC nominal voltage are covered by this standard.

It describes the same design requirements, as the part 1 of this standard, for the equipotential bonding, the compatibility assessment before connection, personnel safety, location of the equipment, protection against moisture and condensation, system studies and calculations as well as the emergency shutdown.

According to the standard LV shore connections shall be provided with a nominal voltage of 400V AC or/and 440V AC or/and 690V AC galvanically separated from the shore distribution system. The operating frequencies (Hz) of the ship and shore electrical systems shall match otherwise, a frequency convertor shall be utilized on shore. Operating voltage and frequency shall be verified on board, prior to connection.

For the quality of the low voltage, the shore supply should be able to maintain the same distribution system voltage, frequency and total harmonic distortion characteristics given in part 1 of this standard in section 5.3.1.

In addition, the shore system requirements are described such as circuit-breaker, transformer, neutral earthing resistor and earthing conductor bonding. The shore-to-ship electrical protection system is described which should trigger at the following conditions:

- overcurrent including short-circuit;
- over-voltage/ under-voltage;
- reverse power;
- earth fault.

The converter equipment and its protection is also described, as well as the ship to shore equipment attaching more importance to the cable management system. The on-board transformers, circuit breakers, instrumentation, protection as well as the procedure of power restoration procedure are also described by the standard.

Moreover, the general requirements for the LVSC system control and monitoring are presented. The general requirements for the control and monitoring systems are:

- ship equipment shall be protected and controlled by the ship's own protection and control systems;
- if the shore supply fails for any reason, supply by the ship's own generators is permitted, after disconnecting shore supply;
- load transfer shall be provided via blackout or automatic synchronization;
- synchronization shall be performed on-board.

In addition the standard describes with a general diagram in Figure 43 the LVSC general operating procedures at the arrival and departure of ships. [110]

