European
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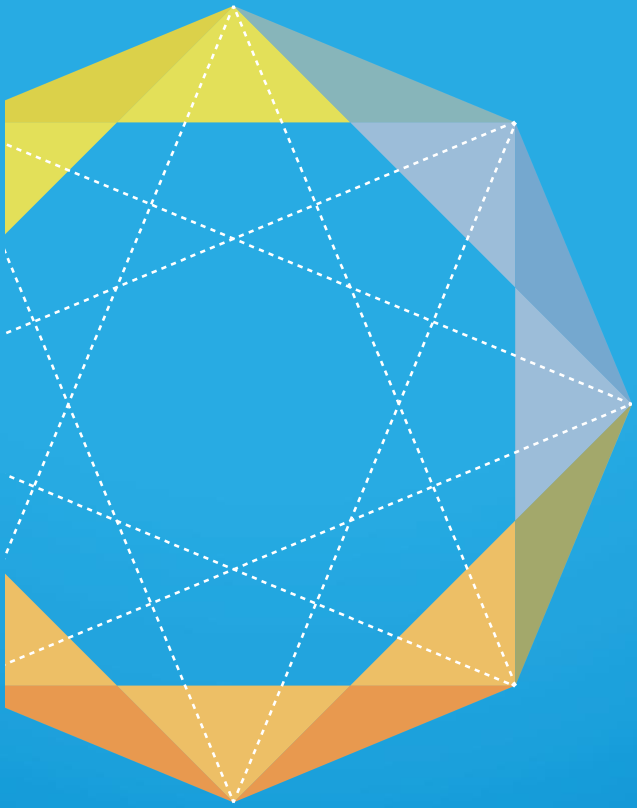
E-mobility deployment and impact on grids

Impact of EV and charging infrastructure on European T&D grids – Innovation needs



ETIP SNET

European Technology and Innovation Platform
Smart Networks for Energy Transition

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EXECUTIVE SUMMARY

The number of electric cars, vans, trucks and buses on the world's roads is rapidly increasing, with a larger variety of electric vehicle (EV) models commercially available. Nevertheless, typical users still have concerns when comparing them to internal combustion engine (ICE) vehicles, such as short-range autonomy and higher prices, which are expected to be solved shortly. The development of a suitable charging infrastructure answering the needs of different stakeholders in the electromobility value chain and the adoption of efficient charging processes, especially smart charging, currently represent the major gap to be covered by most of the actors involved in this complex ecosystem.

The EV charging process represents the tangible interface between transport and energy sectors and the crucial element for guaranteeing their successful development in the future energy systems providing a new flexibility resource for system operators (SOs). According to previously analysed charging use-cases, leaving the charging process uncontrolled might result in significant challenges for the power system, such as peak power demand due to cumulative effects in specific periods. In contrast, managing the charging process in terms of time scheduling and power profile (e.g. with efficient time-economic incentives) 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, SOs will enable improved system management, both in terms of ancillary services and grid congestions, using the flexibility that the charging process of EVs can provide. EV users will also benefit from lower charging energy costs, more reliable services and by contributing to a more sustainable transport.

The relevant aspects underpinning these required actions present a clear regulatory framework that supports a full deployment of EV charging, including the necessary reinforcements in networks, minimum technical requirements and standardisation, dynamic pricing definition and a novel market structure and rules. Additionally, a holistic view and architecture will be required to improve and enhance cooperation among the many different stakeholders from traditionally separated sectors: vehicles, batteries, electronic and automation industries, information and communications technology (ICT), data platforms 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, grid operators, acting in an unbiased and non-discriminatory manner both as operators of the entire power system's grid, are called to play a key role in supporting the optimal integration between the transport and the energy sectors. Despite the current level of technology readiness for EV adoption, demonstration activities and pilot projects will be crucial in testing proposed solutions and identifying open technical and regulatory issues. At the same time, 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.
To avoid the risk of missing the multiple opportunities identified and described in this paper through the implementation of the different solutions, such as smart-charging and vehicle-to-grid (V2G) solutions, ETIP SNET recommends taking into account the following ideas:

- Promote coordinated planning for charging. All the relevant actors should be included in the planning and development process for the deployment of EV charging infrastructure, especially system operators preparing the networks ahead of need.
- Enable a new ecosystem focused on consumer needs by further enhancing the participation of all agents and facilitating competition and maximising benefits by unlocking the potential of EV charging. Also improving cooperation through the defined roles and developing of the proper modelling tools.
- Manage the charging process by promoting an additional and valuable flexibility resource necessary for the secure and efficient grid operation, facilitating a smart charging approach, thus smoothing peaks in the load curve.
- Promote a new market structure, rules and regulatory framework for power grids and for the whole energy ecosystem to implement grid tariffs and power price schemes, launching ambitious deployments for EV charging.
- Deploy electromobility enablers with smart metering, efficient 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 users.
- The alignment of the charging protocols and standards implemented for the charging infrastructure and the battery management system must make possible the participation of the different agents in the electricity markets. Power grids have specific requirements in terms of monitoring, data exchange and time response, and for this reason, standard charging processes have still to be correctly fulfilled.
- Promote a holistic view and architecture for an effective integration of EV charging infrastructure into the power grid, enabling flexible operation and coordinated planning of charging stations.

Today, the electromobility 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 will benefit from cleaner transport and energy systems, who are the final users of both energy and mobility services.
Through this Position paper, ETIP SNET intends to contribute to the debate on technical and connectivity solutions, as well as on EV charging solutions and regulations to be adopted through the constructive cooperation between the power system, transport sector, urban planning, vehicle industry, related stakeholders and decision makers.
The time for action is now, anticipating a massive EV deployment and avoiding the need of the future retrofitting of non-efficient models.

BASIC DEFINITIONS AND SHORT GLOSSARY

Balance Service Providers (BSPs): A market participant providing either or both balancing energy and balancing capacity to transmission system operators.

Battery Electric Vehicle (BEV): A vehicle powered solely by an electric motor and a plug-in battery.

Charging Point Operator (CPO): Infrastructure operator who provides a set of goods and services, such as remote reservation, provision of information on whether terminals are occupied, their location, the type of socket, parking and, lastly, the recharging service per se.

Charging solution: It 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): It refers to small, geographically dispersed generation resources, installed and operated on the distribution system at voltage levels below the typical bulk power system.

Distribution System Operator (DSO): A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.

Dynamic charging: EV charging taking place when the EV is moving; in contrast to static charging, which occurs when the EV is parked.

Electric Vehicles (EVs): For this paper, road vehicles with an electric engine and battery which need to charge electricity from a power grid (BEVs and PHEVs).

Heavy-duty vehicles (HDVs): Trucks, buses, and coaches.

Information and Communications Technologies (ICT): Diverse set of technological tools and resources used to transmit, store, create, share or exchange information.

Internal Combustion Engine (ICE): An engine that creates its energy by burning fuel inside itself.

Light Commercial Vehicles (LCV): Passenger cars and vans.

Mobility as a Service (MaaS): It integrates various forms of transport services into a single mobility service accessible on demand.

National Access Points (NAPs): A digital interface installed by a EU Member State to make traffic and mobility data accessible for a wide range of data users.

Original Equipment Manufacturer (OEM): A company whose goods are used as components in the products of another company, which then sells the finished item to users.

Open Charge Point Protocol (OCPP): An open-source communication standard for EV charging stations.

Passenger Car (PC): A passenger car is a road motor vehicle, other than a moped or a motorcycle, intended for the carriage of passengers and designed to seat no more than nine persons (including the driver)

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.

Renewable Energy Source (RES): Energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave among other natural sources.

Smart Charging: Any charging which is not plug-n-play, i. e. supervised by an external control system.

System Operator: Either a Distribution System Operator or a Transmission System Operator.

Transmission System Operator (TSO): A natural or legal person who is responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity.

Vehicle to Grid (V2G): Smart charging with bidirectional energy flow capability.

1. SCOPE AND TARGET

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 the European Union (EU). Electric mobility represents a crucial opportunity for achieving the environmental goals with a more sustainable transport, and optimal charging management of EVs will generate relevant benefits for all the actors of the energy sector too, fundamentally users of electric vehicles.

Considering the European targets on CO_2 reduction, and the increasingly renewable energy source share in the generation mix, it is inevitable that electric vehicles will become the mainstream of the car industry. The "Fitfor55 package" released by the EU on July 2021 states that the average emissions of new cars must be reduced by 55% from 2030 and 100% from 2035 compared to 2021 levels and therefore all new cars on the European market must be zero-emission vehicles from 2035. "Fitfor55" also modifies the Renewable Energy Directive (RED) and introduces renewable hydrogen quotas for transport by 2030. This is a promising scenario but while zero emission technologies are reaching mass market in the passenger cars sector, a transition of heavy-duty vehicles (HDVs), both trucks and buses, to zero emission is highly challenging.

Batteries and green hydrogen are the two main technologies to decarbonize transport. Battery-powered and fuel-cell vehicles are both electric, sharing the same motors and many other components, although from the grid perspective, the latter do not have a direct impact on the grid since they use green hydrogen molecules from renewable energy resources. Tens of millions of EVs progressively deployed will also impact the energy sector in terms of demand profile and grid adequacy.

Electric charging is the physical interface between these two evolving sectors, emphasising the dual nature of EVs: a means of transportation when on the move but a grid-connected battery when parked (and plugged). Related challenges and opportunities are therefore closely intertwined:

- on the one hand, the proper deployment of charging infrastructures and the optimal management of the charging processes to guarantee the required range and optimal charging costs.
- on the other hand, an opportunity to take advantages of the use the EV charging framework as a flexible resource that can provide added value to grid operators and must be incorporated into grid management and planning.

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 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 academia are spearheading the uptake of electric mobility. To mention just an example, in its "Innovation outlook 2019"[1], 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.

Future trends in mobility, namely inter-modality, mobility-as-a-service (MaaS) 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 or fleet manager and not only of that of individual owners. Similarly, the adoption of other emerging CO2-free transport technologies where direct electrification is not possible such as fuel cells, hydrogen propulsion and green liquid fuels will complete the decarbonisation of transport, while simultaneously presenting different challenges and opportunities to the power system.

1.1 In and out of scope

Electrification is increasingly becoming an essential driver in many transport areas. This paper addresses the grid impact that electric vehicles can have in electricity networks through their charging process and, therefore it is mainly focused on those aspects which are foreseen as being more impactful:

- Sector: Road transport.
- Vehicles: Light Commercial and Heavy-Duty vehicles.
- Technology: Battery-propelled vehicles.
- Charging infrastructure: Conductive, stationary charging systems.

Consequently, and however been part of the electrification of transport, some topics are considered out of scope in this paper for the following reasons:

- Railways: electric traction is already in operation in most of European lines and no disruptive situations are expected for grid impact. They do not use batteries.
- 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.
- 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.

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[1] https://www.irena.org/publications/2019/May/Innovation-Outlook-Smart-Charging

Some niches of transport are also difficult to be directly electrified in the short term and are out of scope of this paper as well:

- Maritime transport 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 in a long-term scenario.
- Fuel cells and green fuels propelled vehicles: they do not perform electric charging so their impact on the energy system is indirect, through the sector integration.

1.2 Previous ETIP SNET papers

In the previously released ETIP SNET Position Paper on Smart Sector Integration, "Towards an EU System of Systems: Building blocks, enablers, architectures, regulatory barriers, economic assessment"[2], published in July 2021, was concluded that electrification of transport within an increasingly clean electricity mix is the most effective, efficient and sustainable way to decarbonise this sector. It reduces its dependence on fossil fuels imports from outside Europe and eliminate air pollution. This requires the deployment of a solid and dense charging infrastructure for electric vehicles in a timely manner to support the development of electromobility. While the number of electric vehicles on European roads keep increasing, it is necessary to ensure the effective integration of electric vehicles in the power system in order to align the network and maintain the required levels of quality and security of supply. Some of these ideas are taken as an input for the present paper.

1.3 Users at the centre

A constant underlying principle in the complex and multifaceted electromobility 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. In other words, it is the person/body who decides how, where, and when to charge EVs.

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 (Figure 1); such customer behaviour must be analysed, understood, and satisfied.

EV users will set the conditions for having their vehicles charged (new tariff schemes, rewards and penalties, extra services). Their direct involvement is the basis for making the charging process a success. The behaviour of the EV users drives the subsequent impact on the electricity grids and thus how system operators must manage them.

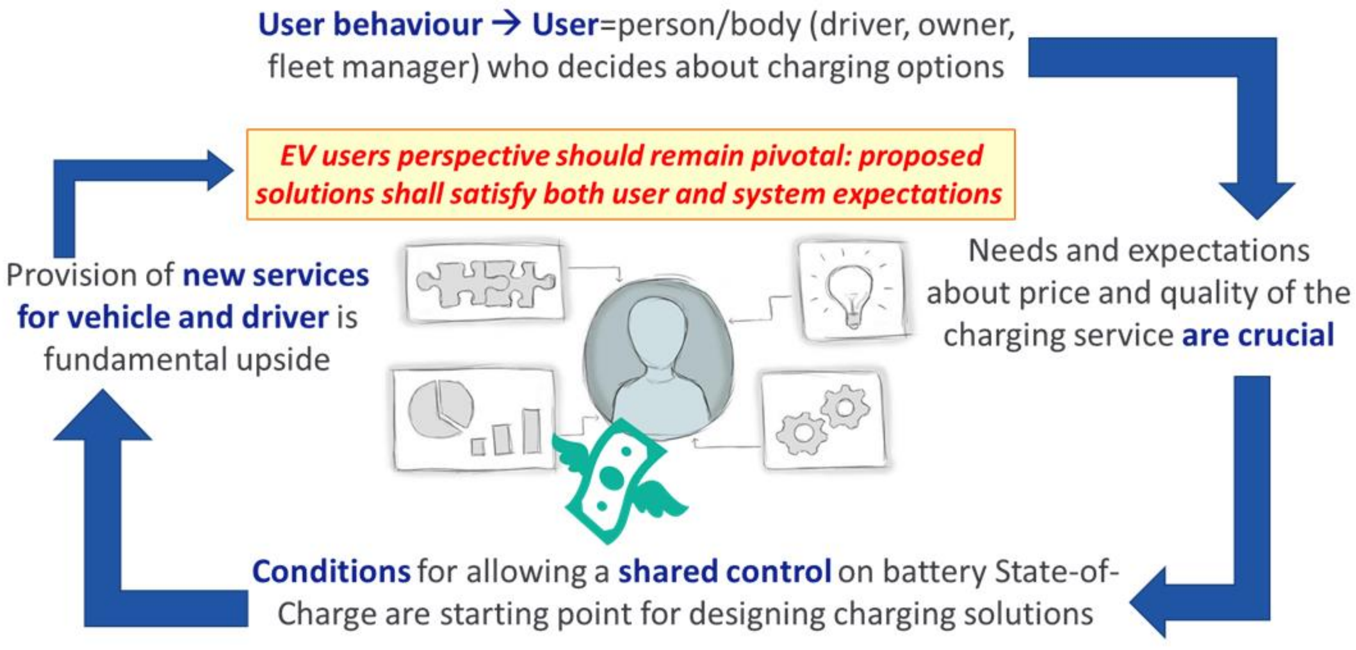

Figure 1 User, both as EV driver and as electricity consumer, at the centre.

1.4 Targets of the paper

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[2] https://www.etip-snet.eu/wp-content/uploads/2021/03/ETIP-SNET-PP-Sector-Coupling-towards-an-EU-System-of-Systems_FINAL_V3.pdf

Electromobility will represent a crucial building block in the future energy system. It might generate important effects as a new load (additional volumes and specific load profile), as an energy storage system and, consequently, as a new flexibility resource for both market actors and system operators. The capability of EVs to provide valuable system flexibility services, including fast frequency control, ramping ancillary services, balancing services, as well as in the future flexibility services for TSO-DSO congestion management, could directly help to improve the management of transmission and distribution grids. Considering the probable acceleration of EV penetration, and the parallel deployment of charging systems, ETIP SNET 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 their early stages; therefore, it is crucial to deploy them at the start of the EVs adoption to avoid the need for future retrofitting.

