ENTSO-E Position Paper

Electric Vehicle Integration into Power Grids

31 March 2021

About ENTSO-E

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the pan-European association of 42 electricity transmission system operators (TSOs) in 35 countries. In 2009, ENTSO-E was registered in the EU legislation and has since then been given a series of legal mandates.

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Executive Summary

After a deep analysis and the pooling of TSO experiences, ENTSO-E considers electromobility a powerful resource, not only to decarbonise the transport sector but also to provide flexibility services to the energy system. An optimal vehicle-grid interaction will guarantee important environmental and economic benefits for consumers and all involved actors, as well as improved system management. To make it real, all the involved actors should cooperate to promote the implementation and deployment of smart charging and vehicle-to-grid (V2G) technology.

This Position Paper (Paper) analyses the most relevant characteristics of E-mobility with a particular focus on its impact on the power system. The intense efforts in this sector by European decision makers clearly sets the path towards the massive adoption of electric cars, commercial vehicles and buses. The number of commercially available models is rapidly increasing, and typical users' concerns when comparing them to internal combustion engine (ICE) vehicles, such as short-range autonomy and higher prices, are expected to be solved shortly. The development of a suitable charging infrastructure answering the needs of different stakeholders in the electro-mobility value chain and the adoption of a smart charging process currently represent the major gap to be covered for most of the actors involved in this complex ecosystem.

The electrical vehicle (EV) charging process represents the concrete interface between transport and energy sectors and is the crucial element for guaranteeing the successful development for both. According to the analysed charging use-cases, leaving the charging process uncontrolled can result in significant challenges for the power system, such as peak power demand due to cumulative effects in certain time-periods. In contrast, managing the charging process in terms of time scheduling and power profile will not only limit the potential challenges but also open new opportunities. This can be achieved by time scheduling and power profile management, or through market-based mechanisms (e. g. flexibility markets). Several opportunities exist to profitably exploit EV charging, each having different aims and beneficiaries, and stacking them is possible to maximise the benefits. "Smart" EV charging can support the integration of a larger share of renewable energy source (RES) generation, by reshaping the power demand curve, supporting generation fleet adequacy, and reducing system costs and CO_2 emissions. In addition, the EVs will enable improved system management, both in terms of ancillary services and grid congestions. EV users will also benefit from lower charging energy costs, more reliable services and by contributing to more sustainable transport.

To avoid the risk of missing the multiple opportunities identified and described in the Paper through the implementation of smart-charging and V2G solutions, ENTSO-E recommends the following:

- **Promote coordinated planning for charging infrastructure and electric grid** through scenario definition, improved modelling and considering the diffusion of "hypercharger hubs" on highways.
- **Manage the charging process** by promoting and facilitating a smart – and, where relevant, V2G – charging approach, thus smoothing peaks in the load curve, which brings advantages for EV owners, for power grids and for the whole energy system at large.
- **Deploy electromobility enablers** including private and public charging infrastructure equipped with metering and communication capabilities and the adoption of common standards to guarantee the interoperability of charging networks and data, as well as effective data management and the setting up of a value proposition for the drivers.
- **Enable a new ecosystem centred around consumer needs** by further enhancing TSO–DSO cooperation and through the defined roles and responsibilities of the different involved actors, to facilitate competition and maximise benefits by unlocking the potential of EV charging as an additional and valuable flexibility resource necessary for secure and efficient grid operation.
- **Update market rules and regulatory framework** to implement grid tariff/power prices schemes, stimulating the further adoption of smart charging, and enable a higher number of services offered by EVs and their participation in flexible markets.

The relevant aspects underpinning these required actions are: minimum technical requirements and standardisation, and dynamic pricing definition and updated market rules, as well as enhanced cooperation among the many different stakeholders from traditionally separated sectors: vehicle, batteries and electronic/automation industries, ICT and mobility service providers, transport and urban planning authorities, electricity market aggregators and operators, consumers and prosumers, and power grid operators. **In this multiple and complex system integration effort, TSOs, acting in an unbiased and non-discriminatory manner both as grid operators and energy system operators, are called to play a key role in supporting the optimal integration between the transport and the energy sectors, together with DSOs**, under the overarching concept of Smart Sector Integration vision or "One System view". Demonstration activity and pilot projects will be crucial in testing proposed solutions and identifying open technical issues, and studies should be performed to assess the most efficient solutions and business models. A strong cooperation among all the actors involved should also be pursued to define new efficient market features and proactively involve EV owners in participating in smart charging solutions.

Today, the E-mobility environment is extremely dynamic, and EV diffusion could receive a sudden boost via the Green Deal and Recovery Plan; the actions stemming from the key findings of the technical and unbiased analysis described in this Paper should therefore be pursued with no delay, transforming a challenge for the system into a valuable resource for its optimal management. The positive effects will be relevant and shared among different stakeholders: first and foremost all European citizens, who are the final users of both energy and mobility services and who will benefit from cleaner transport and energy systems.

Through this Position paper, ENTSO-E intends to contribute to the debate on technical and connectivity solutions, as well as on EV charging solutions and regulation to be adopted through the constructive cooperation with transport, urban planning, vehicle industry stakeholders and decision makers.

The time for action is now, before mass EV deployment, to avoid the need of the future "retrofitting" of non-smart chargers.

Basic Definitions

Battery electric vehicle (BEV):	a vehicle powered solely by an electric motor and a plug-in battery
Plug-in hybrid electric vehicle (PHEV):	a vehicle powered by a combination of an electric motor and a plug-in battery on the one hand and an internal combustion engine on the other, allowing these to work either together or separately
Electric Vehicles (EVs):	for the purpose of this Paper, road vehicles with an electric engine and battery which need to charge electricity from a power grid (BEVs and PHEVs)
Smart Charging:	any charging which is not plug-n-play, i. e. supervised by an external control system
Vehicle to Grid (V2G):	smart charging with bidirectional energy flow capability
Dynamic charging:	EV charging taking place when the EV is moving; in contrast to static charging, which occurs when the EV is parked
Charging solution:	consists of a charger device, charger station (if present), related infrastructure, power connection and supply scheme, charging operation and control, set of services provided to the customer, business model and applied regulation
Distributed Energy Resource (DER):	Refers to small, geographically dispersed generation resources, installed and operated on the distribution system at voltage levels below the typical bulk power system[1]

1 TSO-DSO Report – An integrated approach to Active System Management

1. Introduction

The energy and transport sector will face important challenges in the next decade. Decarbonisation and pollution reduction are no longer optional, and new technologies and solutions need to be deployed to reach the ambitious targets set by international regulation. Electric mobility represents a crucial opportunity for more sustainable transport, and its optimal charging management could generate relevant benefits for the energy sector too.

The transport sector in Europe is responsible for over 25 % of greenhouse gas emissions and, contrary to other sectors, its emissions have increased in the last few years. Considering the European CO_2 reduction targets, and the increasingly renewable energy source (RES) share in the generation mix, it is inevitable that electric vehicles (EVs) will become mainstream in the car industry. Tens of millions of EVs progressively deployed will also impact the energy sector in terms of generation profile and grid adequacy.

EV charging is the physical interface between these two evolving sectors, emphasising the dual nature of EVs: a transport means when on the move but a grid-connected battery when parked (and plugged). Related challenges and opportunities are therefore intertwined: on the one hand the proper deployment of charging infrastructures and the optimal management of the charging processes guarantee the required driving range and the optimal charging costs to EV drivers; on the other hand, they transform the stress on the electric grid into the opportunity to provide benefits as a flexibility resource. The possibility to optimise the charging process according to a wider system view, known as "smart charging", must accompany the widespread adoption of EVs. Further benefits can be seized by extending the smart charging concept to vehicle-to-grid (V2G) solutions, where the use of bi-directional chargers permits a deeper degree of integration of planning and operation of both transport and power systems.

Worldwide institutions and consultants are spearheading smart charging, V2G and vehicle-grid-integration (VGI); to mention just a few examples, in its "Innovation outlook 2019", the International Renewable Energy Agency (IRENA) states that "*Smart charging for electric vehicles holds the key to unleash synergies between clean transport and low-carbon electricity*". Similar messages have come from dedicated reports for the Clean Energy Ministerial and from the Global Smart Grid Federation. This ENTSO-E Position Paper intends to add the specific perspective of Transmission System Operators (TSOs) on the impact of EVS, both on the grids and on the whole energy system, under the overarching principle of "One System View".

Future trends in mobility, namely inter-modality[2], mobility-as-a-service and autonomous drive, although modifying mobility patterns and the types of EV users, will not significantly change the picture previously described for vehicle-grid interaction, which will rely on the more relevant role of mobility / fleet manager and not only of that of individual owners. Similarly, the adoption of other emerging CO_2-free transport technologies such as fuel cells, hydrogen propulsion and green liquid fuels, especially for some kinds of vehicles (heavy duty, buses, non-road transport), will complete the decarbonisation of transport where direct electrification is not possible, while simultaneously presenting different challenges and opportunities to the power system.

2 The possibility of combining different modes of transport (e. g. train + bike sharing) in a seamless travel experience

1.1 Why and How?

E-mobility will represent a crucial building block in the future energy system. It will generate important effects both as a new load (additional volumes and specific load profile) and as a new flexibility resource for both market actors and system operators. TSOs are key actors in the management of the overall energy system, and the preparation towards future scenario evolutions is a fundamental part of planning and operation activities. In particular, the capability of EVs to provide valuable system flexibility services, including fast frequency control and ramping ancillary services, will directly affect the management of transmission grids. Considering the probable acceleration of EV penetration, and the parallel deployment of charging systems, ENTSO-E intends to contribute to the debate on technical and connectivity solutions, as well as on charging processes and regulations to be adopted. These solutions are mainly in the pilot / demo stage; therefore, it is crucial to deploy them at the start of EV diffusion to avoid the need for future "retrofitting".

1.2 In-Scope and Out-of Scope

Electrification is becoming, as of today, a trend in many areas of transportation; this Paper addresses the grid impact, so it focuses on those aspects which are foreseen as being more impactful:

- **Sector:** Road transport;
- **Vehicles:** Passenger vehicles, buses, lorries, trucks;
- **Technology:** Battery-propelled vehicles;
- **Infrastructure:** Conductive, stationary charging systems.

However, some topics are considered out of scope for the following reasons:

- **Railways:** electric traction is already in operation in most of European lines; no disruptive situations are expected for grid impact;
- **Ship, maritime and aviation:** the high amount of energy required for traction could be profitably stored on board only with important improvements in battery technology; decarbonisation should therefore occur through other means (hydrogen, green fuels, fuel cells) and / or in a long term scenario;
- **Micromobility:** the energy consumption related to these means of transport is limited, as well as their impact on the power system; indeed, their charging can be considered part of residential load;
- **Fuel cells and green fuels propelled vehicles:** they do not perform electric charging so their impact on the energy system is indirect, through electrolysers / sector coupling.
- **Dynamic charging (vehicle on the move):** still at an early stage, with long term and niche development; regardless, the fact that the vehicle is charged during its use and not while parked strongly limits the possibility for providing grid / flexibility services.

1.3 User at the Centre

A constant underlying principle in the complex and multifaceted E-mobility environment is the EV user as the key actor and his needs as the centre of all the development:

- The EV user can be the driver, the owner or the fleet manager; it is the person / body who decides how / where / when to charge the EV;
- EV users have specific needs and expectations from the charging process, regarding the price and quality of the charging service: charging points availability, charging power / time, matching with personal habits, data and information availability, interoperability and easy access / payment, interaction with other electrical assets at home / work; such customer behaviour must be analysed, understood and satisfied;
- EV users will set the conditions for allowing smart charging or V2G schemes on their vehicles (new tariff schemes, rewards & penalties, extra services); their direct involvement is the basis upon which to make smart charging a success.

2. E-mobility Framework

Electric mobility is a cross-sectoral topic, largely influenced by technological, industrial, political and social issues. EV market penetration is quickly increasing, driven by progressive improvements in driving range and purchase price which reduce the competition gap between fossil-fuelled vehicles. Moreover, the most recent environmental policies and the industrial efforts in this sector have clearly paved the way for a significant electrification.

2.1 A Wide Ecosystem

2.1.1 Many Actors

EVs have two main operating states: driving and (smart) charging. While performing any of these, several actors are involved. As mentioned, the first and most relevant is the user, able to decide when and how to utilise the vehicle. Manufacturers and charging operators play an important role too, providing the technical capability to effectively drive and charge. While charging, the interaction with the complex energy system and the related operators becomes central. As players able to steer the evolution of the sector, decision makers and research bodies also have to be carefully considered.

EV users

- Private users
- Company fleets mobility managers
- Logistic fleets mobility managers
- Taxi fleets
- Sharing fleets companies
- PA fleets mobility manager
- Local Public Transport managers
- Trucks drivers / owners

Manufacturers

- EV manufacturers
- Battery and BMS (control logic) manufacturers
- Charging stations manufacturers

Charging operators

- Charging Point Operators (CPOs)
- E-mobility Service Providers (EMSPs)
- Value-Added-Services providers
- Mapping / Roaming platforms

Energy system operators

- Energy providers (Power Companies, Traders}
- DSOs
- TSOs
- Balance Service Providers / Aggregators
- Energy / flexibility markets operators

Decision makers

- EU decision makers
- National / local decision makers
- Regulatory Authorities
- Standardisation Bodies
- Urban planning authorities
- Transport authorities

Research bodies and associations

2.1.2 Different Kind of Interactions

Actors involved in E-mobility are inter-related in different ways. From a physical perspective, the electric connection is the fundamental one, linking the vehicle to power generation through DSOs and TSOs. To properly manage the charging process, proper data exchange is required, involving actors as energy providers, Charging Point Operators (CPOs) and Balance Service Providers (BSPs) (Figure 1). Economic fluxes represent the third kind of interaction, related both to energy or flexibility transactions (Figure 2). The respective markets are pivotal for these exchanges, carried out by energy traders and market operators.

2.1.3 Where is the TSO?

With respect to the user and the EV, currently electricity actors are not perceived to be centre stage. Furthermore, in the electricity portion of the ecosystem, EV users today mainly deal with the DSO (for connecting to the grid) rather than with the TSO. However, with the increasingly high number of EVs, the transmission grid and power system as a whole will also be impacted. TSOs have a triple task and therefore a triple perspective, being grid operator, system operator and market facilitator. Their involvement in E-mobility is required during grid planning phases to properly host new charging infrastructure, especially with high power requirements, as well as to enable the flexibility opportunities provided by EV smart charging.

2.1.4 “One System” View and TSO-DSO Cooperation

As underlined in ENTSO-E Research, Development & Innovation Roadmap 2020–2030, TSOs must look beyond the boundaries of their traditional activities to prepare system operations ready for the challenges ahead. The electrification of transport requires TSOs to adapt and support the wider energy system integration, defined as “One-System of Integrated Systems” centred around improved cross-sectoral integration. Smart charging and V2G solutions will create new markets and require new ways of modelling future generation and load profiles. Coordination between TSOs, DSOs, market participants and customers must go the beyond pure integration of markets and operations and expand into proactive planning. Enhanced TSO–DSO interactions for improved power flows and system security, in addition to suitable market platforms, will enable EVs connected at the distribution level to participate in energy and ancillary services markets.