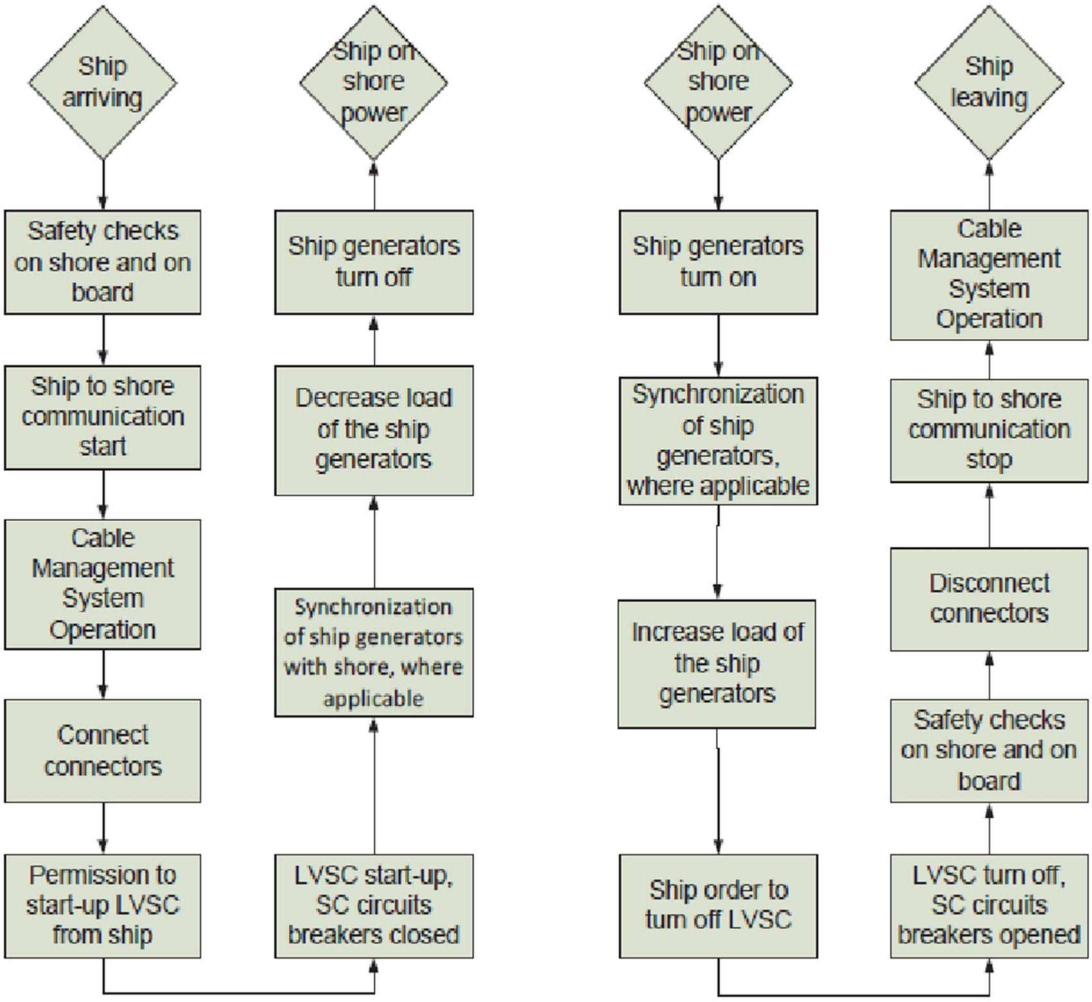


Figure 43 – General Operating Procedures of LVSC systems at a ships arrival and departure. [110]

Finally, the last part of the standard describes the verification and testing at the installation as well as the periodic tests and maintenance. [110]

5.4 CORRELATION BETWEEN SMART GRIDS AND COLD IRONING

The previous chapters imply that the port and ship should be equipped with highly sophisticated equipment on shore which allows for reliable and efficient high power transfer as well as low connecting times for the ships. In addition, electrical grid's constraints should also be taken into account.

For inland applications, smart grids are a technology that can provide the means for fast and efficient power management as well as real-time monitoring of the infrastructure. The integration of their main features (e.g. power converters, energy storage technologies, renewable energy sources, data acquisition systems, controllers) in the frame of the cold ironing process should be investigated as it could provide a valuable solution both in terms of technical feasibility and economic interest.

By combining a smart grid with cold ironing concept a significant reduction in infrastructure can be achieved, especially in the field of communication and IT (Information Technology) equipment, compared to the normal concept of smart grid in power system. The port is considered as an industrial load or centralized load concentrated on limited space, whereas in the case of normal smart grid concept in power system the load is geographically dispersed thus requiring more cost on developing an extended communication system with distributed intelligent devices. [99]

In addition, common R&D domains between cold ironing and smart grids exist such as:

- low emission generation by renewable energy sources with the perspective of "Efficiency up, pollution down";
- energy storage requirements;
- utilization of power converters as coupling and/or maximizing performance interfaces;
- Power Management Systems (monitoring, control of bidirectional power flow, history trend analysis, decision making).

Technologies and concepts borrowed from smart-grids can be applied to ships for increasing also the energy efficiency and reducing emissions not only during berthing but also during the approach to the port. A general plan of electric energy saving policy can be incorporated within Electric Power Management System/Electric Power Management and Control System (PMS/EPMACS) as the Ship Energy Efficiency Management Plan (SEEMP).

In addition, there have been already proposed in literature, infrastructures which combine smart grids and cold ironing. In [111] Harbor Area Smart Grid (HASG) has been proposed as it is presented in Figure 44.