2. E-MOBILITY AND POWER GRIDS: CHALLENGES AND OPPORTUNITIES

2.1 A wide ecosystem, many unrelated decision makers

The use of electricity in mobility is particularly relevant for electric vehicles and the related vehicle to grid possibilities. Nevertheless, differences regarding the acceptance and deployment of electric mobility varies across geographies. These evolving developments show great potential for future deployments and scaling up.

Another relevant aspect to be considered is that the EU Strategy for Energy System Integration[3] proposed by the European Commission explicitly encourages demand side flexibility, mentioning especially electromobility and V2G. Furthermore, development of vehicle-to-grid should be accelerated to be able to use electric vehicle storage as a flexibility tool to improve the network operation. Consideration should be given also to the second life of the EV batteries and how to ensure that they are still used for stationary applications once they are no longer suited for mobile applications. It should also be ensured that batteries are designed in a manner that eases their repurposing and remanufacturing.

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 (including electricity aggregators active in this field) 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 have also to be carefully considered.

EV users	· Private users · Company fleets mobility managers · Logistic fleets mobility managers · Taxi fleets · Sharing fleets companies · Public administration fleets mobility manager · Local public transport managers · Trucks drivers and owners
Manufacturers	· EV manufacturers · Battery and battery management system (BMS) manufacturers · Charging stations manufacturers
Charging operators	· Charging Point Operators (CPOs) (this role will be often played by aggregators and/or suppliers, taking into account the existing electricity regulation) · Electromobility Service Providers (EMSPs) · Value-added services providers
Actors in the energy system	· Energy providers (utilities, traders) · DSOs · TSOs · Balance service providers and aggregators · Energy and flexibility markets operators
Decision makers	· EU decision makers · National/local decision makers · Regulatory authorities · Standardization bodies · Urban planning authorities · Transport authorities
Research bodies and associations	· Universities, institutes, technology associations,…

Different kinds of interactions. Actors involved in electromobility are interrelated in different ways. From a physical perspective, the electric connection is the fundamental one, linking the vehicle to power generation through DSOs and TSOs. Proper management of the charging process requires real-time data exchange with TSO-DSO for congestion management and involving actors such as energy providers, Charging Point Operators and Balance Service Providers, and in the future, Flexibility Services Providers (Figure 2). Economic fluxes represent the third kind of interaction, related both to energy and flexibility transactions (Figure 3). The respective markets are pivotal for these exchanges, carried out by energy traders and market operators.

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[3] https://energy.ec.europa.eu/select-language?destination=/node/1

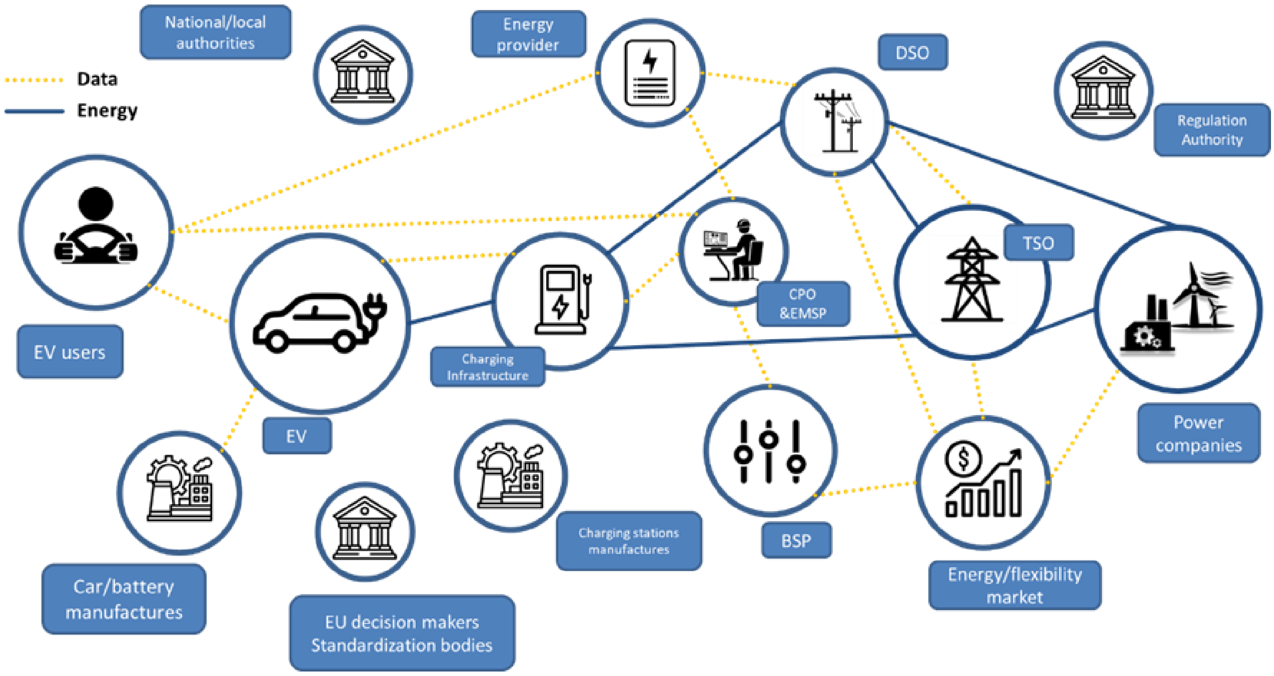

Figure 2 Data and energy interactions among electromobility ecosystem actors.

Where are the electricity system operators? In In terms of the user and the EV, electricity industry actors are not currently perceived as key players. In addition, EV users today mainly deal with the DSO (for connecting to the grid) rather than the TSO. However, as the number of EVs increases, the transmission grid and power system as a whole could also be affected. The TSO involvement in e-mobility is required during long-term grid planning phases to properly host new charging infrastructure, without delay. Both the TSO and the DSO should enable the flexibility opportunities provided by EV smart charging in balancing services, congestion management services or voltage control.

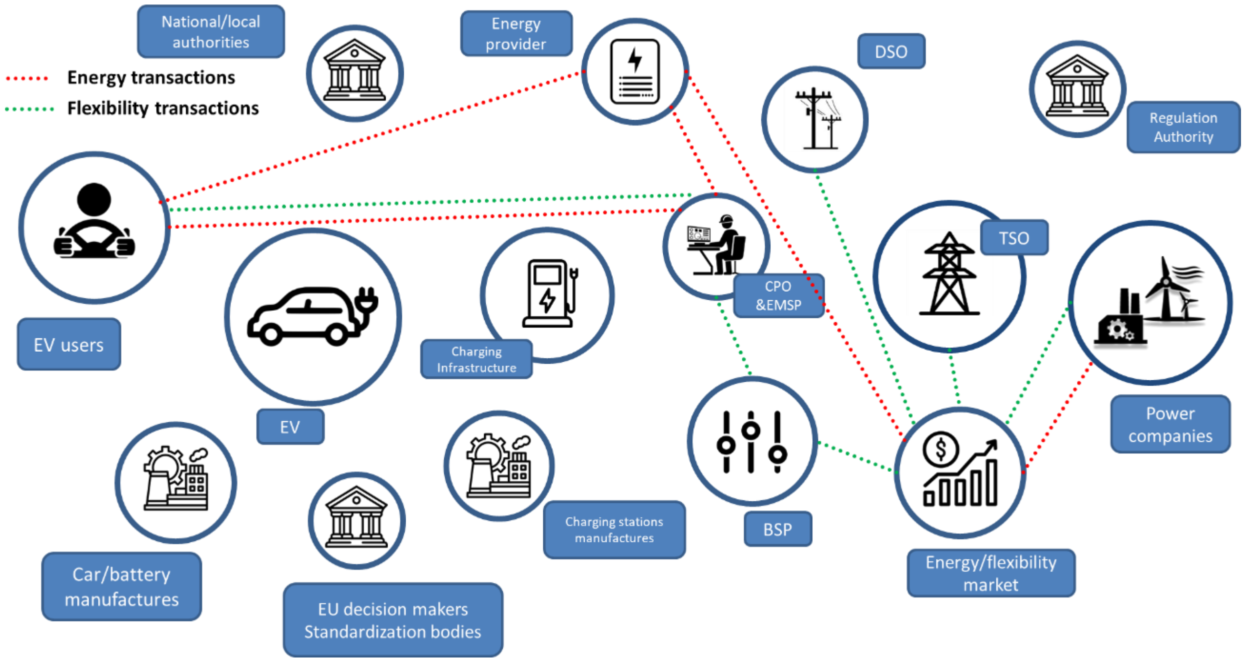

Figure 3 Economic transactions for energy and flexibility services among electromobility ecosystem actors

Electrification of transport requires electricity operators to adapt and support the broader integration of energy systems, defined as “One-System of Integrated Systems: System of Systems” and focused on improved cross-sectoral integration. Smart charging and V2G solutions will increase the liquidity of new markets and require new ways of modelling future generation and load profiles. Coordination between DSOs, TSOs, aggregators, market participants and customers must go the beyond pure integration of markets and operations and expand to proactive planning. Enhanced DSO–TSO 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 the future in energy and ancillary services markets for SOs.

2.2 European regulatory framework on e-mobility

The EU is strongly committed to fighting climate change at the global level, through interventions implemented within its own territory and international cooperation (e.g., EU Green Deal and Fitfor55 Package). With regards to transport, European rules have been a 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 lever to stimulate electromobility. At the same time, regulatory incentives are necessary to ensure that effective charging infrastructures is implemented, both for private and public charging.

MAIN REGULATORY FRAMEWORK RELATED TO ELECTROMOBILITY

- **Directive on Alternative Fuels Infrastructure:**
    - **In force** (2014/94/EU): It 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**: It aims to increase the build-up of publicly accessible charging infrastructure, through possible binding and enforceable targets among others; 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 CO2 standards for cars and vans. A public consultation was 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:** It 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:** It was 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 ELECTROMOBILITY

- **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 a relevant percentage of gross inland energy consumption, including transport. There is a review in progress.

- **Energy efficiency Directive (EU) 2018/2002**: It 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. There is a review in progress.

- **Energy performance in buildings Directive**
    - **In force** (2018/844/EU): It outlines specific measures for the building sector, including preparatory work and the installation of charging points inside residential and non-residential buildings.
    - **Revision**: 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).

Regarding the first, and probably the most relevant of the above, the revision of the AFI Directive was released on July 14, 2021, as part of the package of proposals to make the EU's climate, energy, land use, transport and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels (Fit for 55). The specific objectives are:

(i) ensuring minimum infrastructure to support the required uptake of alternative fuel vehicles (electricity is considered alternative fuel) across all transport modes and in all Member States to meet the EU's climate objectives.
(ii) ensuring the infrastructure's full interoperability.
(iii) ensuring full user information and adequate payment options.

The targeted infrastructure includes electricity installations, as well as Liquefied Natural Gas (LNG) and hydrogen infrastructure. The objective is to enhance the connectivity of this infrastructure to facilitate the uptake of electric vehicles (light- and heavy-duty) and new models of maritime and aviation transport based on alternative fuels. The emphasis, especially for electricity, is on enhancement of grid connectivity rather than grid capacity. Member States are obliged to fulfil the target for refuelling and recharging points by deploying enough of these. Unfortunately, no mention is made of supplementing this with enhancement of grid capacity despite the impact assessment recognizing that "Distribution system operators will have to invest into grid stability and flexibility and – where necessary -into grid extensions, in particularly in view of HDV recharging needs"[4].

The chosen policy approach is to introduce mandatory fleet-based targets for electric recharging points for light duty vehicles (LDVs) and distance-based targets for all road vehicles infrastructure for the TEN-T network, including for urban nodes for heavy-duty vehicle infrastructure. More detailed provisions for ports and airports on the TEN-T network will be developed as well as greater harmonisation on payment options, physical and communication standards and consumers' rights while charging. Additionally, the Directive will strengthen provisions on price transparency and other user information, including physical signposting of recharging and refuelling infrastructure.

Some of the most important points of this proposal are:

- Smart recharging points should comprise a set of physical attributes and technical specifications (hardware and software).

- Smart metering systems as defined in Directive (EU) 2019/944 enable near to real-time data to be produced, which is needed to ensure the stability of the grid and to encourage rational use of recharging services. The use of smart metering systems in combination with smart recharging points can optimise recharging, with benefits for the end user. Smart recharging in particular can facilitate the integration of electric vehicles into the electricity system further as it enables demand response through aggregation and through price-based demand response (e.g. dynamic and/or specific tariffs). System integration can further be facilitated through bi-directional recharging (vehicle-to-grid).

- The development of infrastructure for electric vehicles, the interaction of that infrastructure with the electricity system, and the rights and responsibilities assigned to the different actors in the electric mobility market, have to be consistent with the principles established under Directive (EU) 2019/944. In that sense, distribution system operators, as neutral facilitators, should cooperate on a non-discriminatory basis with any person establishing or operating publicly accessible recharging points. In turn, Member States should ensure that the electricity supply for a recharging point can be the subject of a contract with a supplier other than the entity supplying electricity to the household or premises where this recharging point is located.

- The establishment and operation of recharging points for electric vehicles should be developed as a competitive market with open access to all parties interested in rolling out or operating recharging infrastructures.

The "Fitfor55 package"[5] released by the EU on July 2021 states that the average emissions of new cars must be reduced by 55% from 2030 and 100% from 2035 compared to 2021 levels and therefore all new cars on the European market must be zero-emission vehicles from 2035. This an important step with enormous consequences in terms of electromobility policies.

2.3 Electric vehicles. State of the Art

As a basic classification, electric vehicles can be considered to be part of one of the two following groups:

Battery Electric Vehicles:

More than 20 models currently proposed by big original equipment manufacturers, and a few more in the **premium** sector

Battery capacity:
  - **16 – 50 kWh**, standard segment
  - **50 – 100 kWh**, premium segment

Range:
  - **100 – 400 km**, standard segment
  - **500 – 700 km**, premium segment

Purchase price (including taxes):
  - **30,000 – 40,000 €,** standard segment
  - **70,000 – 100,000 €,** premium segment

Plug-in Hybrid Electric Vehicles
Around 50 models proposed by big OEMs

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[4] https://ec.europa.eu/info/sites/default/files/revision_of_the_directive_on_deployment_of_the_alternative_fuels_infrastructure_with_annex_0.pdf

[5] https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3541

Battery capacity:

- **7 – 15 kWh**

The main differences between EVs and ICE vehicles are shown in Figure 4.

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.

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 40–50kWh 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. Electric buses are typically sold on the request of public authorities 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 250–350kWh batteries, depending on if they favoured opportunity charging or charging at the end of their assigned route, and cost approximately 400,000€.

FOCUS BOX # 1

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 (fewer moving parts, less ancillary devices, less maintenance, less noise, etc.). In addition to it, EVs have the possibility of using the brakes to recover energy.

The EV purchase cost, although rapidly decreasing is still high, excluding from the EV market the small/lower medium car segment costumers. However, **operational costs are considerably lower** compared with ICE vehicles.

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 CO2-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. However, some studies show that the total energy demand for transport is lower when electric vehicles are used if the entire value chain is considered.

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.

Figure 4 Main differences between EVs and ICE vehicles (Source: ENTSO-E).

It is important to introduce the concept of smart charging, usually referred as V1G, which relates to the ability to dynamically modify the charge rate or the charging time. This can help minimize the cost of charging a vehicle, especially in the case of time of use (ToU) and real-time tariffs. Vehicle-to-grid (V2G) refers to the bidirectional flow of energy between the battery of an electric vehicle and the charging station. Energy can be transferred to buildings as well as to the electricity grid. In this way, energy costs can be managed. To put it simple, the electricity produced during the daytime electricity demand peaks is stored in vehicles and returned to the system to be used by other consumers at the same hours. With this method, it is possible for vehicles that are connected 21-22 hours out of 24 hours to contribute to electricity production. Of course, it is important to consider the battery charging efficiency, which is calculated by dividing the energy added to the battery by the energy used in the charging session. The efficiency is less than 100% because some energy is wasted in the process.
A simple classification can be seen in Table 1.