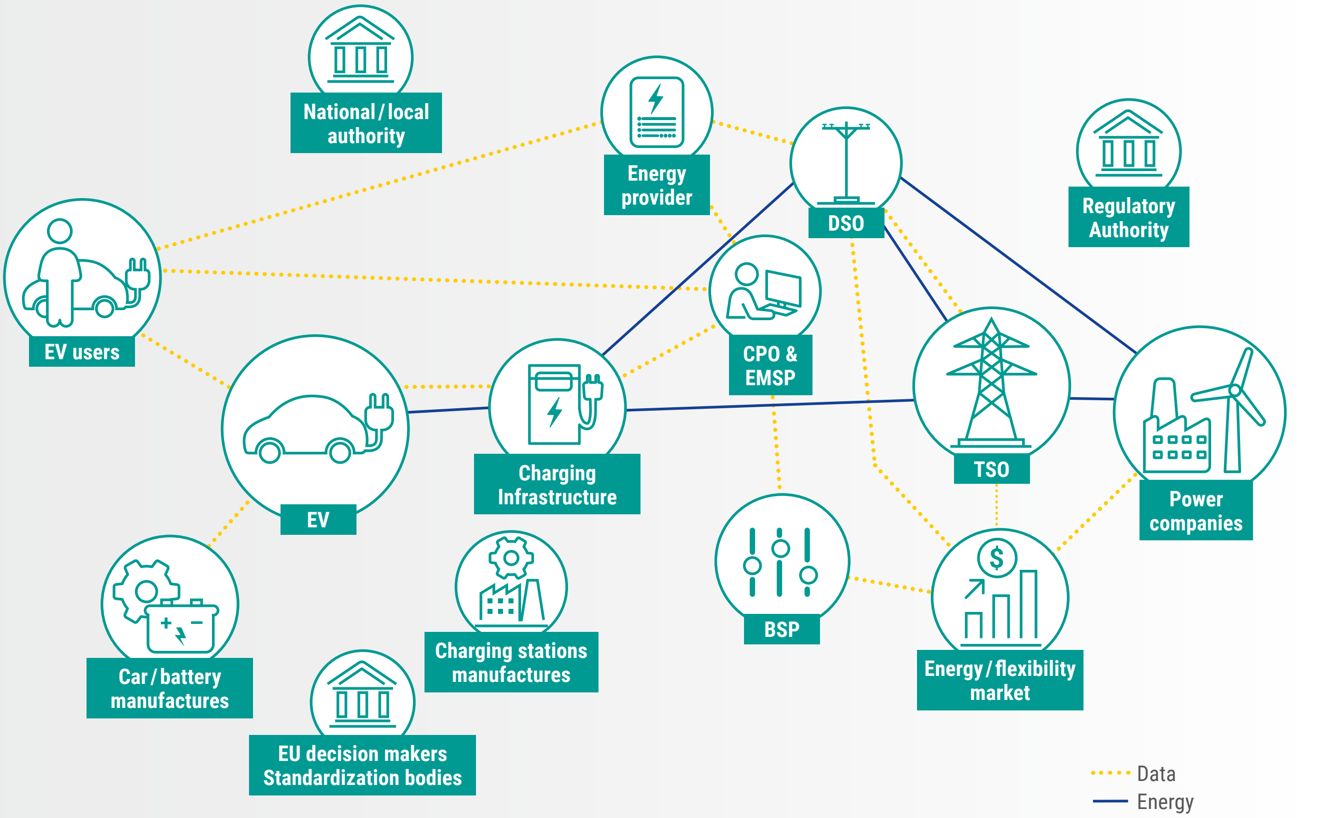


Figure 1 – Data and energy interactions among E-mobility ecosystem actors

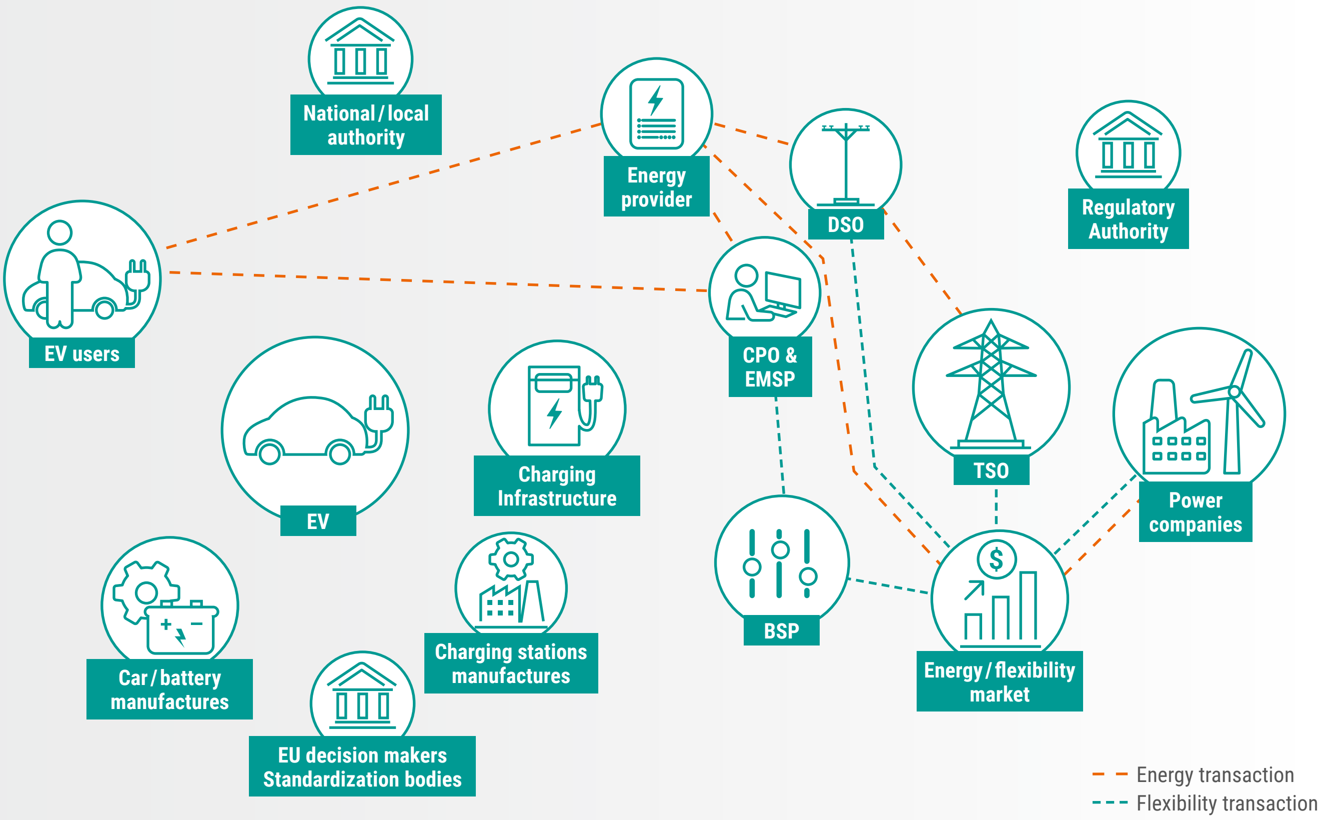


Figure 2 – Economic transactions for energy and flexibility services among E-mobility ecosystem actors

2.2 European Activities and Rules on E-mobility

The European Union (EU) is strongly committed to fighting climate change at the global level, through interventions implemented within its own territory and international cooperation. With regards to transport, European rules have been the main driver of the impressive improvements obtained by vehicle manufacturers in the last 25 years in terms of pollutant emissions. Today, the huge effort required to reduce CO_2 emissions is an indirect leverage to stimulate electric mobility. At the same time, regulation is necessary to ensure an effective charging infrastructure is implemented, both for private and public charging.

Main Regulatory Framework Related to E-mobility

Directive on Alternative Fuels Infrastructure

- **In force (2014/94/EU):** establishes a set of measures for the creation of an alternative fuel infrastructure, to minimise oil dependence and mitigate the environmental impact of transport.
- **Revision:** foreseen for the second half of 2021, it aims to increase the build-up of publicly-accessible charging infrastructure, through, among others, possible binding and enforceable targets; to enable the deployment of smart charging infrastructure and to ensure the full interoperability of infrastructure and infrastructure use services.

CO_2 Emissions for Cars and Vans Performance Standards

- **In force (regulation EU 2019/631):** defines new fuel economy standard for cars and vans for 2021–2030 and a CO_2 emissions standard for heavy-duty vehicles, with specific requirements or bonuses for EVs.
- **Revision:** to implement the new plan towards 55 % CO_2 emission reduction, the Commission is proposing to revise the Regulation on CO_2 standards for cars and vans. A public consultation is presently open, aimed at receiving inputs on the ambition level of the targets, the incentive scheme for zero- and low-emission vehicles and design elements of the regulatory system to possibly consider the contributions of renewable and low carbon fuels.

Trans-European Network for Transport (TEN-T) Regulation review:

- based on the results of two consultations, it will consider the new and far-reaching economic, political, technological and societal challenges of the transport sector, addressing issues such as standards and infrastructure requirements, implementation tools or various aspects of the comprehensive network, as well as soft measures.

Clean Vehicles Directive (EU) 2019/1161

- defines "clean vehicles" and sets national targets for their public procurement. It applies to cars, vans, trucks and buses with different means of public procurement.

Sustainable and Smart Mobility Strategy:

- communicated on 9 December 2020 by the EU Commission, it includes an Action Plan of 82 initiatives for green and digital transport and sets key milestones for 2030, 2035 and 2050.

Energy Regulatory Framework Impacting on E-mobility

Renewable Energy Directive II 2018/2001/EU: aimed at promoting the contributions of the Member States to the achievement of the EU 2030 target of coverage with renewable sources of 32 % of gross inland energy consumption, including transport.

Energy efficiency Directive (EU) 2018/2002 establishes a common framework of measures to promote energy efficiency, including the transport sector, to ensure the achievement of the EU's headline energy efficiency targets of 20 % for 2020 and the achievement of the energy efficiency target of at least 32.5 % for 2030.

Energy performance in buildings Directive

- **In force (2018/844/EU):** outlines specific measures for the building sector, including preparatory work and the installation of charging points inside residential and non-residential buildings.
- **Revision:** foreseen for the last quarter of 2021, it should help to reach the EU's increased climate ambition for 2030 and 2050. It could include new rules and more challenging objectives for EV charging in buildings.

The European Green Deal sets a roadmap for **"making the EU's economy sustainable"** by turning climate and environmental challenges into industrial opportunities and making the transition just and inclusive for all. It provides a set of actions to boost the efficient use of resources by moving to a clean, circular economy, stopping climate change, reverting biodiversity loss and cutting pollution.

The 2030 Climate Target Plan to reduce the EU's greenhouse gas emissions by at least **55% in 2030** (compared to 1990 levels). This implies the revision of existing energy and climate legislation, which also impacts E-mobility.

2.3 Electric Vehicles

2.3.1 Car Models Available

Several models of electric cars are today on the market, mostly produced by car manufacturers with dedicated production lines. The market can be divided into two main segments, mainly according to their purchase price: a "medium" target, below 40,000 €, and a "premium" target, up to 100,000 € and more. The two segments are characterised by different battery capacity and autonomy. In addition to Battery Electric Vehicles (BEVs), Plug-In Hybrid Electric Vehicles (PHEVs) are quickly emerging on the market, particularly in the premium segment.

2.3.2 Duty Vehicles and Buses

After the private car sector, light duty vehicles (LDVs) are expected to represent a new market opportunity for vehicle manufacturers. Today, less than 10 electric models are available, commonly equipped with the same powertrain of same-brand cars. The usage patterns of these vehicles are indeed compatible with the range allowed by 40 – 50 kWh batteries, typical of BEV cars. Heavy duty vehicles (HDVs) are still at the development stage as their energy demand remains a challenge for present batteries. Interesting proposals are expected in the coming years. Regarding buses, a different business model characterises their market. E-buses are typically sold on the request of PAs and many manufacturers are active on the market with small numbers of vehicles sold, often customised. On average, electric buses used for urban local public transport services are equipped with 250 – 350 kWh batteries and cost approximately 400,000 €.

Battery Electric Vehicle

- **28 models** proposed by big OEMs + **13** in the **premium** sector
- **Battery capacity:**
  18 – 50 kWh, standard segment
  50 – 100 kWh, premium segment
- **Range:**
  100 – 400 km, standard segment
  500 – 700 km, premium segment
- **Purchase price:**
  25,000 – 40,000 €, standard segment
  70,000 – 100,000 €, premium segment

Plug-in Hybrid Electric Vehicles

- **49 models** proposed by big OEMs
- **Battery capacity:**
  7 – 15 kWh
- **Range (full electric mode):**
  30 – 70 km
- **Purchase price:**
  30,000 – 150,000 €

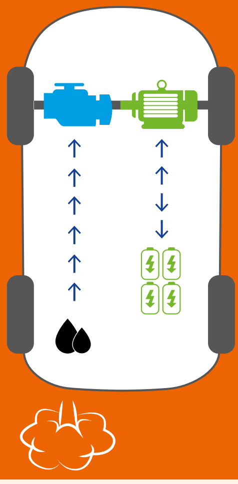
* OEM = original equipment manufacturer

What Is Different in EVs from Internal Combustion Engine (ICE) Vehicles?

- The electric powertrain is intrinsically more performant than an ICE: higher efficiency, higher mechanical reliability (less moving parts, less ancillary devices, less maintenance, less noise, etc.)
- The EV purchase cost is still higher than an ICE vehicle but is rapidly decreasing. Operational costs are considerably lower, however.
- EV do not burn fuels inside the vehicle, meaning **no direct CO_2 emissions, lower air pollutant emissions and a smaller impact along their life cycle;** these environmental benefits are the key rationale for EV deployment, and are provided that electricity is generated CO_2-free.
- EV store energy on-board through electrochemical **batteries,** which have **less energy density than liquid fuels,** which means heavier vehicle and lower endurance range for each refuelling stop-over.
- On-board batteries can be charged at **different power levels;** even the highest power now tested (350 kW DC) allows the vehicles to be charged **at least 5 times slower** than liquid fuel refuelling.

Hybrid Electric Vehicle (HEV)

Small Electric Motor and Battery Supplement the Ice Engine: No Electric Charging



› The electric motor intervenes when the Internal Combustion Engine (ICE) has poor thermodynamic efficiency, (e. g. start-up phase, repeated stop & go)

› The ICE works only around optimal points of operation, reducing fuel consumption.

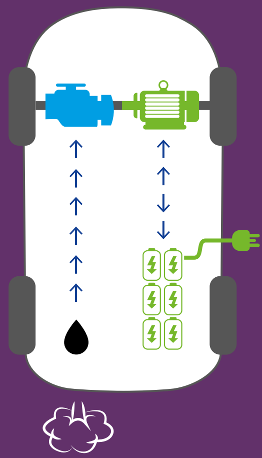
› Few km are allowed in pure electric mode

› The presence of the electrical part allows “regenerative braking”, which contributes to reducing overall consumption

Refuelling is only for traditional fuel (no external electric charging) as the battery is charged only through the ICE when it is ignited.

Plug-In Hybrid Electric Vehicle (PHEV)

Dual Fuel & Dual Traction



› Based on the same principle as HEV but batteries are larger and can be charged from the grid

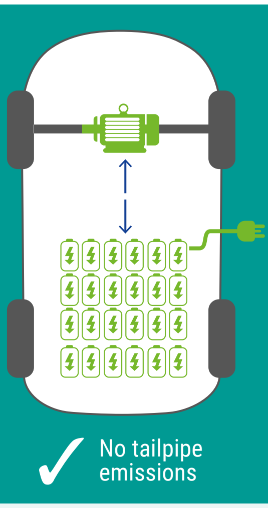
› Most PHEV vehicles adopt a “parallel” configuration: both the internal combustion and the electric engine are connected to the wheels so that both can provide traction to the vehicle

› The vehicle can travel on pure electric up to about 50 km, suitable for the daily use on pure electric of many drivers

› The vehicle refuels both traditional fuel and electricity via a charging plug

Battery Electric Vehicle (BEV)

Equipped Exclusively with an Electric Engine, Powered by Big Size Batteries



› Batteries have to be charged on a regular basis through proper charger and grid connection

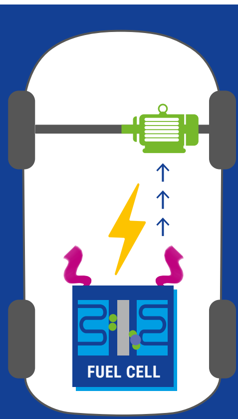
› Driving range typically goes from 200 to 700 km

› **Zero-tailpipe emissions**

› **Zero end-to-end emissions if electricity is generated from RES**

Fuel Cell Electric Vehicle (FCEV)

A Vehicle With Electric Engine, Power Is Generated on Board From Hydrogen; No Electric Charging



› An on-board fuel cell generates electric power from hydrogen and oxygen, used for traction by an electric engine.

› Oxygen is taken from ambient air whereas hydrogen is stocked on board in high pressure tanks and is refuelled in a short time through dedicated filling stations

› Small batteries are normally present to allow regenerative braking

› **Zero tailpipe emission (only H20)**

› **Zero end-to-end emissions if hydrogen is produced CO_2-free (green hydrogen)**

Figure 3 – Definitions and differences among electric vehicles

2.3.3 EV Adoption

Today in Europe

The EV stockpile has been rapidly increasing in the last few years, reaching 1 million units in 2020 (source: European Alternative Fuels Observatory, EAFO); considering PHEVs, the number of "electrified cars" exceeds 1.5 million, to which more than 100,000 duty vehicles and 4,500 buses have to be added. More than 8 % of new registrations are related to EVs.

The highest number of e-cars are sold in Germany, followed by France and Sweden; when considering EV sales percentage, central European countries are still at a low rate, whereas North-European ones reach the highest penetration, with Norway first at more than 30 %.

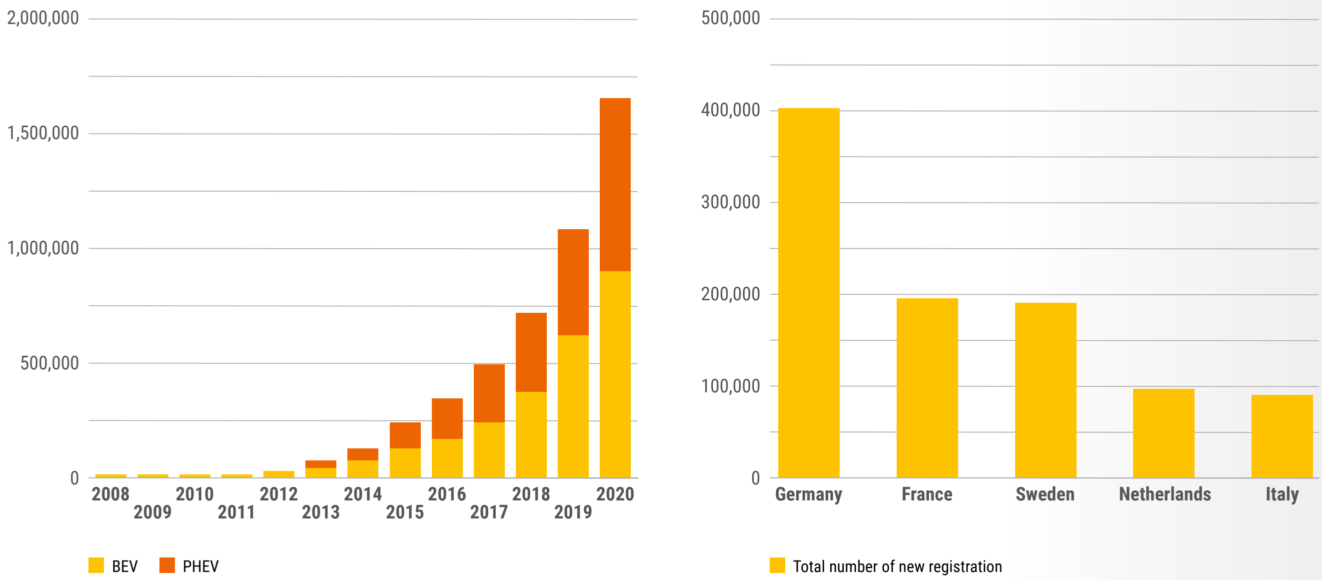


Figure 4 – Electrified cars stock in Europe 2008 – 2020 and top 5 countries for total new registrations during 2020 (source: EAFO)

Tomorrow in Europe and Worldwide

In its "Global EV Outlook 2020", the International Energy Agency (IEA) describes two 2030 worldwide scenarios for E-mobility development: "Stated Policies Scenario" (STEPS)[3], and "Sustainable Development Scenario" (SDS)[4]. According to STEPS, the global EV stock expands from around 8 million in 2019 to approximately **140 million vehicles by 2030** (Figure 6). EV sales will reach almost **25 million vehicles by 2030,** representing 16 % of all road vehicle sales. (Figure 7). After China, Europe will become the second largest EV market. According to the SDS, by 2030 Europe will reach a combined EV market share (for electric LDVs, buses and trucks) **of almost 50 %** (Figure 5).

