Global Smart Grid Federation

GSGF Report

Electromobility in smart grids:

State of the art and challenging issues

Objectives for emissions reductions have large consequences for energy and mobility sectors with respectively the development of renewable energy sources (RES) and low carbon mobility. The latter means the deployment of a full electric mobility with battery electric vehicles (EV). Renewable sources and electric vehicles will impact the power system at different scales: less inertia in the system, more power reserve to compensate the uncertainty, congestions and voltage issues mainly in the distribution grids. Thus, RES and EV play an important role for the evolution of power grids to flexible smart grids that will require more distributed storage capabilities (batteries, thermal inertia, ...). Considering that vehicles are parked most part of the time, it would be pity not to consider these batteries for the optimization of the power grid, either for grid-to-vehicle (G2V) applications (load shifting or load modulation) or for vehicle-to-grid (V2G) applications (power or energy reserve), in order to prevent excessive investment costs.

All distribution systems are not created equal and this often poses a challenge when comparing countries and/or urban cities. Even within the developed world there are large variations in “system strengths”. Different architecture, planning and MV grid operating assumptions, make any sweeping generalization impossible.

The concepts of smart charging and V2G have been introduced by a research team of the University of Delaware[1] in late 1990’s. Presently all actors agree that smart charging will be a mandatory step to prevent a simultaneous charging of numerous EV. But much more can be done considering that EV batteries can also be seen as virtual distributed stationary storage. Under the control of an aggregator, these batteries could deliver services at different scales: (i) V2G for services to the power system operators (DSO or TSO) for mitigating constraints (voltage and congestions) and increase the power reserves, (ii) V2B (vehicle-to-building) at the building scale, and (iii) V2H (vehicle-to-home) at the home scale. Now V2G, V2B and V2H are more generally integrated in the term V2X (vehicle-to-anything). Nevertheless it should be noted, only vehicles that are on a “longer charging” cycle can participate effectively in such grid services. Vehicles that are on a “short cycle” charging duration (such as high-power fast chargers) are unlikely to contribute effectively to such ancillary services.

EV roll-out will require a higher density of charging infrastructure to tackle the range anxiety issue, and to allow long distances mobility. For the latter, several announcements have been done for fast charging stations (FCS) deployment following the model of Tesla Corp. The Ionity consortium has announced 350 kW charging units. Such high values will impact the power grid with needs for reinforcements.

From a general point of view, EV integration into the electric power system is both a technical issue (to reduce the constraints and to take advantage of their flexibility), an economical issue (valuation of embedded batteries), and a regulatory issue (to enable valorization through suitable standards and market rules).

The aim of the report will be to present the scientific and industrial issues to allow a large integration of the electric mobility into a power system under transformation. At the end, the report will present ongoing (or recent) demonstration projects that aim at proposing and testing solutions to facilitate EV integration and the development of the V2G. As a conclusion, recent recommendations will be highlighted.

[1] W. Kempton, S.E. Letendre, (1997) “Electric vehicles as a new power source for electric utilities”, Transportation Research Part D 2 (3), 157-175.

CHAIRMAN'S MESSAGE

I have great pleasure in presenting the Global Smart Energy Federation (formerly known as Global Smart Grid Federation) Report on **"Electromobility is Smart Grids"** which describes the state of the art technologies and challenges globally faced with charging of electric vehicles (EV) and its impact on the electric grids.

Today every country, city and organization is focusing on emission reduction, which has huge consequences on the transport sector. Transportation sector is on the threshold of a paradigm shift: electrification of transportation - both ground and aerial vehicles powered by electricity! Besides the logistical and engineering challenges of charging the ground moving and flying vehicles, their connectivity with the electricity grids is going to pose bigger challenges in grid balancing. The development of renewable energy sources (RES) and electrification of transportation are promoted globally on accelerated pace to meet the NDC goals. Both distributed RES and EVs are typically connected to the low voltage grids and integration of both with the grid could help each other – while EVs are charged with green electricity, the excess energy on the grid at low prices can be stored in the EV batteries which could be pumped back to the grid during peak hours at higher prices; and also the batteries could smoothen the output of solar panels which is inherently intermittent. Aggregating millions of EVs connected to the grid as virtual power plants is soon going to be a reality.

This report has covered the EV charging infrastructure and its integration challenges with the grid. In the emerging scenario, the role of aggregators become very important to handle distributed resources in evolving power market. The report further takes into the consideration, the technology advancements related to electric mobility and their related impacts on the global market. North America and Europe are front-runners in EV adoption while Asia-Pacific, Latin America, Middle East has started picking up lately.

Though electric vehicle was introduced over a century ago, it failed to gain traction owing to various reasons. However, the present wave of electrification in automotive industry primarily driven by constantly falling price of high performance lithium-ion batteries is totally revolutionizing transportation. During last five years the EV stock has grown ten times (excluding two and three wheelers) – that is 900,000 EVs in September 2015 to 9 million EVs in September 2020! Hence time for grid operators to be ready to operate electric grids with EVs everywhere.

REJI KUMAR PILLAI

VICE-CHAIR'S MESSAGE

Electromobility, the cornerstone of decarbonized energy networks.

Electromobility in smart grids is a key issue: the transition towards electric vehicles is crucial to act against climate change, as the transport & mobility sector is responsible for 30% of total greenhouse gases emissions in France only.

With this report, we aim to bring our contribution to the decarbonization effort of all countries, in accordance with the target set by the Paris Agreement But not only electric vehicles (EV) contribute to the decarbonation of the transport sector, they can also participate to the development of smart grids, that are equally necessary for the energy transition. Electrical vehicles can take part to the global flexibility of the system, as it becomes possible to use their batteries. EV, as far as they use renewable energies, bring an important contribution to the reduction of CO2. In Europe, the number of EV sold has increased of 80 % in 2019 compared to the precedent year the trend to buy an EV is now implemented and will continue in the next years as it is the will of the consumers, and because the governments look for incentivize the growth of this tendancy.

On the behalf of Think Smartgrids, I am very proud that Professor Marc Petit, member of the scientific council of Think Smartgrids, accepted to take the lead of this working group on "Electromobility in smart grids: State of the art and challenging issues". This document succeeds to the 2014 GSGF report "Grid user interactions and interfaces" that was directed by our Japanese colleagues from NEDO.

Think Smartgrids, as member of the GSGF that contributes to the development of the smart grids sector in France, is really invested on these questions of electromobility and thrilled to participate to the international research effort through this paper.

It is an honor we succeeded in producing such a significant paper alongside with experts from diverse countries. We hope the ideas presented in the following pages will be an inspiration for our colleagues working in grids across the world to innovate into electromobility, the cornerstone of decarbonized energy networks.

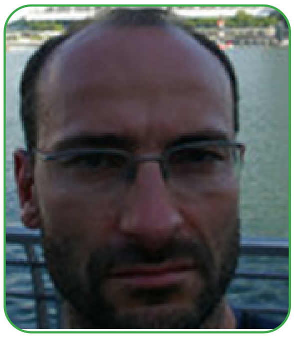
VALERIE-ANNE LENCZNAR

Message by Prof Willett Kempton

This comprehensive report covers the current state and rapid growth projections of electromobility, then analyzes the questions of how electric vehicles will interact with the electric network. It is sophisticated and insightful on both the electric network side and the electromobility side of the analysis, and is a rich source of data. After an insightful analysis of projected demand and the potentials for both managed EV charging and use of EVs as a large storage resource, it reviews demonstration projects worldwide, and concludes with policy recommendations.

PROF WILLETT KEMPTON

Message by Prof Marc Petit, Lead Author



Today, a transition towards smart grids and an evolution of electrical power systems is crucial for the successful development of a new electromobility, that has a critical role to play in the energy transition effort: the electrification of the current vehicle fleet will allow a significant drop in carbon emissions, especially if it is associated with renewable energy sources. The importance of this subject is the reason why I am honored to have undertaken the responsibility to chair the Global Smart Grid Federation Working Group on Electromobility in Smart Grids, and to have benefited from the valuable expertise of talented experts from countries such as Japan, the United States and India to present you this report. I would like not only to thank them, but also all the members of the Global Smart Grid Federation for their valuable comments and supporting our efforts in producing this report.

This report explores how electromobility, through battery electric vehicles, is at the heart of the transformation of current power grids into flexible smart grids. The integration of electric vehicles into smart grid systems, through the use of their batteries as a virtual stationary storage system, can not only reduce constraints and increase power reserves, but also allow a flexibility that can optimize those systems with inspiring applications such as vehicles-to-grid, vehicle-to-building or vehicle-to-home. France, well ahead on these themes of electromobility in smart grids, is very concerned by the potential of this domain. Indeed, in line with the global trends, the electric vehicles sector growth keeps accelerating in France as well: the plug-in vehicle stock went up from 107,592 to 201,913 between 2016 and 2018. Besides being silent and emitting very few CO2 thanks to the country's electricity generation mix, French electric vehicles integration to grid systems would therefore contribute to increase power reserves of the one of the most powerful electrical networks in the world. In order to realize this aim, France can rely on its national enterprises that are leaders in R&D and engineering, and also have a powerful ecosystem of actors working in the sector, represented by organizations such as Think Smartgrids that contribute to innovate for the future of electromobility.

Of course, successful deployment and integration of electromobility into the electrical networks at a significant scale are not without facing challenges, as we identified in the present report: even if the number of electric vehicles continue to increase in many countries, technical, economical and regulatory difficulties are still to overcome in France and at the international level. Nevertheless, there are numerous impulses and progress in this domain that must be encouraged, and I'm delighted to contribute to this dynamic by having explored issues and solutions to the deployment of electromobility, that I believe has a lot of potential on which various stakeholders have to work together. I sincerely hope this "Electromobility in Smart Grids: State of the Art and Challenging Issues Globally" report will encourage further development of electric vehicles and smart grids and contribute to a transition towards efficient low carbon energy systems around the world.