Table 1 Smart Charging Matrix

Features	V1G	V2G
One way charging	✓	✓
Set time of charge	✓	✓
Set charge rate	✓	✓
Acces Energy Markets	✓	✓
Store+ Discharge Energy		✓
Combine Energy from multiple EVs		✓
Perform Grid Services and sell energy back to grid		✓

Regarding the different technologies, a classification can also be made:

Hybrid Electric Vehicle (HEV).

- Small electric motor and battery supplement the ICE engine. No electric charging.
- The electric motor intervenes when the 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).

- 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 H2O).
- Zero end-to-end emissions if hydrogen is produced CO2 free (green hydrogen).

Figure 5 attempts to schematically represent the previous classification.

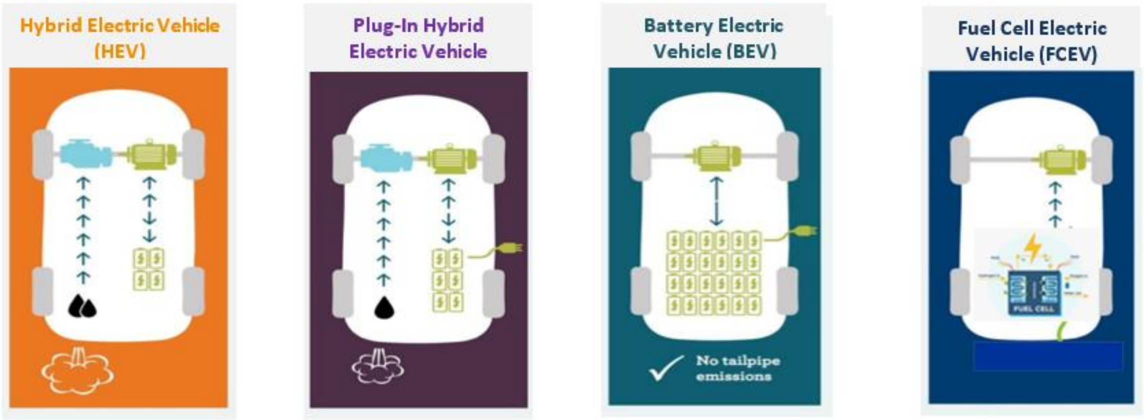


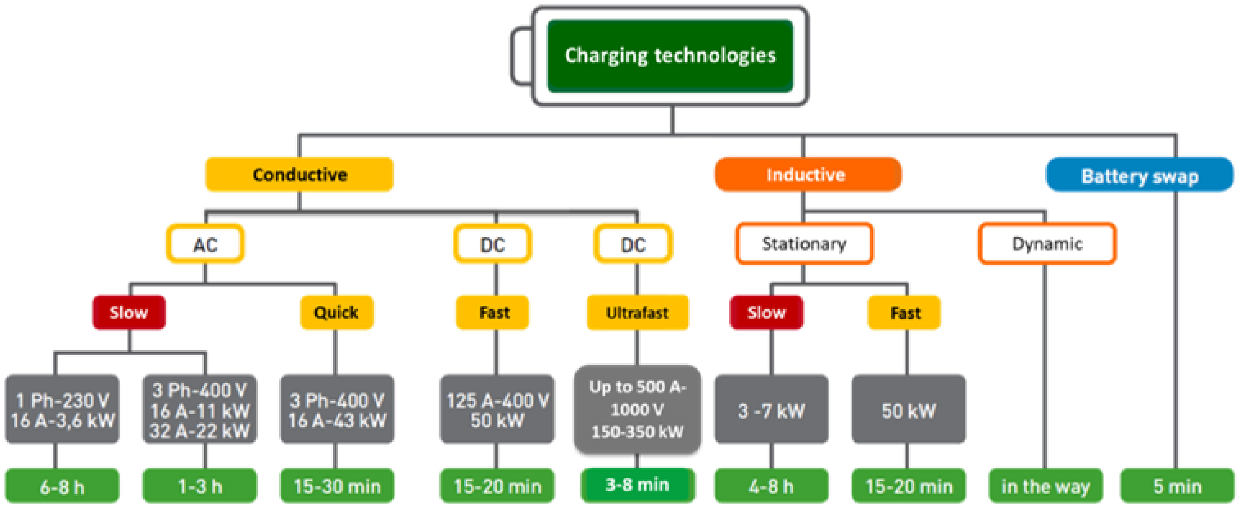
Figure 5 Definitions and differences among electric vehicles (Source: ENTSO-E).

2.4 Charging devices and infrastructures. State of the Art

2.4.1 Charging infrastructures

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. 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 HDV. 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 electromobility 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. For more information on the different available charging technologies, see Figures 6 and 7.

In the meantime, new developments are also made through the ecosystem of charging point suppliers to offer DC charging in home environments, in particular in the context of future V2G deployments. The majority of EV OEMs committing to V2G is today considering its application on DC applications as successfully demonstrated through the CHAdeMO standard.



Time to charge 20 kWh (100-150 km)

Figure 6 EV charging technologies (Source: RSE).

FOCUS BOX # 2

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 every time the opportunity occurs), reducing the risk of finding the EV out of charge when needed.

EV users who generate electricity at home (prosumers) could charge their cars also considering their production profile and take better advantage of self-consumption.

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 "**hypercharges 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.

Figure 7 Focus Box #2: Main differences between refuelling and electric charging (Source: ENTSO-E).

2.4.2 Detailed overview of the current state of the art, standards and trends.

Different standpoints can be considered to describe the state of art:

From the point of view of the charging: The future will be Plug & Charge (under IEC 15118), in this way, the current standard (IEC 61851) will fall into disuse. It will take time because the transition means software and hardware changes. The main features and differences between those standards are:

- IEC 61851:
    - based on client recognition by whitelist-token.
    - Interoperability similar to roaming of mobile communications (based on B2B agreements including interoperability platforms). There is no real universal interoperability today.
    - Radio Frequency ID cards or mobile platform (user opens with card or communicates remotely with charging point from application that starts the session).
    - Promoted for some time from Charging Points Operators, utilities and the energy sector in general.
- IEC 15118:
    - Based on digital exchange certificate.
    - Automatic and total interoperability.
    - The car (not the user) uses a digital certificate to communicate with the charging point, sharing the charging characteristics and who is going to pay for the charge. The charging point shares in turn its CPO ownership certificate and available charging conditions.
    - The vehicle holds the certificate repository (the have a certificate from the energy company linked to the OEM).
    - This standard is currently promoted by OEMs. It is based on total interoperability, what it is in line with the current trends

in Europe.

From the point of view of the charging power. The state of the art for Passenger Cars (PC) and Light Commercial Vehicles (LCV) is as follows:

- Trickle charging. The slowest method of charging an EV at home, using a standard AC single-phase 220V plug.
- AC charging. Having a wallbox installed which charges 3-4 times faster using AC single phase 230V and 11kW. AC public charging is also available.
- DC Charging. The fastest way to charge the EV is at a public DC fast charging station with 50kW and above. With this method, the battery can top up from 20% to 80% in approximately 40 minutes. There are also some ultra-fast charging stations of more than 150kW. For high-end and Heavy-Duty vehicles, higher powers 250 – 400kW are already available.

From the point of view of the connectors (in Europe).

- Charging points owned by the user: Type 2.
- Charging in an opportunity basis (shopping, restaurants, etc.): Type 2 and three-phase 22kW AC.
- Fast/ultra-fast charging and future V2G applications: CCS 2 and CHAdeMO

From the point of view of the battery capacity.

- BEV segment B, C and SUV B, C: 40kWh
- BEV segments D, E, SUV D, E: 75kWh or more (in the luxury and sport segment, usually above 100kWh)
- PHEV for all segments: 15 kWh and above.

Regarding V2G, the concept is that there is energy left in the battery after the use of EVs owners. OEMs in general try to promote it based in the assumption that the car can is permanently sharing data: the E-Call or automatic emergency call imply a 3G SIM card (or a more advanced one) in every car sold in the EU since March 2018. Another consideration is the battery warranty because it can create a significant barrier to entry for other operators. In this sense, and under the concept of virtual aggregator, there are OEMs managing millions of EVs batteries that could participate in flexibility markets.

2.4.3 Charging Infrastructure diffusion

As the number of electric vehicle sales increases, so do charging points. In the last four years, the number of public charging points more than doubled reaching more than 200,000 units (see Figure 8). Approximately 90% of these are standard 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 leading countries in Europe.

A key parameter that is frequently used is the ratio between the vehicle and public charging points. The Alternative Fuels Infrastructure Directive suggests 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 return for the CPOs. However, this number could significantly change for the different areas (e.g., densely populated or rural) and the charging strategies. A low ratio means that each vehicle can stay connected longer, providing more room for flexibility services.

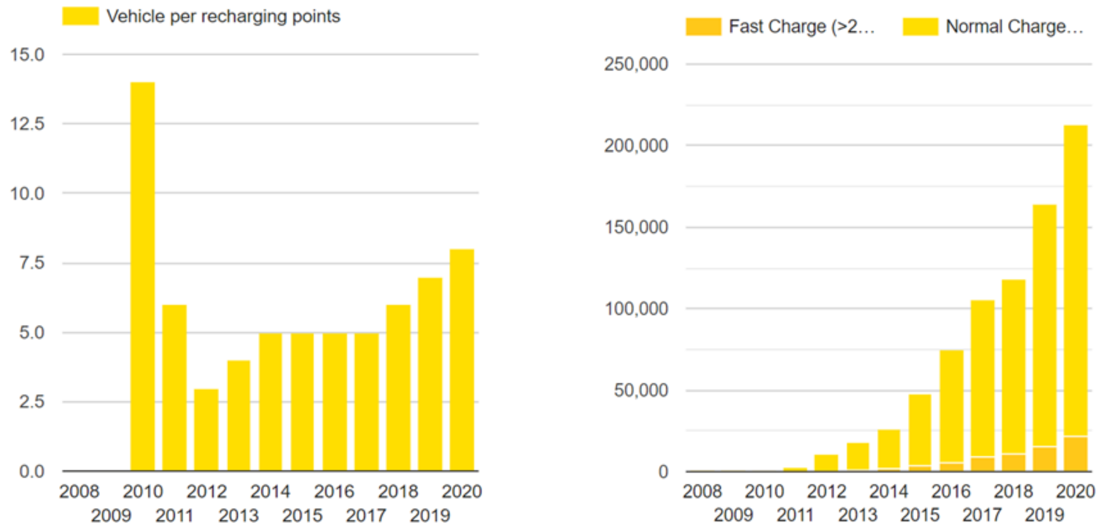


Figure 8 European installed charging stations and vehicle/charging points ration in the period 2008–2020 (Source: EAFO).

2.4.4 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 more than 90% of time, normally at home or at the office, which are also the places where V2G makes the most sense. Slow charging at those locations, when feasible, is indeed a suitable and 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 stopovers 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. Thereby, there is no definitive charging solution for electric buses and HDVs because they have different energy requirements depending on use (urban, suburban…), number and length of stops, orography driven, and climate. Other key aspects are the available time per stop on route and the recovery time at end-line stops, the infrastructure of the power grid and the electric tariffs. The charging strategy for vehicles with fixed routes should consider: available charging time and the ability of the battery to accept fast-charging. The charger technology mainly depends on selected strategy, the possibility of place, the required hardware on-board and the characteristics of power grid (see Figure 9).

Slow charging allows for flexible routing (for example, in the case of road) or changing routes due to travel/business demands. However, charging during the operation is not possible, reducing the availability time of the vehicle and the possibility of long routes. Bigger batteries can solve this problem but adding extra weight to the vehicle and thereby reducing vehicle energy efficiency, its capacity to carry weight, and increasing costs.

Vehicles using fast/opportunity charging use smaller batteries that can be charged at higher power than those using slow charging, about 50 to 200 kW for inductive charging and up to 500 kW for conductive charging. These vehicles have a smaller free range but shorter charging times and therefore higher availability (they can be charged several times during operation). Smaller batteries allow for lighter vehicles and higher energy efficiency resulting in higher freight but the limited available time per stop on-route may not be enough to sufficiently recharge the batteries. It must be pointed out that fast charging is only possible in some battery technologies, reducing battery service life if it is not applied following technical instructions of battery manufacturers. Moreover, fast charging requires higher hardware inversion costs and puts higher stress to the electric grid (high power demand in short periods of time).

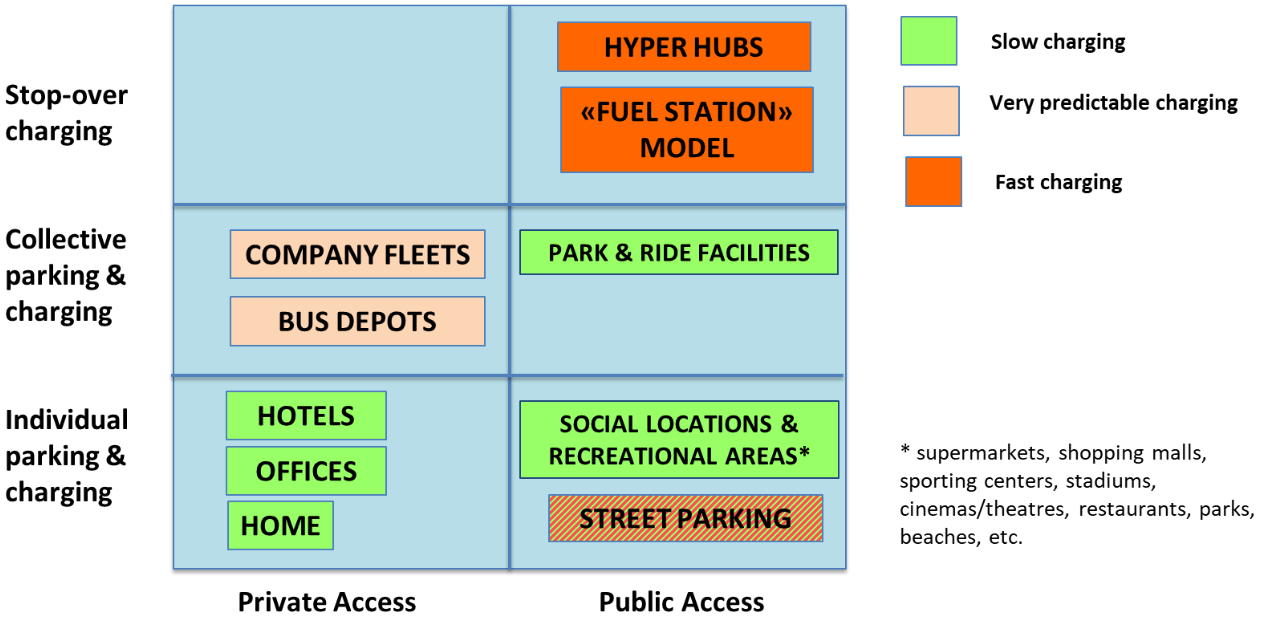


Figure 9 EV charging use cases, structured according to access, parking characteristics and charging time (Source: ENTSO-E).

2.4.5 Overview of communication standards and trends

In addition to the criteria described above, communication standards also present a variety of possibilities.

- From the point of view of the charge station: the current state of the art of the charging devices and infrastructures that allow communications for the monitoring and management of the charging is through the Open Charge Point Protocol (OCPP) for charging station. OCPP implements the following modules:
    - CORE (Mandatory): allows the management and monitoring of the charging infrastructure.
    - Smart Charging: Allows the charging point to work at different currents or powers, performing a smart charging.
    - Other modules that allow increasing the functionalities of the charging devices and infrastructures.

- From the point of view of the charge point operator: the state of the art of the OCPP for a Charging Station Management System to manage all the charging infrastructures and being able to send charging profiles for smart charging based on the operator's needs.

- From the point of view of the electric mobility service providers: the communication protocols designed for exchange information between CPOs and electromobility service providers allow roaming among EV charging with the ability to support authorizing processes, exchange of charging information and smart charging. This allows electromobility service providers to access flexibility.

2.5 2030 changing scenario

According to the International Energy Agency (IEA)[6], the 2030 global charging scenario (see Figures 10 and 11) 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, following the Stated Policies Scenario (STEPS). The cumulative installed power capacity of those chargers will be 0.6TW globally. 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 120GW. They will provide almost 70TWh of energy, roughly one-fifth of the electricity consumed by private chargers.