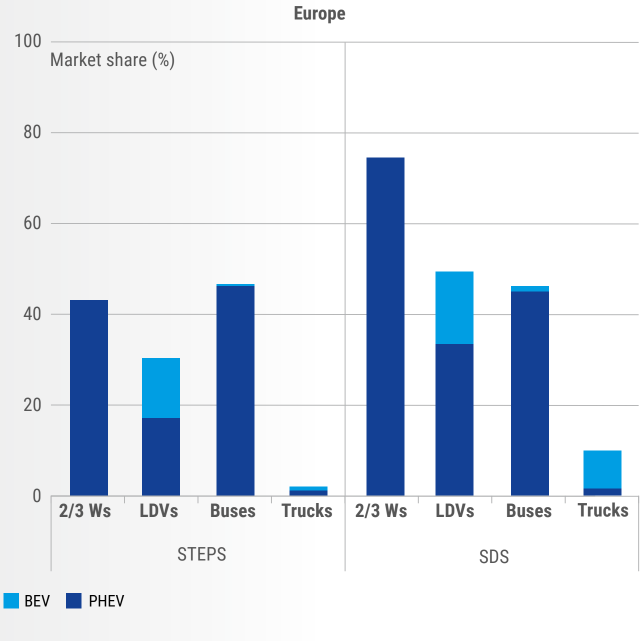


Figure 5 – EV share of vehicles sales in Europe, 2030 (Source: IEA)

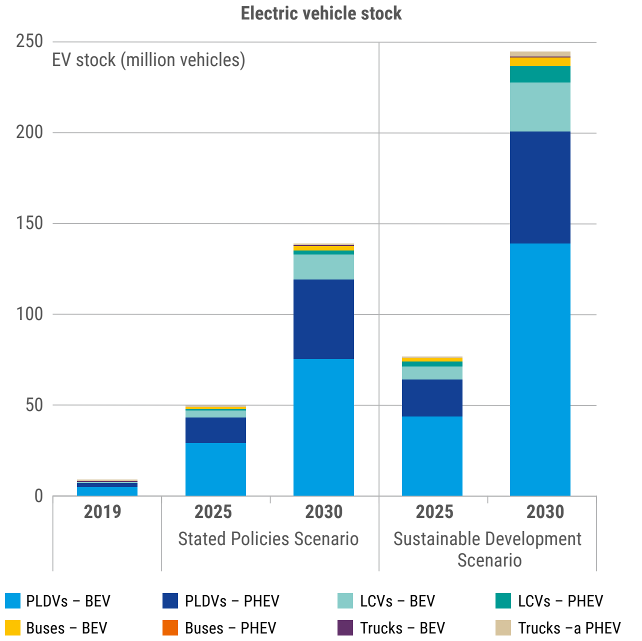


Figure 6 – EV stock in 2019, 2025 and 2030 by STEPS and SDS scenarios (Source: IEA)

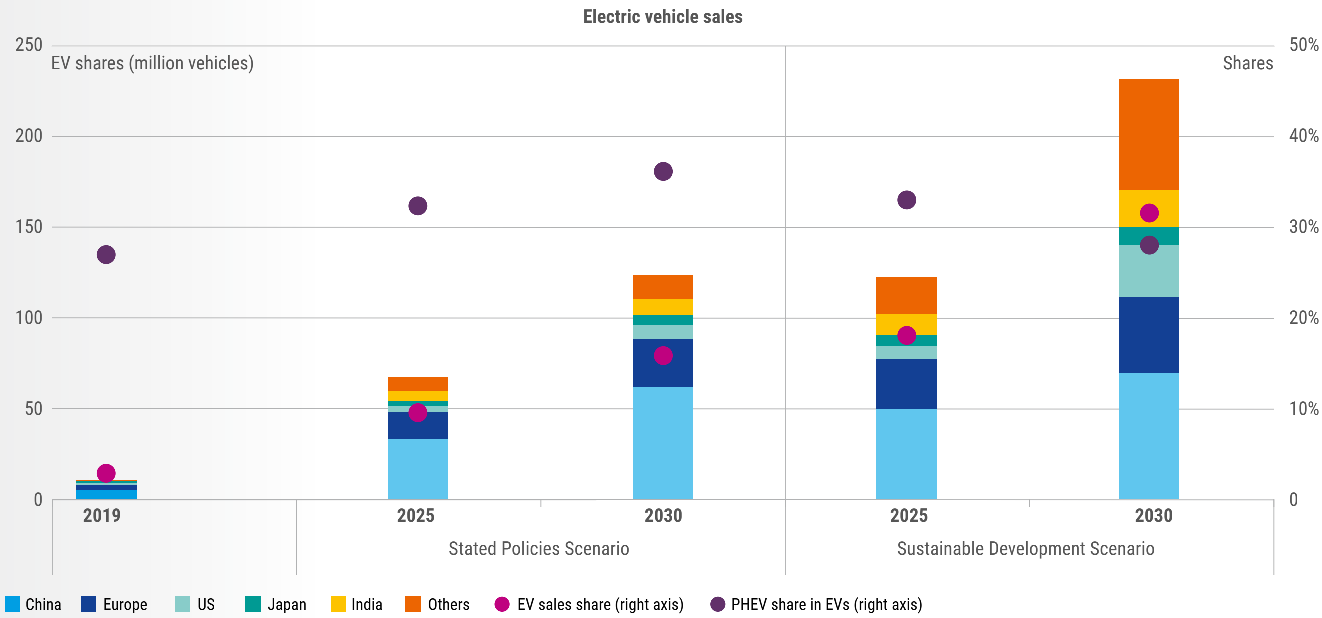


Figure 7 – EV sales and market share in 2019, 2025 and 2030 by STEPS and SDS scenarios (Source: IEA)

3 STEPS aims to illustrate the impact of existing and announced policy measures.
4 The SDS considers more aggressive policies to limit the global temperature rise to below 1.7 – 1.8 °C.

2.4 Charging Infrastructure

Different technologies are available for EV charging. Wired solutions using conductive methods are by far the most diffused as they can easily guarantee the required power level, safety and interoperability with most of the vehicles[5]; non-wired solutions (exploiting the inductivity principles) are being studied for highway applications. Battery swap is for special applications (car races) where rapidity is paramount, and could prove to be suitable for fleets, sharing and/or Heavy Duty application. Alternating Current (AC) infrastructures rely on vehicles' on-board chargers and are limited in power level due to vehicle limited size and cost. However, Direct Current (DC) infrastructures use off-board power electronics, installed at the charging station. This allows for larger/bulkier and more expensive components, meaning a charging power of up to 350 kW in today's best performing devices. Although in the first years of E-mobility development the trend was to improve AC charging power (up to 43 kW in some models), the present approach is to limit AC charging to less than 22 kW (often 7 kW single phase or 11 kW three-phase). In fact, fast charging will be performed by a DC charger, which is becoming standard equipment for all EVs.

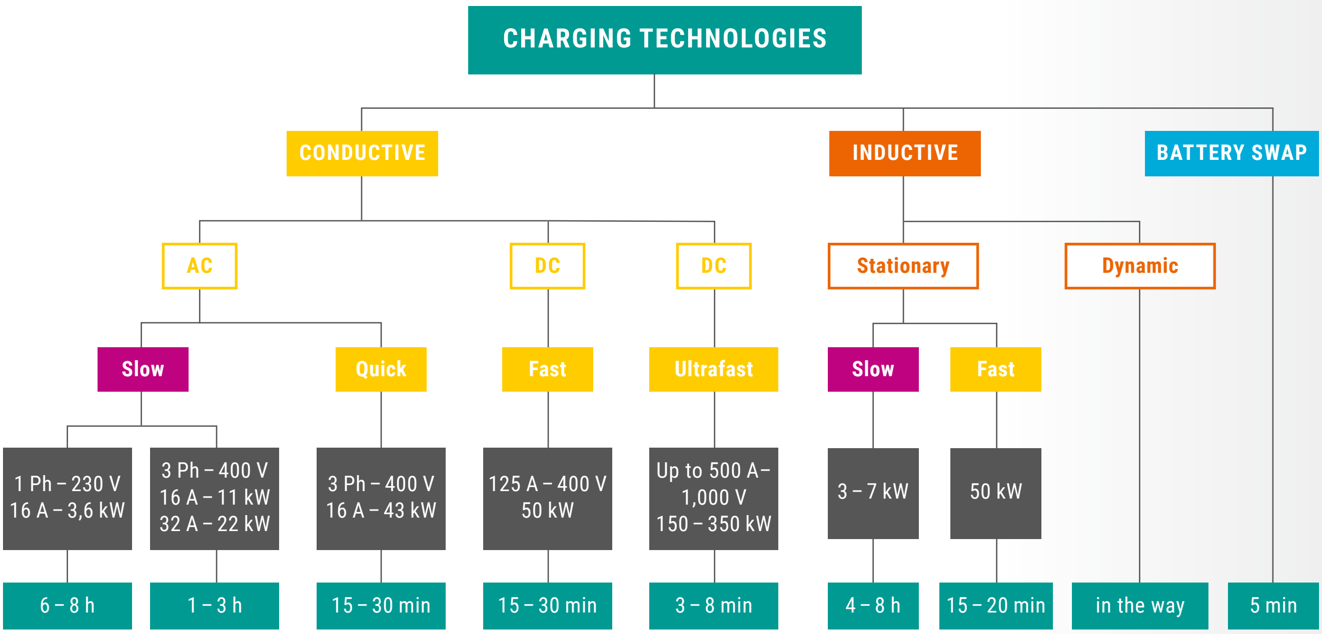


Figure 8 – EV charging technologies (Source: RSE)

2.4.1 Charging Infrastructure Diffusion

Together with the rise of EV sales, the number of charging points is increasing in Europe. In the last four years, the number of public charging points more than doubled, reaching more than 200,000 units. Approximately 90 % of these are "normal chargers" (≤22 kW) and the remaining 10 % are "fast chargers", equipped with a charging power of 50 kW or more. The Netherlands, France and Germany are the numerical leaders in Europe.

A frequently used key parameter is the ratio vehicle to public charging points. The Alternative Fuels Infrastructure Directive states that the appropriate average number of charging points should be equivalent to at least one charging point per 10 cars. This allows both for a good availability of chargers and for the investment remuneration of the Charging Operators. However, this number could significantly change according to the considered area (e. g. densely populated or rural) and the desired charging strategies. A lower value of vehicle to charging points means that each vehicle can stay connected for longer, providing more room for flexibility services.

5 Conductive solutions using other contact types (e. g. plates) are currently in the prototyping/industrialisation phase

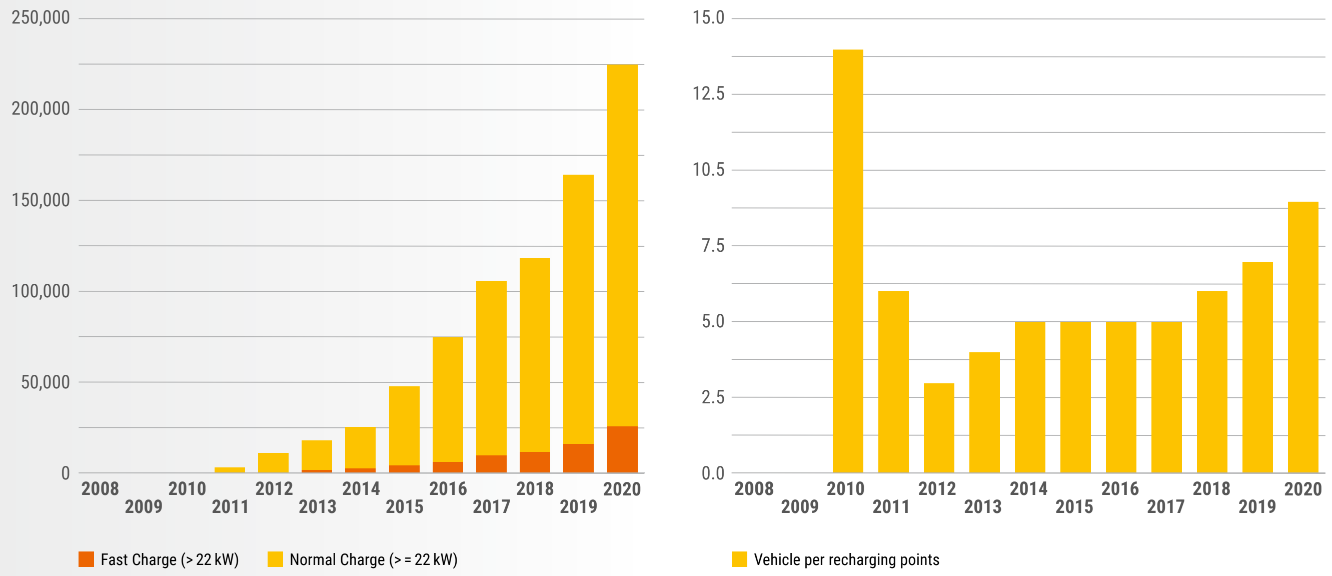


Figure 9 – European installed charging stations and vehicle / charging points ration in the period 2008 – 2020 (Source: EAFO)

2.4.2 Charging Use Cases

EVs are typically charged at different locations and with different power levels. Considering the user's perspective, the optimal charging strategy would take full advantage of the car parking periods, with a coherent power absorption. Private passenger cars are parked for over 90 % of time, normally at home or at the office.

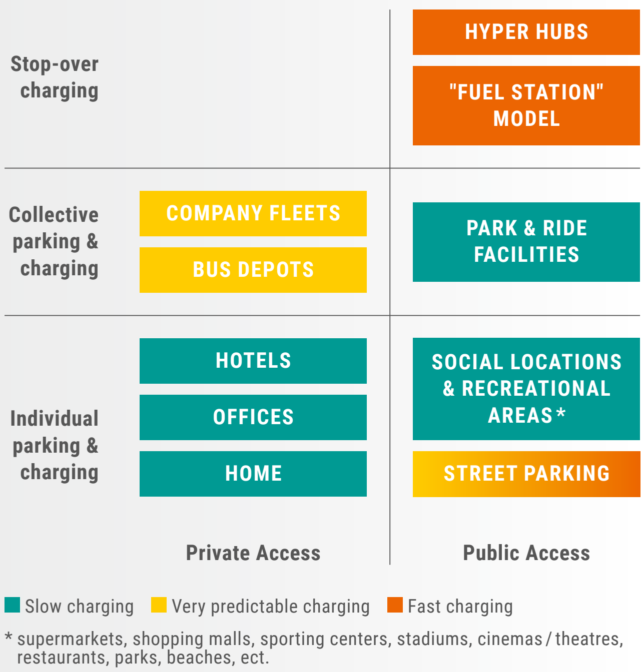


Figure 10 – EV charging use cases, structured according to access, parking characteristics and charging time (Source: ENTSO-E)

Slow charging at those locations, when feasible, is indeed a suitable / valuable solution and is commonly sufficient to satisfy daily mileage. For long trips exceeding the EV range, there is a need to charge with high (or ultra-high) power during short stop-overs in "hyper hubs" or in "fuel station"-like facilities, especially along highways or motorways. Subsequently, there is the possibility to slow charge at "destination chargers" (e. g. hotels). When users do not have the possibility to charge at the home / office, public charging stations are asked to completely fulfil their charging needs. In this case, a combination of slow charging on the street or in park & ride structures and fast charging in urban hubs could be adopted. Extra mileage could be added by EV charging at social locations and recreational areas where the typical parking time exceeds one hour.

For company fleets (cars and duty vehicles) and buses, the usage pattern is easily predictable and there is often a possibility to charge at the company premises or in a deposit. This makes the charging process less complex to manage, especially when the daily mileage is compatible with the EV range. Criticalities could arise if the number of vehicles is high and the desired parking time short, making it necessary to install many chargers with significantly high power.

Mobility future trends, such as inter-modality, mobility-as-a-service and autonomous drive, will have a relevant influence, modifying EV mobility users' pattern towards more mobility / fleet manager and less private owners; such mobility patterns, even if not affecting charging technologies and energy requirements, could also change the volume of EVs and the location of charging points, with a potential effect on the power grid impact.