PROF MARC PETIT, LEAD AUTHOR

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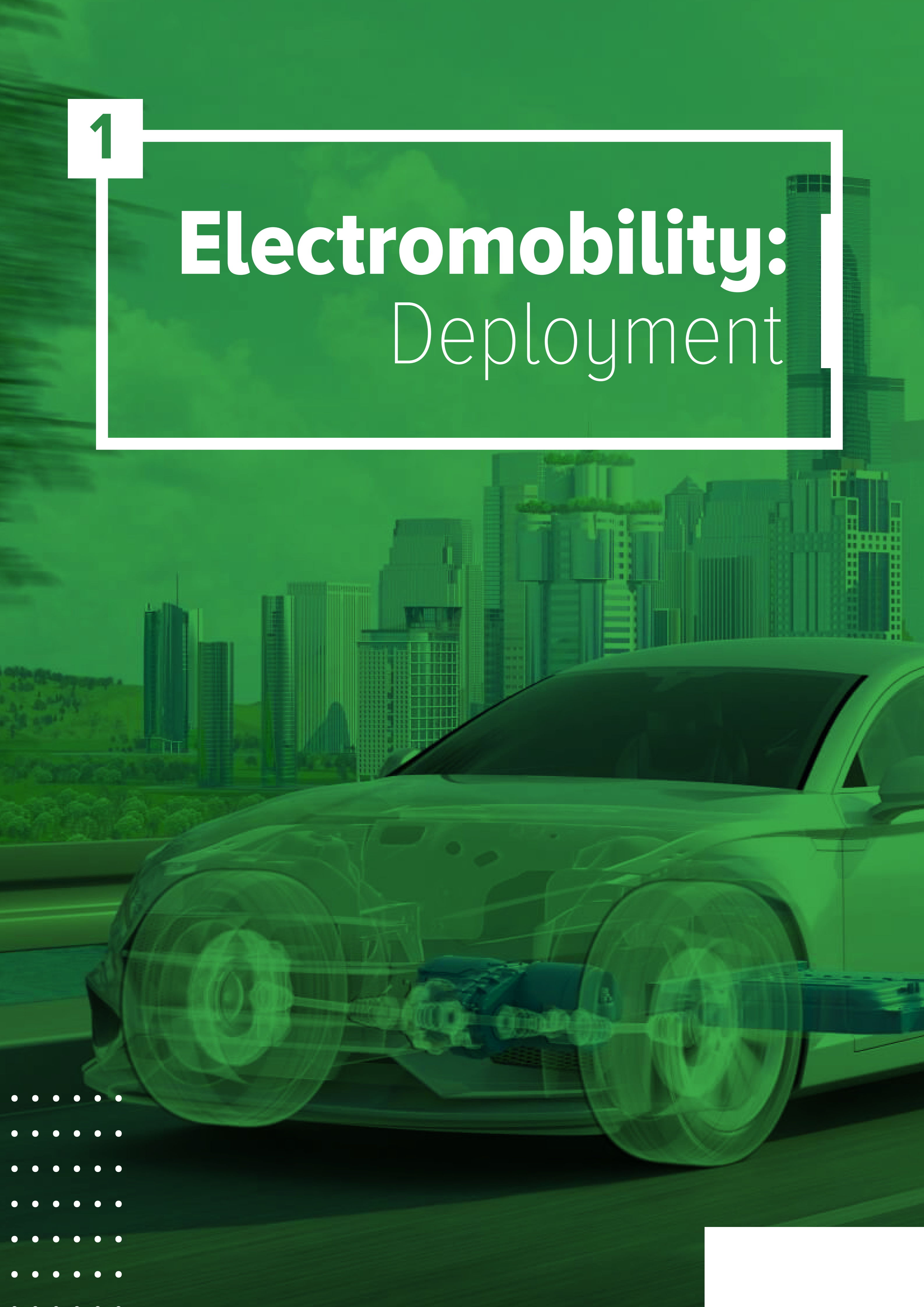
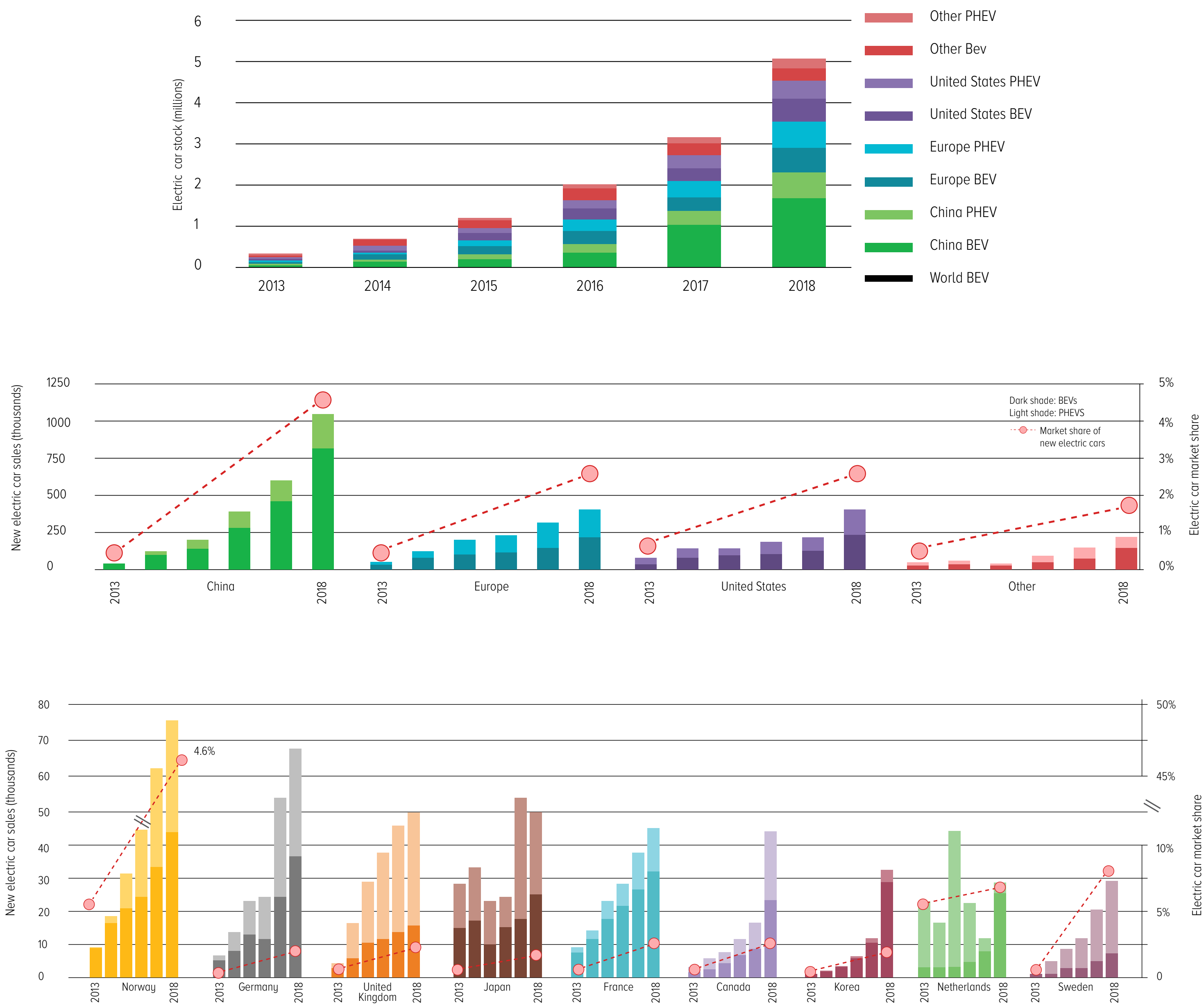
Electromobility: Deployment



1.1 EV and PHEV deployment in the world and for the countries of the GSGF

Growth of plug-in vehicles (battery electric vehicles – BEV – and plug-in hybrid vehicles - PHEV) is continuing in all countries thanks to both public incentives and concerns from drivers for environmental friendly vehicles. Figure 1 gives data from the IEA, and table 1 gives detail figures for selected countries (US, Japan, France, Germany, UK and Norway). Globally 2/3 of the EV are BEV, with China as leading country followed by Europe. In all cases the market share of plug-in vehicles remains low (less than 5%), except for Norway where it is close to 50% thanks to numerous incentives[2] settled since 1990.

Figure 1 : EV deployment and market share (IEA, Global EV Outlook 2019)



[2] Norvegian EV policies, http://elbil.no/english/norwegian-ev-policy/

Table 1 : Plug-in vehicles stocks (BEV + PHEV) for six countries (US, Japan, France, Germany, UK and Norway)

Year	France	Japan	US	Norway	Germany	UK
2010	0	NA	158	2500	600	
2011	5293	NA	17583	4800	2754	1082
2012	15273	55988	70190	9500	5710	3336
2013	30027	84928	167697	20000	13146	6922
2014	46591	114718	290135	43500	26195	21440
2015	73818	137641	406234	83000	49659	49628
2016	107592	160167	564848	133500	74813	86720
2017	149316	206780	764666	205000	129305	135902
2018	201913	235762	1125973	291000	196809	195813

Finally, all countries have built scenario for EV deployment in 2030, 2035 or 2050. Such scenario are used to assess the impact on the electric power system (both energy and power capabilities) and to estimate the needs for public charging stations (slow, fast or very fast charging)

Table 2: EV and PHEV deployment scenarios (year 2030)

Country	France	Japan	California	Norway	Germany	UK
Year	2030	2030	2030	2025	2030	2035
EV target	3 to 5 million in stock	20-30% of new sales and 16% in stock	5 million in stock	100 % private cars are zero-emission	7 to 10 million in stock	100 % private cars are zero-emission

1.2 EV range

The lower range of pure electric vehicles is the main drawback that limits their market share. Recently the battery capacity of a mass market BEV was around 24 kWh (Nissan leaf and Renault Zoe), but the drop of battery costs (figure 2) and the increase of energy density has allowed the automakers to increase the battery capacity (41 kWh for the Leaf and Renault Zoe in year 2017, and 60 kWh in 2019). Examples of battery capacity for both BEV and PHEV are given in table 4 and 5. This increase will contribute to reduce the range anxiety issue, and should push for the EV deployment. With such capacities, autonomy is in the range 250-400 km. The battery capacity will also influence the frequency of recharge (every day, twice a week, once a week, ...) and possibly the impact on power grid in case of similar behaviors.

In the specific case of PHEV, the common target is to be able to drive 50-60 km in pure electric mode, what is compliant with the main part of daily trips (in Europe 87% of daily trips are less than 60 km with an average equal to 34 km).

Figure 2: Evolution of battery costs (source: Bloomberg New Energy Finance)

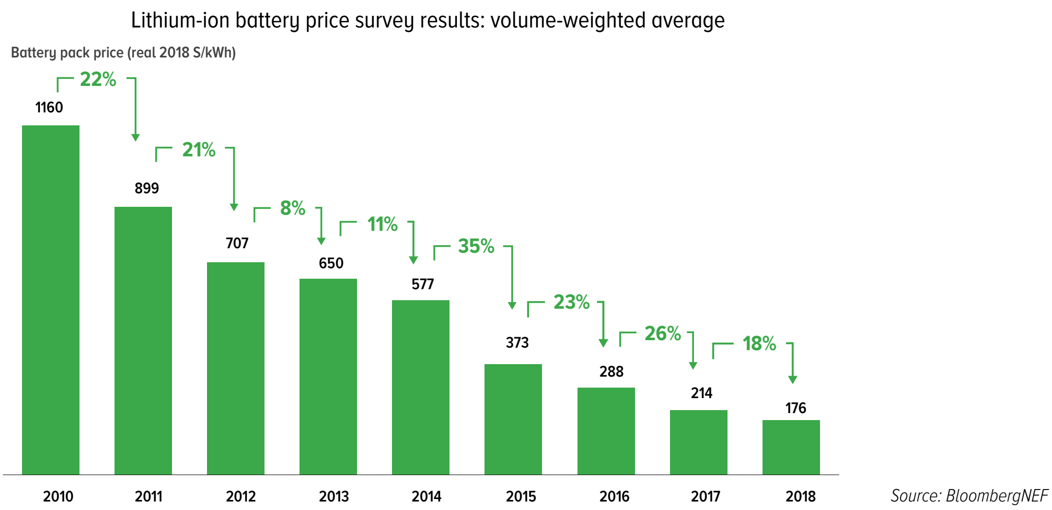


Table 3: Evolution of battery costs

Year	2010	2015	2020	2030
Battery cost (USD/kWh)	1000	400	150	80

Table 4: Battery capacity (BEV in the market)

BEV	Nissan Leaf	Renault Zoe	Peugeot e-208	BMW i3	Volkswagen e-Golf	Tesla
Battery capacity (kWh)	40-62	41-52	50	42	35-48	85-100

Table 5: Battery capacity (PHEV in the market)

PHEV	Toyota Prius	Mitsubishi Outlander	Honda Clarity	Hyundai Ioniq	DS7 e-tense	Mercedes C-class
Battery capacity (kWh)	8.8	13.8	17	8.9	13.2	13.5

1.3 Charging infrastructures

Charging infrastructure (EVSE, electric vehicle supply equipment) is a key element to enable EV deployment with different configuration: AC, DC, low power, high power, wireless chargers, or futurist electric road (EV charging could be close to a railway system but without catenary).

- For AC EVSE, the AC/DC power converter is embedded inside the vehicle, and the EVSE embeds the protection equipment (overcurrent relay). Charging power goes from some kVA to tenths of kVA. A metering system and a RFID chip can be included inside the EVSE. Such EVSE are cheap (around 1,000 USD in single phase connection mode). Regarding the connector, different standards exist but the IEC 62196-2 type 2 is the most commonly used.

- For DC EVSE, the AC/DC power converter is inside the EVSE. This solution is mainly dedicated to higher charging power (typically above 50 kW). It allows to reduce the sizing of the converter embedded in the vehicle (thus the mass, the volume, and then the energy consumption). Such EVSE are much more expensive (around 10,000 USD). The connector follows the CCS Combo or CHAdeMO standards.

- Wireless EVSE allows to transfer power without connection of a heavy cable. Coils must be installed inside the EV and in the road. A first type is the "static transfer" when EV can be charged when it is parked, and the second type is the "dynamic transfer" when EV can be charged while driving (this is also called the electric road). A review of wireless charging system (static and dynamic) has been proposed[3]. Several technological issues remains, such as electromagnetic compatibility and interference, or the impact of high frequency (kHz to MHz) power transfer. Standards are proposed by various international organizations (IEC, IEEE, ISO, SAE, JEVS). Additionally, deployment can only be scheduled after overcoming industrial challenges: funding, infrastructure development and maintenance. For static charging high power charging have been recently demonstrated by the Oak Ridge National Lab[4]. If static charging is more mature, the dynamic charging is more recent with several ongoing research program that include demonstration tracks[5] [6].