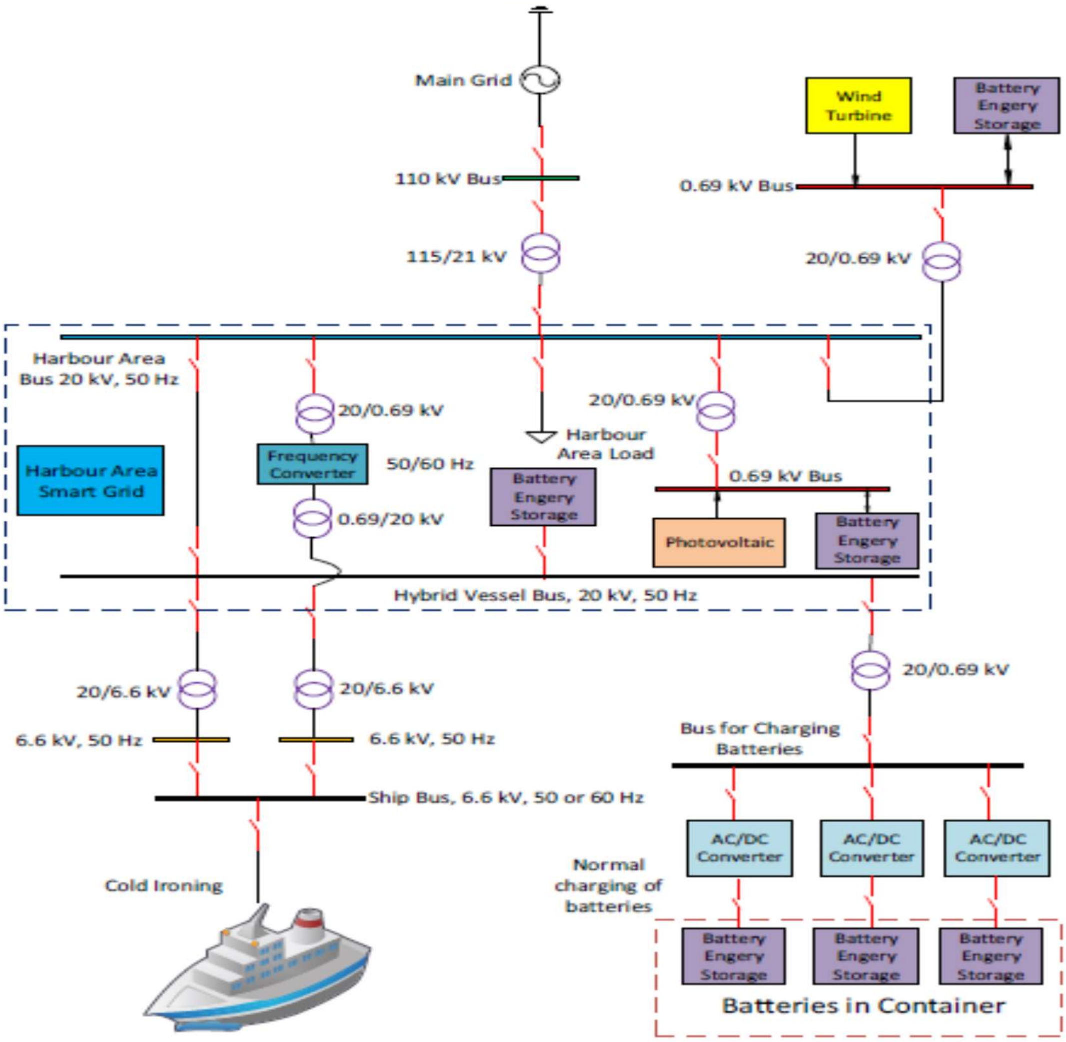


Figure 44 – Harbor Area Smart Grids (HASG). [111]

This infrastructure consists of a bus with a converter, which can provide power in 50Hz or 60Hz to a vessel for ship to shore supply purposes, as well as distributed generation and storage. The point of common coupling for the HASG with the main grid supply is the harbor area bus of 20kV, 50Hz, where the wind turbine from some nearby area is also connected. Thus, the harbor area bus is considered as the main bus of the harbor area from where the power flows towards the HASG can be controllable by the distributed energy sources as well as the storage.

The hybrid vessel bus and the frequency converter stations are located nearby the seaports in the harbor area. The shore side transformers according to the HVSC standard requirement are connected with hybrid bus and frequency converter station to step down the voltage from 20kV to 6,6kV at 50Hz and 60Hz respectively. The main objectives of the proposed system, as illustrated in the single line diagram can be achieved by supplying the power to the vessels during cold ironing as well as charging the batteries for hybrid vessels.

In addition, a complex Central-Distributed Power Management System can be utilized in order to manage smart transactions of electric energy in the port are via smart interfaces consisting of power meters measuring bidirectional power flows and controllers which can be monitored and controlled. Appliances are no longer merely passive devices but active participants in the electricity infrastructure that can be utilized for energy reduction, energy storage, and the optimization of the electrical grid for greater compatibility with its "green" energy generation sources.

For example, energy storage at ports as well as other storage facilities (e.g. electric vehicles) can be widely exploited in order to smooth the power demand curve of the port. During the periods of low demand at ports (e.g. during night) the energy storage devices and/or the EVs can be charged in order to be operated in regenerative mode during load-peaks. Thus, the power provided from the grid to the port can be reduced in high load periods when ships with high load demand are berthed. This utilization could provide financial benefits to the port and minimizing also the grid's stress, that the high load port demand due to cold ironing can cause to the grid's infrastructure.