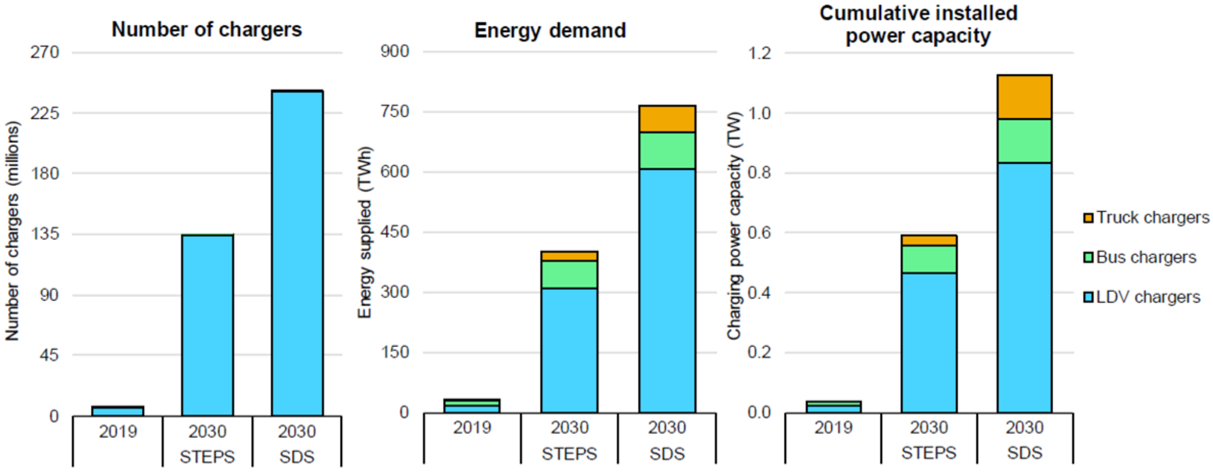


Figure 10 Private charger diffusion, energy demand and power capacity in 2019 and 2030 by STEPS and Sustainable Development Scenario (SDS) (Source: IEA).

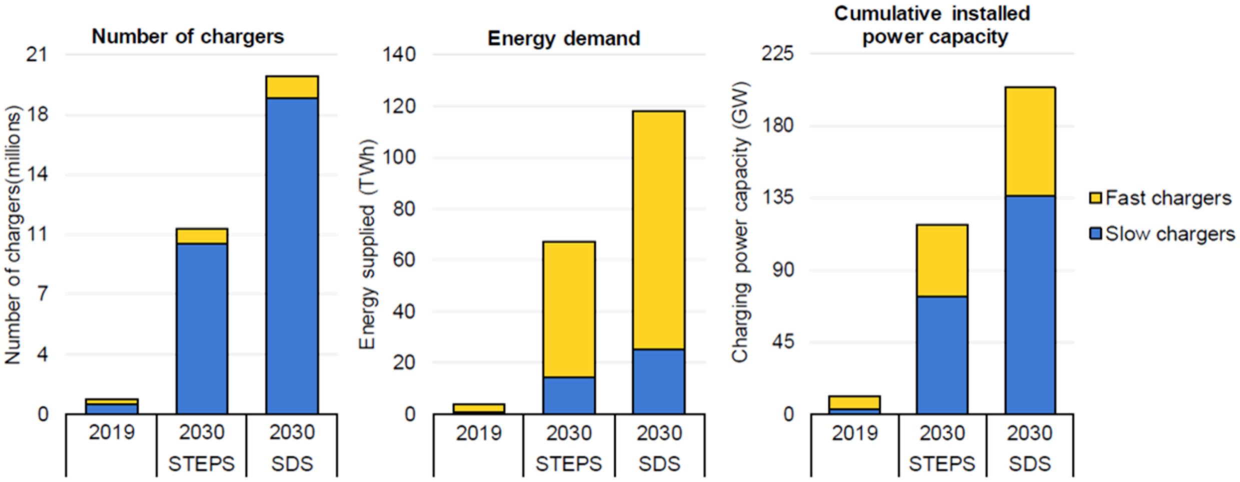


Figure 11 Public charger diffusion, energy demand and power capacity in 2019 and 2030 by STEPS and SDS (Source: IEA).

2.6 E-mobility deployment through a holistic approach

As mentioned in the previous chapters, a cost effective and secure transition to lower carbon electricity system will require the development of novel architectures that can reliably meet the needs of the emerging power system, especially in the uptake of new electromobility possibilities and technologies. One of the key tasks associated with the new emerging architectures is to enhance the controllability associated with future power system operation in order to enhance the infrastructure utilization while cost-effectively managing security and resilience.

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[6] https://www.iea.org/data-and-statistics/charts/cumulative-installed-charging-power-capacity-for-electric-ldv-chargers-by-scenario-2020-2030

The holistic architecture presented in this chapter unifies the interactions within the actors described through the paper ("a wide ecosystem"), thus creating the possibility to harmonize and facilitating all processes which are necessary for a reliable, economic and environmentally friendly operation of smart power systems.

The massive increase of online services and consequently small package services during the COVID-19 crisis significantly challenges the transport industry: the fleet should expand. The electrification of those large fleets and common vehicles, combined with the desired fast-charging infrastructure, is expected to pose massive transmission and distribution grids challenges. The holistic consideration of these two parts of the power grid and the customers, including EVs, is essential to ensure a secure and sustainable power supply. *LINK* holistic architecture[7][8] described below considers the power grid, customers, and the market as a whole.

2.6.1 *LINK* holistic solution

The architectural paradigm for Smart Grids *LINK* is derived from the signature of their fractal structure[9]. *LINK*-Paradigm is fundamental to draw the holistic, technical, and market-related Smart Grid model with large DER shares. It is used as an instrument to design the *LINK*-based holistic architecture that facilitates modelling of the entire power system from high to low voltage levels, including CPs. *LINK* architecture allows for the description of all power system operation processes such as load-generation balance, voltage assessment, dynamic security, price and emergency driven demand response, etc.[10].
For a better understanding of the *LINK* solution, some of the fundamental concepts and abbreviations used in this chapter should be explained beforehand:

2.6.1.1 Fundamental concepts and abbreviations

a) Popular control strategies in power systems

The most popular control strategies in power systems are local controls in open and closed loops. When the secondary control loops are set, the local controls in closed loops are usually called primary controls (PC).

Local control (LC)

It refers to control actions that are carried out locally without considering the holistic real-time behaviour of the relevant grid part. Its action path may be realised in open- or closed-loop:

- Open-loop path – The input variable usually differs from the output one; the output variables are influenced by the input variables but **do not act on themselves continuously and again** via the same input variables. Figure 12 shows the open-loop action path of a switched-capacitor bank, where the output variable is always reactive power. In contrast, the input variable may be voltage, current, time, and so on.

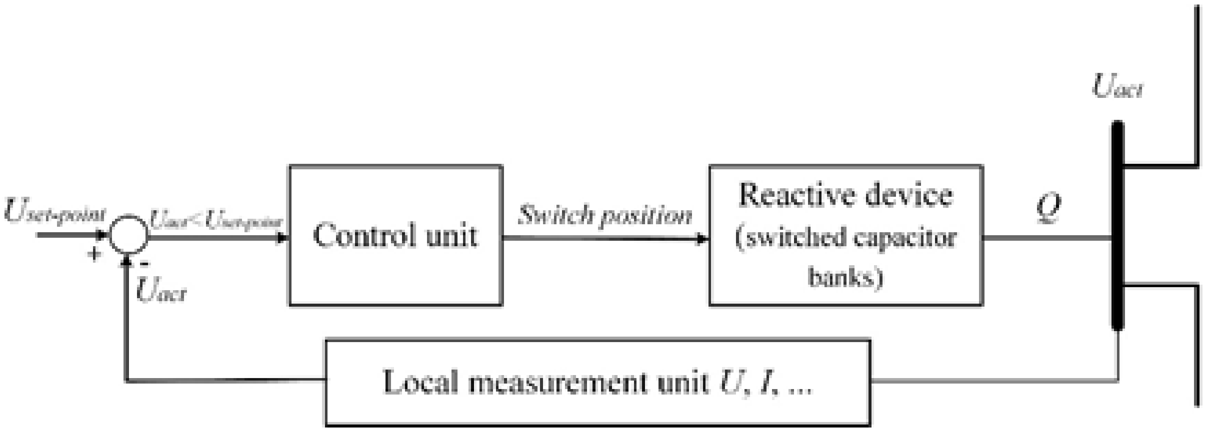

Figure 12 Open action path of the Local Control of switched capacitor banks.

- Closed-loop path – In this case, **the controlled variable continuously influences itself.** The deviation of the actual measured value from set-point results in a signal, which affects the valves or frequency, excitation current or reactive power, transformer steps, and so on in such a way that the desired power is delivered or the desired voltage is reached. Figure 13 shows the closed-loop action path of the Local Control of OLTC. It keeps the voltage to the $U_{set\text{-}point}$.

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[7] ETIP SNET (2019) White Paper Holistic architectures for future power systems. https://www.etip-snet.eu/white-paper-holistic-architectures-future-power-systems. Accessed 12 March 2021

[8] A. Ilo, D.L. Schultis „A Holistic Solution for Smart Grids based on LINK– Paradigm", Springer Nature Switzerland, 2022, XVIII, 348. ISBN 978-3-030-81529-5

[9] Ilo A (2019). Design of the Smart Grid Architecture According to Fractal Principles and the Basics of Corresponding Market Structure. Energies, 4153.

[10] Vaahedi E (2014) Practical power system operation. John Wiley & Sons, New Jersey.

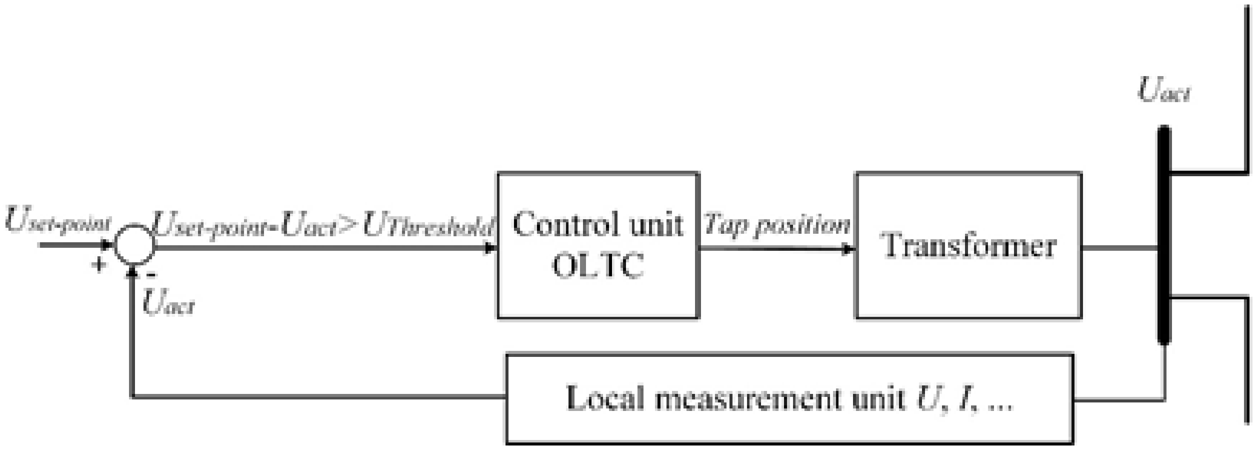

Figure 13 Closed action path of the Local Control of switched capacitor banks.

LC automatically adjusts the active/reactive power contributions, tap and switch positions, etc., of the corresponding control device based on local measurements or time schedules (Sun et al. 2019; Roytelman and Ganesan 1999; Farivar et al 2015). They usually maintain a power system parameter, which is locally measured or calculated based on local measurements, equal to the desired value. The fixed control settings are calculated based on offline system analysis for typical operating conditions. Local controls are simple, reliable, and quickly respond to changing operating conditions without the need for a communication infrastructure (Zhou et al. 2021; Nowak et al. 2020; Roytelman and Ganesan 2000).

Secondary control (SC)

SC in power systems is quite popular in the case of load frequency control (LFC). LFC's significant purposes are maintaining the operation area's frequency and keeping power exchange in the tie lines conform to the schedules. PC's objective is to maintain a balance between generation and consumption (demand) within the synchronous area. SC maintains a balance between generation and consumption (demand) within each control area and the synchronous area's system frequency. Tertiary control is primarily used to free up the SC reserves in a balanced system situation by considering the economic dispatch (ENTSO-E 2015).

Control set used in *LINK*-Solution

A control set is used in the *LINK*-Solution that consists of a Direct, Primary, and Secondary Control loop, Figure 14.

Primary Control (PC) refers to control actions done locally in a closed-loop: the input and output variables are the same. The output- or control-variable is locally measured and continuously compared with the reference variable, i.e. the setpoint calculated by secondary control. The deviation from the setpoint leads to a signal that influences the valves or frequency, excitation current or reactive power, transformer steps, etc., in a primary-controlled power plant, transformer, etc., so that the desired power is delivered or the desired voltage is reached.

Direct Control (DiC) refers to control actions performed in an open-loop, taking into account the real-time holistic behaviour of the grid part he belongs. Secondary Control calculates its control action.

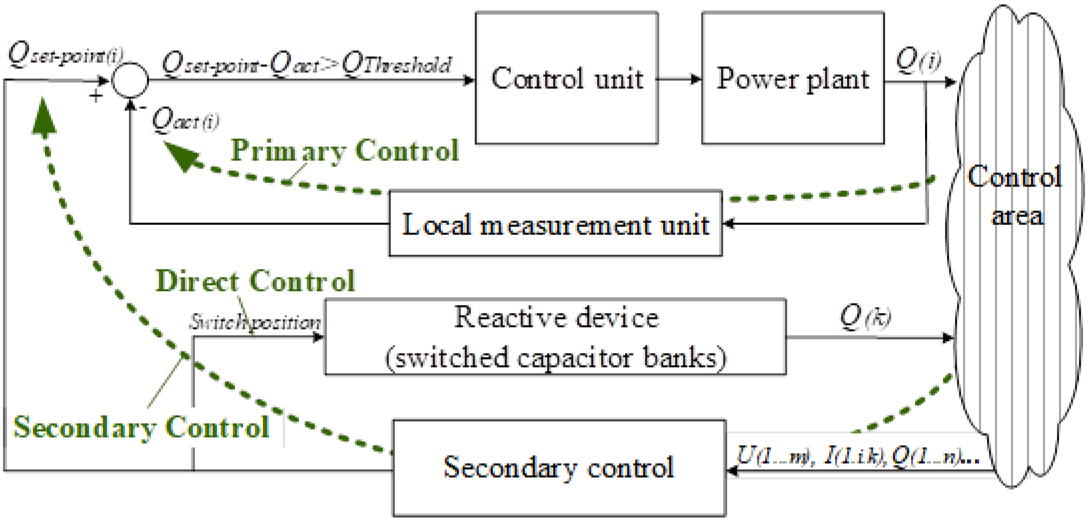

Figure 14 Overview of the control set used in LINK-Solution.