[3] Chirag Panchal, Sascha Stegen, Junwei Lu, "Review of static and dynamic wireless electric vehicle charging system", Engineering Science and Technology, an International Journal, Vol. 21, Issue 5, October 2018, Pages 922-937

[4] V. P. Galigekere etal, "Design and Implementation of an Optimized 100kW Stationary Wireless Charging System for EVBattery Recharging", 2018 IEEE Energy Conversion Congress and Exposition

[5] S. Laporte, G. Coquery, V. Deniau, "The Versailles Satory charging infrastructure for Dynamic Wireless Power Transfer systems testing", EVS32 Symposium, Lyon, May 2019

[6] Fabric Project (Feasibility analysis and development of on-road charging solutions for future electric vehicles) https://www.fabric-project.eu/

For cabled EVSE, the power cable is coupled with a communication bus to exchange data between the EV and EVSE: maximum charging current and charging authorization delivered to the BMS (battery management system). In the future the communication will allow smart charging and V2X applications under the IEC/ISO 15118 standard and IEC 63110 (see later).

A critical issue is the standardization of the plugs to enable (1) the interoperability between all EVSE and all EVs, and (2) the smart charging and V2X applications for all EVs. For V2X applications the charger can either be off-board (choice of Nissan) or on-board (choice of Renault).

Two classes of EVSE can be considered: private EVSE (at home or at work) and public EVSE (charging station) to deliver a service and to answer to the range anxiety. Generally EV owners install an EVSE at their home, but it can be complex in the case of collective apartments where the parking space belongs to the community. Step by step, solutions are designed to enable an easy and safe connection of EVSE up to the point of common coupling of the building[7] [8].

The choice of EVSE power (table 6) is a trade-off between several constraints:

- The vehicle availability (i.e. one hour or 8 hours) for charging
- The size of the battery and its lifetime (it is admitted that for a C capacity battery, the maximum charging power is between 1C and 2C)
- The impact on the power grid (higher power can generate local constraints and peak load)
- The cost for power capacity for the user (in French households the contracted power is mainly 6 or 9 kVA for a single phase connection, thus installing a 7.4 kVA or higher EVSE can oblige to increase the power capacity, then the charging cost is increased)

For V2X applications, only EV that stay connected for enough time can be used. Thus they will mainly be connected to a low or medium power EVSE (typically AC single phase or more rarely 22 kVA)

Table 6: Typical EVSE power

Area	Mode (AC ou DC)	Connector	Voltage ; current	Power
Europe	AC 1ph	Type 2	230 V; 16 A 23V; 32 A	3.7 kVA 7.4 kVA
	AC 3ph	Type 2	400 V ; 32 A	22 kVA
	DC	CHAdeMO / CCS Combo		>50 kW[9]
USA	AC 1ph	SAE J1772	Level 1: 120 V; I < 16 A Level 2: 240 V; I < 40 A	1.92 kVA 9.6 kVA
	DC	CHAdeMO	480 V DC I < 125 A	60 kW

[7] BienVEnu project, a demonstration project to test a charging solution for collective apartments http://www.bienvenu-idf.fr/en
[8] https://www.parkingenergy.com/
[9] Ionity charging station: Idc < 500 A and 200 V < Vdc < 920 V

1.4 Public policies for public charging points deployments

Even if the charging will probably mainly be done at home (in 2018, 90% of charging points are private slow chargers[10]), public charging points must be installed to reduce the range anxiety and then to allow longer trip distances. Thus, several questions arise: how many charging points? Where? Slow charging or fast charging (thus low or high power?), which price for a charge?

Except the case of the Tesla charging points that are a private initiative of an automaker, public charging points are deployed following public policies that aim to support the EV penetration.

Regarding to the European policies a survey was published in 2018 by the Transport & Environment organization[11]. It recalls the EU commission recommendation for one public charging point per EV, and the EU directive that states that "Member States shall ensure, by means of their national policy frameworks, that an appropriate number of recharging points accessible to the public are put in place by 31 December 2020, in order to ensure that electric vehicles can circulate at least in urban/suburban agglomerations and other densely populated areas, and, where appropriate, within networks determined by the Member States." The rate of use of public charging station still remain a question. Some responses can be brought by analyzing the case of Norway where public urban stations are used less when the maturity of the EV market increases. Only the use of fast charging station along the corridors is increasing.

In Japan, 22,287 slow chargers and 7684 fast chargers have been deployed in 2018 (Source: IEA Global EV Outlook 2019). The Ministry of Economy, Trade and Industry states that there should be one fast charger every 30 km; on average, such density has already been accomplished. The next goal is to make sure that such density of chargers is realized in all regions of Japan. For destination charging, the following goal has been proposed (table 7).

Table 7: Target number of EVSEs installed for destination charging (source: Meti, Japan)

Destination	Total #	EVSE target
Large commercial buildings	3,000	9,000
Hotels	12,000	5,000
Tourism facilities	890	1,000
Recreational Parks	2,500	2,000
Public buildings	93,000	3,000

The Japanese government is continuing its funding for charging infrastructure in FY2019. This includes funding for fast chargers installed along highways major roads, chargers installed at commercial facilities, and chargers installed at multi-family dwellings and factories. Subsidies can be provided for chargers with output from 10kW to 90 kW. Fast chargers in Japan are compliant to the CHAdeMO standard.

Recently, consortiums have been built up to deploy fast and ultra-fast charging points in the coming years (table 8). The goal is to allow long distance trips without increasing too much the embedded battery (more battery = more cost + more weight + more volume, thus more consumption for EVs). In Europe projects have been initiated to mainly install these stations along the trans-European transport network[12]. Similarly, the US DOE has published a survey[13] for the deployment of DC fast charging stations along cities (71 % of US population), towns (10 % of US population), rural areas (19 % of US population) and Interstate highway corridors. Nevertheless high power charging will impact the design of the battery[14], and the electric power network.

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[10] IEA, Global EV outlook 2019

[11] Transport&Environment,"Roll-out of public EV charging infrastructure in the EU", September 2018 https://www.euractiv.com/wp-content/uploads/sites/2/2018/09/Charging-Infrastructure-Report_September-2018_FINAL.pdf

[12] https://ec.europa.eu/transport/themes/infrastructure_en

[13] US DoE, Office of Energy Efficiency and Renewable Energy, "National Plug-In Electric Vehicle Infrastructure Analysis", Sept 2017

[14] Battery (design of the electrode materials).

Additionally the battery size optimization will be influenced by the density of fast/ultra-fast charging points[15].

Table 8 : Ultra-fast CP in Europe

Consortium	Location	Power	Charging stations	Standard
Ionity	Europe (24 countries)	50 - 350 kW	400	CCS
Ultra - e	Europe (4 countries)	50 - 350 kW	25	CCS
E-Via Flex-E	Europe (3 countries)	150 - 350 kW	14	
MEGA - E	Europe (10 cities)	350 kW	39	CCS
FastCharge				CCS

The position of large companies about electromobility is a good indication for the future. It can also demonstrate the beginning of an integration phase with less but bigger stakeholders. Example: in Europe, three large petroleum companies have recently invested in EVSE operators, EVSE suppliers, or providers of EV charging solutions: Shell with the NewMotion (October 2017) has joined the Ionity consortium, BP with Chargemaster (June 2018), and Total with G2Mobility (September 2018).

[15] S. Funke, P. Plotz, M. Wietschl, (2019) “Invest in fast-charging infrastructure or in longer battery ranges? A cost efficiency comparison for Germany”, Applied Energy, vol. 235, pp. 888-899

2

Electromobility:

Review of the impacts and opportunities for the power system

2.1 Energy and power needs for EV charging

When dealing with plug-in vehicles and their impact on the electric power system, it is important to distinguish energy and power issues. As the power system is sized and operated in power, the power issue will be the most critical. As an example, for delivering 40 kWh to an EV it can be done with a 3.4 kVA (around 13 hours), a 22 kVA (around 2hours) or a 120 kW (around 20 minutes) charging point. The energy is the same but the power that has to be delivered by the grid is not. The higher the power, the higher the constraints. Regarding to the energy needs, they are related to the trip distances. Presently most surveys are based on national transportation surveys[16] that are related to trips with combustion vehicles. Under the hypothesis that the mobility needs would remain similar (that is highly unsure with the development of new mobilities such as car sharing), it gives useful input data to estimate the future energy needs.

To illustrate the issue, let us consider some figures to evaluate the electricity needs for an EV fleet. In many countries the average daily trip is around 30-40 km mainly for commutating between home and work. Under the hypothesis of a 0.2 kWh/km energy consumption, an EV only used for commuting 250 days per year would require between 30-50 kWh per week and 1.5 and 2 MWh of energy per year, thus 1.5 to 2 TWh for one million of EV. These figures are compared with energy and peak power demand in several power systems (table 9).

Three conclusions arise:

- the global energy demand is low in comparison with the total electricity demand,
- the impact on the peak power (typically around 7pm) will be more important on case of uncontrolled charging
- with the EV battery capacity, EV only need to charge between once and twice per week, but there can be a risk of peak load in case of similar behaviour. It can reinforce the additional peak power if the charge is uncontrolled.

Nevertheless, EVs must not only be seen as a drawback. They are also batteries connected (at some periods) to the grid that can be seen as a virtual stationary storage system that could contribute to the grid security with participation in the flexibility services (see later).

Table 9: EV demand (energy and power)

Country	**Global electricity demand** (TWh/y)	**Peak Power** (Summer -Winter)	**Mobility needs** (1 million EV; 7500 - 10000 km/y ; recharge every day) **1.5-2 TWh/y ; 1 GW** (uncontrolled)	
			Energy ratio	Peak power ratio
France[17]	500	55 GW - 100 GW	0.3 - 0.4 %	1 - 2 %
US PJM	800	150 GW - 130 GW	0.2 %	0.7 %
US CAISO	223	45 GW - 32 GW	1 %	2 - 3 %
Japan	850	165 GW	0.2 %	0.6 %
Norway	136	25 GW	1.3 %	4 %

2.2 Distribution and transmission grids

2.2.1 General issues

The reliability and security of the electric power systems relies on several key aspects: a balancing at each instant between the generation and the demand to keep the frequency around its rated value (50 or 60 Hz), a respect of the current limits of the equipment (no congestion), a respect of the voltage deviations inside the contracted limits, and a high level of power quality (criteria such as harmonics limitation, voltage drops, or phase unbalancing limits).

[16] For example the French national survey for transportation that is updated every ten years

All power systems are structured with a transmission grid (operated by a TSO, RTO or ISO and with a meshed topology for a better security of supply) and a distribution grid (operated by a DSO, and that is commonly operated with a radial topology). The TSO has the responsibility of the global balancing of the power system (and the others issues in the perimeter of its grid), whereas the DSO aims at delivering a high quality of supply in the respect of the physical constraints (voltage and current limits).

With the increasing share of variable energy resources in the electricity mix, the grid operators have faced new difficulties. To reduce the reinforcement costs, the grid operators try to use the assets closer to their physical limits. For the TSOs, there are more uncertainties in the balancing, and the global inertia of the power system is expected to decrease in the future (less rotating machines). Thus more reserves will be required and the resources will have to be more flexible (shorter starting duration, shorter response time).

As the resources may be far from the main consumption centers new grid infrastructure may be required to prevent congestion and risks of grid failure (see the issue in Germany with a need of more lines for the north-south axis). At distribution level, the roll-out of distributed energy resources and EV have change the role of the grid operators. The distribution network operators (DNO) are evolving to a role of distribution system operator (DSO). The voltage profile along feeders is no more only dropping from the substation to the loads (power injection at a node increases the voltage). Typically they have to manage voltage or current constraints with a limited number of control devices (capacitor banks and on-load tap changer in the HV/MV substation, or participation of distributed generators in the voltage control). In the future, flexibility delivered by resources (generators or loads) could help the DSO to solve some hard constraints.