In the same direction, the aspect of demand response could also be investigated. Within the framework of Directive 2009/72/EC, that tariffs should allow suppliers to improve consumer participation in system efficiency. One measure that is specifically mentioned is demand response, where the consumer can participate in the electricity market by adjusting the load according to price signals. Well aligned with this policy is the Cold Ironing concept. More specifically, by investing in cold-ironing infrastructure with power connection interfaces (plugging devices, electric substations, switchboards, battery substations) the port can participate in the national electricity balancing markets by adjusting the port's consumption and/or generation according to electricity market price signals, using the flexibility that is offered by the combination of cold ironing and Smart Grids technologies. Vessels at berths could also participate in demand response adjusting their flexible loads. [111]

In [112] is proposed an innovative decentralized demand response method that eventually turns a port comprising flexible loads and power generation from renewable energy sources to a prosumer Microgrid. According to this paper large ports comprise a variety of flexible loads like refrigerated containers, electric vehicles, onshore electric power supply to ships at berth etc., while they can benefit from the local RES production potential for local energy generation from renewable energy resources, like offshore wind, tides, waves etc. Smart grids can be proved very efficient in increasing port power demand flexibility and controllability.

According to the paper, increased complexity of a large port power system is a major operation constraint [112]. This becomes apparent by considering a large port comprising some thousands of loads of different types. Decentralized control systems provide an efficient solution in such complex systems as most of the required computations are performed locally. However, this paper doesn't include cold ironing as part of flexible loads but the same rational of this paper can also extend to ships with flexible loads, extending the case to cold ironing.

The described solution can be achieved by the multi agent system (MAS). In the adopted concept the agents can be categorized into three major types:

- local agents that are responsible to represent a single component of port power system,
- cluster agents that are responsible to aggregate the responses of a cluster of agents and also send command signals to local agents, and
- aggregation agents that are mainly responsible to aggregate the responses they receive from the cluster agents they supervise.

Next, the operation of each type of agent is briefly described. The flexible loads in the port area are considered to be:

- 'reefers' which are refrigerated containers and are very flexible loads and comprise a major part of the total port energy consumption;
- electric vehicles (EVs).

A wind park is also considered a part of this system.