Secondary Control (SC) refers to control variables calculated based on a control area's current state. It fulfils a predefined objective function by respecting the static, i.e., electrical appliances' constraints (*PQ* diagrams of generators, transformer rating, etc.), and dynamic conditions dictated by neighbouring areas. At the same time, it calculates and sends the setpoints to PCs and the input variables to DiC acting on its control area.

b) Abbreviations used in the LINK approach description

AC	Alternating Current
BEV	Battery of Electric Vehicle
CP	Customer Plant
CPG	Customer Plant Grid
CVR	Conservation Voltage Reduction
DER	Distributed Energy Resources
Dev	Device
DG	Distributed Generation
DiC	Direct Control
DMS	Distribution Management System
DR	Demand Response
DSO	Distribution System Operator
DSSE	Distribution System State Estimator
DTR	Distribution Transformer
EC	Energy Community
ElA	Electrical Appliance
EMS	Energy Management System
EPO	Electricity Producer-Link Operator
ESI	Energy Systems Integration
FENIX	Flexible Electricity Network to Integrate the expected 'energy evolution'
GDPR	General Data Protection Regulation
GriLiO	Grid-Link Operator
HMU	House Management Unit
HV	High voltage
HVG	High Voltage Grid
HVSO	High Voltage System Grid-Link Operator
ICT	Information and Communication Technology
LC	Local Control
LFC	Load Frequency Control
LRM	Local Retail Market
LV	Low voltage
LVG	Low voltage grid
LVR	Line Voltage Regulator
LVSO	Low Voltage System Grid-Link Operator
“M”	Market interface
MC	Manual control
MSR	Mechanically switched reactor
MV	Medium Voltage
MVG	Medium Voltage Grid
MVSO	Medium Voltage System Grid-Link Operator
OLTC	On-Load Tap Changer
P2Ch	Power-to-Chemicals
P2X	Power-to-X
PC	Primary Control
PV	Photovoltaic
RES	Renewable Energy Resources
RTU	Remote Terminal Unit
SC	Secondary control
SCADA	Supervisory Control and Data Acquisition
SE	State Estimator
SO	System Operator
StO	Storage-Link Operator
STR	Supplying transformer
“T”	Technical interface
TSO	Transmission System Operator
UML	Unified Modelling Language
VvSC	Volt / var Secondary Control
Uact	Actual measured voltage
WSC	Watt Secondary Control

2.6.1.2 Holistic model

Figure 15 shows the holistic technical model (the “Energy Supply Chain Net”). It illustrates the links’ compositions and their relative position in space, both horizontally and vertically. In the horizontal axis, the interconnected High Voltage Grids (HVG) are arranged. They are owned and operated by TSOs. Medium (MVG) and Low Voltage Grids (LVG) and the Customer Plant Grids (CPG), including the HVG to which the MVG is connected, are set vertically. MVGs and LVGs are owned and operated by the DSOs, while customers use CPGs. Electricity producers (hydroelectric power plants, wind and PV plants, etc.) and storage (pumped hydroelectric power plants, batteries, EV batteries, in the form of heating and cooling, hydrogen production, etc.) are connected at all levels.

An “Energy Supply Chain Net” is a set of automated power grids intended for chain links (abbreviated as links), which fit into one another to establish a flexible and reliable electrical connection. Each link or link bundle operates autonomously and has contractual arrangements with other relevant boundary links or link bundles.

The holistic model associated with the energy market is derived from the holistic technical model, the “Energy Supply Chain Net,” as shown in Figure 15b). The whole energy market consists of coupled market areas (balancing groups) at the horizontal and vertical axes. TSOs operate on the horizontal axis of the holistic market model, while DSOs operate on the vertical. Based on this model, TSOs and DSOs will communicate directly with the whole market to ensure a congestion-free distribution grid operation and take over the task of load-production balance. *LINK* solution postulates the restructuring of the actual market structure and creation of the local market to facilitate the effective local trade[11]. The owner of the distributed energy resources as well as the prosumers (producers and consumers of electricity) may participate directly in the market or may do so via Energy Communities (ECs)[12].

The Battery of Electric Vehicles may be connected into the customer plant or low voltage level as shown below. BEVs of a district garage

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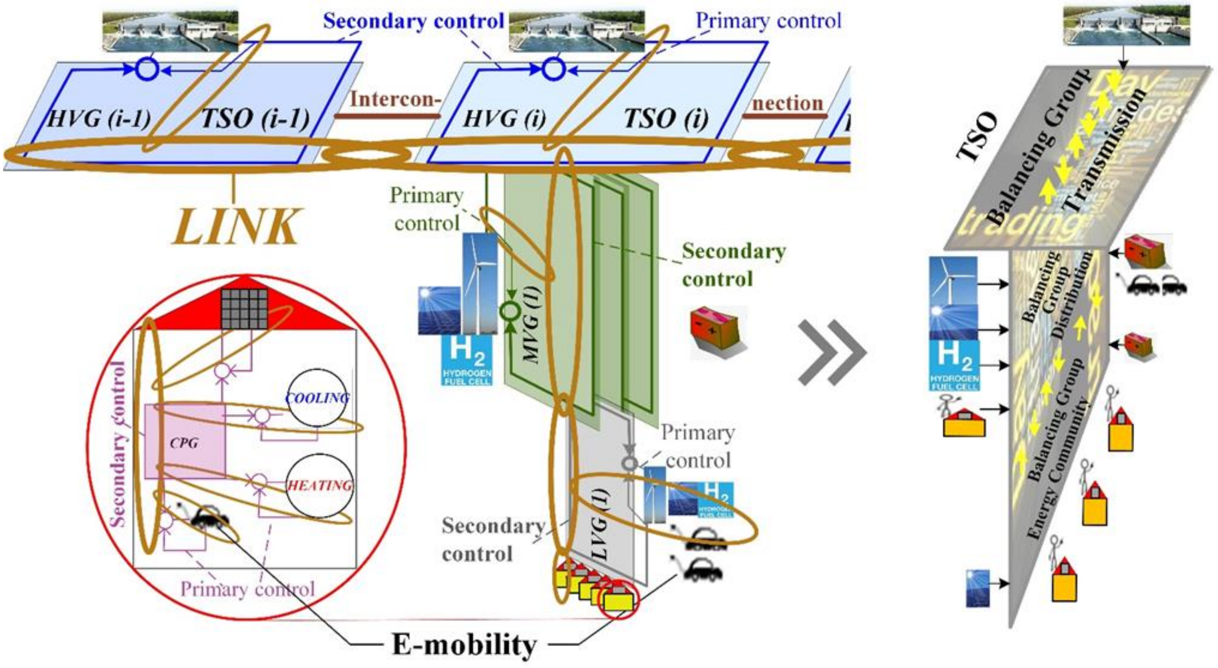
[11] A, Ilo, H. Bruckner, M. Olofsgard, M. Adamcova “Deploying e-mobility in the interact energy community to promote additional and valuable flexibility resources for secure and efficient grid operation”, accepted to be published in CIRED workshop, 2-3 June 2022, Porto, Portugal.

[12] Ilo A, Prata R, Iliceto A, Strbac G (2019) Embedding of Energy Communities in the Unified LINK-Based Holistic Architecture. CIRED, Madrid, 3-6 June, pp 1–5.

may participate into the Balancing Group Distribution or Energy Community. The contribution of BEV(s) of a CP-garage is realised through the customer.



(a) (b) (c)

Figure 15 Overview of the holistic models highlighting e-mobility: (a) Zoom in CP; (b) Technical model the "Energy supply chain net"; (c) Market model.

2.6.1.3 Holistic architecture

The holistic architecture level is the core of the *LINK*-based architecture (Figure 16). It comprises the Smart Grids and the electricity market. The market surrounds the generalised architecture and communicates with it through the market interfaces "M" by exchanging aggregated meter readings, external schedules, etc. At this architectural level, the grid links of customer plants are removed from the generalised presentation because they are too small to participate directly in the whole market. They may participate in the common market through energy communities. For the sake of privacy and cybersecurity, the market interfaces "M" are designed apart from technical interfaces "T". This architectural level forms the base for designing and implementing the demand response process, the most comprehensive and complex operation process in Smart Grids: All voltage levels, customers, and the market are affected here.

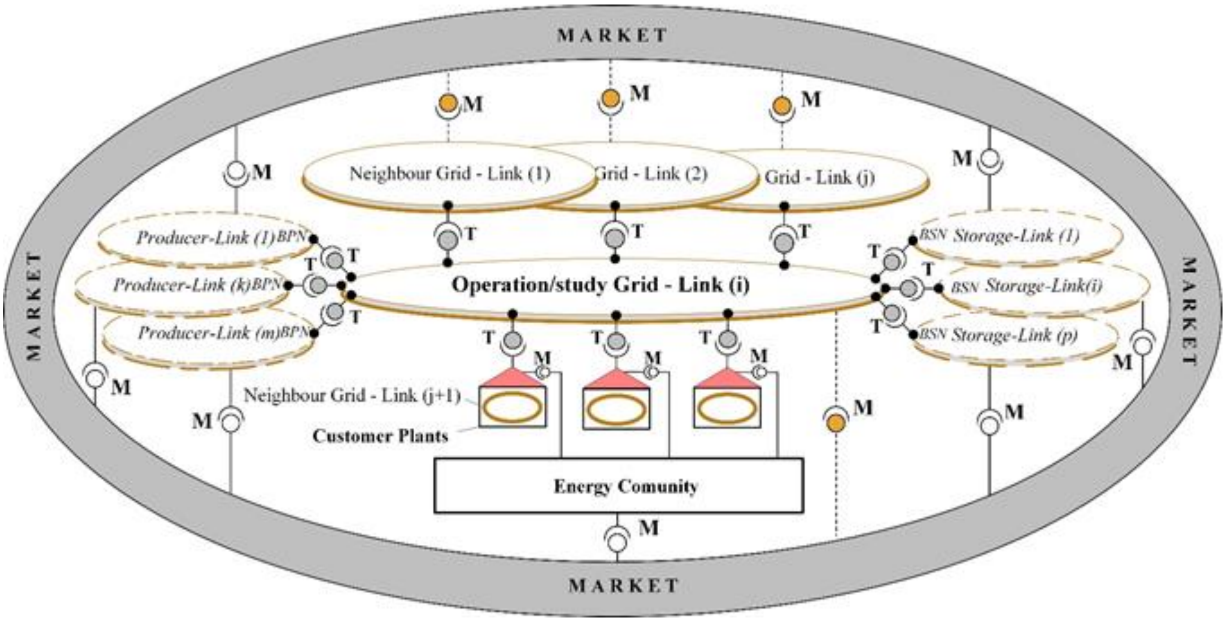


Figure 16 Holistic architectural level of the LINK-based architecture.

The three fundamental components of the architecture are the Producer, Storage, and Grid. They are an integral part of one of the three constituent elements of the *LINK*-Paradigm: Electrical appliances. The components of the holistic architecture are Producer-Link, Storage-Link, and Grid-Link.

The third and most complex fundamental component of the new architecture is the Grid-Link. Figure 17a shows an overview of it, while Figure 17b illustrates the Link-Grid.
Grid-Link is a composition of a grid part, called Link-Grid, with the corresponding Secondary Control (SC).
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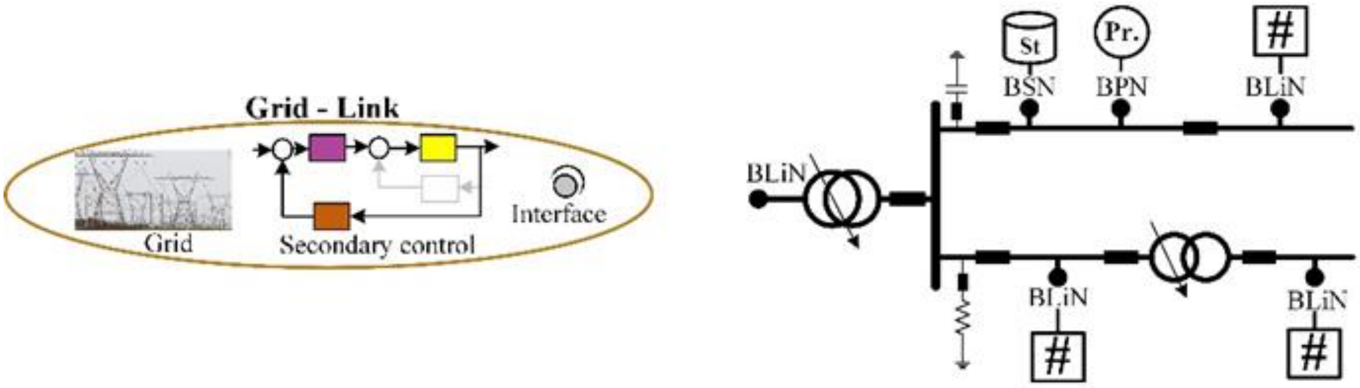


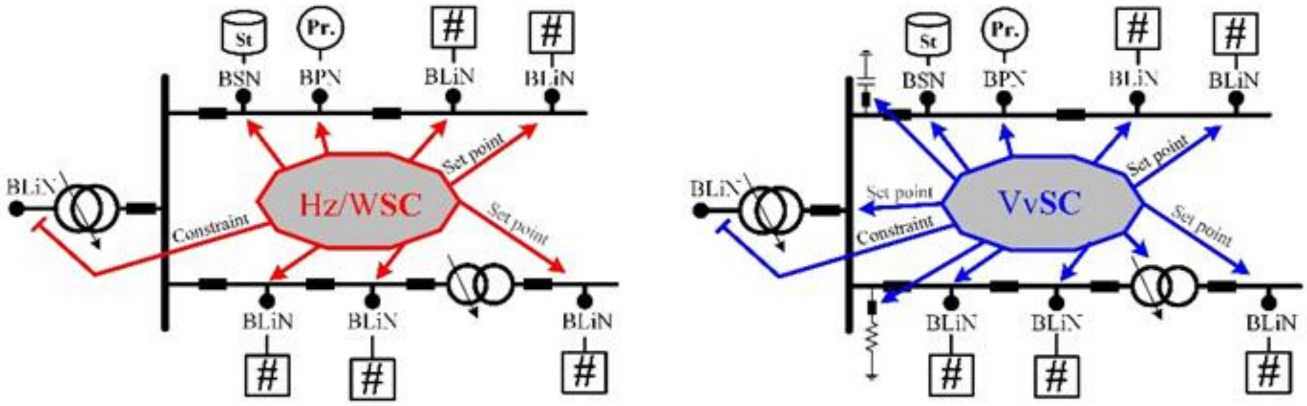
(a) (b)

Figure 17 Overview of the Grid-Link: (a) General depiction; (b) Link-Grid.

Link-Grid is the grid part included within the Link. It refers to electrical equipment like lines/cables, transformers, and reactive power devices connected directly to each other by forming an electrical unity. Link-Grid size is variable and is defined from the area where the Secondary-Control is set up.

Thus, the Link-Grid may include, e.g., one subsystem (the supplying transformer and the feeders supplied from it) or a part of the sub-transmission network, if the SC is set up on the respective area. As a result, depending on its size, the Link may represent the high-, medium-, low-voltage and even the customer plant grid.

Figure 18 shows the control schemes set on a typical Link-Grid. Figure 18a depicts the Hertz/Watt secondary control, while Figure 18b the Volt/var secondary control. Each Link-Grid has many Boundary Link Nodes (BliN) through which it connects with neighbouring Link-Grids. The neighbouring Link-Grids are represented with the symbol (#). Producers inject directly into it via Boundary Producer Node (BPN); Storages inject or consume power via (Boundary Storage Node) BSN.



(a) (b)

Figure 18 The control schemes set on a typical Link-Grid: (a) Herz/Watt secondary control; (b) Volt/var secondary control.

By definition, the Link-Grid is upgraded with secondary control for both significant power systems entities pairs the frequency/active power and voltage/reactive power based on the fact that the frequency depends on active power whereas voltage mainly on reactive power.
Its algorithm needs to fulfil technical issues and calculate the connected facilities' primary controls' set points by respecting the dynamic constraints necessary to enable a stable operation. The Link-Grid's facilities, such as transformers and the reactive power devices, are almost upgraded with primary or local control. Thus, SC sends set points to its facilities and all entities connected at the boundary nodes.

2.6.1.3 Transmission and distribution levels and customer plants at a glance

Charging stations are usually connected to the low voltage grid. Except for large fleet parking lots, they are connected to the medium voltage grid via a MV/LV transformer. The shape of load connected in low voltage grid is usually spiky and discontinuous depending on the devices in operation. Fast charging stations in particular can further deform the shape of the load. The load itself increases notably thus making the load shape deformation in subordinated grids more obvious.

Figure 19 shows a schematic presentation of the Grid-Links in the *Y*-axis with the corresponding Hz/WSC chain. Since frequency is a global parameter of power systems, the sub-process load-frequency control that happens minute-to-minute is attributed only to HV^T Grid-Links (set up on today's transmission grids).