Why is EV Charging Different from Traditional Refueling?

- Electric vehicles can be charged at **low power while parked** for medium / long times (at home, office, depot, recreational or duties stop-overs, etc.); for most use-cases characterised by limited daily or trip mileage (i. e. excluding long range trips and passengers / goods transportation) EV users can couple parking and charging needs, avoiding the need to have a widespread network of fuel stations, as is the case with conventional fuels. By doing so, the EV users would refuel not on a need-basis (going to the petrol station when the tank is empty) but on an opportunity basis (charging the EV everytime the opportunity occurs), reducing the risk of finding the EV out of charge when needed.

- To allow long-range travel, EVs also require a **widespread charging infrastructure and fast charging process to satisfactorily meet the users' needs.**

- A significant share of EV users (70 – 85 %, depending on country and on urban architecture according to the IEA) will count on private chargers (at home, office); the others will rely on a **diffused publicly accessible charging infrastructure, either on private areas** (malls, supermarkets, service compounds, recreational areas, etc.) or on public streets.

- On extra urban highways **"hyperchargers hubs"** are an option, with a power capacity of up to tens of MW, therefore being HV connected, especially when trucks go electric; additional stationary storage systems might be required to limit peak power demand, except when hypercharger hubs are strategically positioned (e. g. in the direct proximity of substations).

- Slow charging infrastructure makes mass-deployed EV usable as "batteries on wheels", where Capex has already been paid by vehicle user and remuneration is needed only for Opex: battery degradation, smartening of charging device and user's commitment to the service.

Framework Analysis Takeaways

- The shift to E-mobility road transport (cars and LDVs) is likely to accelerate in the EU, both due to European and national legislation; for HDVs, green fuels and fuel cells may be more competitive; instead, new mobility behaviours should be less impactful as a power grid stressing element. Air and sea transport electrification are still far from materialising.

- TSOs' interest today is on facilitating the electrification of road transport (cars & trucks): TSOs positioning themselves both as grid operator, market facilitator and as electric / energy system manager and supervisor ("One System view")

- EVs have to be considered as part of a wide and intertwined ecosystem that involves both transport and electric systems, as well as urban planners, tariff and market regulatory authorities and new charging operators.

- Electricity actors are not at the centre; furthermore, in the electricity portion of the ecosystem, TSO are not at the core, unless they create / lead a joint standpoint with DSOs as Grid Operators.

- The diffusion of other emerging technologies as well as future trends in mobility, such as hydrogen fuelled EVs and shared mobility, should be carefully considered as they could also play a relevant role in addressing transportation needs and in offering flexibility to the power system.

- EV owners are the key actors of electric mobility deployment. It is crucial to understand and satisfy their expectations in terms of the charging process, especially focused on comfort, economic interest and functionalities. Relevant aspects would include: charging point location, reservation, access, charging duration, monitoring, payment and additional services (e. g. services provided while waiting for the recharge to end) and the interaction with other electrical assets at home / work.

- EV powertrains and vehicles are intrinsically efficient and are progressively becoming mature; important improvements are still expected on the charging infrastructure and the charging process, including digital services, data management, business models and value proposition

- Several charging use-cases will be deployed (private / public, individual / collective, fast / slow, fleet depots / street/, fuel stations / highways hubs); grid operators should support the tailored grid-friendly combinations of the above options.

3. E-mobility and Power Grid: Challenges & Opportunities

The increasing number of EVs that will interact with the power grid in the coming years will certainly require special attention from grid operators. EVs will both represent an additional load and a distributed flexible resource for grid services. Only through an optimal management of the charging process will it be possible to solve the potential system challenges and take advantage of all the potential opportunities.

3.1 2030 Charging Scenario

According to the IEA, the 2030 global charging scenario will be based on a combination of private charging (home/office), slow public charging (≤22 kW on streets, recreational areas, other) and fast public charging (150 kW). Private charging will cover the highest percentage of charging needs: over 70 % in densely populated countries (China, Japan) and over 85 % in other regions. This means that, on average, approximately one private charging station will be available for each EV. The number of private chargers for light vehicles and dedicated chargers for buses and trucks will reach almost 135 million in 2030 (STEPS). The cumulative installed power capacity of those chargers will be 0.6 TW globally, with approximately 400 TWh of electricity consumption. The contribution of bus and truck chargers is expected to be significant. In addition, publicly accessible charging will be installed to complement private charging in dense urban areas, where multi-unit/apartment complex dwelling is more prevalent, home charging access is scarce and workplace charging is restrictive. The number of publicly accessible slow and fast chargers will increase to almost 11 million in 2030 (STEPS), with a cumulative power capacity of 120 GW. They will provide almost 70 TWh of energy, roughly one-fifth of the electricity consumed by private chargers.

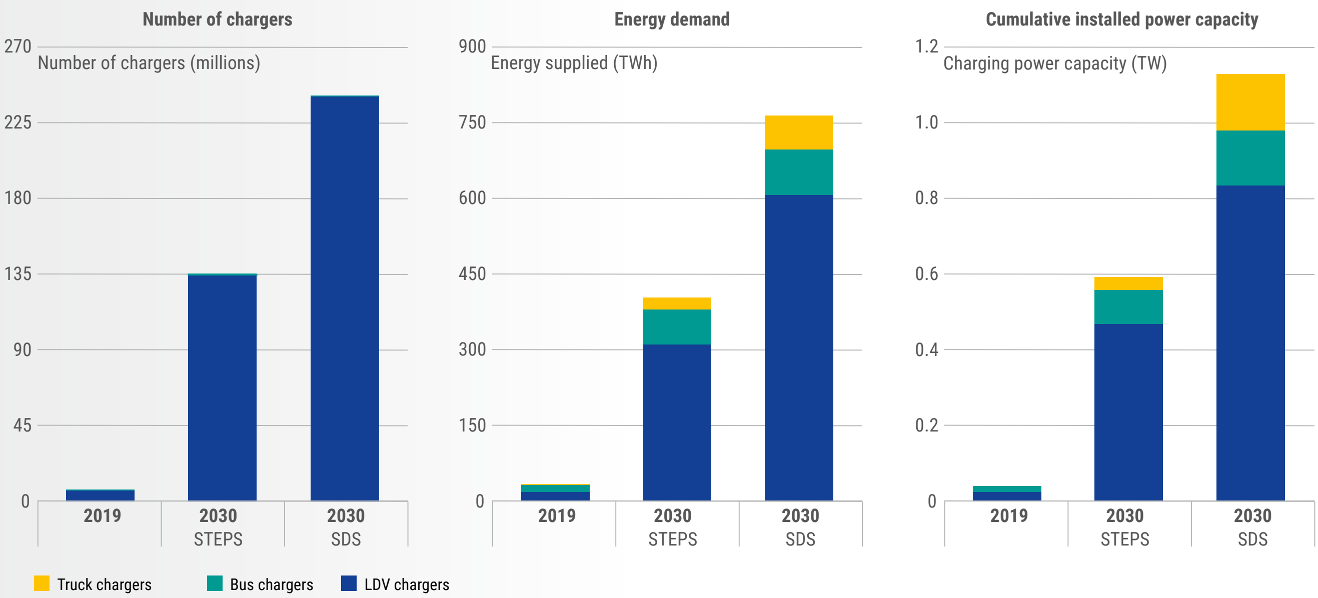


Figure 11 – Private charger diffusion, energy demand and power capacity in 2019 and 2030 by STEPS and SDS (Source: IEA)

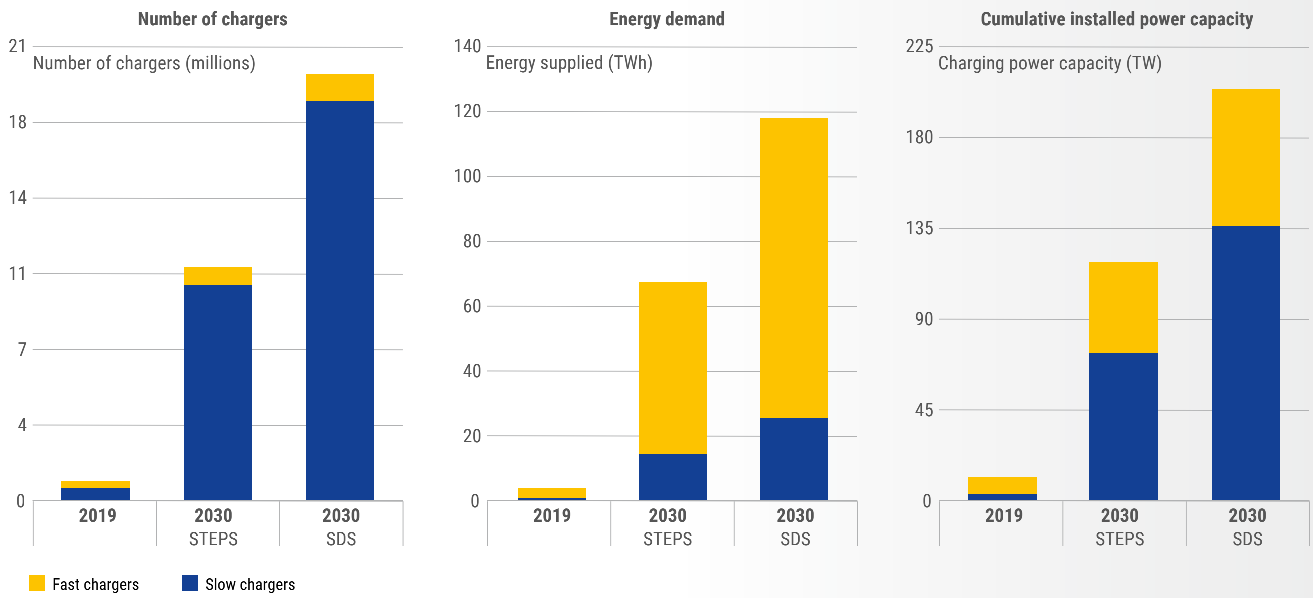


Figure 12 – Public charger diffusion, energy demand and power capacity in 2019 and 2030 by STEPS and SDS (Source: IEA)

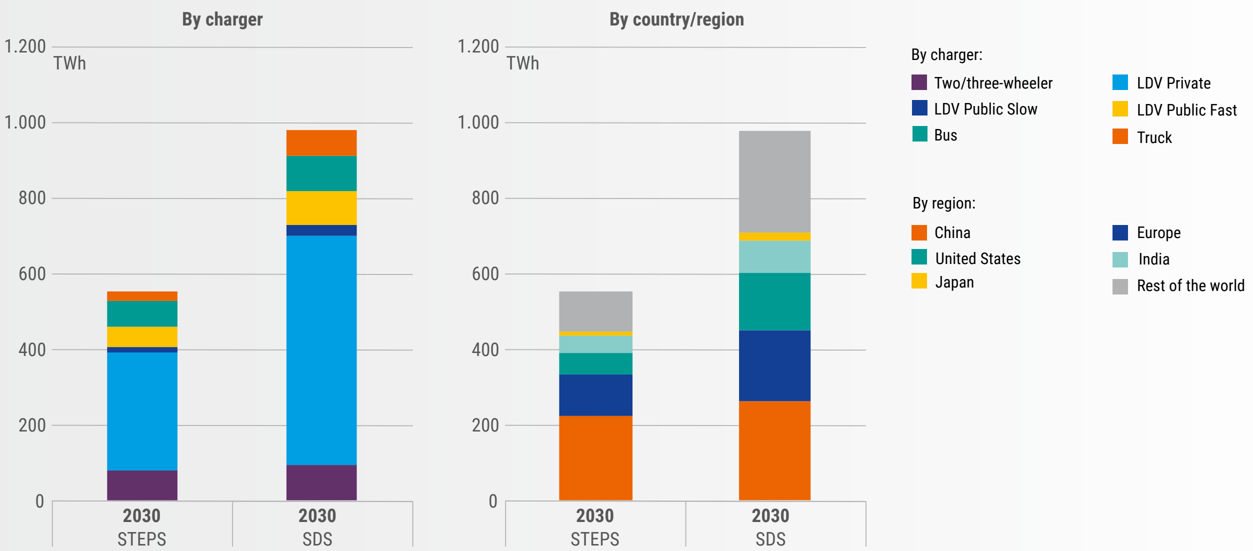


Figure 13 – Additional electricity demand due to EV charging, by charger and by country / region (Source: IEA)

3.2 An Energy Issue?

EVs are projected to consume approximately 550 TWh of electricity by 2030, with LDVs accounting for almost 70 % of the total EV power demand, followed by two / three-wheelers (15 %), buses (13 %) and trucks (4 %). EV contribution with respect to total final electricity consumption will increase from present values to 1 – 6 % (see Table 1). Despite being an important growth, percentage values in total electricity consumption are still low and will not imply significant challenges in the future for the power system in terms of energy consumption. In advanced economies, the increasing demand associated with EVs is expected to occur in the context of a steady or even reduced total electricity demand, due to energy efficiency improvements. In emerging economies, the consumption from EVs will be embedded in the context of fast-growing electricity consumption from all sectors. However, as is explained in Section 3.4.3, in the event that smart charging is not properly deployed, power issues could arise due to massive EV diffusion.

Country or Region	2019	STEPS 2030	SDS 2030
China	1,2 %	3 %	3 %
Europe	0,2 %	4 %	6 %
India	0,0 %	2 %	3 %
Japan	0,0 %	1 %	2 %
United States	0,1 %	1 %	4 %

Table 1 – EV electricity consumption in selected countries and regions (Source: IEA)

3.3 Grid Impact Use Cases

The charging strategies described in section 2.4 can have different impacts on the power grid. At the same time, network characteristics (e. g. urban or rural grids, other connected loads, grid topology and operational characteristics) could lead to certain criticalities. For a correct impact assessment, the analyses on specific grid portions should, therefore, be performed. However, some common elements can be identified to provide a general overview of the potential grid issues related to different use cases. The following table summarises some of the most interesting use cases that have been considered in terms of power and energy issues, grid reinforcement needs and potential flexibility services.

For the considered use-cases, three main conclusions can be derived. At first, **diffused slow charging** could generate excessive power demand due to contemporaneity effects. This will occur mostly when many other loads are connected to LV lines (typically during evening-peak hours) and could create overloads on Secondary Substations or on LV lines themselves. As shown in the next section, smart charging can dramatically reduce this problem. Secondly, when **high power connections** are punctually required, new, dedicated substations (and connection lines) must be installed. This generates additional costs and time. Finally, when **charging infrastructure is aimed at buses and trucks**, tens of MW could be additionally required. In this case, new lines or even new primary substations could be necessary. A strong coordination among charging operators and grid operators is highly recommended to identify the best location and the best technical options.

Use cases	Connection characteristics	Grid Impact analysis	
› **Public, Slow Charging** Street parking, Social / recreational areas, Park & Ride › **Home / private Charging** Single houses, apartments, hotels, offices › **Company Fleets** Pool vehicles (utilities, public services, private companies)	› Slow, AC charging › Connection to low voltage lines › **Medium / long connection time**	**Power issues:**	In the event of multiple installations, significant impacts can be expected in Secondary Substations (MV / LV transformers) and MV and LV lines where power flows sum up. Peak shaving solutions could significantly limit this problem. Voltage issues can be expected in rural areas.
		Energy issues:	no significant issues in terms of energy supply.
		Grid reinforcement:	It could be necessary to replace MV / LV transformers and / or MV and LV feeders.
		Potential for flexibility:	High potential due to long connection times. Best case: company fleets with predictable use patterns.
› **High Power Chargers – "Fuel Station" Model** Fast chargers (50 – 150 kW) in existing fuel stations › **Urban Hyper Hubs** Hyper fast chargers (150 – 350 kW) in new dedicated areas. Designed for cars in urban areas.	› Fast or ultrafast, DC charging › Connection to medium voltage lines, through shared (fuel station) or dedicated (hyper hub) POD. › **Short connection time**	**Power issues:**	Also, single installations may require a significant increase of power absorption. Loads generated by EV charging add up to other LV and MV loads. The impacts could be significant, also on MV lines.
		Energy issues:	energy withdrawal from the network could be significant but no issues are expected
		Grid reinforcement:	it could be necessary to install a dedicated MV substation with additional cost and time. MV lines (and in some cases, MV / LV transformers) could need to be replaced.
		Potential for flexibility:	minimum potential due to time constraints. Energy storage systems could be installed to limit peak power and to allow the participation to flexibility services
› **Bus Depots** High number (tens / hundreds) of buses performing night charging	› High power (50 – 100 kW / bus) charging, both AC and DC. › Connection to medium voltage lines. Possibility to share connection with other LPT loads (e. g. subway). › Long connection time, but coherent with required charging time (high battery capacity)	**Power issues:**	A single deposit could require 5 –10 MW, often in urban areas. There is a strong need for coordination between grid operators and local public transport operators.
		Energy issues:	Moderate additional energy demand.
		Grid reinforcement:	In the event of the high number of buses, new primary substations could be required. Interventions could be required for MV lines.
		Potential for flexibility:	Good control of vehicle consumption and of the charging process due to predictable usage. Only a partial opportunity for flexibility services, due to time / power constraints.
› **Highway Hyper Hubs** Hyper fast chargers (150 – 350 kW) in new dedicated areas on highways both for cars and for heavy duty vehicles.	› Multiple ultrafast, DC charging › Connection to High Voltage Lines, through dedicated POD. › **Short connection time** and high contemporaneity factor	**Power issues:**	A single hub could require more than 10 MW, often in rural areas. There is a strong need for coordination with grid operators in order to locate hubs close to existing HV lines.
		Energy issues:	Energy withdrawal from the network could be significant but no issues are expected.
		Grid reinforcement:	A new Primary Substation would be required. A well-planned location would minimise the need for new HV lines.
		Potential for flexibility:	Minimum potential due to time constraints. Energy storage systems could be installed to limit peak power and to allow the participation to flexibility services

3.4 EVs as an Opportunity to the System

3.4.1 Managing the Charging Process

In the traditional charging process, absorbed power is given by the technical capability of both the vehicle and the charging station. It is the maximum power that both components can stand and could be limited by either the vehicle or the charging device, depending on the use case. Once the accepted power is identified, it remains constant at its maximum level for most of the charging process. Therefore, the charging will occur in the shortest possible time and with the highest power absorption. Especially when the vehicle connection time is long, this logic should be completely modified. Charging stations, both private and public, are (or should be) equipped with communication and control systems that allow for the real-time control of the power set-point to manage the charging process according to the most appropriate power absorption profile from the system perspective.