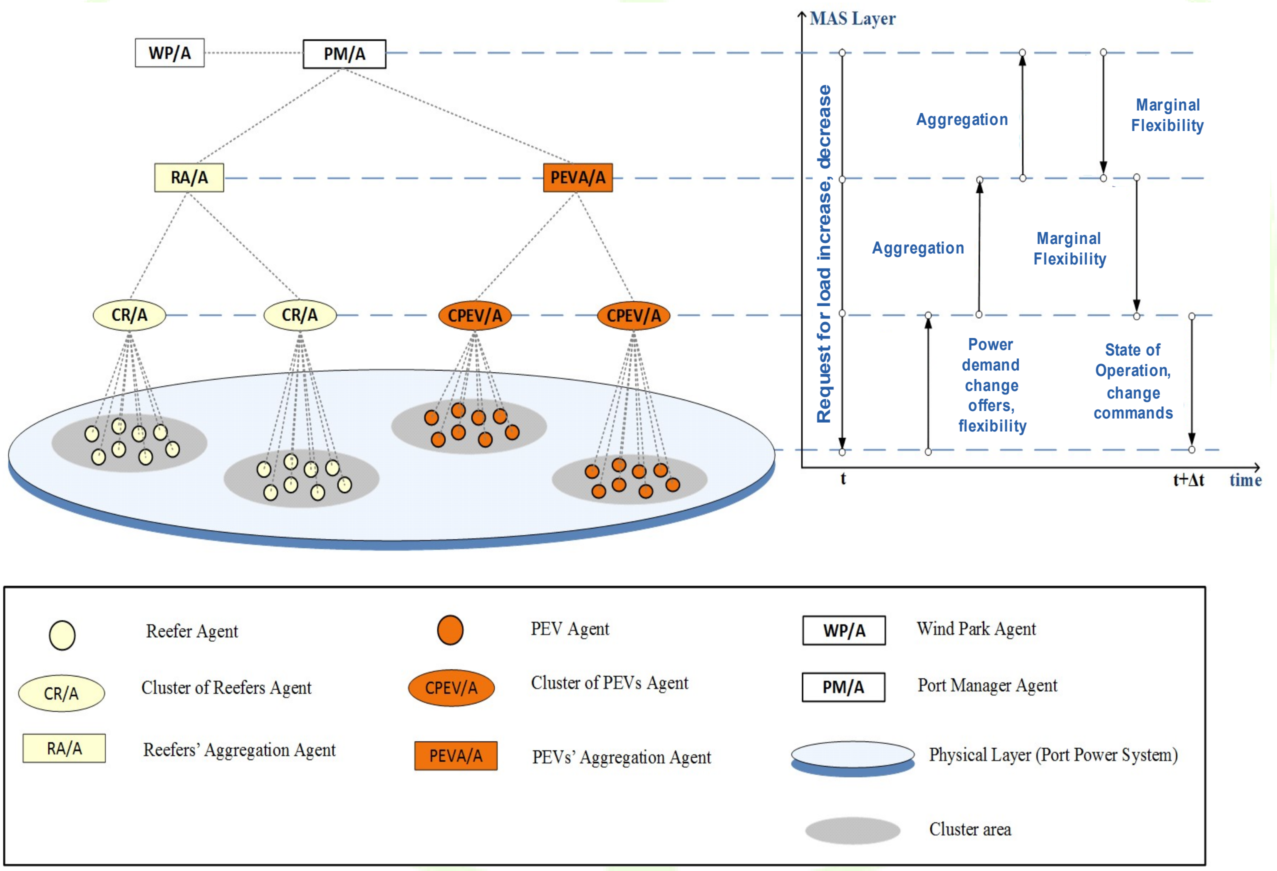


Figure 45 – MAS of port with flexible loads. [112]

The operation of each type of agent presented in Figure 45 can be described as:

- **Port Manager Agent (PM/A)** is the agent placed higher in the hierarchy. PM/A receives the aggregated responses from all local agents via aggregation and cluster agents and also information from wind park agent WP/A including the desired and the forecasted actual power production over the next time interval. PM/A is responsible to process the gathered information and then calculate a marginal flexibility such that every port load with a higher flexibility should change its operation state according to the needs of the port. PM/A is designed to provoke suitable change of port power demand that will virtually cancel the difference between the forecasted actual wind power production and its set-point (desired wind power production).

- **Wind Park Agent (WP/A)** communicates directly with PM/A. In the proposed method, WP/A is responsible for defining wind park operation set-point and also performing very short-term power production forecast one minute before the actual production takes place. Moreover, WP/A sends the above information to PM/A at every control time interval.
- **Cluster of Reefers Agent (CR/A)** and **Cluster of Plugged-in Electric Vehicles Agent (CPEV/A)** are agents hierarchically placed just above the agents assigned to each reefer and PEV. They are usually located at MV/LV transformers that supply exclusively clusters of reefers or PEVs and provide mainly ancillary communication and aggregation services. CR/As and CPEV/As aggregate the responses received by the reefers and PEVs in the areas they control and form the flexibility-change of power demand curve for the cluster they control. Then, the calculated flexibility-change of power demand curve is forwarded to the upstream aggregation agents. Moreover, CR/As and CPEV/As define the operation state for every reefer and PEV they supervise according to the marginal flexibility estimated by the PM/A. Afterwards, they send the respective command signals to the agents assigned at each reefer and PPEV inside their cluster.
- **Reefers' Aggregation Agent (RA/A)** and **PEVs' Aggregation Agents (PEVA/A)** are placed one level under PM/A in the proposed MAS hierarchical structure. Except from providing communication services they aggregate the flexibility-change of power demand curves they received from all clusters of reefers and PEVs they supervise. Moreover, they forward the marginal flexibility received by PM/A to cluster agents. It is noted that one type of aggregation agents could have been used instead of two as they process the same type of data. However, it is preferred to use two types as the aggregation agents are expected to supervise the same type of cluster agents (CR/As, CPEV/As) due to their spatial proximity. It is also noted that the adoption of two aggregation layers reduces the required communication range and increases the reliability of the proposed control system. Although one aggregation layer could have been used it would not be the most reliable solution for large port power systems.
- **Reefer Agent (R/A)** and **Plugged-in Electric Vehicle Agent (PEV/A)** are responsible for the modeling of the operation of the reefer and PEV they control. They estimate the flexibility of reefers and PEVs to change their power demand according to the needs of the port. R/A and PEV/A comprise the necessary computation facilities to run fast enough models simulating the behavior of the components they represent with the necessary accuracy. The calculated flexibility and the respective change of power demand are then sent to the CRA/As and CPEV/As.

The formulation of this control problem is then described in this paper and results are presented. [112]

It is quite obvious that the above implementation can be extended to cold ironing implementations with ships' agents calculating the flexibility of ships loads when connected to the port and the respective change in power demand. The ships' agent can also communicate to a cluster of ships' agents followed by a ships' aggregation agent according to the above implementation. In addition, the power demand of the port can be changed in order to achieve different goals such as responding to modification of demand for financial purposes or responding to a demand set-point sent by the electrical grid operator for stability purposes in the electrical system.