2.2.2 EV impacts

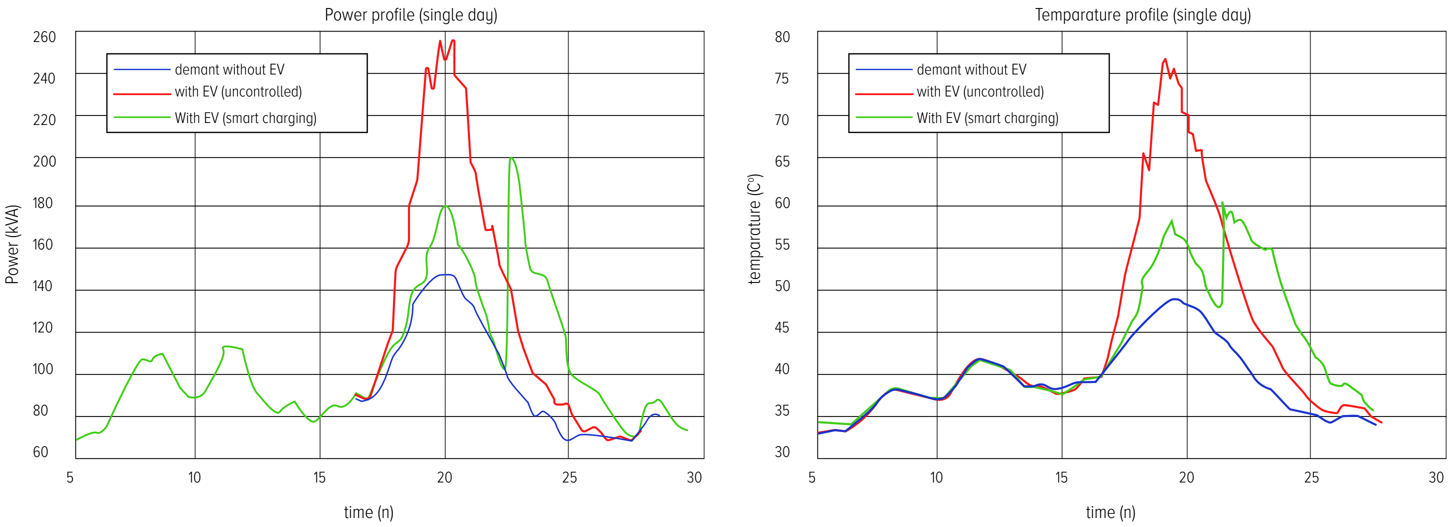
EVs will be connected at distribution level, either in low voltage (individual CP or small station) or medium voltage (fast and ultra-fast charging stations with several charging points). Thus the DSO and TSO have a different analysis of this integration.

A TSO wants to assess the future energy needs and the risk of a peak power increase that could hazard the power capacity margin. For the TSO there is no matter of local constraints. To illustrate the impact at the global scale, a survey recently published by the French TSO will be presented later.

DSO wants to assess the risk of large voltage drop (voltage constraint) and the risk of equipment overloading (current constraint for lines or transformers). Figure 3 shows the influence of EV load on the hot spot temperature without and with smart charging. Without any control a high temperature peak is induced. This thermal stress can reduce the transformer lifetime. Typically, rural networks undergo voltage constraints (because of longer feeders) and urban networks undergo current constraints (because of high population density). If the DSO wants to identify the investments needs, he has to forecast where EVs will arrive first: which region (for an MV scale analysis) or which city and which street (for a LV approach)? But EV integration is not only a current and voltage issue. More generally it is a power quality issue: harmonics, EMC (electromagnetic compatibility), and load unbalance must also be taken into account. EV will be connected through a rectifier power converter (embedded or not) that is highly nonlinear. The harmonics level must fulfill the limitations given by the standards (CEI 61000-3) and the risk of critical coupling between harmonic sources and the grid must be anticipated. Additionally, the installed smart meters mainly use the PLC (power line communication) technology for communication (measurement transmissions to the concentrators in LV substations). EVs must be compliant with this communication signal without inducing perturbations.

[17] RTE, « forecast survey for the balancing in France », edition 2017

Figure 3: Impact of EV charging on transformer loading conditions (power and temperature). Simulation with a 250 kVA transformer, 40 EV and 7.4 kVA charging points in a collective residential building



Different countries employ different last-mile power delivery architecture to homes and small businesses. For example, homes in North America have single-phase (120V) and two phase (240V) power supplies Other similar properties in EU may enjoy a single phase (230 V) or three-phase (400 V) power supply. In most of Asia, homes have a simple single-phase (230V) connection. These different connection architectures (particularly single-phase and two-phase power supply connections) cause very severe EV charging capacity constraint imposed by the grid operator (due to phase unbalance and low voltages) even at the L1 and L2 charger levels. Thus, two neighboring homes having L1 or L2 chargers (on the same phases) fed by the same distribution transformer, can cause low voltage and severe unbalance in the feeder voltage at that point of supply.

If the different types of impact of EVs is quite clear, their quantification is much more complex as it depends on numerous factors that are still unknown. The most complex factor is the sociological one: how will EV be adopted? How EV will be used? What will be the geographic deployment of EVs? Are users ready to adopt a smart charging attitude? Are they ready to participate to grid services? At the very local scale this is complex because it will impact the investment choices of the DSO (investment at the right place, at the right time, with the right sizing). A model of EV deployment and its distribution grid impact has been proposed by a research team[18] from INESC (Portugal). They used deployment models used in marketing to assess the temporal and geographical EV adoption.

In a previous section it has been seen that fast and ultra-fast charging points are planned to be roll-out in the future. When these charging points are installed along the mains corridors (rest or service areas in highways) they may necessitate grid reinforcements because the areas are usually in rural areas with a lower capacity distribution grid. The reinforcement needs have to be evaluated (technically and economically) by the DSO. Thus the charging point operator can decide to choose a hybrid solution[19] (charging points with stationary storage and/or local generation) to reduce the power capacity needs and their associated costs. This choice was chosen in France for the Corri-Door project. The 50 kW charging points may be coupled with a 14 kW stationary batteries to limit the grid capacity at 36 kVA (limit for a lower grid tariff in France). This strategy could be extended to higher power (150 or 350 kW and more).

[18] F. Heymann, V. Miranda, F. J. Soares, P. Duenas, I. Perez Arriaga , R. Prata, "Orchestrating incentive designs to reduce adverse system-level effects of large-scale EV/PV adoption – The case of Portugal", Applied Energy 256 (2019)

[19] D. Sbordone, I. Bertini, B. Di Pietra, M.C. Falvo, A. Genovese, L. Martirano, "EV fast charging stations and energy storage technologies: A real implementation in the smart micro grid paradigm", Electric Power Systems Research, Vol. 120, March 2015, Pages 96-108

2.3 Potential of flexibility

As mentioned previously, EVs can also be seen as a virtual stationary storage system that could contribute to the grid security with participation in the flexibility services. Batteries are characterized by their power and energy capabilities. Energy means how long they can charge or discharge, and power means the intensity of the effort. This virtual storage may have the following characteristics (table 10):

Table 10: EV flexibility virtual storage characteristics

EV Battery size	EV fleet number	Virtual storage capacity	Charge point power	Maximum virtual power	Discharge duration (20% SOC → 80% SOC)	Scale
20 kWh	1 million	20 GWh	7 kW	7 GW	1h45min	HV grid
50 kWh	1 million	50 GWh	20 kW	20 GW	2h30min	HV grid
50 kWh	2000	100 MWh	7 kW	14 MW	4h20min	MV grid
50 kWh	50	2.5 MWh	3.3 kW	160 kW	9h20min	LV grid

Additionally power can be available with short response time (less than one second) thanks to the fast response of the electronic power converter that makes the link with the grid. It makes EV suitable for services for short response time (such as power reserve for frequency containment reserve).

The flexibility that can be delivered by EV can be classified according to the following criteria:

- Only power (capability for fast variation of the power in a very short time)
- Energy and power

A list of twelve services have been identified as deliverable by storage systems[20]. These services can be applied to electric vehicles, and can be classified in three categories:

Power system balancing
- Frequency regulation
- Resource adequacy
- Replacement reserve
- Black start
- Energy arbitrage

Grid operation optimization
- Investment deferral
- Congestion
- Voltage support

Customer oriented services
- Bill optimization
- Peak-load reduction
- Increased PV self-consumption
- Back-up power

Thus several cases of flexibility can be considered for plug-in EV/PHEV:

- Case 1 of flexibility → load shifting following the peak/off-peak electricity prices or dynamic prices. Charging mode only.
- Case 2 of flexibility → reduction of the charging power in case of grid constraint (a signal can be sent by the DSO or by an aggregator). Charging mode only .
- Case 3 of flexibility → variation of the charging power to follow the instantaneous grid frequency variations (participation into the frequency containment reserve). Charging mode only[21].
- Case 4 of flexibility → reactive power exchange for voltage support
- Case 5 of flexibility → bidirectional control of EV (called V2G or V2X capabilities) for energy exchange
- Case 6 of flexibility → bidirectional control of EV for participation into the frequency containment reserve.

[20] Rocky Mountain Institute, "The economics of battery energy storage", 2015
[21] Flexpower project in Amsterdam, Netherland. https://www.elaad.nl/projects/flexpower-amsterdam/

Finally, flexibility can be used to solve a global grid constraint (balancing with the different power and energy markets) or a local grid constraint (mainly in MV or LV distribution grids). In the former case EV can be connected to any point of the grid, whereas in the latter case EV fleets must be well located respectively to the grid constraint. Typically, for a radial network the flexibility asset will have to be downstream the constraint to be efficient.
Notwithstanding all of the above measures, there could be times and/or locations where the grid operator may impose a "curfew or ban" on EV charging. This is more likely in equatorial urban residential communities (i.e. developing countries), as the night load (often the peak) is substantially high due to residential air-conditioner usage and tend to overload the distribution transformers. In such cases, off-site neighborhood charging may be the only way out.

An equally important factor in distribution asset planning (that often gets missed) is that the distribution transformers are sized to get about 3-4 hours of lower-load (cooling off) prior to the onset of the daily uptake ramp (morning and nights). Such cooling-off ensures transformer longevity in the long-term to meet dynamic conditions (load spikes, overloads, ramps, etc.) EV charging can upset this planning assumption leading to a larger distribution transformer and line conductor oversizing.

To enable the smart integration of EV into the electric power system and to develop smart energy communities, bidirectional charging points will be mandatory. Japan is leader in the V2H (vehicle-to-home[22]) charging points with commercially available systems since 2012 (table 11), after disaster-resiliency concept gained increasing attention due to the Great East Japan Earthquake in 2011. Since then, about 7,000 V2H charging points have been sold in Japan. The V2H chargers are DC (CHAdeMO compliant) and their output is around 6 kW.

Table 11: Available V2H chargers in Japan

Manufacturer	Charger name	Output (when grid connected)	Output (when islanded from the grid)
Nichicon	VCG-663CN3	6 kW	3 kVA
	VCG-663CN7	6 kW	6 kVA
	VCG-666CN7	6 kW	6 kVA
Mitsubishi Electric	EVP-SS60B3-M7	6 kW	6 kVA
	EVP-SS60B3-Y7	6 kW	6 kVA
	EVP-SS60B3-Y7W	6 kW	6 kVA
Denso	DNEVC—D6075	6 kW	6 kVA
	CFD1-B-V2H1	3 kW	

2.4 Example of case study

Recently the French TSO published a detailed survey[23] done in close collaboration with the French AVERE association. Beyond the results, it is interesting to analyze the key parameters that have been identified, and the scenario that have been considered to simulate the impact of plug-in vehicles:

Main key parameters

- Mobility needs (commuting, other trips, long distance trip)
- Number of light electric vehicles (BEV and PHEV)
- Share of mobility (car, common transportation, bikes)
- Share of plug-in vehicles (BEV and PHEV)
- Battery size
- Access to charge points (home or work)
- Power of charge points
- Frequency for charging (every day or when needed)
- Ratio of smart charging and V2G

Several charging strategies have been considered

- Dumb charging
- Unidirectional Peak/off-peak
- Unidirectional with participation to the frequency containment reserve
- Vehicle-to-home with grid injection
- Vehicle to grid with participation to the frequency containment reserve or to the energy market
- Coupling with PV (self-consumption + V2G)

[22] https://www.nissan-global.com/EN/TECHNOLOGY/OVERVIEW/vehicle_to_home.html
[23] RTE, "challenges of the development of the electromobility for the electric power system", May 2019 (in French)
[24] AVERE France, French association for the development of the electromobility, http://www.avere-francerg/

Finally, impacts for the power system and the users can be compared for three different use cases (table 12, see the report for more detailed results). A scenario with reinforced flexibility allows to reduce the evening peak power through V2G, and the flexibility also allows to reduce the RES curtailment in case of grid constraints. A systematic plug of the vehicles allows to better take advantage of the flexibility even if the EV charging is not mandatory. In that way the roll out of EVSE at work is an opportunity. Reduction of the system constraints allows to reduce the generation cost for EV charging and thus the users charging cost.