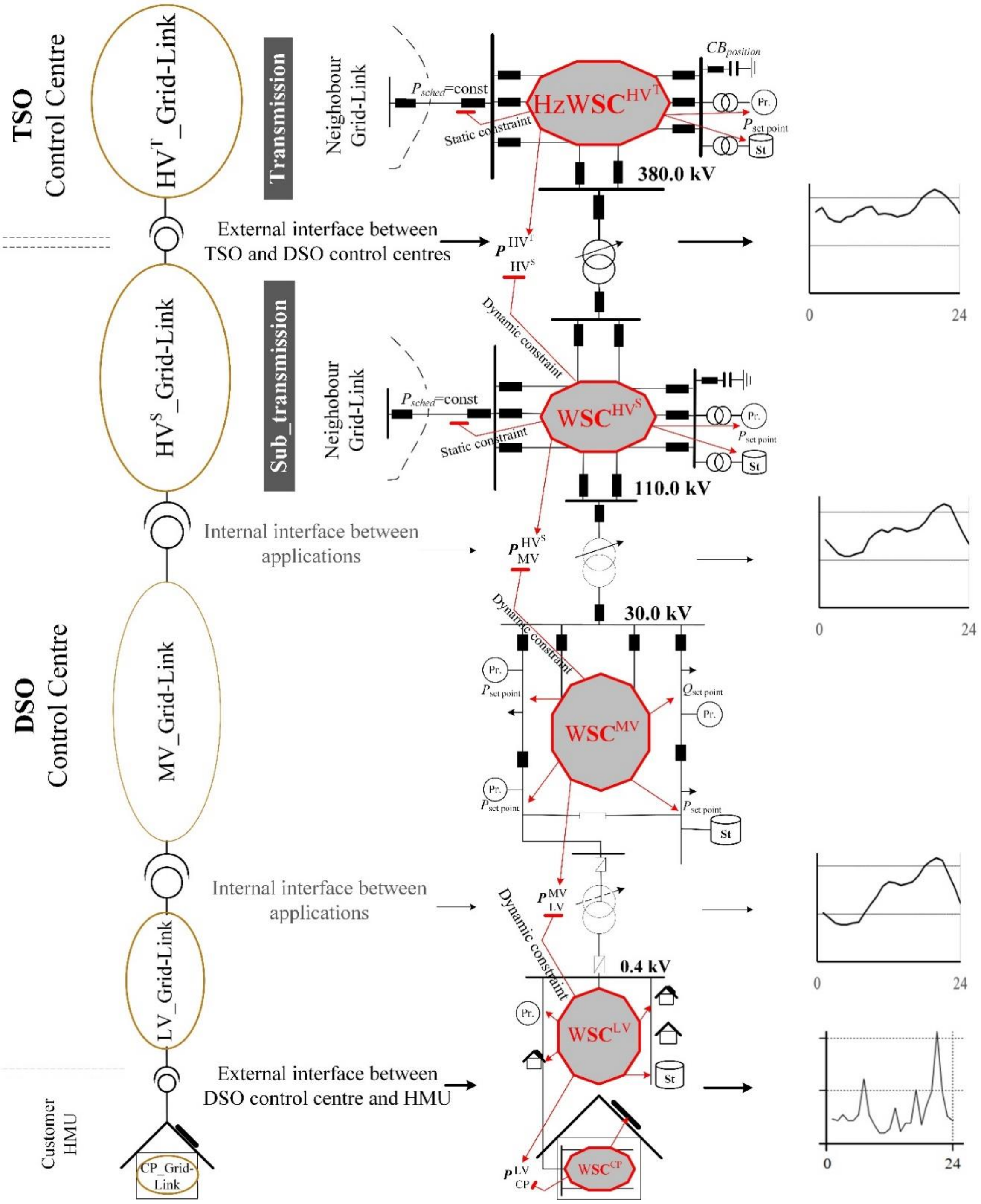


Figure 19 Schematic presentation of the resilient HzWSC chain: (a) Link structure; (b) Hertz/Watt control loops; (c) Active power profile.

$HzWSC^{HV^T}$ is stipulated for this Grid-Link. Meanwhile, both sub-processes, the operation planning and economic dispatch apply in all Grid-Links. Consequently, the load-generation balance process in Grid-Links in distribution and customer plant levels includes only the operation planning and economic dispatch sub-processes. For them, only WSC is stipulated. Figure 19b shows the [Hz]WSC loops of each Link: $HzWSC^{HV^T}, WSC^{HV^S}, WSC^{MV}, WSC^{LV}, and\ WSC^{CP}$. Similar to VvSC, each SC application calculates the relevant set points by optimising its own decisions that are subject to:

- Its constraints, and
- Dynamic constraints imposed by neighbouring Grid-Links

Dynamic constraints control the active power flow in a HzWSC chain. They change or should be recalculated in real-time, depending on the current situation. For example: if the active power $P_{MV}^{HV^{S}}$ supplied from HVS_Grid-Link into the MV_Grid-Link should be reduced by 20%, a new desired constraint is sent to the MV_Grid-Link. WSCMV recalculates the set points in its area by respecting the new condition with the superordinated grid. Otherwise, if the actual $P_{MV}^{HV^{S}}$ is not optimal for the MV_Grid-Link operation, a request is sent to the HVS_Grid-Link to change it, and so on. The same schema works across the entire HzWSC chain. This permanent exchange of desired active power P between different HzWSC loops creates a resilient interaction between them. Figure 19c shows the active power profile.

2.6.2 E-mobility and sector coupling

Figure 20 shows e-mobility and the Cross-Vector and End-Use Sector Coupling embedded in the LINK-Architecture. Energy vector areas are presented in different colours. The lime-green area presents the electricity energy vector, while the apricot area presents other vectors such as gas, heating and cooling, and so on. Its main elements outline the generalised LINK-Architecture:

- **Producers** include all available plants regardless of size and technology, such as conventional, hydro, wind, solar, geothermal, bioenergy, waste heating, etc.
- **Grids** include transmission (very high and high voltage level) and distribution (medium and low voltage levels); and
- **Storages** include all available facilities regardless of size and technology. It comprises the traditional storage facilities and the "virtual storage" resources.

For transparent monitoring of storage and its appropriate consideration in algorithms of various applications of management systems, the Storage-Link is classified as follows:

- **Cat. A:** The stored energy is injected at the charging point of the grid, such as pumped hydroelectric storage, stationary batteries, etc.
- **Cat. B**: The stored energy is not injected back at the charging point on the grid, such as Power-to-Gas (P2G), batteries of e-cars, etc.
- **Cat. C:** The stored energy reduces the electricity consumption at the charging point in the near future, such as cooling and heating systems (consuming devices with energy storage potential).

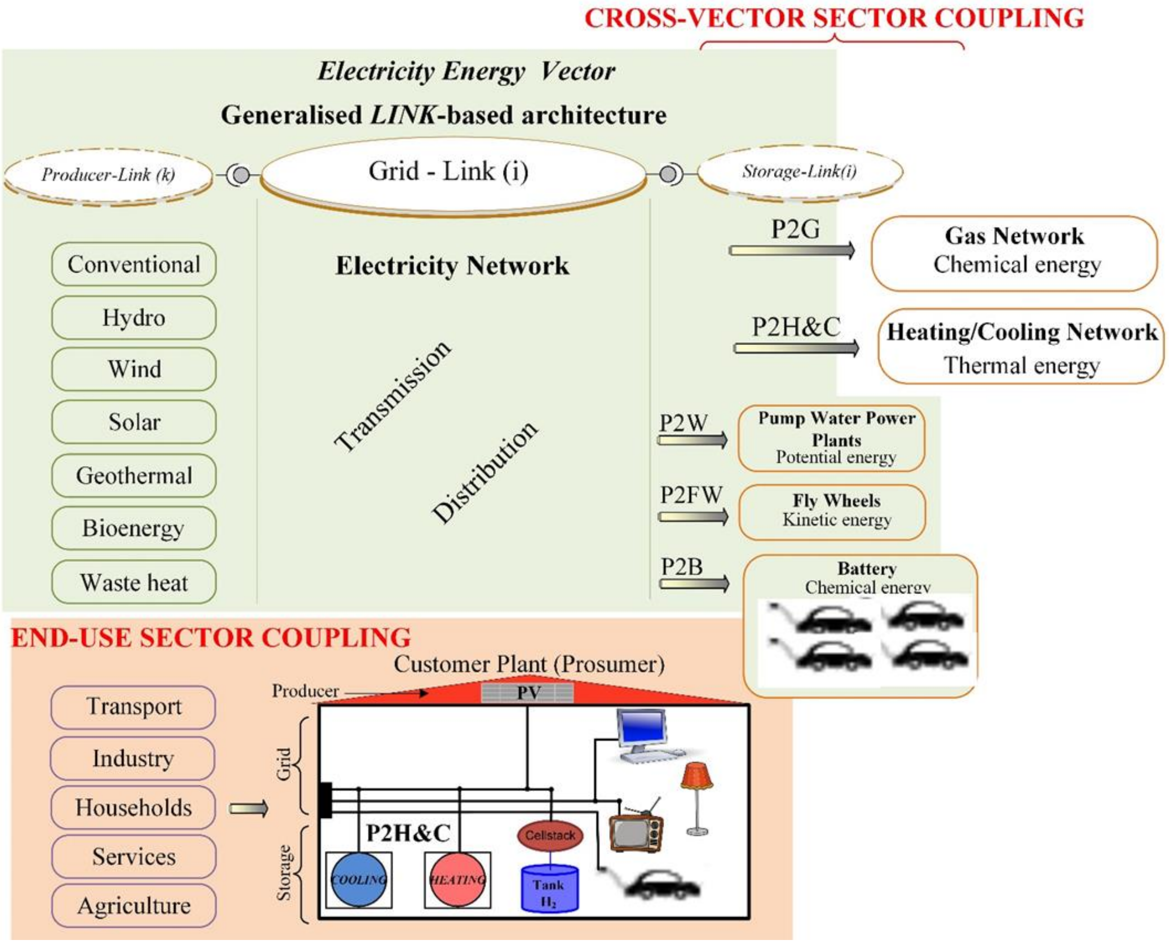


Figure 20 E-mobility and Cross-Vector and End-Use Sector Coupling embedded in the LINK-Solution

2.6.2.1 Smart cities' LINK architecture

Smart Cities are places where decarbonisation strategies for energy, transport, buildings, and even industry and agriculture coexist and intersect (European Commission 2020). LINK-Solution supports the decarbonisation of all economic sectors by enabling Energy Systems Integration in the context of smart cities. The flexible setting of the Grid-Link size allows the easy application of LINK-Solution to the Smart City grid. Figure 21 shows the technical/functional architecture of a district. An LV subsystem with a distribution transformer and two feeders connects a residential building, a district PV facility, a district garage with e-cars and many single-family houses. On the residential building is installed a common roof PV system for all residents, while on the basement is a garage with e-cars. In the one family houses are also installed rooftop PV facilities, while on the basement of each house is a garage with an e-car (these are not shown in detail).

Two LV Grid-Links are identified: the one includes the distribution transformer and the feeders, the other the grid within the residential building. The corresponding secondary controls are set up on the LV grids. CP Grid-Links are put on each flat and one family house. On the PV facilities and charging station of e-cars are set Producer- and Storages-Links.

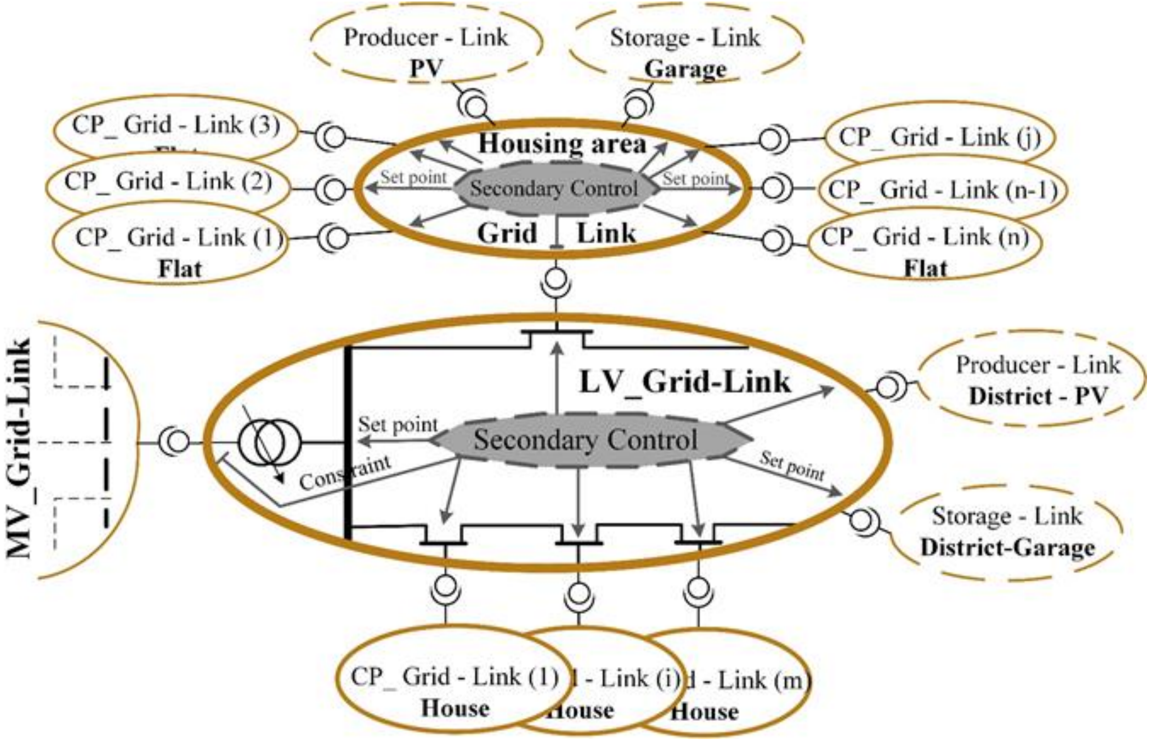


Figure 21 Technical/functional architecture of a Smart City district.

2.6.2.2 E-mobility demand response: congestion on high voltage grid.

The current structure of the grid and operation of the electricity market push the operation of the transmission system to its limits requiring a COSTLY re-dispatch process for congestion management. In this process, TSOs are interested in knowing whether active power flows decrease or increase at the intersection points with DSOs, but less about how they occur; whereas the DSOs are required to keep voltages throughout the grid within limits at all times, also during the demand response process. Figure 22 shows the demand response process used to support the congestion alleviation process. Suppose an increase in the overload is expected in a high-voltage transmission line up to 8% in the following hours. TSO starts the congestion alleviation process: using the relevant applications, he defines the BLiNs AH and BH on his grid where the load decrease should be 2% and 6%, respectively. Both Grid-Links connected on the BLiNs are MV_Grid-Links. They are operated from the same operator DSO_A. Afterwards, TSO initiates a demand decrease request and proposes two new set points accompanied by the setting and duration. After receiving the request for the new set points, DSO_A starts the demand response process and investigates all possibilities to realize the demand decrease using their internal resources, e.g., the CVR. The 2% power reduction in the BLiN AH was realized by performing the CVR on MV_Grid-Link. No other actions are needed. The new set point is notified to the TSO.

The reduction desired on the BLiN BH is more extensive than at AH, about 6%, and only one part of it, e.g., 5.4%, can be reached by performing CVR in MV_Grid-Link_2. For the rest, about 0.6% demand reduction, other actions are necessary. DSO_A investigates his Link-Grid and the day-1 schedules and identifies the BLiNs A2M and B2M as the most suitable ones, where the flow should be reduced by 0.4% and 0.2%, respectively. LV_Grid-Link_1 and LV_Grid-Link_2 are connected respectively to the BLiNs A2M and B2M. Both links are operated from the same DSO. Afterwards, DSO_A initiates a demand decrease request and proposes two new set points accompanied by the setting and duration.