Finally, data analysis techniques used in smart grid applications can also be utilized in cold ironing applications both in the designing stage of the cold ironing system and for every day purposes (e.g. load forecast). The historical data can be accessed in port easily from the port authorities by AIS systems described in section 5.2.

6 CONCLUSIONS AND RECOMMENDATIONS

The present report focuses on the analysis of the electric transportation sector. It mainly describes the e-mobility sector and the shore to ship power supply as well as their characteristics, constraints and potential.

6.1 CONCLUSIONS ON E-MOBILITY

The analysis of e-mobility section has pointed out the opportunities and the benefits it could provide as well as the constraints and the potential problems which could emerge.

From the social perspective e-mobility can offer both direct benefits, with emission and noise reduction as well as indirect benefits such us new opportunities for companies that invest on innovative technologies, thus creating job positions and promotion of research.

In addition e-mobility could offer new business opportunities such as mobility as a service and the electrification of a fleet of EVs.

Furthermore, through literature review on current EV and EVSE technologies the advantages of an EV versus a conventional vehicle have been pointed out. Some of the most important benefits are:

- Significant decrease of vibrations level produced by the propulsion system.
- Simplicity of construction of electric motors in comparison with traditional combustion engines.
- Simplicity of the necessary ancillary systems for the propulsion system.
- Simplicity of the vehicle maintenance processes.
- Reduced operational costs (i.e. price of electricity compared to price of fuel, reduced taxes, etc.)
- Higher efficiency of the electric motors compared to the combustion engines.
- Incentives offered for promoting e-mobility (i.e. free parking spaces, free use of toll-controlled areas, etc.).

On the contrary, there exist also some disadvantages that nowadays the electric vehicle has such as:

- The autonomy of an electric vehicle is lower compared to the autonomy of conventional vehicle.
- The duration of the recharge is still high, ranging from 20 minutes to several hours for a full recharge.
- Limited recharge infrastructure.
- Higher purchase price comparing to a conventional vehicle of the same segment.
- Bigger weight, which might cause some increase wearing of tyres and cause longer breaking distances.

Taking under consideration the analysis of EV and EVSE technologies special focus is given on the characteristics of EV fleet and EVSE management. A description of their characteristics and limitations has led to some recommendations which are in the direction of achieving a more ideal management. This analysis will be further utilized in the following steps of WP8 for the specification of the advanced modules that will be implemented by this WP.

Firstly, constraints and recommendations on the different domains of EV fleet management are reported.

For the public transportation sector a public bus operator in Madrid which uses 100% electric buses is described. The objectives of a public EV fleet operator are:

- punctuality and regularity of services
- real time information of the operator and the drivers.

The requirements in software and hardware that this system must have are:

- inductive charging points infrastructure installed at bus line terminal stops,
- inductive charging technology installed at the buses,
- monitoring system of both of road-side infrastructure and of buses at any time.

In order to address the communication issues the BUS-FMS-Standard is recommended, which is an open standard adopted by major manufacturers (MAN, Scania, Volvo among others) with the objective of defining the information exchange between vehicle and Fleet Management Systems (FMS).

In addition, there are functionalities which are proposed for the EV public fleet management system for an optimal operation. The recommended functionalities should include information for:

- driver assistance (visualization of battery status and ongoing charging session, real-time forecast of range distance of the bus, KPI (Key Performance Indicator) on driving efficiency, estimation of minimum time required for the next opportunistic charge)
- public transport operator assistance (real-time monitoring of all parameters of the electric buses, status of charging points and collection of the minimum required times for the next opportunistic charges).

For an EV fleet in the private transport sector, the objectives of an EV fleet management in this sector include:

- availability according to the schedule,
- synchronization between charging times and required SoC with the tasks of the company.

Two different approaches are proposed in order to achieve the above requirements:

- optimizing the routes (properly rearranging the tasks that a member of the organization has to perform in order to reduce the distance that need to be covered) or
- optimizing charge sessions (taking into account that vehicles are used for dealing particular tasks within the organization, optimally select the proper charge order of the vehicles of the fleet, optimize the charging sessions in order to minimize the energy-associated costs).

In the direction of EVSE management a description on how EVSE managers are able to offer their services – installation, maintenance and exploitation of charge point – according to the location of the station (private, public) is reported.