In addition, the charging time scheduling should also be managed. This could occur in two ways:

- The user is encouraged, through a charging solution representing a valid value proposition for him, to connect the vehicle at specific moments of the day (e. g. during daytime rather than during evening-peak hours).
- When the vehicle is connected, the charging profile is adjusted in terms of intensity of energy withdrawal and in timing (postponed but also anticipated) by an operational algorithm of the energy management system.

By combining the power profile control and the time scheduling, the charging process can be significantly improved to obtain benefits with respect to standard charging. This approach, commonly known as smart charging, can be further enhanced when considering bi-directional charging (V2G). In this case, power control operates not only on power absorption but also on the EV battery discharge power. Both smart charging and V2G are performed with two main objectives. The first one is to limit peak power demand at times where renewable electricity production will be low (and also inject power in the grid), and the grid congestion issues associated with EV charging. The second objective is generally to take advantage of the batteries' capabilities offered by EVs for flexibility services (e. g. frequency control and ancillary services). Today, V2G solutions provide higher flexibility capacity but also a higher technology cost, which limits their viability to only a portion of EVs; their widespread diffusion could occur in the medium-term future, especially for households.

As detailed further in the next sections, the possibility of dynamically adapting grid tariffs and providing energy price signals will be crucial for engaging EV users in smart charging schemes. To allow this, the massive rollout of smart meters performing minimum hourly / quarter-hourly metering represents a fundamental pre-requisite, as well as the related data management system.

EV Features as Flexibility Sources

- EVs can remain connected to the electric grid for many hours; this allows for their use as a flexibility resource and as a distributed pool within one electricity market zone, provided the **charging process is not purely passive.**
- Automotive batteries have a **small capacity** (30 – 100 kWh) and slow EV chargers have **small power** (3 – 11 kW) necessity to **aggregate many vehicles, and / or other local small-scale flexibility resources to enable ancillary services.**
- Vehicles have to satisfy users' driving needs. This limits the energy and time availability to provide flexibility services:
- The flexibility provider has to balance out single EV unpredictability through aggregation at the proper level to offer the aggregated amount as a marketable resource of flexibility
- Low **attractiveness of price signals for EV users, to be potentially enhanced** by providing a comfortable experience through automatic charging and extra services (smartphone application, gamification, driving & non-driving amenities)
- Simple and reliable information about the location of the charging points and their availability in near real time needs to be provided
- The same **EV can charge at different places, times and state of charge.** Platform-based forecasting should tackle these **multiple charging options** through stochastic aggregation.
- The **increase** of EV adoption could be very quick; **therefore, it is paramount to immediately begin the deployment of smart charging and, whenever viable, of V2G solutions.**
- **Research & innovation** are focused more **on vehicle cost and performances** (e. g. ultra-fast charging) than on grid-friendly aspects (e. g. flexibility provision). Regardless, EVs with higher capacity batteries will be well-suited to provide flexibility services.

3.4.2 Main Opportunities Provided by EV Charging Management

Opportunity #1: Reshaping the Power Load Curve

What?

The EV charging process can be shifted from peak (evening hours) to off-peak hours to avoid the need for additional (marginal and therefore more expensive) power capacity during the peaks (typically fossil-based). Just the time-shift of the charging process will have an important effect, removing the additional load. The positive effect can be significantly increased if EVs charge during the day and provide energy back to the grid during the peak, through V2G technology. This way, the use of EVs would actually reduce the need for fossil-based power generation during peak hours.

How?

Different solutions can be applied. To drastically shift charging from the evening to more suitable times, a change in users' habits needs to be stimulated. This can be achieved through new tariff schemes and by facilitating the possibility of charging EVs at office premises or in Park & Ride facilities. To shift charging from the evening to the night, both time-of-use (ToU) tariffs or charging management by aggregators could be adopted.

Who benefits?

Benefits would be obtained by the energy system as a whole. Generation-oriented peak shaving will reduce generation costs and CO_2 emissions. An effective method of identifying tariff values, reflecting the general benefits, should be defined by the regulatory authorities. As a service provided by vehicles, the economic benefits would be also felt by EV owners.

Opportunity #2: Ancillary Services for Transmission Grid Operation

What?

EVs can be used to support the balancing of the transmission grid, keeping the frequency close to the reference of 50 Hz. EVs could modulate their charging profile (or even the generated power in the V2G scheme) and participate in reserve markets (where in place), providing frequency-response reserve and replacement reserve. Due to the technical characteristics of automotive batteries, EVs can also provide fast-frequency reserve, which is becoming progressively more relevant for transmission grid operation. With V2G chargers, voltage control for transmission grid could also be performed.

How?

EVs could modulate their charging / discharging power according to the requests of the TSO, channelled through a BSP and defined in proper flexibility markets. Modulation could occur for seconds or up to hours, according to the kind of service offered. New rules should be applied to flexibility markets to avoid excluding a promising technology such as EVs from participating in the Ancillary Services Markets.

Who benefits?

Most relevant benefits will be obtained by TSOs and grid users as EVs' support contributes to guaranteeing transmission grid safety, adequacy and quality as a partial substitution for traditional frequency-control systems (e. g. rotational inertia) and synthetic inertia solutions. As a service provided by vehicles, the economic benefits would be also felt by EV owners.

Opportunity #3: Management of Grid Congestions

What?

EVs can be used as distributed resource to reduce the risk of transmission grid congestions, so to minimise sub-optimal "re-despatching". Being widely diffused on the territory, they offer the TSO important possibilities to effectively intervene in areas where congestions in lines and nodes typically happen.

How?

EVs could modulate their charging / discharging power according to the requests of the TSO, channelled through a market service provider. This could occur either in advance (day-ahead market) or during operation (intra-day and balancing market).

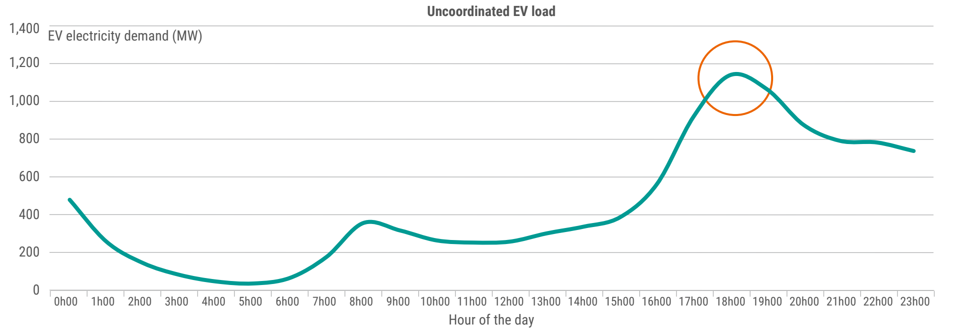
Who benefits?

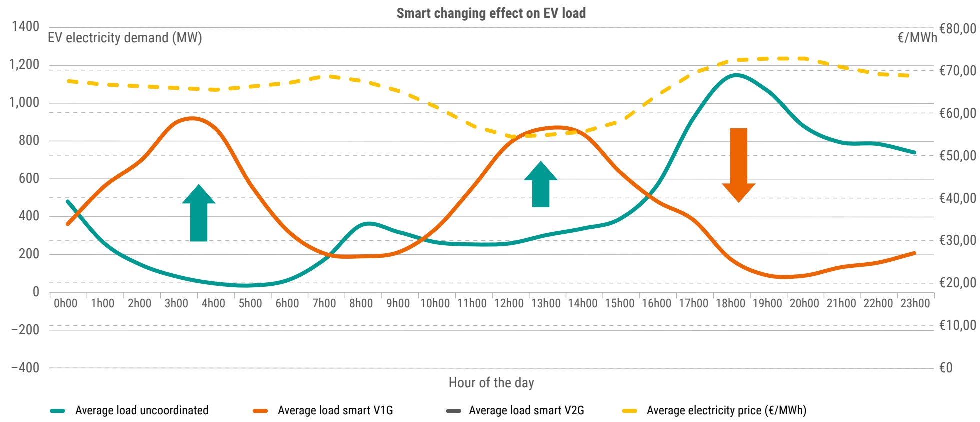
Most relevant benefits are to be obtained by TSOs, as they limit "re-despatching" costs (use of sub-optimal generation or loads). As a service provided by vehicles, economic benefits would be also reflected to EV owners.

The Effect of Smart Charging and V2G on EV Load Curve

Graphs representing the case of Belgium clearly depict these effects, highlighting the impressive regulation capacity which can be offered by EVs.

Considering the typical user's driving behaviour, EVs would be commonly plugged-in during evening hours. This would generate a fast ramp-up of EV electricity demand which comes on top of the already existing critical evening ramp of the residual load (total load less PV and wind generation), even without any EV charging. Therefore, uncoordinated charging creates a problem of sharpening the peak, requiring costly generation to intervene and the potential instability of the grid. Smart charging can beneficially reshape the EV load curve, shifting the power request at suitable times (from the blue curve to orange curve): later in the night (when the power request is smaller) and during the daytime (when PV production is higher). If some smart charging is also equipped for V2G, the reshaping effect is emphasised (grey curve), therefore contributing to smoothing out not only the EV load but even part of the global residual load.





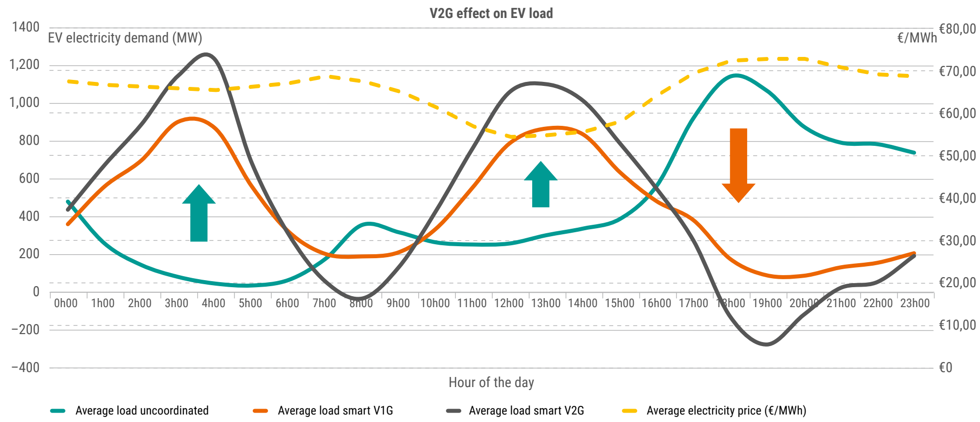


Figure 14 – Uncoordinated EV load, smart charging effect and V2G effect in Belgium 2030, EV penetration scenario (Source: Elia Group)

Opportunity #4: Avoid Overloads on Distribution Grids

What?

EV charging can be shifted from evening peak hours to off-peak hours, (e. g. night-time) to avoid additional loads on distribution grids and limit electrical and thermal stresses on MV, LV lines and secondary substations. This solution particularly suits home charging, avoiding the risk of cumulated effects when vehicles arrive home (high contemporaneity factor also with domestic appliances).

How?

Both a reshaping of the vehicle charging curve (flattening power absorption for longer period) or a complete charging postponing would have positive effects. Tariff schemes and especially ToU tariffs are the first solution to stimulate charging time-shift. Regardless, static ToU tariffs could generate the risk of price-led congestions on the distribution grid. Instead, dynamic tariffs reflecting local grid constraints and communicated through automatic price signals could guarantee the best results.

Who benefits?

Most relevant benefits will be obtained by DSOs, reducing the need to reinforce distribution grids. As a solution driven by tariff schemes, final uses will have a direct economic advantage.

Opportunity #5: Voltage Control in Distribution Grids

What?

Bi-directional DC chargers can be used to perform voltage control on distribution grids. This would occur through reactive power control by power electronics equipment installed in the chargers. Voltage stability guarantees grid correct operation and is especially required when high shares of volatile RES are connected.

How?

Voltage control has to occur through a direct control of bidirectional chargers as performed by charging point operators or by BSPs.

Who benefits?

Most relevant benefits are to be obtained by the DSOs. They will experience a better grid operation and the reduction of traditional voltage regulators usage (less aging and maintenance costs). As a service provided through vehicles and chargers, economic benefits would be also felt by EV owners and CPOs.

Opportunity #6: Reduction of "Over-Generation" by RES

What?

Considering the increasing amount of RES generation expected in the next decades, over-generation and curtailment of green energy will become a relevant issue. EVs can schedule their charging process so as to fully match and hence exploit renewable generation availability. In regions relying on wind power generation there is lower predictability, but night-charging could be effective. In regions relying on PV generation, charging should be concentrated during day-time central hours.

How?

To align wind generation and night charging no special measures are required. To match EV charging with PV production, a change in users' habit need to be stimulated. This can be done through new tariff schemes (hourly / quarterly or potentially real time-based tariffs) and by facilitating the possibility of charging at the office premises or in park & ride facilities.

Who benefits?

Benefits would be obtained by the energy system as a whole. Over-generation reduction will lower generation costs and CO_2 emissions. An effective method of identifying tariff values reflecting the general benefits should be defined by the regulatory authorities.

Opportunity #7: "Behind the Meter" Services (Consumer Perspective)

What?

EVs can be used for the same purposes as other domestic storage systems. They can increase self-consumption in the presence of RES generation (prosumer case), thus reducing the electricity bill. Even in the absence of RES generation, EV batteries can be used to perform tariff optimisation, charging during low-price periods and then providing their energy for domestic loads during high-price ones. The same objectives and benefits can be achieved both with private cars and with company fleets.

How?

Tariff schemes and especially time-of-use (ToU) and dynamic tariffs are the key enablers for these services. Once these are in place, the user or an automatic energy management system can control vehicle charging / discharging to maximise benefits. For these purposes, bi-directional chargers can significantly increase the advantages.

Who benefits?

EV owners (both private and companies) can obtain interesting economic benefits by performing behind-the-meter services. With respect to standard domestic storage systems, the use of EVs allows battery investment costs to be avoided, even if partially / temporarily limiting storage availability. If grid tariff and power price schemes are properly designed (for example, avoiding double charging for bidirectional flows), the energy system can benefit from these services, shifting EVs charging during off-peak hours and also reducing domestic loads power absorption during peak hours.

Opportunity #8: Take Advantage of Hyper Chargers for Heavy Duty Vehicles

What?

HDVs will ask for a relevant amount of power, and their intensive usage pattern will not leave much room for performing smart charging or providing services. The daytime use of hyper chargers (150 – 350 kW and more) connected to HV grids and properly located will both avoid the risk of overloads in lower voltage levels of the grid during peak hours and enable the significant use of renewable energy.

How?

Hyper chargers designed for heavy duty vehicles should be connected to HV grids and located close to existing lines. To ensure this, strong cooperation between the TSOs and the hub investors / operators would be required, thus installing other facilities (eg. stationary batteries) could also be taken into consideration to limit the peak power demand. In addition to this, specific tariffs or driving schemes should also be supported to stimulate daytime charging. Additional services for drivers during charging hours should be also promoted.

Who benefits?

DSOs will experience relevant benefits avoiding critical loads on their grids. The proper management of heavy duty vehicles, according also to opportunity #1 and #6, will have a positive impact on the overall energy system too. An effective method to identify tariff values reflecting the general benefits should be defined by the regulatory authorities.

3.4.3 Stacking the Opportunities

Some of the opportunities provided by EV charging, even if distinguishable as objectives, can be stacked. Several benefits can be obtained with the same "smart charging" solution. The most relevant example is shifting EV charging from evening hours to daytime. In this case, electricity cost reduction will be obtained for final users (Opportunity #7), overloads on distribution grids will be reduced (Opportunity #4), the power generation curve will be beneficially reshaped (Opportunity #1) and over-generation will be limited (Opportunity #6). All these objectives will be reached simultaneously and the benefits would be enjoyed by multiple actors. As an example, in Figure 14 the effects of smart charging on the German load profile is depicted, together with a PV generation histogram, showing the shift of demand peak to a time-slot where more electricity is being generated.

Similarly, several benefits can be obtained by performing real-time control on the charging process. Charging peaks can be shaved (Opportunity #4), voltage control can be performed by DSOs (Opportunity #5), ancillary services for the transmission grid can be provided (Opportunity #2) and grid congestions can be managed (Opportunity #3). Differently from the previous example, in this case the four objectives cannot be simultaneously reached as different control strategies would be needed. While pursuing one strategy, cross effects could occur, and they could be both positive or negative for other strategies. These cross relationships should be carefully considered, so a complete knowledge of the total effect is gained by the involved actors. For example, the sum of individual behind-the-meter optimisations could not result in the optimal system-wide load profile. It is necessary to study the interactions between the two as well as appropriate price signals for end users. The described examples could also be stacked. Performing fine-tune, real-time control on a daytime charging process could indeed provide the greatest number of opportunities.