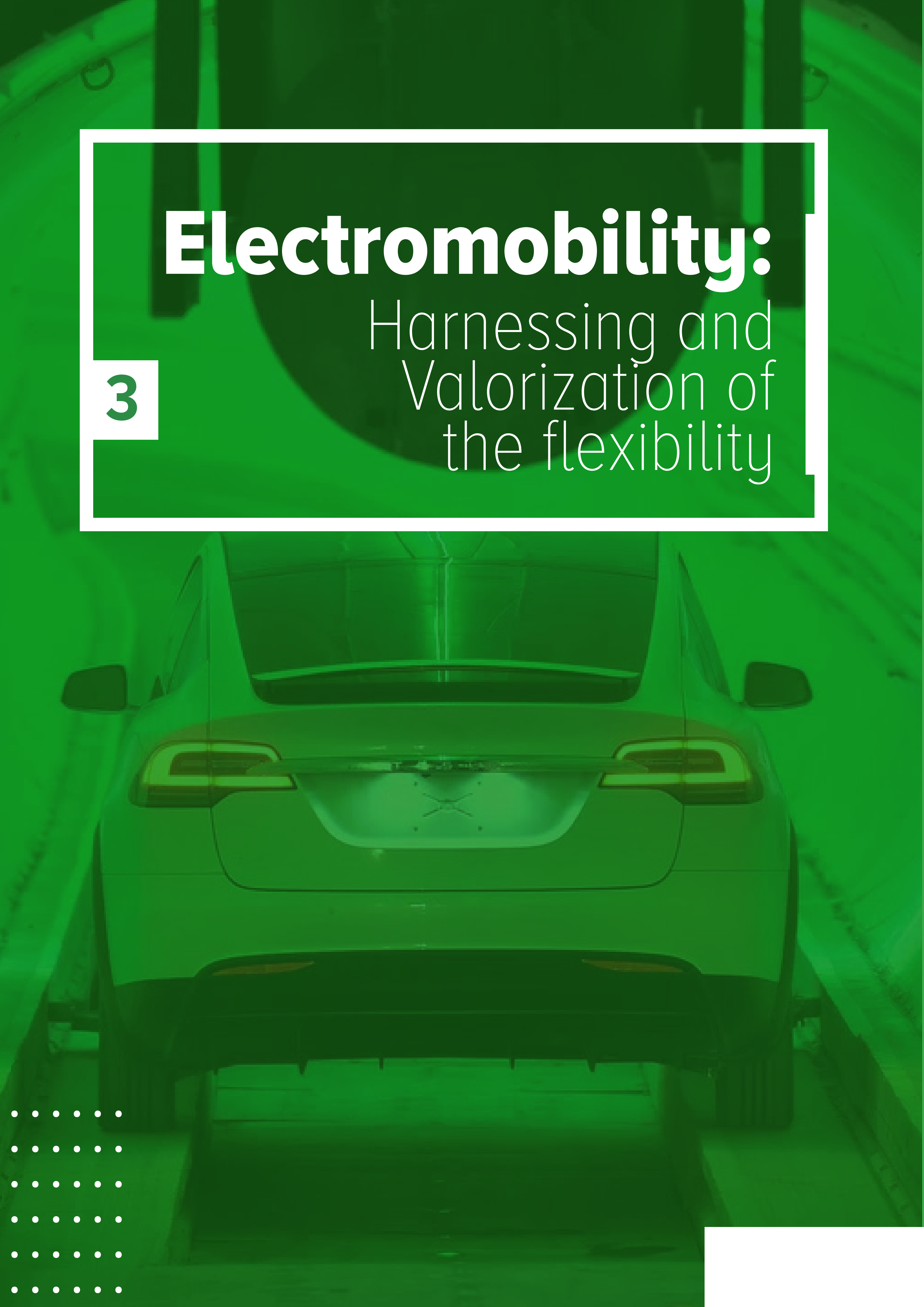
Table 12: Partial results of the RTE survey about EV integration

		Scenarios		
Parameters		**Standard**	**Reinforced flexibility**	**Under stress**
EV battery capacity		73 kWh		89 kWh
Distance trips (km/y)		14000		15300
EVSE access outside home		28 %	45 %	16 %
Average charging power at home		6.2 kW	6.7 kW	
Charging frequency: “systematic” and “when needed”		65 %, 35 %	85 %, 15 %	
Smart charging (with part of V2G)		60 % (3 %)	80 % (20 %)	40 % (0%)
Power system impact	Peak power	+ 2.2 GW	- 5.2 GW	+ 5.7 GW
	Energy	+ 29 TWh	+ 28 TWh	+ 32 TWh
	Additional green charging	+7.7 TWh	+ 11.1 TWh	+ 6.6 TWh
Generation cost for EV charging		35 €/MWh	23 €/MWh	45 €/MWh

3

Electromobility:

Harnessing and Valorization of the flexibility



3.1 Standards and interoperability

Definition of standards is a key element for harnessing the flexibility of EV and PHEV. Standards will ensure each vehicle to be able to exchange power and data with the grid and different shareholders (utilities, aggregators, suppliers …). From an industrial perspective, standardization allow to reduce the costs of the technical solutions with mass market approach.

In that way the US DOE and the EU have respectively set their own "Electric Vehicle-Smart Grid Interoperability Centre" (set in Argonne in 2013) and "European Interoperability Centre for Electric Vehicles and Smart Grids" (set in Italy in 2015) with the ambition to closely collaborate in order to have a completely interoperable charging structure across the world. The topics cover communication between the charging station and the vehicle for identification, authorization and billing of the vehicle as well as to determine how much energy the battery needs and how fast it can be charged.

Standards organizations (IEC, ISO and SAE) are working together to enable common standards for EV/PHEV grid interfaces.

The IEC 61851-1 standard is a simple analog communication between the EVSE and the EV to enable a safe charging system. The main requirements of the standard are:

- Continuous checking of the link to ground (people safety)
- Checking of the PWM signal propagation
- Checking of the correct connection of the EV
- Charging power limitation to comply the physical infrastructure, and for dynamic smart charging
- Energizing and shutting down of the system

The EVSE sends information to the EV through a PWM (pulse width modulation) signal, and the EV answers with a voltage level that indicates its current state (state A → EV non connected, state B → EV connected but not ready to charge, states C and D → EV connected and ready to charge, states E and F → charging system in error mode).

The ISO/IEC 15118 standard aims at giving specifications for high level bidirectional communication between EVSE and EV. Although ISO/IEC 15118[25] is entitled "Road vehicles – Vehicle to grid communication interface", the vehicle-to-grid feature has at first been described only as a use case in ISO 15118-1. ISO 15118-2 was published in 2014, but does not define any messages that would allow a bidirectional power transfer. The 15118 standard allows to complete the 61851-1 standard with the following characteristics:

- User ID from EV
- Energy needs from battery SOC
- Charge management
- Enabling high value services (diagnostic, internet access, …)

This standard enables the optimization of the grid and the charging cost. The charging process is organized in eight functional groups, amongst them: begin of charging process (A), Identification, Authentication, and Authorization (D), Target setting and charge scheduling (E), Charge controlling and re-scheduling (F).

Presently, the deployment of the 15118 standard faces the chicken & egg problem. Cars manufacturers do not implement this standards in EV because it is not supported by EVSE, but EVSE manufacturers says they can't implement because it is not supported by EV! Nevertheless, the deployment of the DC CCS that needs the 15118 should contribute to break this vicious circle.

The next generation of ISO 15118 features, defined in ISO 15118-20, include wireless and bidirectional charging. ISO 15118-20 currently enables the EV to act as a distributed energy resource (DER) and feed energy back to the grid. DC Bidirectional EVSE seem to be more convenient to better fulfill the local grid code when injecting power into the grid: the local grid codes constraint can be programmed into the controller of the charging station that manages the power flow to and from the grid. No specific information has to be exchanged between EVSE and the EV communication controller.

[25] https://v2g-clarity.com/knowledgebase/vehicle-to-grid/

These standards are also completed by the IEC 63110 (Standardizing the Management of Electric Vehicle (Dis-)Charging Infrastructures) that defines the links between EVSE and CPO (charging point operator), and the IEC 63119 (Information exchange for Electric Vehicle charging roaming service) standard.

Standards must also cover power quality issues (harmonics) and protection issues (in V2X mode the vehicle is a source that must be tripped in case of a close fault).

A bi-directional EVSE must follow the security standards. In US the grid code only accept stationary power converters. Thus only V2G with dc EVSE are compliant with this code. The SAE standard SAE J3072 has been set for the mobile converters (embedded charger), and is in effect in the Delaware state. The SAE J3072 *established interconnection requirements for a utility-interactive inverter system which is integrated into a plug-in electric vehicle (PEV) and connects in parallel with an electric power system by way of conductively-coupled EVSE. This standard also defines the communication between the PEV and the EVSE required for the PEV onboard inverter to be configured and authorized by the EVSE for discharging at a site.*

In Europe, any device that can inject power into the grid must have a decoupling relay to trip in case of islanding configuration after a relay tripping in the main grid. The main standard to follow is the DIN VDE 0126-1-1. To enable the connection of bidirectional EVSE, the French regulator[26] has asked for analyzing their compliance with this standard. Additionally, there is a key question regarding the location of the decoupling relay: i) inside the vehicle for all EV that could do V2X, ii) inside the EVSE, or iii) at the point of common coupling if a generation system is connected downstream.

3.2 Technical requirements

Vehicle-to-grid applications have been demonstrated to be technically feasible. Lab tests have been done at the University of Delaware[27] for more than 10 years. Then a commercial solution has been developed by the Nuvve Company that is leader in V2G solutions. Mainly, the battery charger must be reversible (two-ways power flows). Either it is embedded in the vehicle (ac EVSE), or it is inside the dc EVSE.

Recently technical solutions have been tested with commercial electric cars (Parker project[28] in Denmark). According to the project leader, the main result is that the "V2G-technology works in a number of commercial electric cars. We have shown that the technology can be commercialized, and has been commercialized in Denmark".

To fully harness the flexibility of EV/PHEV, the response time of the resources is fundamental. For example, many experimentations have been conducted about participation to the frequency containment reserve (FCR). In the Parker project the control of EV is done in a centralized way by an aggregator. Communication link was based on IEC 61850 (V1G configuration) or CHAdeMO (V2G configuration). If the response time (around 5sec) seemed to be compliant with FCR requirements, it is still too slow in case of future power systems with low inertia which should require response time of less than one second (see the calls for tender of National Grid in 2016 and the finnish TSO Fingrid in 2020). Additionally, the IEC 15118 seems to be slower in its present configuration. The case of a local frequency measurement inside the car is a question, but it might increase the cost of the EV. An equally compelling case in distributed resource systems is fast response in VAR injections at several points to maintain adequate minimum power factor (usually above 0.9) and acceptable nodal voltages (+/- 6%). There are often less than 2-3 sec. in response timing.

[26] French regulator CRE, "electric vehicles and power systems" working paper. In French, October 2018, https://www.cre.fr/content/download/20044/256210
[27] https://nuvve.com/2019/06/27/delaware-v2g-policy/
[28] Parker project, https://parker-project.com/

3.3 The case of distributed resources: the role of the aggregators to take advantage of distributed flexibilities.

Participation of flexible distributed resources in electricity markets has often to face with the definition of technical characteristics that can been seen as barriers to entry. Typically, the minimum size that can be bid on the markets, or the minimum time frame of availability. Additionally, participation to electricity markets may require (depending on the targeted market) the connection with a BRP (balancing responsible party). Finally, rules are not easy to understand for unwarned customers. All these characteristics are a barrier for valuation of small and variable resources like EVs. Thus an aggregator can gather a large amount of small resources to comply with the market rules, and make the things transparent for the users with the opportunity of revenues. Aggregators will act as an intermediate between the customers (flexible assets owners) and the electricity market shareholders. They develop tools to optimize the assets management and valuation, and take the financial risk.

Concerning the specific case of EVs, aggregators can bid only with EV fleets or merge EVs with other assets to reduce the uncertainty. EVs still remain a new assets for aggregators who have more experience with small/medium/large industrial assets that are typically valorized on RR (replacement reserve) markets. Nevertheless, the short response time of EV battery can give them the opportunity for bidding in specific markets.