The tariffs usually consider a base price and a price per supplied kWh, including extra charges for additional terms such as location of the charge point (private or public premises) or additional offered services (booking or longer collection times once the charge is complete).

Hence, the metering for the operation of the EVSE managers, since it is the basis for the billing of the service, is quite important. In addition, the interoperability between different EVSE managers is of great significance.

In order to address the above issues the Open Charge Point Protocol (OCPP) is recommended for communication between the EVSE and the management station, due to the advantages that emerge for its usage for EVSE from the perspective of:

- vendors (allows the EVSE management platform to communicate with devices independently of their vendor avoiding vendor lock in, encouraging competition among EVSE providers and facilitates scalability of the EVSE network);
- communications (The OCPP protocol contemplates the EVSE registration process in the control platform, which is initiated from the EVSE side. This facilitates enormously the task of maintaining the EVSE communication details from the perspective of the EVSE management platform);
- booking (book a charge point in advanced first defined in OCPP v1.5).

Finally, an important issue on the EV charging is the increase in power demand that could be introduced to the distribution grid. Specifically, an extensive EV roll-out could impose congestion issues on the distribution grid when their charging isn't efficiently controlled.

There exists the necessity of moving towards the paradigm of smart charging which basically implies the capability of the EVSE to modulate the power that is supplied to the electric vehicle along the duration of the charging session, even with the capability to reverse the flow of energy and make the electric vehicle operate as an energy production resource – concept known as Vehicle-to-Grid (V2G) or Vehicle-to-home (V2H).

Depending on the location and owner of the charge point, this capability can provide many benefits and gets therefore some very interesting options:

- An agreement between EVSE operator and DSO (Distribution System Operator) which includes a limit on the peak power that can be supplied. Smart charging can, in such cases, modulate the power supplied to each of the vehicles of the hub in an optimized way in order to achieve these objectives taken account the customer constraints.
- Reduce economic costs associated to energy when EVSE manager is exposed to dynamic prices that may change accordingly to external context parameters.
- Reduce environmental impact of the EVSE manager by promoting green energy consumption (supply curves can be optimized to prioritize supply of energy at those moments when production of green energy is higher).
- Explore new business models by providing ancillary services to third parties: EVSE manager is in position of controlling a significant amount of batteries – as much as vehicles connected to its network. Capability to modulate demand and even reverse the power flow and provide energy back to the grid (V2G) can be very beneficial to support DSOs.

OCPP is recommended for smart charging also since OCPP 1.6 supports three use cases of smart charging:

- **Load balancing:** Internal load balancing within the Charge Point where the Charge Point controls the charging schedule per connector. The Charge Point is configured with a fixed limit, for example the maximum current of the connection to the grid.
- **Central smart charging:** This charging allows the EVSE manager to perform optimization over the complete set of EVSEs accordingly to the organization optimization objective. With Central smart charging the constraints on the charging schedule, per transaction, are determined by the Central System. The Central System uses these schedules to stay within limits imposed by any external system (e.g. a DSO).
- **Local smart charging**: Optimization over the operation of a set of charge points operated by a local controller in a more hierarchical control architecture. The Local Smart Charging enables Charge Points have charging limits controlled locally by a Local Controller, not the Central System. The use case for local smart charging is about limiting the amount of power that can be used by a group of Charge Points, to a certain maximum.

6.2 CONCLUSIONS ON PORTS AND SHIPS

A part of this report focuses also on shore to ship power supply or ‘cold ironing’. The cold ironing concept has to do with a ship covering its demand by connecting to the mainland grid while in port instead of using its auxiliary engines.

The International Maritime Organization (IMO) has imposed regulations for emission reduction in port areas. Even though different strategies can be applied, cold ironing can be an effective solution in the direction of emission and noise reduction in the port area.

It is pointed out that a shore to ship supply system could be quite complex. The main reason is the differentiation in the electrical characteristics of ships since even vessels of the same type could differ in frequency, voltage and power demand. In order for the port to be able to supply power to different ships a complex power system must be designed in the port area able to transform the grid’s voltage and frequency according to a vessel characteristics.

In addition, cold ironing is a quite novel approach. Therefore, the IEC/ISO/IEEE 80005 standard is described in detail which addresses the issue of High Voltage (or Low Voltage in 80005-3) Shore Connection as well as the communication between the ship and the shore.