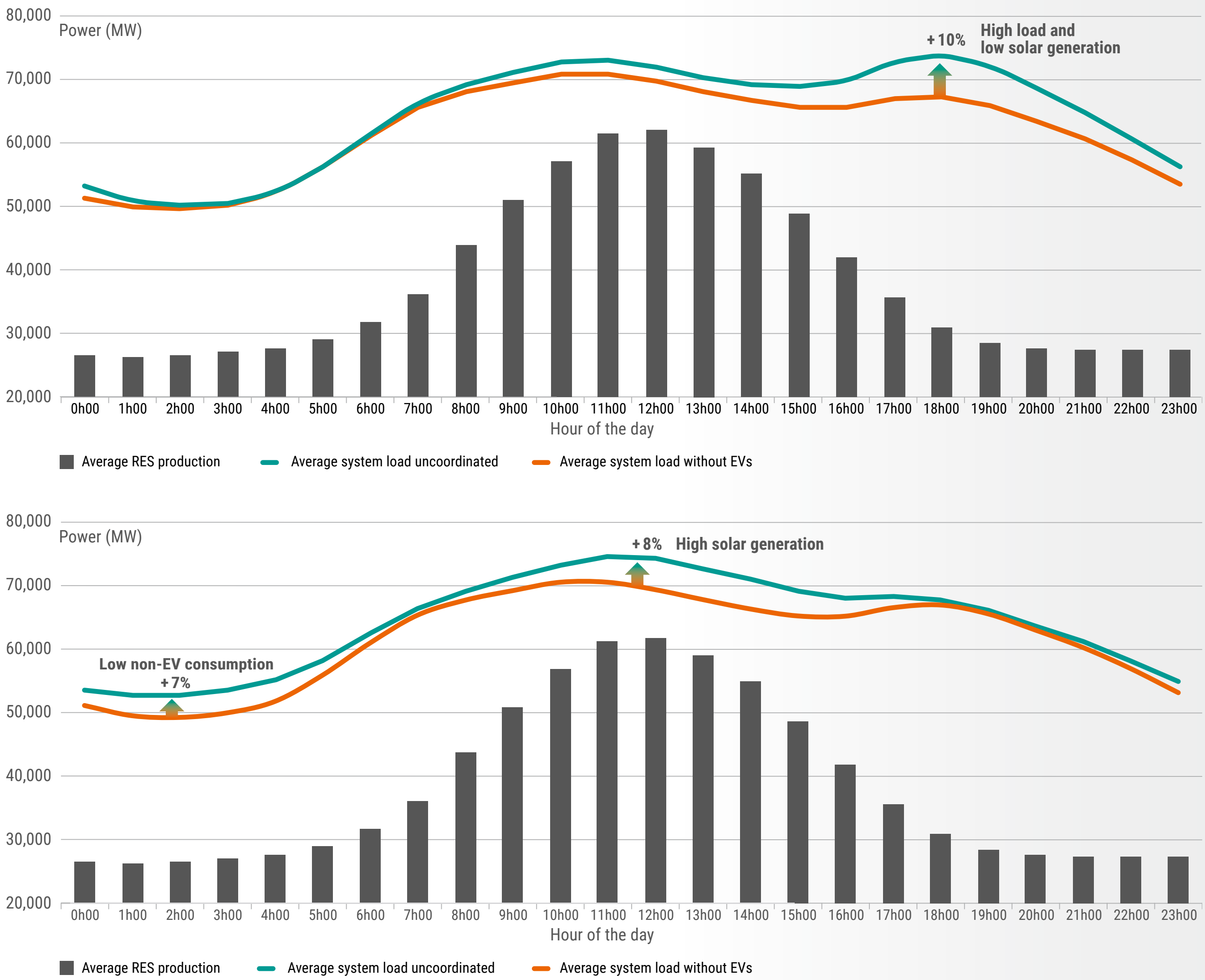


Figure 15 – Average total electricity load in Germany with uncoordinated (left) and smart charging (right). (Source: Elia Group)

4. Key Findings & Messages

It is necessary to set up a proper environment to allow the optimal exploitation of EV opportunities. The present situation still limits the possibilities offered by smart charging and V2G technologies, which have to be fostered through coordinated planning and updated regulation. TSOs have an important role to play, both directly as grid operators and as facilitators (system operators through market services).

4.1 Promote integrated planning for charging infrastructure & electric grid

1. **Charging infrastructure planning should consider transport, urban planning, private households buildings and energy system needs.** The charging behaviour of EV users and configuration/characteristics of the charging infrastructure will have an impact both on transmission and distribution grids, as well as on the power system as a whole. Hence, a synergic and coordinated approach should be adopted. Moreover, by **coupling the user's parking need with the charging need**, the charging process can become a new, cost-effective resource of flexibility.

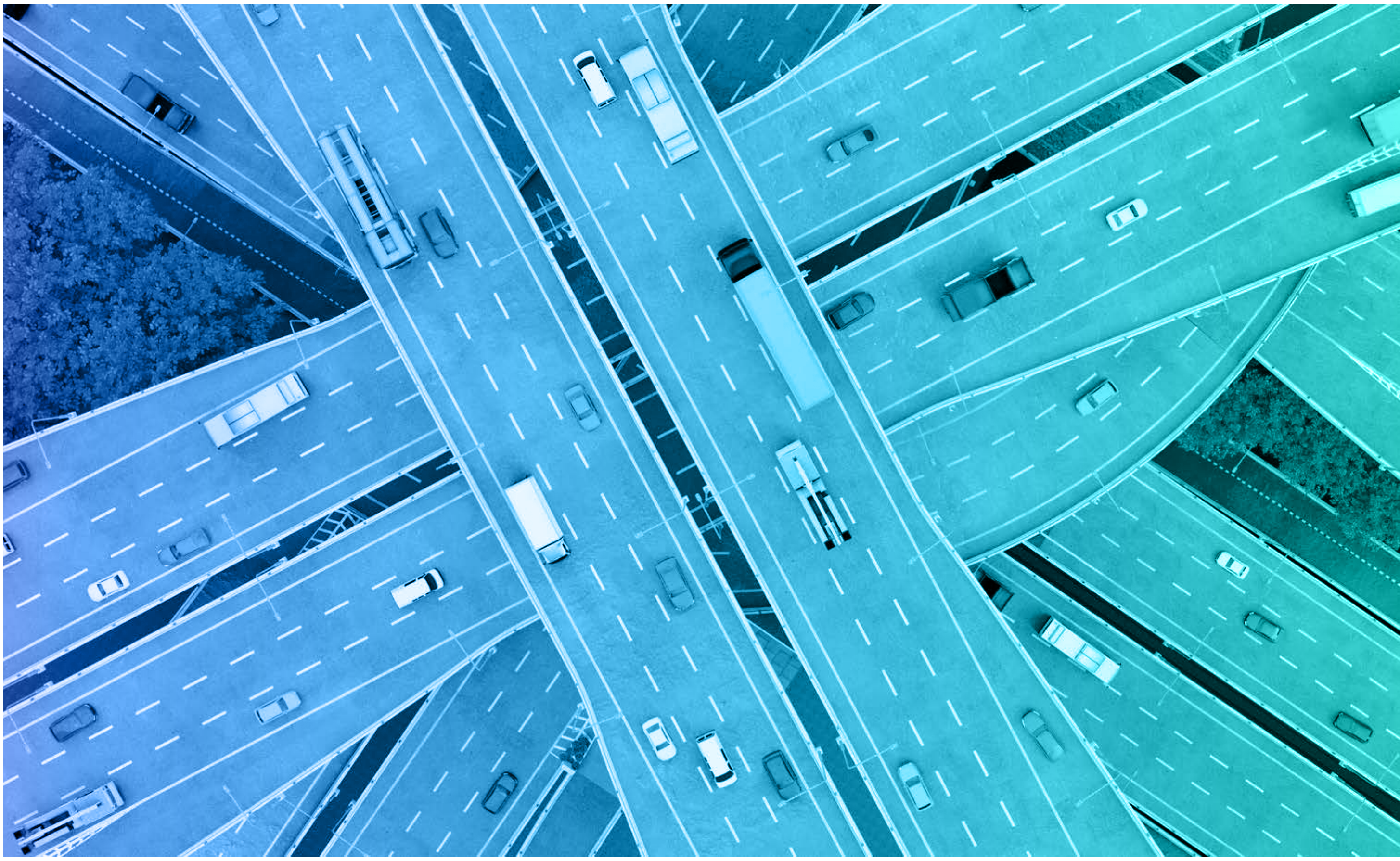
2. **Grid planning should be performed through a careful scenario definition**. Improved modelling should be adopted to perform robust simulations of grids' impact and cross-sector optimisations scenarios by means of new models and algorithms as well as what-if and sensitivities analysis. Quantitative parametric and probabilistic models should assess the impact of progressive massive EV penetration on the electricity system, including modifications of hourly/weekly/seasonal load profiles, conditions for energy adequacy (primary energy supply) and power adequacy (grid congestions/reinforcements).

3. **TSOs should carefully consider the diffusion of "hypercharger hubs" on highways**. Hypercharger hubs requires relevant power (tens of MW) and could be connected directly to HV grids. This issue could assume more relevance if both electric cars and electric trucks have to be served. Strong cooperation between the TSO and the hub operators should be pursued. The option of installing stationary storage systems to limit peak power demand should also be considered.

4.2 Manage the Charging Process

4. **A "smart" management of the charging process should be pursued.** It is, indeed, a crucial solution to limit the need for additional peak capacity when renewable production is scarce, and prevent grid overloads (especially at local level). It also may avoid, limit or postpone grid reinforcement costs and enable new opportunities of providing services to the power system. Smart charging and V2G can solve peak power issues, increase RES penetration and provide flexibility services; for grid operators they will be a valuable source of flexibility, complementing others such as traditional demand response.

5. **A proper management of the EV charging process should be based on planned and optimised schemes to obtain advantages for both EV owners and the energy system.** The management of an EV optimal charging strategy has to be performed by E-mobility service providers and/or aggregators, operating through market mechanisms with proper inputs and cooperation among system operators. The user will have multiple charging options regardless, making optimal scheduling more complicated. EVs can be also profitably included in "prosumer" schemes and domestic multi-energy configurations to optimise domestic energy flows in the presence of renewable energy generation and storage systems (batteries, water heaters, others). The Internet of Things (IoT) and cloud-based monitoring and control systems will facilitate the adoption of these schemes.



4.3 Deploy Electromobility Enablers

6. **Both private and public charging infrastructure should be equipped with a minimum level of "smartness" by default, avoiding passive charging whenever feasible, for all charging use cases**. Metering and communication capabilities are a fundamental prerequisite to managing the charging process and delivering services at scale to EV owners. Furthermore, in private households, plug-n-play solutions should be avoided in favour of smart chargers that guarantee remote monitoring and control. To stimulate users to frequently connect their cars, automatic connectivity systems should be encouraged, reducing the need for user-unfriendly cable connections.

7. **Common standards should be developed and adopted to guarantee the interoperability of charging networks and to perform V2G**. Current regulation still does not completely cover certain standardisation issues. For instance, communication aspects between the charging stations and the control system are not completely defined, creating interoperability issues for both EV users and service providers. Moreover, the Combined Charging System standard (CCS) still does not allow bidirectional charging, thus hindering the possibilities of implementing V2G schemes.

8. **Access to data and data management should be well defined and regulated as a key enabler to implement new services**. To effectively implement smart charging and provide flexibility services, a relevant amount of data must circulate among the involved actors. Vehicle usage patterns, battery state of charge, infrastructure and vehicle power capabilities, grid tariffs and energy prices, distribution and transmission grid situation, and renewable production (forecast and real-time) are just some of the pieces of information required to properly manage the charging process of EV aggregates. Clearly, these data are today owned by different actors and no exchange rule / protocols / platforms have been yet defined. In addition to technical aspects (e. g. protocols and sharing methods), other crucial aspects need to be tackled, such as data propriety, data privacy and data economic value. As EVs will be increasingly integrated in the energy system, security from cyber-attacks will also represent a key issue, so as to avoid data being intentionally manipulated to generate negative impacts on the system balance. Moreover, control systems of EV-charging should be designed in such a manner that data failure or manipulation does not lead to a substantial change in system balance (cyber-resilience) and emergency situations are properly managed (e. g. restoration after black-outs).

4.4 Enable a New Consumer-Oriented Ecosystem

9. **The roles and responsibilities of the different actors involved in electric mobility should be clarified**. A uniform and homogeneous framework should be settled at the European level, able to include all the relevant actors with a cross-sectoral approach to deliver consumer-oriented services. Electricity grid operators will play an enabling role in fostering competition and unlocking the potential of flexibility from EVs.

10. **TSO–DSO cooperation should be enhanced, being essential to favourably managing EV charging**. The optimal system configuration can be defined only by means of the increased visibility of the distribution and transmission grids status and of the connected flexibility resources. In this regard, TSO–DSO cooperation has to be fostered during grid planning, load forecasting, grid operation, system despatching and flexible resources management. Cooperation between market actors and system operators will also be crucial to maximise the benefits for the different players across the value chain.

4.5 Update Market Design and Rules

11. **Final users charging tariffs and energy price should stimulate the adoption of smart charging schemes**. They should dynamically reflect infrastructure costs (capital and operational), energy costs and grid constraints. This way, both locational and time-of-use price signals could be set. EV users should benefit from both reduced tariffs and energy price as they contribute to reducing grid investments, stabilising the grid and providing ancillary services. Double taxation and double counting of grid tariffs must be avoided to avoid hindering V2G services: As for electrochemical storage systems, taxes and grid tariffs have to be applied exclusively on the amount of energy actually exploited by the final user, by means of a proper metering and settlement system.

12. **Regulation authorities should intervene to enable new forms of participation to energy and flexibility markets**. Present regulations allow only the partial adoption of smart charging schemes and represent an obstacle to introducing new flexibility schemes with new actors. Technical and dimensional requirements for market access are, indeed, too demanding to allow EV fleet participation. Even V2G implementation would require updates in regulations, e. g. on energy ownership, imbalance issues, the EV user role as energy producer, etc.

13. **A strategy should be defined to manage the services offered by EVs and their participation in flexibility markets**. The strategy should be based on the evaluation of each of the potential services, considering their needs / capacity (how many EVs could participate or are required?) and an evaluation of their benefits (Who benefits? Are there economic or environmental advantages? How are they transferred to final users?). Benefits from the sector coupling transport-power system should be assessed under different angles: for the EV user (who is also an energy consumer), for the grid operator and for the whole energy system. TSOs are both grid operator and system operator, so they have a double task and double perspective here.

5. TSO Positioning

The findings from the analysis phase can be categorised and put in a graphical storyline as per Figure 16, which also highlights the issues requiring TSO actions and positioning.

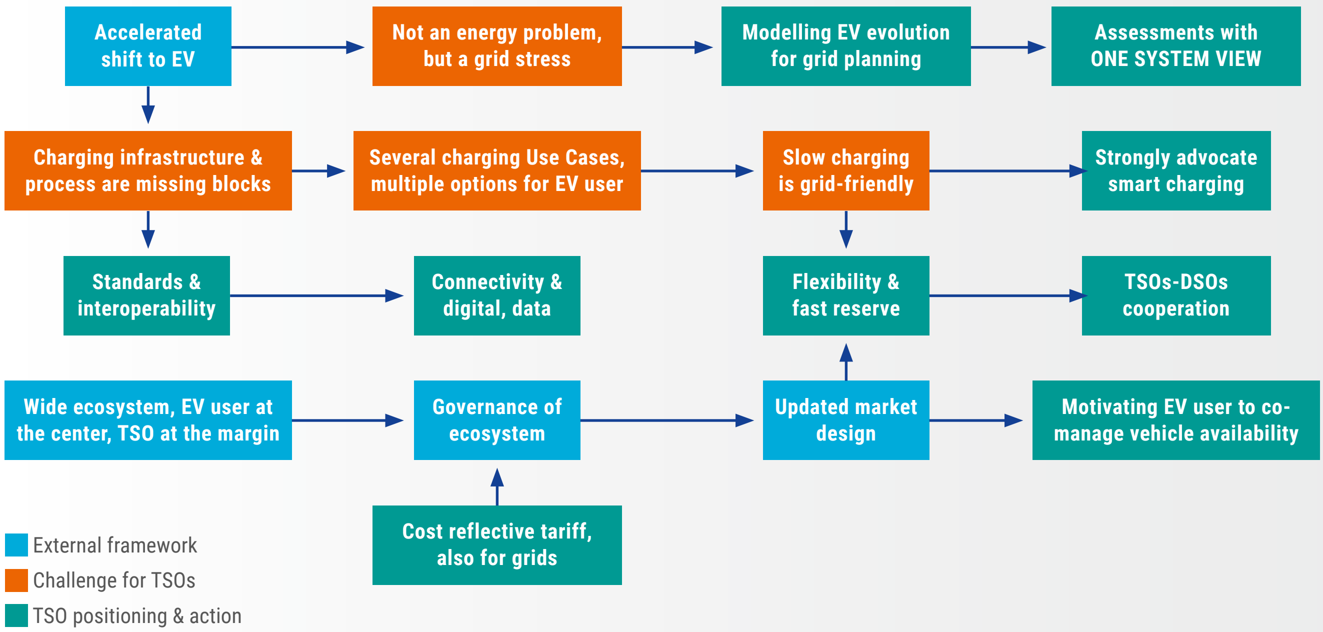


Figure 16 – Synthesis of main findings and positions

5.1 What Should TSOs do?

TSOs should be involved in many aspects of E-mobility development to properly address the foreseen challenges and maximise all the opportunities offered by EV adoption to facilitate the delivery of consumer-oriented services in terms of grid/system management (Fig. 16). Furthermore, TSOs should devise a multisided action plan including technical, economic, political, regulatory and social aspects:

1. **TEST**: TSOs should work to characterise the EV related technology as a flexible resource through dedicated pilot projects; this will enable the identification of technical, standardisation and regulatory issues and suggest viable solutions.