3.4 Which opportunities for valorization? Which markets?

Presently there is several electricity markets that could enable the valorization of EV/PHEV flexibility: frequency regulation markets, balancing markets, capacity markets, intraday markets, Day-ahead markets, transmission congestion markets, local markets (at distribution scale) for congestions or voltage issues. Depending of the markets, EVs can be consider as energy or power type resources. Energy depends on battery size and trips, whereas power depends on the charging point and the maximum power authorized by the car manufacturer. Several key factors of flexibility can be defined[29] :

- Flexibility direction (upward/downward and unidirectional/bidirectional)
- Flexibility characteristic (energy and/or power)
- Availability ratio
- Predictability
- Technical response time

Regarding to the electricity markets, they are characterized by:

- Time frame (real time, short term, medium term and long term)
- Traded product: capacity or energy
- Notification delay (automatic regulation, 10-15min, 1-2h, 1-24h, day ahead, year head)

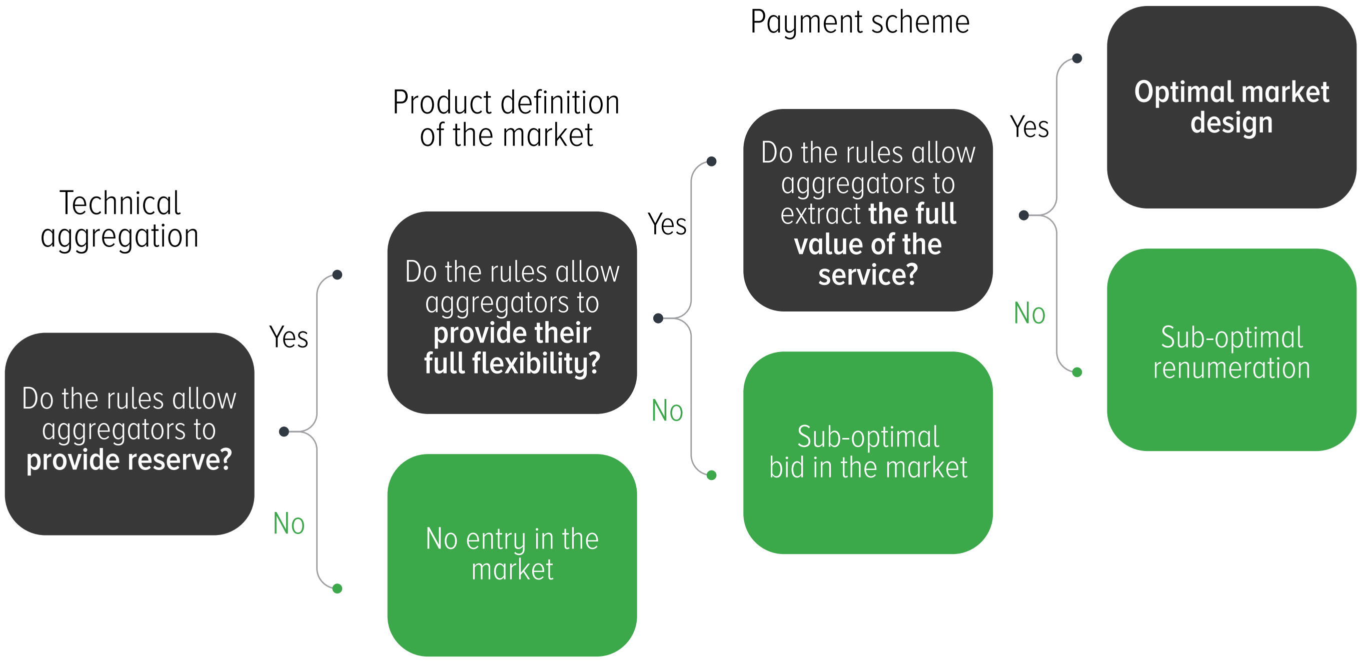
Incentives for flexible use of EV/PHEV can be price based such as Time-of-Use pricing (TOU), Real-Time Pricing (RTP) and Critical Peak Pricing (CPP). Other incentives - Peak Time Rebates (PTR), Interruptible capacity programs (ICAP) and Emergency demand response – require baseline consumption definition. Nevertheless, the efficiency of all these incentives depends on the willingness of the users to participate. Thus direct control of EV/PHEV by a shareholder (system operator, aggregator, and retailer) are probably more suitable for real time and short term provision of flexibility services[29].

With a more general approach, a decision tree with three issues (technical aggregation, production definition on the market, and remuneration scheme) has been proposed to analyze the opportunity for an aggregator to enter in a market with distributed resources[30].

[29] C. Eid, P. Codani, Y. Perez, J. Reneses, R. Hakvoort," Managing electric flexibility from Distributed Energy Resources: A review of incentives for market design", Renewable and Sustainable Energy Reviews, vol. 64, pp. 237–247 (2016)

[30] O. Borne, Y. Perez, M. Petit, "Market integration or bids granularity to enhance flexibility provision by batteries of electric vehicles", Energy Policy, vol. 119, pp.140–148 (2018)

Figure 4 : Proposal for a decision tree for aggregator[30]



Finally, valorization does not always mean market. It can be a private optimization (controlling its own load curve through local storage or EV) for developing self-consumption or optimizing the subscribed power.

3.5 Evolutions of the market designs.

In fact there are two issues whether we deal with transmission system (global balancing) or with distribution grids. Market designs for services for global balancing are generally well organized (spot, intraday, balancing, reserve) but not fully adapted to distributed resources such as EV (minimum volume for bidding in markets, temporal granularity of markets: one hour, 4 hours, one week ...).

Considering the specific case of the European FCR market[31] (a common platform is used to exchange reserves for several EU countries), rules are under evolution. Up to 2017 the main required characteristics of capacity reserve were:

- Minimum bid: 1 MW
- Incremental bid: 1 MW
- Direction: symmetrical (up and down)
- Time frame: one week
- Gate closure: Tuesday before the week of delivery

The long time frame is very disadvantageous for uncertain resources like EV/PHEV that have periods of high connection rate (at night) and low connection rate (during the day). Additionally the participation of distributed resources may be limited by TSOs. After a consultation with the main participants, evolutions have been planned. In July 2020 the time frame will be reduced to four hours with a gate closure in day-ahead. But, it must be kept in mind that FCR is a niche market because the reserve need is 3000 MW for the whole continental EU system (ENTSOe area). In the case of France, RTE is responsible for around 600 MW of this reserve, with a limit of 25% delivered by distributed resources (such as EVs), thus 150 MW. In this condition it has been shown[32] that the maximum fleet number is around 30000 EVs to maximize the revenue.

[30] O. Borne, Y. Perez, M. Petit, "Market integration or bids granularity to enhance flexibility provision by batteries of electric vehicles", Energy Policy, vol. 119, pp.140–148 (2018)

[31] https://www.entsoe.eu/network_codes/eb/fcr/

[32] O. Borne, "Vehicle-to-grid and flexibility for electricity systems : from technical solutions to design of business models", PhD thesis, University paris-Saclay, March 2019

At local scale (medium and low voltage distribution grids) grid operators mainly undergo current and voltage constraints. In order to postpone grid reinforcements or in case of temporary grid limitations (i.e. due to a period of works by the DSO), DSO may need flexibility. Initiatives are coming to build flexibility call for tenders (market is not always possible due to the low numbers of actors at a local scale). In France the main DSO (Enedis) has launched a consultation to set the main characteristics that would be required for a future flexibility call. Then, a platform has been opened to receive a declaration of the available flexibilities[33]. In UK the DSO UKPN is already operating tenders for flexibility at distribution level through an electronic platform[34] to define the characteristics of the tenders, such as:

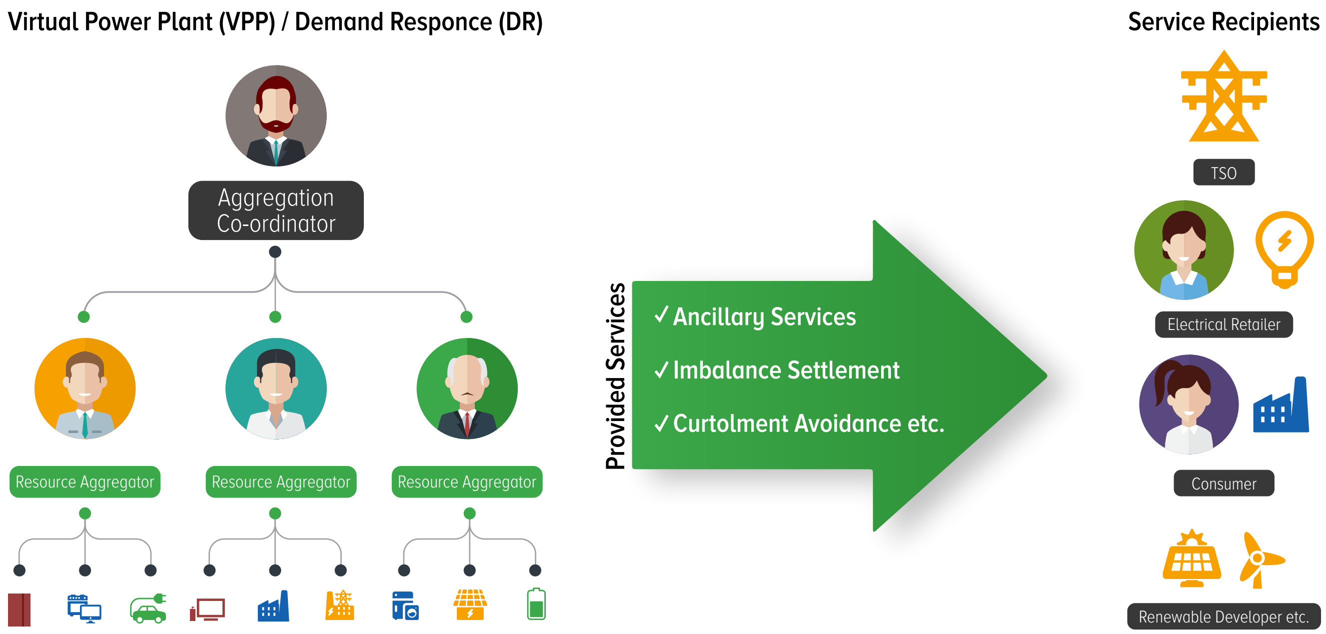
- Location
- Period (contract start/end, days and time required)
- Power type (active/reactive power)
- Need type (reinforcement deferral, pre fault, post fault)
- Need direction (Generation turn up / Consumption turn down)
- Minimum aggregate size, minimum run time
- Estimated utilization (events and hours)

In the latter case minimum aggregate size of 50 kW and utilization duration of 3-5 hours per day can be compliant with energy reserve of a small fleet (less than 20) of EV/PHEV.

In Japan, the Ministry of Economy, Trade and Industry have provided funding for pilot projects on Energy Resource Aggregation Business (e.g. VPP and DR) in Japan. Two roles are assumed in such business scheme: 1) aggregation coordinators (AC), who trade aggregated flexibility with DSO/retailer/market, by sending control signals to its affiliated resource aggregators based on flexibility needs, and 2) resource aggregators (RA), who make contract with end consumers and control their resources based on aggregation coordinators' signal.

Such energy resource aggregation business is expected to provide services such as ancillary services, imbalance settlement avoidance services, and curtailment avoidance services. Currently, Japan is in the process of establishing an ancillary service market. The ancillary service market is planned to start operation in 2021; market design is under consideration. The results of energy resource aggregation business pilots, of which some projects include smart charging and V2G, will be reflected on the market design.

Figure 5 : VPP / DR overview (Japanese model)



[33] Enedis flexibility website, https://flexibilites-enedis.fr/
[34] UKPN flexibility tenders platform, https://picloflex.com/

In US, the FERC has asked for evolution in market designs to better allow the participation of electric storage resources (see next section). States that are promoting storage systems also need to adapt their rules for the specific case of EV/PHEV.

3.6 The position of national regulators.

EV/PHEV that could deliver services to the power system is a new asset that requires a special attention from the regulators.

As an example, the French regulator has recently published a working paper[35] for electric mobility deployment from EVSE accessibility to smart charging and V2X issues. Twenty-two recommendations are proposed to cover topics such as smart charging and flexibilities, bidirectional power flows and experimentations. Bidirectional EVSE are a critical issue because EV/PHEV are both consumer and producer. Thus they have to comply with both technical requirements. A recommendation deals with the decoupling protection (see in section 3.1). As for the generation units, the bidirectional EVSE must be declared to the DSO. The French regulator asked for a simplified declaration.

In the same way, fast declaration is expected in US for bidirectional EVSE. In a first step accelerated declaration have been set for stationary storage systems, but it is expected to be extended to mobile storage.

In US, the participation of electric storage resources (a resource capable of receiving electric energy from the grid and storing it for later injection of electric energy back to the grid) in electricity markets is recommended by the FERC (Order No. 841[35]). Order 841 aims at creating a clear legal framework for storage resources to operate in all wholesale electric markets and expands the universe of solutions that can compete to meet electric system needs. Order No. 841 requires each RTO/ISO to revise its tariff to establish a participation model for electric storage resources if it has not already done so. The participation model must 1) ensure that a storage resource is eligible to provide all capacity, energy, and ancillary services that it is technically capable of providing; 2) ensure that a storage resource can be dispatched and can set the wholesale market clearing price as both a wholesale seller and wholesale buyer; 3) account for the physical and operational characteristics of storage resources (FERC has defined 13 characteristics) through bidding parameters or other means; and 4) establish a minimum size requirement for participation that does not exceed 100 kW. Additionally, each RTO/ISO must specify that the price for sale of electric energy from the wholesale markets to an electric storage resource that the resource then resells back to those markets must be set at the wholesale locational marginal price ("LMP").