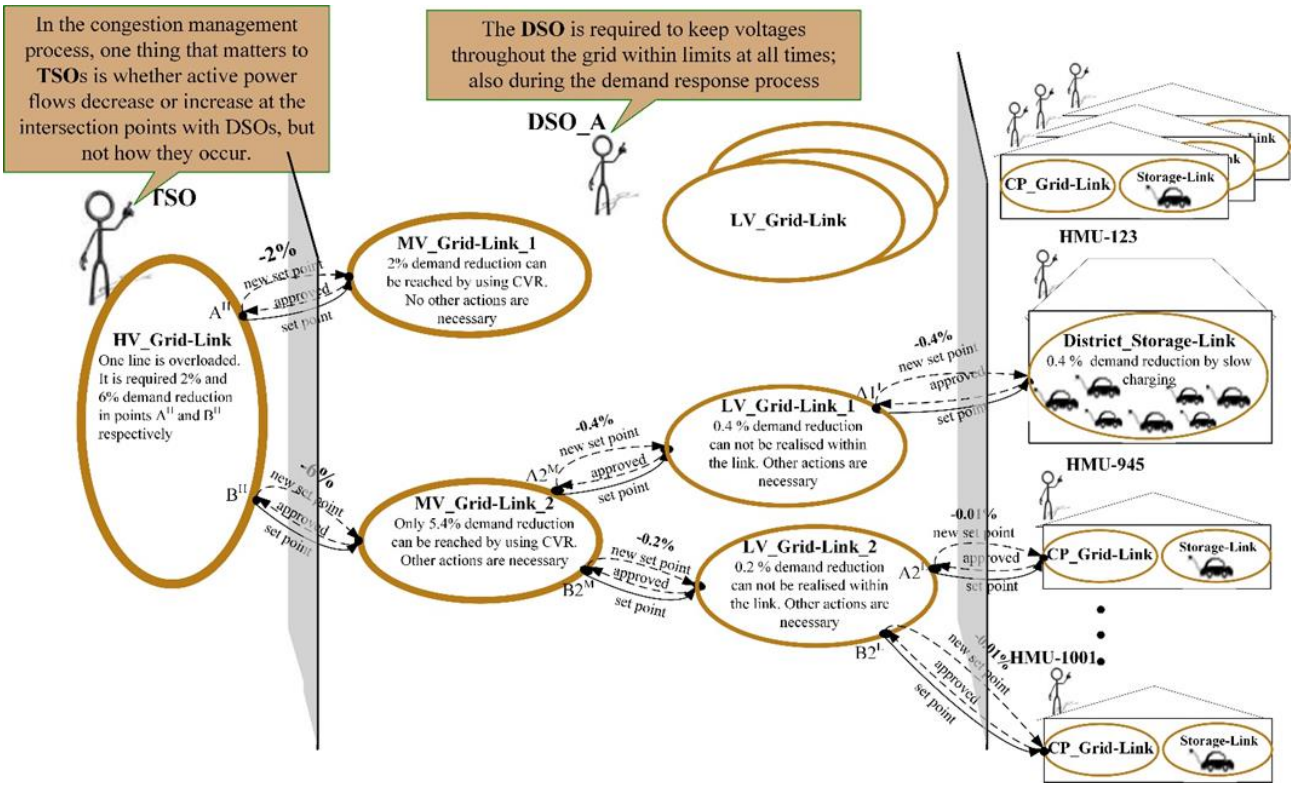


Figure 22 Information of emergency-driven DR process: Congestion on HVG e.g., line overload.

After receiving the request for new set points, DSO_A investigates all possibilities to realise the demand decrease. He cannot perform the CVR in its Link-Grids, and therefore, he should pass over the request to the customers, who already have signed a contract for participation in the DR process. After performing the calculations, DSO_A finds three BLiNs that are most suitable to realise the demand reduction: A1L in LV_Grid-Link_1 and A2L and B2L in LV_Grid-Link_2. Consequently, DSO-A initiates a demand decrease request and gives over the load decrease of 0.4%, 0.01%, and 0.01%, respectively. The request is accompanied by the setting and duration time of the new set points.

HMU-123, which is a district garage with e-cars, is connected to the BLiN A1L. After receiving the new set point request, HMU-123 investigates all possibilities to realise the demand decrease. He approves the new set point and notifies the DSO-A. The same approval and notifying procedure is also used by HMU-945 and HMU-1001. After collecting all replies, LVSO-B agrees on the new set points for the BLiNs A2M and B2M. Having the approvals from relevant BLiNs, DSO_A can also fulfil the BLiN BH requirements, approve the new set point, and inform the TSO. The latter sent the ultimate set points accompanied by the setting and the duration time. DSO_A makes the final changes on the set point schedules and sends the information further up to HMUs.

3. TSO PERSPECTIVE

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 represent an additional load, a big scale energy storage system, and a distributed flexible resource for grid services. Only through an optimal management of the bi-directional charging process will it be possible to solve the potential system challenges and take advantage of all the potential opportunities.

3.1 Impact on energy and capacity adequacy

EVs are projected to consume approximately 550TWh of electricity in the year 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 2). 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, in the event that smart charging is not properly deployed (e.g. coordinated with the actual grid capacities), power issues could arise due to massive EV diffusion.

Table 2 EV electricity consumption in selected countries and regions (Source: IEA).

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%

3.2 Grid impact use cases: private and public charging solutions

The regulatory framework as well as the associated technology to the public charging network are moving forward to develop an intelligent charging infrastructure. Thus, the integration to the electricity system will not be an issue. Profitable business models are expected to emerge as soon as the penetration of the EV in the transport sector increases enabling the flexibility of electromobility in the power system.

Nonetheless, and although the majority of chargers developed in private environments are today V1G enabled and there are many use cases demonstrating V2G functionality in a prosumer environment, not all private charging stations are intended to be smart, in the sense of observability and controllability, at least in a very first stage. Therefore, the implementation of implicit demand side flexibility mechanisms to incentivize the charging in valley periods by means of price signals will be very useful to counteract the fast and ultra-fast recharges promoted by public and semi-public infrastructures.

The charging strategies 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. Table 3 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.

Table 3 Use cases of charging strategies with different impacts on the power grid.

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

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.

3.3 EV as an opportunity to the system

3.3.1. Managing and monitoring 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 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 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.

FOCUS BOX # 3

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 (3-11kW) thus requiring to aggregate many vehicles, and/or other local small-scale flexibility resources to enable ancillary services.

Vehicles must satisfy users' driving needs. This limits the energy and time availability to provide flexibility services:

- The flexibility provider must 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.

Figure 23 Focus Box #3: EVs as a flexible resource (Source: ENTSO-E).

Charging stations, both private and public, will (or should) also be equipped with communication systems that allows real-time monitor of the power of the charging/discharging process. Observability will be crucial in advanced scenarios in which the EV will contribute to satisfy the energy needs of households and small and medium-sized enterprises by mean of V2H (Vehicle to Home) or V2B (Vehicle to Building) technologies. From the point of view of the system operation, the lack of observability will introduce uncertainty in the consumers demand patterns that will undoubtedly affect to the demand forecast. The guarantee of the security of supply by means of the balance between demand and generation has not to be compromised.

3.3.2. Main opportunities provided by EV charging management

Based on the previous arguments, a detailed analysis shows that several opportunities can emerge from the EV charging management (Figure 24).

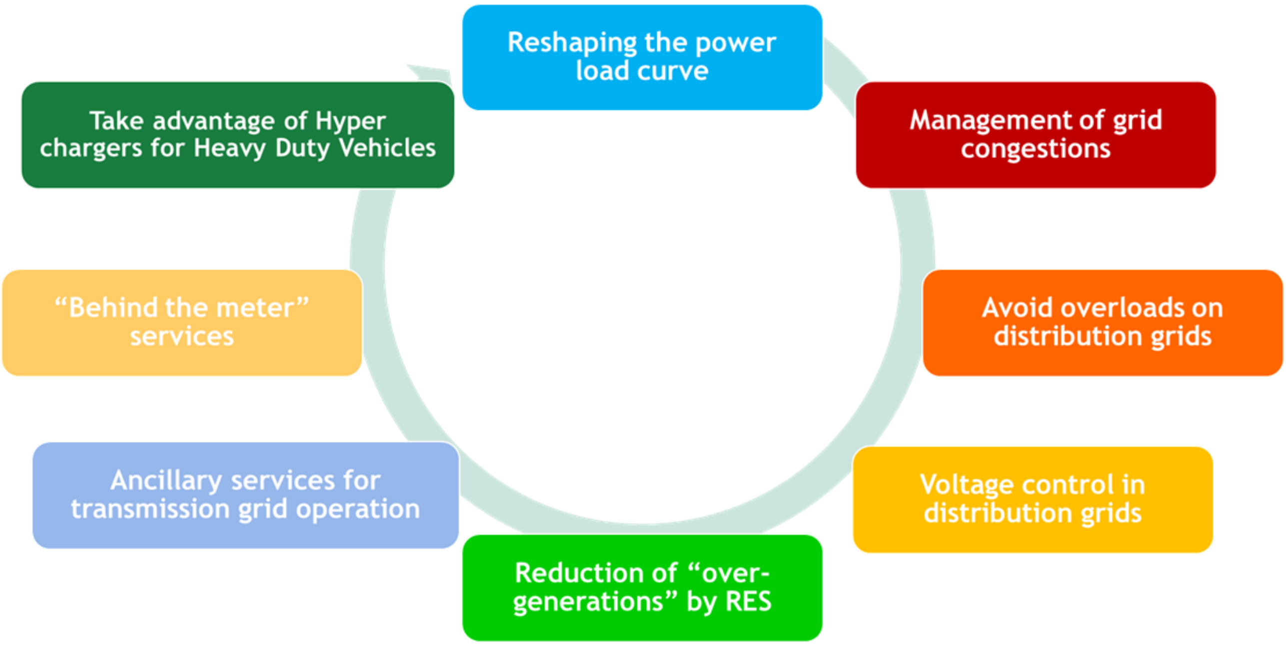


Figure 24 Opportunities for the whole system and actors.

OPPORTUNITY #1 – Reshaping the power load curve (Figure 25)

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 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 (e.g., hourly) 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 ToU tariffs and charging management by aggregators could be adopted. It is important to highlight the main differences between them: ToU tariffs cannot be changed frequently (e.g., weekly, daily) to be effective, while aggregators can provide flexibility requested the day-ahead (or in real time) and when necessary in some specific parts of the grid. In short, both solutions are complementary.

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. Moreover, grids will be operated in a more efficient way when some peak consumption is moved to off-peak times. 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 (e.g., in the case of charging EV instead of exporting the surplus of generation to the grid (from self-consumption); this might be very useful particularly in holiday days when self-consumption installations might create a surplus energy exported to the grid).

FOCUS BOX # 4

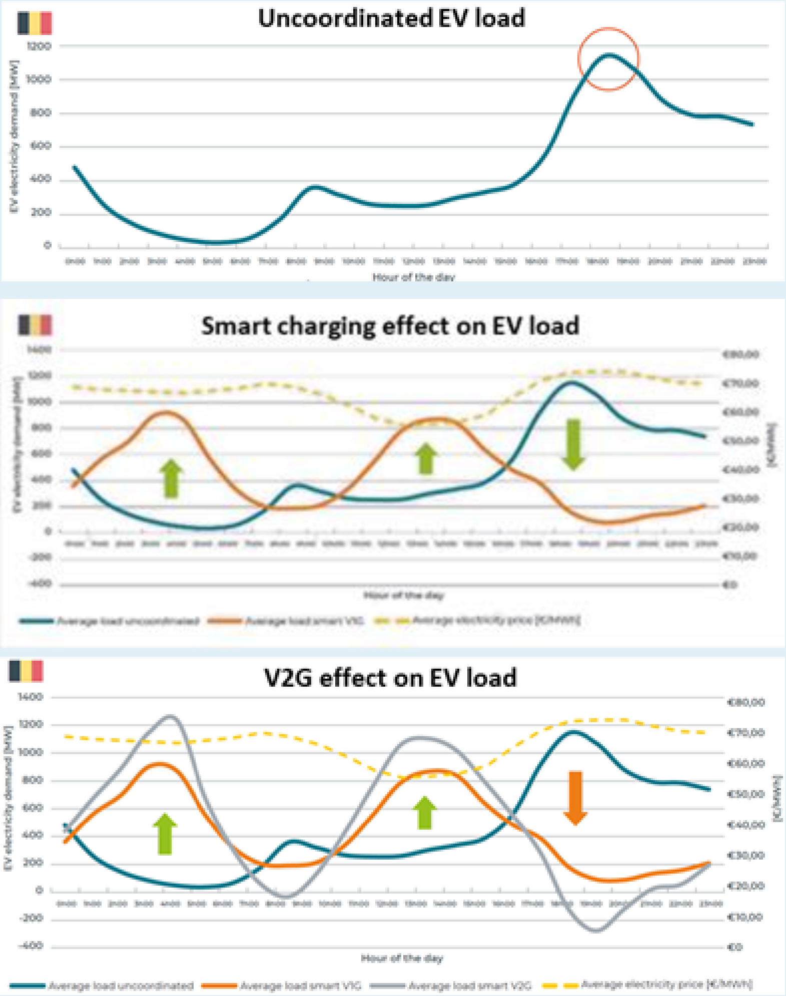
THE EFFECT OF SMART CHARGING AND V2G ON EV LOAD CURVE

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. Regarding grid reinforcements, the issue will be tackled in the next chapter.

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.



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

Figure 25 Focus Box #4: The effect of smart charging and V2G on EV load curve.

OPPORTUNITY #2 – Ancillary services for system operation

What?

EVs can be used to support the balancing system, keeping the frequency close to the reference of 50Hz. 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 the system 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 (e.g. aggregators) 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 in line with the actual and future European regulatory framework.

The charging infrastructure could also modulate the charge/discharge power based on system frequency values to provide primary frequency response according to Figure 26 and under the request of the TSO.

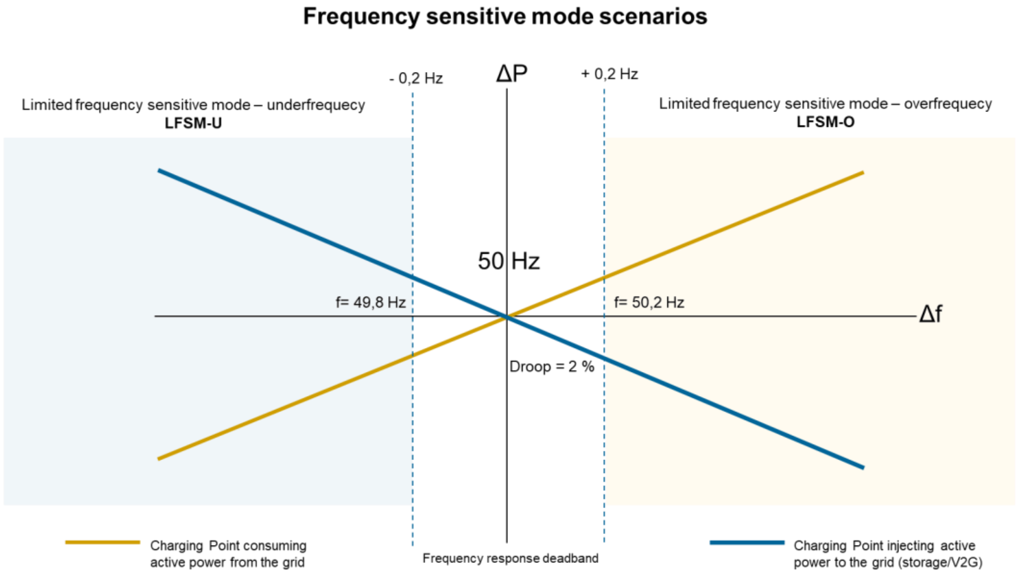


Figure 26 Charging point with frequency sensitive functionality possible scenarios.

Who benefits?

Most relevant benefits will be obtained by TSOs and grid users as EVs' support contributes to guaranteeing the whole power system grid stability, 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 minimize “re-despatching”. Being widely diffused on the territory, they offer TSOs and DSOs 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 and DSOs, as they limit “re-despatching” costs (use of sub-optimal generation or loads). Redispatching costs are reduced because EV are offering flexibility services and increasing the liquidity of the markets. As a service provided by vehicles, economic benefits would be also reflected to EV owners.