2. **STUDY**: TSOs, with the support of research institutions, should analyse the potential opportunities of the services provided by EVs in their grid operation activity. They should analyse near-future scenarios and identify the cumulative effects of different services in terms of grid stability, energy savings, and environmental and economic benefits.

3. **COOPERATE**: TSOs should cooperate with other grid operators (i. e. DSOs), market operators, technical commissions and the regulatory authority to jointly define and implement the best solutions to unlock the potential of EV to provide energy and flexibility services. Coordinated grid planning, data access and data management and market tools should be implemented as well as an overarching strategy for introducing an improved electricity market design.

4. **PROMOTE**: TSOs should interact with decision makers, underlining the importance of smart charging and V2G solutions. This particularly concerns the need to immediately deploy a smart infrastructure with hourly/quarter-hourly metering, avoiding passive charging and adopting common standards. New market rules and tariff schemes are required, and TSOs should ensure a market-based request of flexibility by exploiting the massive EV deployment as a new DER.

5. **MOTIVATE**: TSOs, together with charging operators and energy system operators, should make a special effort to find the best ways to motivate EV owners to adapt their charging habits towards smart charging schemes.

6. **MONITOR**: TSOs should carefully monitor the evolution of the EV sector. New mobility trends (e. g. mobility-as-a-service and autonomous drive), new alternative fuels (hydrogen or synthetic fuels) and technological developments, especially regarding batteries and charging stations, should be continuously analysed as they could significantly affect EV grid integration opportunities. Whenever possible, TSOs and other energy system operators should try to influence the mobility sector towards grid-friendly solutions.

Consistently with this vision, many European TSOs have already begun projects and activities focused on various aspects of E-mobility. Some examples are reported in Appendix I.

5.2 Who Will Be Involved?

Both transport and energy actors should be involved in the necessary transformation. All the stakeholders who are part of the ecosystem will have a role (Table 2). EV users will play the crucial role of main decision makers in the EV charging process. The framework to profitably channel users' decisions will have to be developed and managed by energy system operators and decision makers. Charging operators, as well as research centres, will be fundamental to define and support the new charging schemes. Manufacturers will have the key task of technically implementing the new solutions in their products (both EVs and charging stations).

Main issues Stakeholders	EV users	Manufacturers	Charging operators	Aggregators / energy market operators	Grid / System operators	Decision makers	Research and associations
1. Multidimensional infrastructure planning	●●●	●●	●●●	●	●●●	●●	●●●
2. Planning through scenario definition			●●	●	●●●	●●	●●●
3. Hyper hubs integration		●	●●		●●●	●	●
4. Smart charging & V2G	●●●	●●	●●	●●●	●●●	●	●●●
5. Charging management to ensure benefits for users and the system	●●●		●●	●●●	●●●	●	●●
6. Minimum smartness requirements		●●●	●●●	●	●	●●●	●
7. Standards & Interoperability	●●	●●●	●●	●●	●●	●●●	●
8. Data management rules	●	●●	●●●	●●●	●●	●●	●
9. Roles and responsibilities	●	●	●●	●●●	●●●	●●●	●●
10. DSO–TSO cooperation			●	●●	●●●		●
11. Dynamic tariffs and price signals	●●●		●●●	●●●	●●●	●●●	●●
12. New market regulation			●●	●●●	●●	●●●	●●
13. Strategy for flexibility markets			●●●	●●●	●●●	●●●	●●●

Table 2 – Stakeholders and actions (● = relevant; ●● = very relevant; ●●● = extremely relevant)

6. Conclusions

This Position Paper analyses the most relevant characteristics of E-mobility with a particular focus on its impact on the energy system. The intense effort on this sector by European decision makers clearly paves the way towards the massive diffusion of electric cars, commercial vehicles and buses. The number of commercially available models is rapidly increasing, and typical hurdles such as the short range and higher price compared to ICE vehicles are expected to be solved shortly. The development of a suitable charging infrastructure and the adoption of a smart charging process are, at present, the major gap to be covered for most of the actors involved in the complex E-mobility ecosystem.

After a deep analysis and pooling TSO experiences, ENTSO-E considers electromobility a powerful resource, not only to decarbonise the transport sector but also to provide flexibility services to the energy system. An optimal vehicle–grid interaction will guarantee important environmental and economic benefits and improved system management. To make it real, all the involved actors should cooperate to promote the implementation and deployment of smart charging and V2G technology.

Several opportunities exist to profitably exploit EV charging, each with their different aims and beneficiaries, and stacking them is highly desirable to maximise the benefits. EV diffusion can support the larger shares of RES generation by reshaping the power demand curve and reducing system costs and CO_2 emissions. In addition, the presence of EVs will enable better grid management, with regards to both ancillary services and grid congestions.

TSOs, acting as grid operators, system operators and market facilitators, can play a relevant role in supporting optimal vehicle-grid integration. Demonstration activity would be crucial to identify actual technical issues, and studies should be performed to clearly assess the actual cumulative effects of EV smart charging solutions.

The strong cooperation among all the actors involved in energy system management should be pursued to commonly define the optimal market update in view of delivering consumer-oriented services and unlocking flexibility from EVs. While carefully monitoring the evolution of both energy and transport sector, TSOs, together with charging and energy system operators, should involve EV owners in smart charging solutions, whereas the decision makers should stimulate the quick adoption of the required measures.

The E-mobility environment is today extremely dynamic, so ENTSO-E is proposing to take the identified actions according to the key findings of the unbiased analysis described in this Paper. This will contribute to the progressive implementation of a fruitful framework to take advantage of the existing synergies and opportunities. The positive effects will be relevant and shared among different stakeholders, first and foremost European citizens, who are final users of both energy and mobility services and who will benefit from cleaner transport and energy systems.

Appendix I

Examples of TSO Projects on E-mobility

Project name	Involved TSOs	Main activities
EQUIGY	Terna, Tennet, SwissGrid, APG	Creation of a Crowd Balancing Platform as a link between existing ancillary services markets and the aggregators of distributed flexibility.
INCIT-EV Project	ELES (Slovenia)	Simulate cross impacts between Electricity and Transport sector in terms of grids and electric markets
E8 concept	ELES (Slovenia)	Address human behavior, logistics and technical issues related to private vehicle and private location (smart) charging
Professional vehicles charging pilot project	ELES (Slovenia)	Realisation of a charging area for professional vehicles close to the Ljubljana highway.
CECOVEL	REE (Spain)	A tool for monitoring and forecasting the electrical demand associated with the charging system of EV in real time.
Frequency responsive smart charging	REE (Spain)	Analysis of different kinds of regulation (power-frequency-subfrequency) both for EV charging and discharging (V2G).
FCR pilot project	TenneT (NL and Germany)	Providing primary reserve capacity using "new" technologies, cooperating with four parties.
aFFR pilot project	TenneT (NL and Germany)	Control of a fleet of vehicles with start / stop charging signals, in response to TenneT requests.
Bidirectional load management (BDL)	TenneT (NL and Germany)	Test of intelligent V2X charging management to reduce load peaks and for network stabilisation
Study EVs Impact on Polish power system	PSE (Poland)	Forecasts for the development of the Electric Vehicles market and EVs expected impact on the Polish power system balancing
Sustainable mobility hub	Terna (Italy)	Vehicle-to-grid (V2G) pilot project
Towards electric mobility in France	RTE (France)	Study on integrating up to 16 million EV: adequacy under stress events, different chargers and batteries, economics of smart charging and V2G, carbon footprint
mFFR pilot project	Statnett (Norway)	Enabling EVs and other new technologies in the mFRR market by lowering the minimum bid size to 1 MW and using electronic bid ordering.
Fast Frequency reserves	Statnett (Norway)	Test and development of a market for fast frequency reserves. Providers in 2018 included a portfolio of EVs.
Grid support from multiple assets	Statnett (Norway)	Improve estimation methods and estimates of flexibility in assets, particularly commercial buildings and EVs at long term parking. Project owner NMBU, Norwegian University of Life Sciences.
Using EVs to balance the network	Elia (Belgium)	Within this use case, the partners assessed the possibility of combining unidirectional and bidirectional charging points for the delivery of frequency containment reserve (FCR) services in the Belgian power system.
Flexity – Enabling end-consumer to contribute in the energy transition	Elia (Belgium)	Within the IO.Energy use case "Flexity", several companies wanted to investigate the drivers for consumers to participate in flexibility services and their possible interest in letting third parties operate their flexible assets. Over the course of 10 month development & test phase, the focus was on investigating the technical capability and, economic potential for consumers and service providers to operate flexible household assets, such as EVs.

Project name	Involved TSOs	Main activities
Facilitating all-inclusive leasing contracts for EVs	Elia (Belgium)	Fully enabling energy-as-a-service for EV drivers would mean that any commercial third party could become the electricity provider for an EV, regardless of the charging location and the consumers' current electricity contract. With this project, the partners are aiming to demonstrate how new market rules would facilitate the development of all-inclusive mobility contracts, such as leasing contracts that include the provision of electricity to charge the EV.
Charging EVs directly with green power generated by an energy community	Elia (Belgium)	In this project the partners want to develop an energy community featuring buildings equipped with charging points. The charging behavior of the energy community participants will be optimized to allow them to maximize their use of local electricity generation, and to benefit from lower electricity market prices
Blockchain-based digital identities to integrate EVs into the power system	50Hertz (Germany)	A Digital Identity (DiD) is a unique representation of a device – like a passport. It forms the basis for a secure, trusted and efficient interaction between two parties. In the future, an EV driver might have access to multiple services from multiple providers. This creates the need to rethink and reinvent the interaction to develop a scalable, automated, end-to-end solution to enable flexibility from EVs. Partners therefore want to demonstrate that representing devices in the form of DID facilitates the integration of EVs in the power market.
Digital measuring systems to capture the flexibility of EVs	50Hertz (Germany)	To use electric vehicles and other flexible consumers with the goal of stabilising the electrical system, digital measuring systems in connection with so-called Smart Meter Gateways (SMGW) and control equipment will be indispensable technology in the future. This project is investigating and testing what kind of data exchange is necessary for this and how balancing power can be provided by a network of electric cars.
aFRR provisioning from BEV	TransnetBW (Germany)	Piloting of an existing smart charging solution for aFRR in the TransnetBW control area.
Smart charging project / DSM platform 2.0	TransnetBW (Germany)	Demonstration of smart charging and development of a platform to identify and visualize flexibility potential for the grid.
ELLA-futurae	TransnetBW (Germany)	Development and operation of a decentralized data and information router in a European-wide virtual balancing area to enhance imbalance settlement process, market-based services and support grid operations.

TSO Projects on E-mobility – Details

Project number 1	
Name or short description of the activity	Equigy, Crowd Balancing Platform
TSO involved	Terna, TENNET, Swissgrid
Year / years of the activity	› 2020 ongoing
Type of activity (study, pilot project, internal testing, …)	New solution
Main topic of the activity	The realisation of a platform that constitutes the link between existing ancillary services markets and aggregators of distributed flexibility, including EVs. The Blockchain technology facilitates the bidding, activation and settlement processes associated with the flexibility transactions of Virtual Power Plants, guaranteeing quality, security and minimum transaction costs. The Crowd Balancing Platform is intended as a tool to promote the standardisation of processes and protocols to massively enable distributed flexibility resources, promoting pan-European cooperation between different stakeholders of the electricity value chain and leveraging the Blockchain technology.
Relevant outcomes	Equigy platform launched in April 2020. New agreements signed during 2020 and in early 2021 with a variety of players.
Evidence of recommendations or positions by the TSO	Grid balancing is becoming increasingly complex as more renewable energy sources are fed into the system. The volatility of renewables in the electricity system requires TSOs to find innovative and sustainable balancing solutions.

Project number 2	
Name or short description of the activity	INCIT-EV Project (H2020)
TSO involved	ELES (Slovenia)
Year / years of the activity	2020
Type of activity (study, pilot project, internal testing, …)	European Project
Main topic of the activity	Simulate cross impacts between the Electricity and Transport sector in terms of grids and electric markets
Relevant outcomes	› Still work in progress Available: Schemes of Decision Support Systems including both electric and traffic issues
Evidence of recommendations or positions by the TSO	Not evident

Project number 3a	
Name or short description of the activity	E8 concept
TSO involved	ELES (Slovenia)
Year / years of the activity	2019 – 2020
Type of activity (study, pilot project, internal testing,…)	Internal analysis
Main topic of the activity	Address human behavior, logistics and technical issues related to private vehicle and private location (smart) charging
Relevant outcomes	8 points needed to allow the integral development of infrastructure for the mass charging of EVs
Evidence of recommendations or positions by the TSO	› The 8 points suggest some technical / management issues regarding the infrastructure. 2 points are most related to TSOs: › Multi-level integration: Private charging stations are integrated into the control centres of the electricity grid (DSO, TSO). › Market acting: Charging stations are active on the demand side management.

Project number 3b	
Name or short description of the activity	E8 concept
TSO involved	ELES (Slovenia)
Year / years of the activity	2019 – 2020
Type of activity (study, pilot project, internal testing,…)	Pilot Project
Main topic of the activity	Demonstration project for the purpose of: › investigating the aspect of users of e-vehicles and providing employees with the user experience of E-mobility with 14 company e-vehicles; › setting up a network of 21 smart charging stations for long-term charging at ELES's locations across Slovenia; › establishing a central system for the remote power control of charging stations.
Relevant outcomes	› employees travelled more than 30,000 km with e-vehicles; › following the E8 concept, companies can significantly reduce the risk of the rejection of E-mobility among employees; › the need to develop a system of smart charging stations at private parking lots, which will enable users to charge their e-vehicles at low cost with electricity from RES
Evidence of recommendations or positions by the TSO	Long-term, mass transition to sustainable E-mobility cannot be realised without the close cooperation of key stakeholders – from automobile manufacturers, manufacturers of smart charging stations, owners of buildings and parking spots to the operators of the distribution and transmission grid.

Project number 4	
Name or short description of the activity	Partnership for professional vehicle charging
TSO involved	ELES (Slovenia)
Year / years of the activity	2020
Type of activity (study, pilot project, internal testing, …)	Pilot project
Main topic of the activity	Realisation of a charging area for professional vehicles close to Ljubljana highway. Little information available.
Relevant outcomes	No information available yet.
Evidence of recommendations or positions by the TSO	Not evident. Interest in evaluating the impacts of a big charging area directly connected to the High Voltage grid.

Project number 5	
Name or short description of the activity	CECOVEL
TSO involved	RED electrica de Espana
Year / years of the activity	2014 – 2020
Type of activity (study, pilot project, internal testing, …)	New technical solution
Main topic of the activity	A tool for monitoring and forecasting the electrical demand associated with the charging system of EV in real time.
Relevant outcomes	Real mapping tool. More than 600 charging stations connected. Realised thanks to the cooperation of mobility service providers.
Evidence of recommendations or positions by the TSO	Not evident. Important example of cooperation with service providers in order to have evidence of charging sessions.

Project number 6	
Name or short description of the activity	Frequency responsive smart charging infrastructure
TSO involved	RED electrica de Espana
Year / years of the activity	2019 – 2020
Type of activity (study, pilot project, internal testing, …)	Pilot project
Main topic of the activity	Analysis of different kinds of regulation (power-frequency-subfrequency) both for EV charging and discharging (V2G).
Relevant outcomes	No information available yet.
Evidence of recommendations or positions by the TSO	Not evident.

Project number 7	
Name or short description of the activity	FCR pilot project
TSO involved	TENNET
Year / years of the activity	2016 – 2018
Type of activity (study, pilot project, internal testing, …)	Pilot project
Main topic of the activity	Pilot project with five parties for providing primary reserve capacity using "new" technologies. The main objectives of the pilot are: › To investigate the barriers and technical feasibility for entering the FCR market with an aggregated pool of new technologies such as RES and demand response; › To create a level playing field for all technologies and therefore enlarge the number of market participants in the FCR market
Relevant outcomes	Aggregated assets are able to deliver FCR; › The main barriers to participate in the regular market proved to be a real time data communication with a leased line and the measurements requirements for a pool. › These conclusions resulted in the development of a web service for FCR data delivery and changes in the product specifications for the regular market. Supported by the findings, an FCR manual for BSPs has been prepared.
Evidence of recommendations or positions by the TSO	Some aspects can create challenges for the market entrance of new FCR providers or assets, without compromising the system security. Example include: minimum bid size, requirements in aggregation, prequalification.