Nevertheless the specific case of EV/PHEV is not specifically considered. Currently in North America, the value realization of smart charging and V2G is still far from being solved. A few lower EV charging tariff initiatives are being mooted to solve the day-time "duck curve" surplus power in California which is a special situation. The regulatory treatment is still far from a steady state cure until more EVs proliferate. Curtailment seems to be the immediate tool at this time. But the Electricity Advisory Committee has given to the US DOE five recommendations for "Enhancing Grid Resilience with Integrated Storage from Electric Vehicles"[36] (see later in section 5).

[35] US FERC Order n°841

[36] Electricity Advisory Committee, « Enhancing Grid Resilience with Integrated Storage from Electric Vehicles, Recommendations for the U.S. Department of Energy", June 2018

4

Electromobility: Demonstration Projects

This section gives an insight about several smart charging of V2G projects. A list of V2G projects around the world has recently by published by UK Power Networks (UKPN) that has launched a website (V2G-hub[37]) showing global vehicle-to-grid (V2G) projects. It can be seen that there is numerous completed and ongoing projects, what shows the relevance of the topic as a mean to enable the way to the energy transition.

4.1 French projects

For France, three projects are presented in this section: BienVEnu, GridMotion and aVEnir.

4.1.1 BienVEnu project

BienVEnu (www.bienvenu-idf.fr/en, led by Enedis, completed in 2019), was dedicated to the deployment of EV in collective residential buildings, with smart charging strategies and the capability in reducing the charging power in case of distribution grid constraints (a signal is send by the DSO to the local energy management system for defining new charging profiles). This project was supported by the ADEME (French Agency for Environment and Energy Control) under the "Investments for the Future" program, and by the Ile de France region.

Figure 6 : Partners and supporters of the BienVEnu project

This project proposes a three steps solutions to enable the roll-out of e-mobility in collective dwellings:

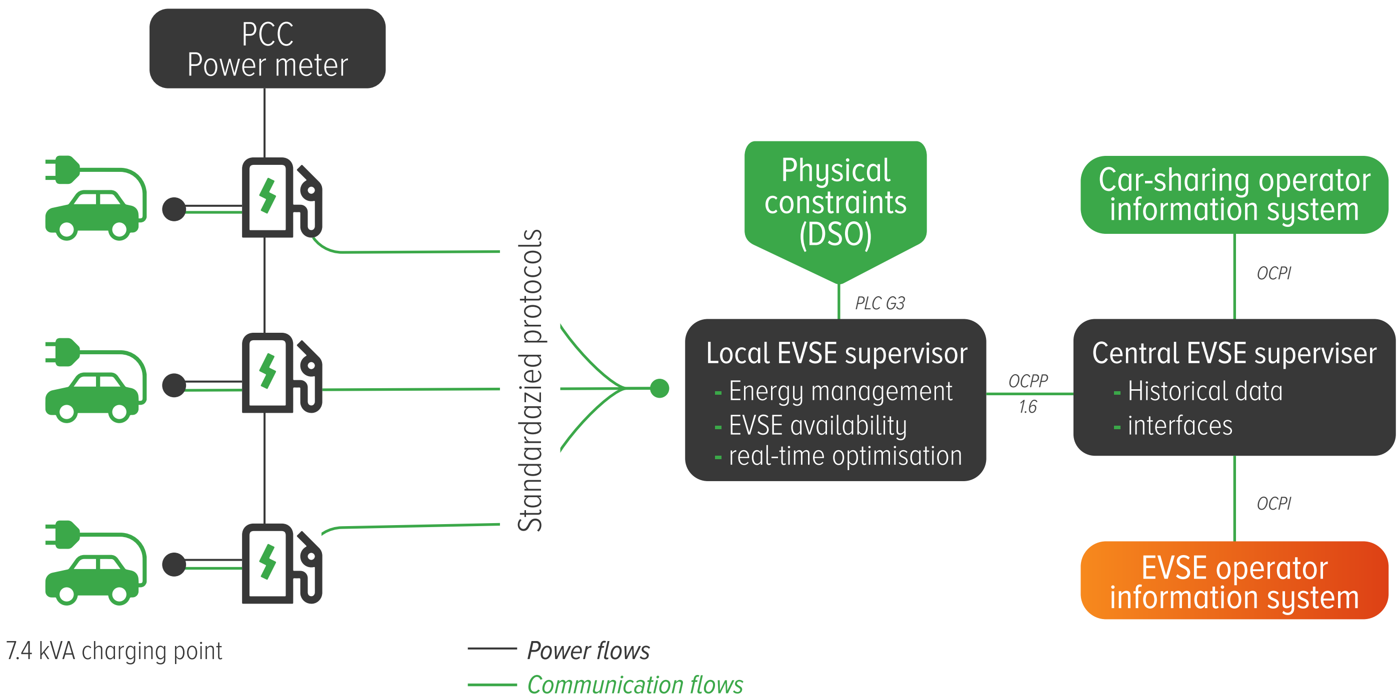
- LV feeder for an easy EVSE connection in the parking
- A smart charging solution
- A Carsharing solution

During the project six solutions have been proposed for the EVSE connection in the parking places[38]. The smart charging strategy[39] aims at (i) reducing the contracted power for the EV cluster and (ii) responding to a signal representative of a local grid constraint to activate the EV flexibility.

[38] White book for the EVSE connection in collective dwellings (in French), https://www.enedis.fr/sites/default/files/Livre_Blanc_IRVE_en_residentiel_existant.pdf

[39] M. Petit, M. Hennebel, "EV smart charging in collective residential buildings: the BienVEnu project", IEEE Powertech Conference, Milan, June 2019

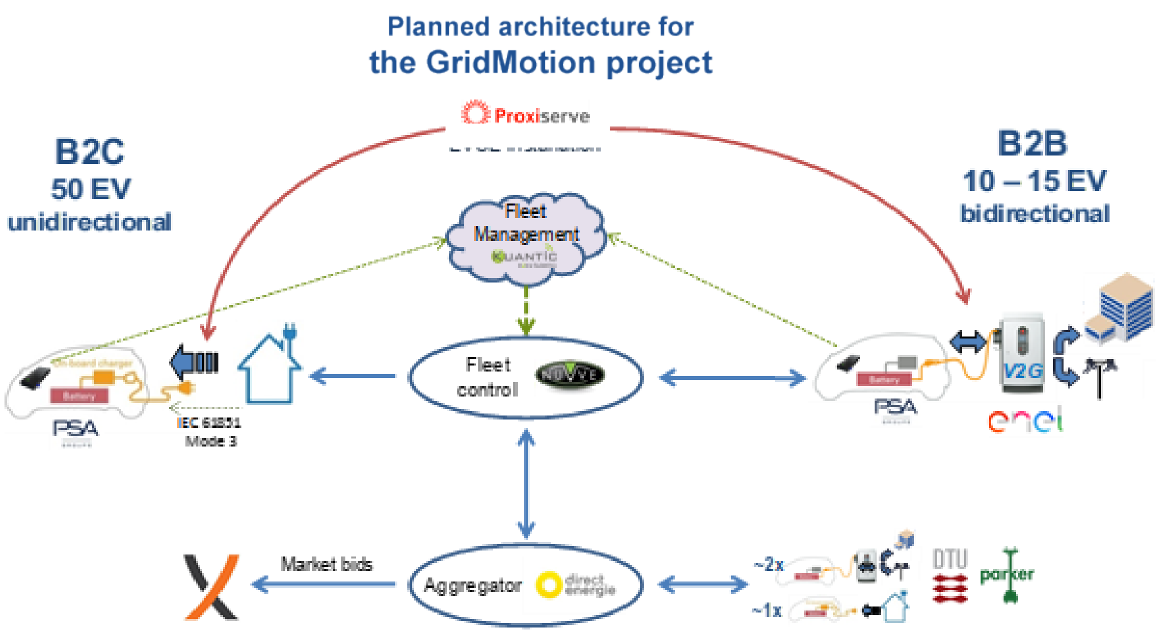
Figure 7 : Partners and supporters of the BienVEnu project



4.1.2 GridMotion project

GridMotion (led by PSA groupe), will test the participation of an EV fleet to the frequency containment reserve (FCR). An aggregator will exchange information with each EV to estimate the power reserve of the fleet, and then bid to the power reserve market. EV are private vehicles connected with a unidirectional plug, and commercial vehicles connected with bi-directional plugs. This project is a continuation of the Parker project (led by DTU, Denmark) with commercial vehicles and real users.

Figure 8 : Partners and supporters of the BienVEnu project



4.1.3 aVEnir project

aVEnir project[40] (led by Enedis with 11 partners) is a 3-year demonstration project that has started in 2019. This project is supported by the ADEME (French Agency for Environment and Energy Control) under the "Investments for the Future" program. It is located near the city of Lyon (urban area) and in the South-Est region "Provence Alpes Côte d'Azur" (rural area). The project has been built around three main objectives: i) test in real conditions of the EV smart charging, ii) development and test of new smart charging strategies (including coupling with PV generation and V2G), and iii) contribution of EV to the local flexibilities.

4.2 Japanese Projects

Table V2G Demonstration Projects started in FY2018

Utility	Members	AC	RA	Pilot partner
Kyusyu	Kyushu electric	○	○	
	Central Research Institute of Electric Power			○
	Mitsubishi Motors			○
	Mitsubishi Electric			○
Tokyo (TEPCO)	TEPCO holdings	○		
	TEPCO Power grid			○
	TEPCO Energy Partners			○
	Hitachi System power service			○
	Mitsubishi Motors			○
	Shizuoka gas		○	
	Hitachi Solutions		○	
Chubu	Toyota Tsusho	○	○	
	Chubu Electric Power Co.			○
Tohoku	Tohoku Electric Power Co.	○	○	
RA: resource adequacy AC:				

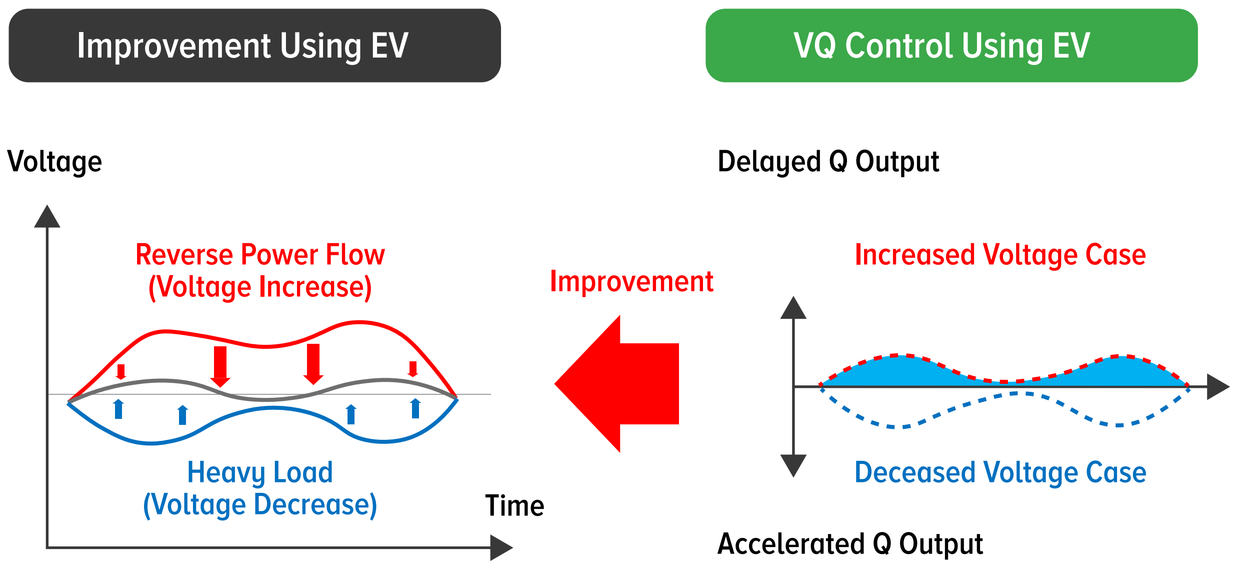
The V2G demonstration project by TEPCO aimed to clarify the necessary requirements for supplying a service that balances usage as the grid stabilization control with usage as mobility, and demonstrate the feasibility of leveraging V2G for RA service to provide the grid stabilization function. In this project two use cases, grid congestion management and voltage control, were investigated (figure 9)