A major constraint of a cold ironing implementation is the demand increase in port areas and to the electrical grid as a whole. It is reported also that this increase in demand can lead to issues in the electrical grid such us voltage drops, power congestion, harmonics issues as well as stability issues in small islanded systems.

In order to address this issue the traffic in ports must be taken account. In this direction, it is stated that a ship is berthed at specific places at port (according to financial or technical reasons). Furthermore, AIS (Automatic Identification System) can provide real time information as well as historical data of port traffic which can be used in order to estimate on the port consumption increase due to cold ironing.

Finally, in order to address the increased electrical demand issues in the port area the possibility to correlate cold ironing with smart grids is also investigated.

One significant advantage is that the port can exploit smart grid technologies since it can contain smart grid equipment (distributed energy sources, smart loads, controllers and smart meters) aggregated in the premises of the port, thus have a significant cost reduction in IT and communication equipment compared to a typical smart grid implementation.

Finally, through some literature review some smart grid applications, such as demand response and power demand smoothing of the port through energy storage, are suggested in order to address the issue of the high demand in ports.

Specifically, a harbor area smart grid is described with main objectives the supply of power to the vessels as well as charging the batteries for hybrid vessels.

Finally, a proposed multi agent system is described which utilizes decentralized demand response method that eventually turns a port comprising flexible loads and power generation from renewable energy sources to a prosumer Microgrid.

Such systems could be proven quite useful in order to adjust the demand of the port to constraints provided by a DSO or provide financial benefits to the port authorities.

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7.2 ACRONYMS

Acronyms List	
AC	Alternating Current
AIS	Automatic Identification System
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
CCS	Combined Charging System
CEN	European Committee of Standardization
CENELEC	European Committee of Electrotechical Standardization
COSEM	Companion Specification for Energy Metering
CP	Consortium Plenary
CPEV/A	Cluster of Plugged-in Electric Vehicles Agent
CPT	Clean Power for Transport
CR/A	Cluster of Reefers Agent
DC	Direct Current
DLMS	Device Language Message Specification
DM	Dissemination Manager
DoD	Depth of Discharge

Acronyms List	
DoW	Description of Work
DR	Demand Response
DSO	Distribution System Operator
EC	European Commission
ECA	Emission Controlled Areas
EM	Exploitation Manager
EPMACS	Electric Power Management And Control System
EREV	Extended Range Electric Vehicle
ETSI	European Telecommunication Standard Committee
EU	European Union
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FMS	Fleet Management System
GHG	Green House Gas
HASG	Harbor Area Smart Grid
HV/MV	High Voltage/ Medium Voltage
HVSC	High Voltage Shore Connection
ICE	Internal Combustion Engine
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical Electronics Engineers
IMO	International Maritime Organization
IPR	Intellectual Property Rights
ISO	International Standardization Organization
IT	Information Technology
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LIC	Lithium Ion Capacitor
Li-ion	Lithium Ion
LNGC	Liquid Natural Gas Carriers
LVSC	Low Voltage Shore Connection
MAS	Multi Agent System
NEMA	National Electrical Manufacturers Association
Ni-Cd	Nickel Cadmium Batteries
Ni-MH	Nickel Metal Hybrid Batteries
OBD	On Board Diagnostics

Acronyms List	
OCA	Open Charge Allience
OCPP	Open Charge Point Protocol
ODS	Ozone Depleting Substances
PC	Project Coordinator
PEV/A	Plugged-in Electric Vehicle Agent
PEVA/A	PEVs' Aggregation Agents
PHEV	Plug in Hybrid Electric Vehicle
PM/A	Port Manager Agent
PMS	Electric Power Management System
PPR	Project Periodic Report
PSC	Project Steering Committee
QM	Quality Management
QR	Quarterly Report
R&D	Research and Development
R/A	Reefer Agent
RA/A	Reefers' Aggregation Agent
RES	Renewable Energy Sources
RFID	Radio Frequency Identification
RM	Risk Management
S-AIS	Satellite - AIS
SEEMP	Ship Energy Efficiency Management Plan
SoC	State of Charge
SUV	Suburban Utility Vehicle
SVN	Subversion
TM	Technological Manager
TSO	Transmission System Operator
UKC	Under Kneel Clearance
V2G/B/H/V	Vehicle to Grid/Building/Home/Vehicle
VOC	Volatile Organic Compound
VPP	Virtual Power Plant
VTS	Vessel Traffic Services
WP	Work Package
WP/A	Wind Park Agent

Table 19 – List of Acronyms