Project number 8	
Name or short description of the activity	aFFR pilot project
TSO involved	TENNET
Year / years of the activity	2017 – 2020
Type of activity (study, pilot project, internal testing, …)	Pilot project
Main topic of the activity	Wide project with 7 partners to investigate the options for offering local (sustainable) electricity generation capacity on the market for balance maintenance in the Dutch high-voltage grid. For EVs, a fleet of vehicles managed by Vandebron is controlled with start / stop signals, in response to TenneT requests. EV owners receive a fee for their contribution.
Relevant outcomes	Creation of data communication between market parties and TenneT (on activation and measurements) achieved using TenneT's mobile network. Use of a private blockchain to enable each car to participate by recording their availability and their action in response to signals from TenneT.
Evidence of recommendations or positions by the TSO	Not evident. Interest on ICT aspects and data.

Project number 9	
Name or short description of the activity	Bidirectional load management
TSO involved	TENNET
Year / years of the activity	› 2019 ongoing
Type of activity (study, pilot project, internal testing, …)	Pilot project
Main topic of the activity	Funded research project involving Tennet and BMW, with the aim to analyse hurdles and solutions for an improved "V2X" friendly framework, realise a pool control system with marketing interface for V2G functions and monitor a pilot fleet for V2X use cases for researching customer benefit and friendliness.
Relevant outcomes	No details available. The first 50 BMW i3s with bidirectional charging technology should be tested under real-life conditions from the beginning of 2021.
Evidence of recommendations or positions by the TSO	The conviction that the V2X solution can contribute to EVs vehicles in such a manner that the power grid is kept stable and the existing energy from renewable sources is optimally used.

Project number 10	
Name or short description of the activity	EVs Impact on Polish power system
TSO involved	PSE
Year / years of the activity	2018
Type of activity (study, pilot project, internal testing, …)	Study
Main topic of the activity	Realisation of scenarios of directions for the development of electric passenger cars with the accompanying charging infrastructure in Poland. Estimation of the increase in demand for power and electricity in the Polish National Power System (PNPS). Presentation of possible regulatory changes optimising the impact of the development of electromobility on the PNPS.
Relevant outcomes	› Stimulating the growth of the EV market requires the parallel development of the network of charging points. › The development of electromobility will not cause any balance problems in the PNPS by 2030. › The greatest impact on the PNPS will be exerted by EV buses (public transport in cities) that will be loaded quickly during the day (including peak demand). › Until 2030, the local increase in the demand of many EVs in a small area may cause problems in the functioning of distribution networks.
Evidence of recommendations or positions by the TSO	› Testing of various types of smart charging, including the use of V2G technology. › Testing of voluntary DSR programs at strictly defined hours of the day. › Further simulation studies of electromobility development with the use of simulation tools, considering the ENTSO-E network.

Project number 11	
Name or short description of the activity	Sustainable mobility hub
TSO involved	Terna
Year / years of the activity	2020 – ongoing
Type of activity (study, pilot project, internal testing, …)	Pilot project
Main topic of the activity	V2G pilot project, involving Terna, FCA and ENGIE, focused on providing services by fleets of car directly at the production site while waiting to be sold / delivered. Phase 1 of the project consisted of the installation of 32 V2G columns capable of connecting 64 vehicles, aimed at piloting the technology and managing the logistics of the storage area. By the end of 2021, the project will be extended to interconnect up to 700 electric vehicles, making it the largest facility of its kind ever built in the world.
Relevant outcomes	First phase of installation completed. No results yet.
Evidence of recommendations or positions by the TSO	The smart, bidirectional interaction between cars and the grid gives the TSO more flexibility resources and innovative services that, together with the TSO distinctive skill set, ensures increasingly reliable and efficient service operations.

Appendix II

Summary of Reference Documents Used as Input for This Paper

Document number 1	
Type of document	Report
Title	Enquête comportementale auprès des possesseurs de véhicules électriques: habitudes de roulage et de recharge
Author	ENEDIS
Year of publication	2020
Authors affiliation	ENEDIS
Affiliation core business (research, industry, consultancy, standardisation body, …)	DSO
Main topic	Analysis of typical usage of EVs by their owners, performed through a survey on 802 French owners.
Key contents / messages	› EV is the second car and the mean mileage is 43 km / day. › Many users charge at home with mode 2. › Many users have not modified their energy contract. › 70 % of the owners never used a public charging station. › Only a third of the owners use a wallbox with "power management", but many owners declare their availability to use it.
Connection with TSOs' roles and activities	No direct connection. Useful results to clarify the relevance of domestic charging for future schemes of flexibility. The wide use of Mode 2 charging could, regardless, hinder flexibility schemes.

Document number 2	
Type of document	Presentation
Title	Challenges and opportunities of E Mobility for the TSO community. Collaboration alternatives on E-mobility
Authors	Mante Bartuseviciute, Cristina Gomez
Year of publication	2020
Authors affiliation	ENTSO-E
Affiliation core business (research, industry, consultancy, standardisation body, …)	TSO Association
Main topic	Short description of E-mobility status and suggestions on most relevant aspects for TSOs
Key contents / messages	Interesting questions posed by the authors: › Are price signals the best instrument for smart charging? › Should Flexibility services (V2G) be obtained through market participation? Who will participate? › Who will gather information on EVs to manage flexibility services? How will cyber-security be addressed? › Will fast chargers on the highways be connected directly to the HV grid?
Connection with TSOs' roles and activities	The document is directly addressed to TSOs. All the key messages are considered as hints for discussion among TSOs.

Document number 3	
Type of document	Report
Title	Electric Vehicle and Power System Integration: Key insights and policy messages from four CEM workstreams
Authors	Ellina Levina, Matteo Muratori, Enrique Gutierrez et al.
Year of publication	2020
Authors affiliation	Clean Energy Ministerial
Affiliation core business (research, industry, consultancy, standardisation body, …)	International association on energy. Four "workstreams" involved: 21CPP, EVI, ISGAN, PSF
Main topic	Comprehensive key messages for policy makers regarding EV development and their interaction with the grid
Key contents / messages	The document itself highlights 5 key messages: › Vehicle electrification is a critical building block in the ongoing energy transition towards a more sustainable and resilient future. › Maximising the benefits of transport electrification requires the active engagement of stakeholders at many levels. › Mechanisms to integrate EVs and the power system must be designed with regard to EV users and their mobility needs as well as the optimal use of grid assets; [interesting points on smart charging with price signals, services for DSOs and flexibility services through market participation]. › Infrastructure planning is central to supporting vehicle electrification. › Enabling the successful integration of EVs into the power system at both grid-wide and local levels will require a diverse array of technological solutions, closer collaboration among stakeholders, and potentially changes to regulations and market design.
Connection with TSOs' roles and activities	Most of the suggestions related to grid planning and operation are addressed to DSOs. "Power system operators" are mentioned with regards to access to charging data for their day-to-day operations and their future planning.

Document number 4	
Type of document	Report
Title	Integration of electric vehicles into the power system in France
Author	RTE
Year of publication	2019
Authors affiliation	RTE
Affiliation core business (research, industry, consultancy, standardisation body, …)	TSO
Main topic	Opportunities and perspectives for the introduction of millions of EVs in the French electric grid. 2035 perspective and many references to the Multiannual Energy Plan (MEP) by the French government
Key contents / messages	› The French electricity system will be able to integrate a huge number of EVs with just a small smart charging. › Vigilance will be required regarding the management of peak demand periods, but smart charging will shift load to off-peak moments. › There is interesting data on mobility patterns in France. › Long journeys or summer traffic will not be a problem as they happen in off-peak periods. › Six different forms of smart charging are outlined. › It is very important to ensure coordination between energy and mobility roadmaps to optimise the contribution of RES and to leverage EV flexibility (in France, RES and nuclear is predominant, so there is a small amount of flexibility in power generation) › There are five scenarios considered for E-mobility development in 2035, with different levels of smart charging / V2G also considered. › Smart charging could allow savings of around 1 billion €/year. › Final users could save 60 – 170 €/year thanks to smart charging and price signals. › Flexibility services (ancillary services, frequency regulation…) could be completely covered by 500,000 – 900,000 EVs. The rest of the electric fleet would not benefit from this possibility. The annual reward could be approximately 900 €/vehicle. › EV charging could be used to manage the electricity price, avoiding the situation of an overly high or low price due to the RES and nuclear generation. It also helps to reduce subsidies to RES.
Connection with TSOs' roles and activities	TSOs are mentioned with regards to the participation of EVs (just a portion of them) in the flexibility market for ancillary services. It is also generally stated that E-mobility development could require some reinforcement on distribution and transmission systems, but the issue is addressed in another study.

Document number 5	
Type of document	Presentation
Title	EV integration in the power system: Challenges and solutions
Author	Xavier MOREAU
Year of publication	2020
Authors affiliation	Clean Energy Ministerial (Nuvve)
Affiliation core business (research, industry, consultancy, standardisation body, …)	International association on energy. Four "workstreams" involved: 21CPP, EVI, ISGAN, PSF
Main topic	Presents 12 challenges about vehicle-grid integration and proposes the solutions.
Key contents / messages	The presentation highlights the importance of: › Architecture of the system, communication and standards › Different possible markets for V2G / V1G solutions › Multiple taxation and metering
Connection with TSOs' roles and activities	TSOs are considered as a relevant part of defining the grid requirements in V2G / flexibility options for EV.

Document number 6	
Type of document	Report
Title	Electromobility in smart grids: State of the art and challenging issues
Author	Marc Petit (Professor in France)
Year of publication	2019 – 2020
Authors affiliation	Global Smart Grid Federation GSGF (Indian chairman)
Affiliation core business (research, industry, consultancy, standardisation body, …)	International association
Main topic	Interaction between EVs and the power grid, also analysed from a technical perspective.
Key contents / messages	Many interesting considerations: › Detailed technical issues of EV deployment for DSOs › Citation of RTE study as an example of TSO activities on E-mobility; › Interesting description and considerations regarding flexibility markets and options › Interesting analysis of regulatory activity around the world concerning EV integration › Set of pilot project examples about V2G
Connection with TSOs' roles and activities	TSOs are mentioned as being interested in managing the grid balance. The RTE report (see document 4) is recalled here as a good example of E-mobility analysis from a TSO perspective.

Document number 7	
Type of document	Report
Title	INNOVATION OUTLOOK: SMART CHARGING FOR ELECTRIC VEHICLES
Authors	Multiple authors for IRENA
Year of publication	2019
Authors affiliation	IRENA
Affiliation core	International association
Main topic	Complete outlook on smart charging for EVs
Key contents / messages	› Smart charging for EVS holds the key to unleashing synergies between clean transport and low-carbon electricity. Batteries in cars, in fact, could be instrumental to integrating high shares of renewables into the power system. › EVs present a viable opportunity to introduce a much higher shares of renewables into the overall power generation mix. › Uncontrolled charging could increase peak stress on the grid, necessitating upgrades at the distribution level. › A modelling exercise was conducted to study the benefits of smart charging at the system level, for both system operation in the short term and system expansion in the long term › EVs will have to "stack" the revenue by serving multiple applications, providing services to both system level and locally. In many places, competitive balancing / ancillary services markets are absent, and local grid operators are not allowed to manage congestion in their grids in ways other than by reinforcing the grid. › Aggregated EVs will need to have access to these markets and to several markets in parallel. › A 6 MW capacity would be a good order of magnitude for a highway station with 30 charging points, in the medium term. › 6 MW is also the power that would be needed by an electric car to charge energy at the same speed as a conventional ICE car (e. g. typically 100 km charged in 15 seconds). This is neither economically viable nor realistic with the current and medium-term battery technologies. › In Hamburg, a 9 % EV share, corresponding to 60 000 EVs loading in private infrastructure, will cause bottlenecks in 15 % of the feeders in the city's distribution network. › Simple time-varying electricity price structures might create pronounced rebound peaks in the aggregate residential demand. › Several business models on the EV-grid nexus are being developed but are not yet fully commercialised or widespread. › The original "niche" energy services provider and aggregator model will develop into an energy services platform provider, combining multiple VGI revenue streams and other energy products and services. › In some countries, wholesale electricity markets exist, but competitive balancing / ancillary services markets and retail markets are often missing – that is, they are still regulated services executed centrally by a TSO.
Connection with TSOs' roles and activities	TSOs are often mentioned as relevant actors in "system flexibility" management. The interaction with DSOs in managing smart charging is mentioned too. Finally, TSO are indicated as an active part in several pilot projects on V2G (e. g. TenneT)

Document number 8	
Type of document	Vision paper
Title	Accelerating to net-zero: redefining energy and mobility
Authors	ELIA Group associates
Year of publication	2020
Authors affiliation	ELIA Group
Affiliation core	TSO
Main topic	EVs role in climate neutrality from TSO perspective
Key contents / messages	› E-mobility provides the fastest and cheapest lever for abating climate change in the coming decade. And if we do so intelligently and jointly across mobility and power sectors, then electric vehicles (EVs) can support the integration of more renewable energy in the power system which is an essential element on the road to decarbonisation. › By 2030, EVs will no longer solely be a means of transport; they will be integrated with other assets and services enhancing the lives of consumers. Now is the time to jointly test, learn, adjust and scale so that the system and new EV services are available once EV growth goes exponential. › More than 80 % of charging will happen at home or work. We need to put maximum effort on providing smart charging infrastructure in these market segments via economic incentives. This needs to be supplemented with a number of fast charging facilities along major transport routes in order to overcome range anxiety and allay any hesitation about switching to EVs. › To enable new EV services, efficient data exchange and communication between all players involved and consumers is required. The development of digital identities for consumers (citizens) by a trusted government agency is the necessary basis so data can be easily shared by consumers with respect to their privacy, and in an open way for everyone who provides services designed to enhance the EV driver experience. › Charging needs to be smart so consumers can fully exploit the opportunities their EVs provide for the power system, while at the same time enjoying a smooth charging experience. Therefore, system operators will send signals (mainly price signals, but others too) that incentivise smart charging behaviour, maximising the consumer experience (comfort, convenience, cost, etc.), while also taking into account the needs of the power system (renewable availability, grid constraints, etc.).
Connection with TSOs role and activities	The paper advocates in favour of smart charging in order to enable services to the power system, analysing EV trends and future options from TSO perspective, in addition it mentions TSO as active player in several pilot projects on V2G (ELIA, 50Herz)

Document number 9	
Type of document	Report
Title	GC ESC Storage Expert Group: PHASE II FINAL REPORT
Authors	Members of GC ESC Storage Expert Group
Year of publication	2020
Authors affiliation	GC ESC members
Affiliation core	European association
Main topic	Report on storage plant relation with the Connection Network Code
Key contents / messages	The Expert Group recognised the following policy recommendations included in the ACER technical position paper to promote greater electromobility, ensure compliance with the EU Grid Connection Network Codes and minimise market barriers and distortions in the EU: › Setting the applicable requirements at the connection point of the electrical charging park. › Ensuring the demonstration of full compliance of the electromobility entities with the relevant GC NCs. › The Connection Network Codes do not need to recognise the on-board technologies of EV's from the scope of application of GC NCs, and should only focus on the connection point. › The application of requirements should be based on the technical capabilities and means of interaction with the system and no differences should exist whether an electrical charging park is located at residential level or in a business facility. › Setting the criteria to define electrical charging parks as 'existing' or 'new' and applying a transitional period for the application / development of appropriate certificates and certification processes. For the time being it is recognised that as Storage is "new" this issue is relevant only as the connection network codes develop in future. › Defining the list of the electrical charging parks under the scope of application of the DCC. So far as Electric Vehicles are concerned, a charging park (in particular V1G) would be treated as demand under DCC. › Removing barriers and limitations for the classification of small electrical charging parks concerning the RfG.
Connection with TSOs role and activities	The report assesses V2G services in relation with the Connection Network Code

Appendix III

Glossary

AC	Alternating Current
BEV	Battery Electric Vehicle
BMS	Battery Management System
BSP	Balancing Service Provider
CCS	Combined Charging System
CO_2	Carbon-dioxide
CPO	Charging Point Operator
DC	direct current
DER	Distributed Energy Resource
DSO	Distribution System Operator
EAFO	European Alternative Fuels Observatory
EMSP	E-mobility Service Provider
ENTSO-E	European Network of Transmission System Operators for Electricity
EV	Electric Vehicle
EU	European Union
FCEV	Fuel Cell Electric Vehicle
HDV	Heavy Duty Vehicle
HEV	Hybrid Electric Vehicle
HV	High Voltage
Hz	Hertz
ICE	internal combustion engine
ICT	Information and Communication Technology
IEA	International Energy Agency
IoT	Internet of Things
IRENA	International Renewable Energy Agency
Km	kilometre
kW	kilowatt
kWh	kilowatt-hour
LCV	Light Commercial Vehicle
LDV	Light Duty Vehicle
LV	Low Voltage
MV	Medium Voltage
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicle
PLDV	Passenger Light Duty Vehicle
RES	Renewable Energy Source
SDS	Sustainable Development Scenario
STEPS	Stated Policies Scenario
TEN-T	Trans-European Network for Transport
ToU	Time of Use
TSO	Transmission System Operator
TWh	terawatt-hour
V2G	Vehicle-to-grid
2/3 W	2 or 3 Wheelers
US	United States

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The core team to develop the Position Paper:

Antonio Iliceto . . . Terna

Norela Constantinescu . . . ENTSO-E

Audrius Baranauskas . . . Litgrid

Rafal Czapaj . . . PSE

Kari Dalen . . . Statnett

Manuel Galvez . . . ELIA

Mathilde Françon . . . RTE

Jussi Matilainen . . . Fingrid

Francisco Reis . . . REN

Fabian Zimmermann . . . TenneT

Filippo Colzi . . . RSE

Luciano Martini . . . RSE

Lóránt Dékány . . . ENTSO-E

European Network of
Transmission System Operators
for Electricity

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