[40] aVEnir demonstration project for electric mobility
https://www.enedis.fr/sites/default/files/field/documents/CP_11_partenaires_sengagent_au_cote_dEnedis_dans_le_projet_aVEnir_221._.pdf

Table 13 : Grid stabilization function investigated by TEPCO demonstration project

Grid stabilization function	Details
Grid congestion management (current control)	Control to absorb revers power from DER to manage the capacity of distribution network
Voltage control	Control to avoid voltage fluctuation caused by reverse power flow from DER in distribution network using reactive power control

Figure 9: participation of EV to voltage regulation in distribution grid (source : TEPCO)



4.3 US Projects

4.3.1 Scholar buses

Scholar buses are widely used in North-America with more than 8 billion of trips between home and schools, and more than 9 billion of km in US. To reduce the buses emissions, the electrification of buses fleets is seen as a solution. As the daily usage duration is quite short, the large batteries and the high power charging points are seen as an opportunity to deliver grid services. Buses manufacturers as Lion and Blue Bird have indicated that they will propose V2G compliant buses in the near future. The associated revenue could be seen as incentives for the municipalities. Locally some DSO have set incentive policies: in Virginia State the DSO Dominion has bought 50 V2G electric buses that will be free distributed to the schools, and for 1000 others buses[41]. Dominion will pay the extra cost of the electric buses in comparison to thermal buses. Each bus will have a 220 kWh battery and will be charge through a 60 kW bidirectional V2G charging system. The cost will be included in its current base rate (With state approval, Dominion will grow the fleet by 200 vehicles per year through 2025, at an estimated cost of $1 per month for a typical residential customer). Thus for Dominion it will represent a 220 MWh-60 MW virtual stationary storage when all buses will be grid-connected.

Nuvve will be part of the experimentation, after similar experimentations in New-York and California where tested services were frequency response, bidirectional V2B (vehicle-to-building) load shifting, and demand charge management.

[41] Virginia's massive V2G electric school bus procurement, "https://electrek.co/2019/12/18/daimler-first-winner-in-virginias-massive-v2g-electric-school-bus-procurement/"

4.2.2 Delaware University

After initiating the V2G concept, experimentations are under continuation in the campus of the University. The EV connected to charging points in the campus participate to the frequency regulation mechanism of PJM. EVs are used with unidirectional or bidirectional power flows. The power flow are changed to follow the frequency variations. In the campus users are not paid for the service, but they can charge for free. Nuvve is the aggregator that bids its hourly available capacity on the weekly PJM tenders. To reduce the risk of penalties (due to EV availability uncertainty), Nuvve has installed a stationary battery made from ten second life batteries from Chevy Volt (220 kWh in total).

4.4 UK Projects

4.4.1 Bus2Grid

The 'Bus2Grid'[42] project is being hailed as the first of its kind and will involve over 30 e-buses using smart technology to provide bi-directional charging that enables the e-bus batteries to interact with the energy system. This project is led by the SSE Company in partnership with:

- BYD, providing V2G enabled electric buses, charging infrastructure and charging management systems
- the DSO UKPN, providing DNO use cases and local network modelling intelligence
- Leeds university (academic partner), leading on business model design and barriers to market analysis

The project is funded by the Department for Business, Energy and Industrial Strategy (BEIS) and the Office for Low Emission Vehicles (OLEV) and is delivered by Innovate UK

The project will test the following services: frequency response, energy arbitrage, load shifting.

4.4.2 E4future

This project (2018-2021) led by Nissan is a large-scale V2G demonstrator (1000 V2G installations), deployed in groups and controlled by an innovative aggregator platform stacking multiple services that supports a more efficient electricity system and decreases ownership costs to vehicle users. Data will be collected to understand the technical characteristics of vehicle to grid charging for both the vehicles and the electricity networks.

The demonstrator will determine the technical and commercial potential of V2G to support the GB electricity system. The innovative V2G platform will stack multiple services to the System Operator (National Grid) and Distribution Network Operators (UKPN and Northern Powergrid). Research and analysis activities will be supported by Newcastle University and Imperial College London.

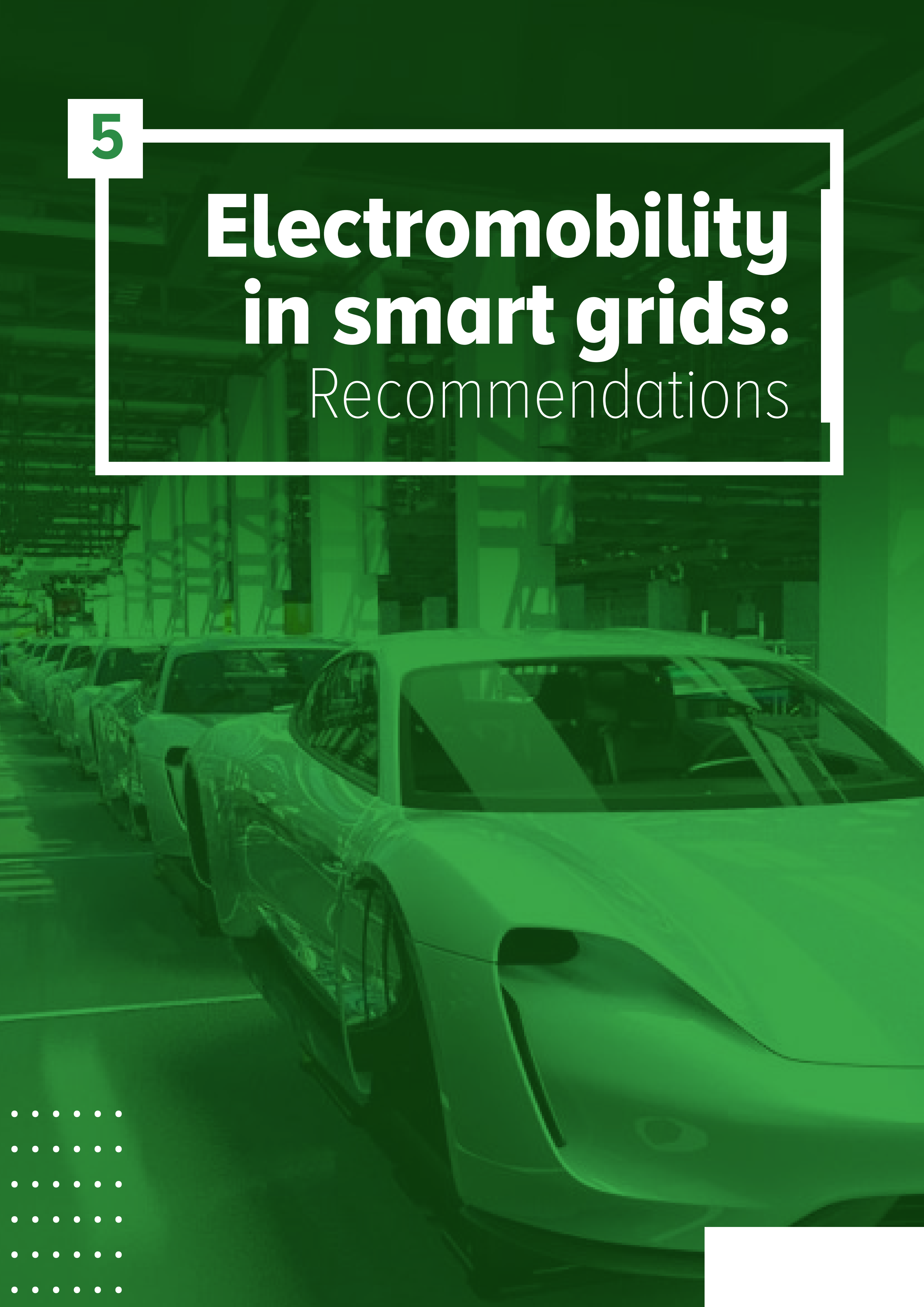
The project will identify key barriers in the policy and regulatory framework, market barriers and cybersecurity issues, and propose solutions so that V2G can contribute to much needed system flexibility. Learning outcomes will be exportable to electricity systems worldwide.

The project will test the following services: frequency response, energy arbitrage, load shifting, and distribution grids services.

[42] Bus2grid project, https://sse.com/newsandviews/allarticles/2018/02/sse-enterprise-led-consortium-wins-funding-to-power-the-smart-electric-buses-of-the-future/

5

Electromobility in smart grids: Recommendations



The larger and larger number of V2G and smart charging projects show that the technology is close to be ready for commercialization. But it is dependent on the deployment of "V2G compliant" EV and EVSE (only the next generation of EV will most probably largely integrate V2G capabilities), and policies requirements are still not ready for such new assets (mainly for V2X use). Things are under progress step by step to support the deployment of EV/PHEV.

Recommendations are made in different countries to overcome scientific and industrial issues (technical, economical and regulatory issues) in order to take advantage of EV storage capabilities to mitigate constraints.

More specifically, the next steps must be reached:

- Enforce the smart charging at LV distribution level with two use cases : i) dedicated off-peak tariffs, ii) controllable EVSE to reduce charging power in case of local constraint, iii) smart charging for local EV fleet (behind a same point of common coupling)
- Develop the bidirectional capabilities (for EVs and EVSE) to operate the EV batteries as virtual stationary storage system.
- For V2G, clarify the characterization of a mobile battery behind a connection point. Typically, the declaration of the battery size may be required. If it is simple in the case of a stationary battery, it is much variable for an EV (an EVSE can charge different EV with different battery capacity).
- Valorization of EV batteries to reduce TCO (total cost of ownership) for EV owners

As an illustration, five recommendations from EAC for the US DOE were formulated in 2018:

1. The DOE should increase support for research to create and harmonize standards needed for EVs to integrate with the grid and participate in the market, particularly with respect to bilateral exchanges;
2. The DOE should increase support for research to evaluate the range of possibilities for using EVs for grid services, effects at both the distribution and transmission level, mitigation techniques to avoid negative grid impacts, and impacts of bidirectional charging on the lifetime of EV batteries when used within such systems;
3. The DOE should commence a comprehensive economic study that analyzes US EV penetration scenarios, grid impacts and investment requirements to provide charging infrastructure and generation requirements;
4. The DOE should increase support for research on the range of business models for EV charging infrastructure, policies that create barriers or incentives to each, and provide materials to guide state decision making for ownership, control and rate-basing methodology given the objective of increased reliability and resilience;
5. The DOE should fund additional V2G pilot projects to better understand these challenges, public acceptance, the costs and benefits to vehicle owners, and best practices to best optimize the outcome of electric transportation and grid infrastructure development

[43] https://nj.gov/emp/pdf/draft_emp/University%20of%20Delaware%20comments.pdf

In September 2019, several recommendations were also proposed by UDel in response to the New-Jersey State energy master plan[43] :

A Clarify and broaden V2G technology in EMP storage definition
Even if stationary storage and V2G technology are different, they do not differ in their use. V2G can provide ancillary services, demand response, peak power reduction, shifting load, increased local energy resiliency, and other grid services, exactly as traditional batteries can do. Thus it is relevant to include V2G in the classification of "storage".

B Addressing insufficient safety standards
Regulations for small resources have often been designed for solar units which stationary inverter must be compliant with the standard UL 1741. It is not applicable with AC charging station for which the inverter in onboard the EV. Thus the standard SAE J3072 has been developed for V2G with AC on-board charger. But it remains the issue of equipment testing that could be done by the vehicle manufacturer or by the equipment supplier.

C Addressing inadequate interconnection processes
The level 1 interconnection for distributed resources is mainly dedicated to renewables. It should also consider storage (including V2G). Additionally, the upper limit for a level 1 interconnection should be raised.

D Allowing for equal credit-for-export
The objective is to imagine a specific tariff for VEG that can encourage V2G deployment. A "credit-for-export" can recognize the unique nature of a distributed energy resource such as a V2G. Such tariff would ensure that EV users are billed when they charge and credited when they discharge. Such tariff was adopted in Delaware in 2009: utilities provide V2G users with a credit against their monthly bill in dollars, at the rate per kWh in effect at the time of export.

E Evaluating the accounting options now allowed by FERC Order 841
For a storage system like an EV battery, there is a part of purchased energy that is used for own mobility, and another part that is bought for being sold later in the wholesale markets.

Report coordinated and directed by

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