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). Related to this opportunity there are two different concepts: on the one hand, long-term flexibility markets are used to solve structural congestions, and on the other hand, short-term flexibility markets are used to solve unforeseen congestions, normally made now with redispatching markets (EV might be a complementary solution to deferring grid investments in reinforcements or additional capacity and unforeseen loads).

Implicit flexibility (e.g., ToU tariffs) might be another possibility.

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 (regarding LV grids, voltage is mostly controlled by active energy instead of reactive energy due to R/X ratio; however, if EV charging points are directly connected to the MV, then reactive flows become more efficient to control the voltage). 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 in periods of small national consumption, such as national holidays. EVs can schedule their charging process 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?

Although this opportunity can be considered form the user perspective in Chapter 5, it is important also to recognize that 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 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 and/or MV 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 (e.g., 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. However, if EV charging points participate in balancing services (FCR), sudden changes in their consumption (ramps) might result in relevant voltage problems in the distribution grids. This case could be more impactful in grids with low levels of short-circuit currents.

3.3.2. 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 can be reached simultaneously, and the benefits would be enjoyed by multiple actors. As an example, in Figure 27 the effects of smart charging on the German load profile are depicted, together with a PV generation histogram, showing the shift of demand peak to a time-slot where more electricity is being generated.

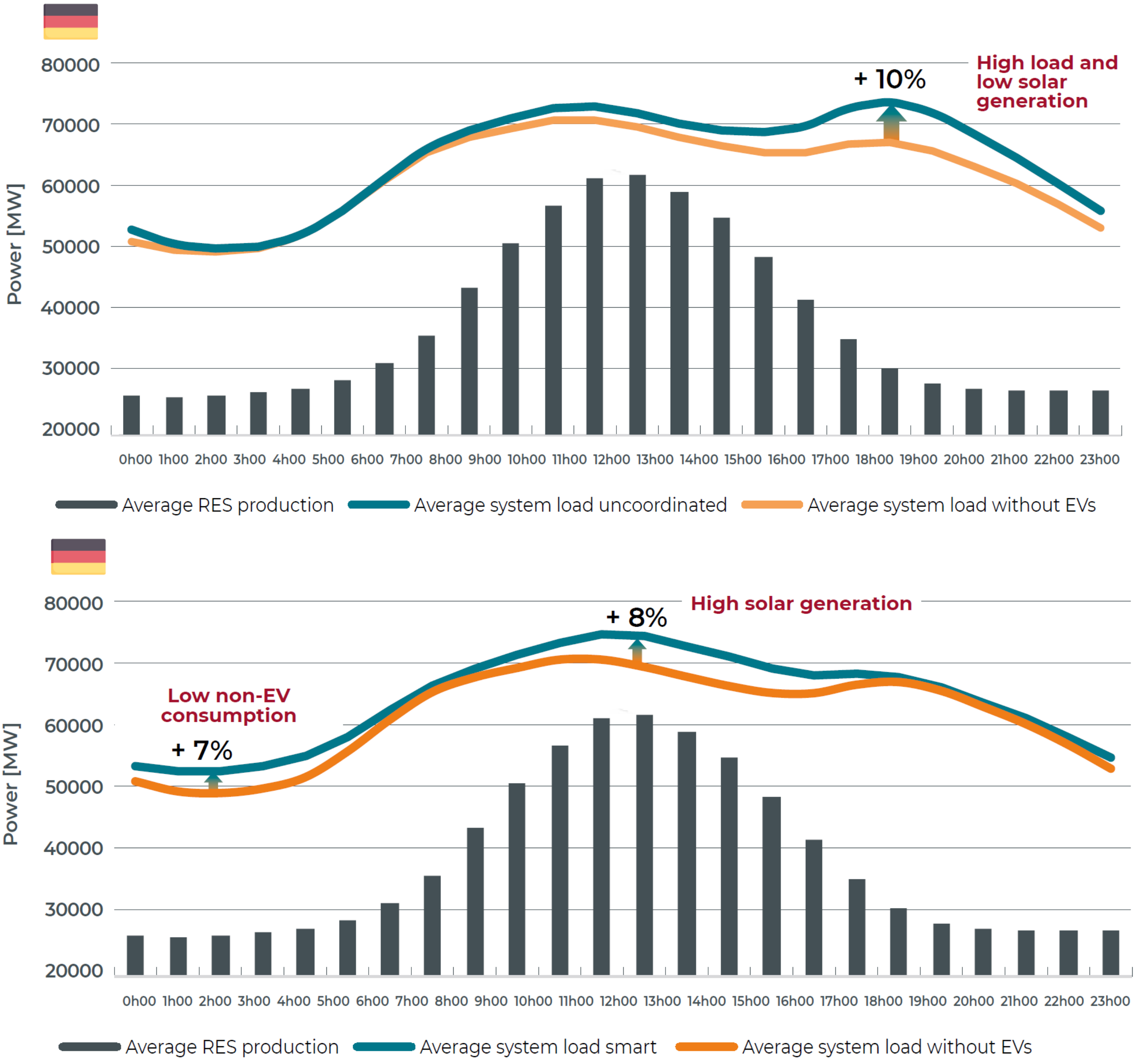


Figure 27 Average total electricity load in Germany with uncoordinated (up) and smart charging (down) (Source: Elia Group).

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 and all of them cannot provided at the same time. While pursuing one strategy, cross effects could occur, and they could be both positive and 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.

3.4 Demand side flexibility from electromobility

Storage and demand side management are two key flexibility tools for the system operation. In that sense, electromobility it's called to become an important player for the flexibility in the energy transition. But smart charging comes first in providing system flexibility.

The CEP (Clean Energy Package) places storage and demand facilities at the same level of generation plants, boosting integration of electromobility into the electricity network also through its participation in the power markets and new flexibility service markets for distribution networks. In addition, thanks to the transposition of the CEP into the Member States regulation, on the path of convergence towards the internal electricity market, as well as the implementation of the Electricity Balancing Guideline, balancing markets are beginning to open the participation to demand and storage facilities. It is the role of TSOs accompany these changes adapting their operating procedures in the field of scheduling, balance services, settlement, and measures to make this happen.

Harmonized and standardized products tailored to these new flexibility resources must be implemented within the EU markets. Smaller product sizes and shorter scheduling timeframes will allow these flexibility resources to compete at a level playing field. Therefore, on one hand, despite requiring smaller products, it is essential that the regulatory framework of the aggregator, and specifically the independent aggregator, be developed in the member states regulation. And on the other hand, it is also necessary the implementation of long-term contracts and quarter-hourly day-ahead and intraday markets to enable their participation. The quarter-hourly offers allow greater flexibility to the electric vehicle smart charging aggregators, being able to assign a greater number of offers than in the case of hourly markets.

TSOs can make use of demand-side flexibility not only on the balancing markets and non-frequency ancillary services, but also in other capacity markets needed to tackle the collateral effects of increased uptake of generation facilities from renewable energy sources that due to its variability and intermittency, certain risks may appear in the security of supply.

Another perspective of demand side flexibility for distribution networks can be read in chapter 4.3.

3.5 Different performances and their limitations: Vehicle-to-Grid

In a world in which is necessary to increase the use of renewable energies to reduce pollution and fight climate change, we also need large energy storage systems to deal with the variability of renewable generation.

With the main problem being large-scale electricity storage, the role of the EV presents a possible solution. The scenario of millions of electric vehicles connected to the grid can also be understood as having millions of battery energy storage systems (BESS) connected if V2G technology is finally fully deployed. Further technological innovation in this field will allow the use of the EV as a mechanism for energy storage, an increased integration of renewable energies into the electricity system and bidirectional energy flows (from the EV to the grid, V2G, and from the grid to the EV, G2V). The previous developments will enable new services, such as buying and selling electricity using the electric vehicle batteries. Users will have the opportunity, for instance, to export (sell) energy from their EVs at peak times, and then be able to charge (buy) energy during at hours when the price of energy is lower. These kind of activities for EV users could indirectly have important benefits for the electricity system since they could be considered a tool to reduce peak demand and, thus, making unnecessary additional power generation from power plants.

V2G can equally be use for peak shaving targeting moments of peak demand, by using the energy stored in EVs and bringing some economic advantages to both SOs and consumers:

- Savings in bills by avoiding high prices in demand peaks.
- Providing demand response services that can reduce demand peaks.
- Providing flexibility service to TSOs based on the set of BESSs.
- Reducing the intermittent operation of power plants (saving on start-up/shutdown and maintenance costs), and thus avoiding extra costs.
- Postponing investments in infrastructures and optimizing their utilization.

Nevertheless, there still exist important limitations nowadays. Charging infrastructure will need a significant investment effort for public and private chargers to implement these types of services. On the other hand, one of the most relevant tass of TSOs is to match power generation and consumption in a continuous way, and for this reason the current regulation requires that generation facilities have the availability of increasing or decreasing power generation under the real-time control of the TSO in the different balancing services. V2G (implementing controlled charging) provides grid connected EVs with a volume of stored energy that the grid operator can request as a service to regulate the network frequency. Nowadays this frequency regulation is mostly provided by large generators, with lower liquidity in the balancing markets for the system, probably leading to great costs, and used to balance active energy supply and demand. The fast charge and discharge cycles of EV batteries make V2G an alternative to those traditional frequency regulation mechanisms. More simulations of electronic interfaces will be needed to perform centralized control actions adapting the operating conditions of EVs, as in the case of providing frequency regulation services.

It can be deduced that EVs with higher capacity batteries will be well-suited to provide those flexibility services. EVs can be connected to the grid during large periods of the day acting as an electricity market zone resource, provided the charging process is also active (it must be noted that providing this kind of flexibility requires a battery with high charging efficiency and a high maximum number of cycles, which might be an economic barrier to participate in these markets if not properly fulfilled). In addition, it is recommended to have simple and timely information about the location of the charging points and their availability in near real-time needs. As well, improved demand forecast models will be necessary considering the user behaviour when connecting their EV to the grid.

3.6 Cross-border impact of transport electrification

There are different types of cross-border impacts caused by the electrification of transport. On the one hand, there are impacts derived from the freedom of movement in the road transport of passengers and goods at the borders of the EU. But on the other hand, there is an impact related to the internal electricity market that has nothing to do with passenger traffic.
The impact produced by direct road transport affects the planning of the charging infrastructure and therefore that of the electricity grid. In Europe there are cross-border migratory flows of people who travel to spend vacation periods in other countries. Road transport of goods will also produce a significant increase of the cross-border electricity demand due this activity that nowadays it is carried out by means of vehicles based on internal combustion engines. It is expected that Pan-European transport corridors will attend these flows, and in that sense, accompany the deployment of the charging network to the progressive increase of electric vehicles. But the fact is that it is not necessary to cross the border with your own vehicle: one can rent a car at destination, also producing a local increase in the use of roads.

Therefore, there is also an indirect significative impact produced by the increase of vehicles coming from other regions, which, added to those from rental fleets can, in some cases, even double or triple the usual volume. This seasonal variability in demand means that the intensive or light use of the charging infrastructure must be accurately forecast. Consequently, there is an impact on the planning of the grid, but the challenge it poses for the operation of the system to balance generation with demand under potential stress situations should not be underestimated.

There is another impact of a different nature that is related to the convergence of the EU in the internal electricity market. European regulations contemplate the cross-border participation of demand and storage facilities in electricity markets. This will allow system operators to have additional flexibility resources to attend to the balancing services. Coordination and information exchange between cross-border TSOs will be crucial to avoid imbalances between their grids.

4. DSO PERSPECTIVE

DSOs play a major role in facilitating customers and markets, including electromobility development. The uptake of electric vehicles might be a challenge for DSOs, but also an opportunity: car batteries' flexibility opens possibilities for integrating renewables, as an electric car can charge at any point when not in use. EVs are thus not only part of the energy transition, but they can also help foster its development. DSOs are ready to facilitate electromobility deployment, across low- and medium- voltage levels, from AC to DC and up to ultrafast chargers.

Today, the low numbers of EVs across Europe do not yet pose significant problems in distribution grids. As their share will be rising in the coming years however, DSOs will need to improve their network operations to meet a higher instantaneous (peak) capacity demand. This will be needed particularly as most of the charging will be performed at the low-voltage levels. The electric mobility load is expected to grow faster impacting mainly the Low Voltage (LV) network in the short term (the limiting factor for the LV grid is the capacity of cables, transformers and other parameters such as voltage levels or asymmetry), while in the medium and long term the impact will be extended to the Medium Voltage (MV) and eventually to the High Voltage (HV) networks.

4.1 Impact on distribution grids: visibility, monitorization and forecasting

Electricity distribution infrastructures, while playing a core role in renewable energy integration and improvements in the deployment of innovative technologies in the transition to sustainable and smart mobility, are also a crucial element for the decarbonisation and resilience of the energy system. Focusing on the electromobility angle, distribution system operators are challenged to ensure that the distribution network is prepared to connect chargers to the power grid.

One of the most relevant challenges that the electrification of transport poses to DSOs, together with operation, is related to the development of innovative methodologies for network planning that can take into account the uncertainties related to the forecast of future load capacity and the location of charging points, private and public. In this sense, smart grids managed by DSOs are an important source of information. Distribution smart grids and smart meters directly connected to the DSO grid will be the main source for measurement of the energy withdrawn from the grid or injected into the grid by electric vehicles. These main meters will guarantee the quality of the measurement and are used for the system observability that DSOs need to assess dynamic and permanent network conditions and to establish when, where and how the grid can be impacted by a higher demand coming from charging activity. On the one hand, planning for future loads makes explicit the requirement for reliable forecasts, and on the other hand, more accurate predictions can anticipate the ideal solutions for the system.

DSO must ensure the security and quality of supply and, just as any other load on DSOs' networks, AC and DC loads of EVs may impact system stability and safety. As described in chapter 2.1, there is a complete ecosystem with interactions between all actors, and effects on power quality, such as asymmetry, harmonics, and voltage quality, that can be reduced if electric vehicle and charger manufacturers adopt the relevant requirements. Therefore, and since DSOs are primarily focused on safety and reliability standards based on meeting peak demand, data input from customers in general, and services providers (e.g., charging points) in particular, is essential to have accurate load forecasts on distribution networks. In this sense, it improves the reliability of the specific criteria of operation and investments in infrastructure, and the integration of electric vehicles in the network could occur in a timely manner. Smart and reliable operation of distribution systems depends on the visibility over charging activities, planned charging stations' location and capacity and deploying smart distribution networks to enable widespread roll-out of charging stations requires proactive dialogue and coordination between DSOs and all parties.

Therefore, some levels of analysis and modelling of systems are required, including real-time state estimation based on real-time data and sophisticated demand forecasts tools using metering data and bottom-up aggregation of various load categories. At the same time, looking at synergies between forecasting tools applied by DSOs and other agents (e.g., TSOs and aggregators) can help DSOs to improve forecasts. For example, through common design, data exchange and cooperation of the different system operators. That also includes a holistic approach to urban planning that could successfully integrate charging load distribution of electric transport (cars, buses) and benefit both grids and municipalities. Beyond cities, early engagement with DSOs can also speed up the installation of fast chargers on motorways which places higher power demands on Medium Voltage grids. These forecasts are extremely relevant for network planning and operation.

In the case of smart charging management, the accuracy in the process of forecasting is more easily achievable. Since the amount of energy required for the charging process and the charging capacity are known up to a point, the charging process can be optimally adapted to the system. For this purpose, different kinds of data from the EV are required: the necessary electricity for charging can be calculated from the current state of charge and the battery capacity. The maximum and minimum charging capacity of the vehicle battery can be used to know the range in which the charging capacity can be adjusted for smart charging management. Smart meters remain the most powerful tool to obtain the information.

Therefore, it is extremely important that the data from the EV are transmitted to the charging device and made available to DSOs. Usually, the end consumer can often view this information via a display in the vehicle or an app from the vehicle manufacturer, but it still exists the need that external service providers can access the same data. This could be done by vehicle manufacturers if they provide a standardized technical interface for data exchange at no extra cost for third-party service providers. With such a communications service, DSOs and providers can have direct access to the relevant data and manage the flexibility potential of electromobility.

4.2 Network planning and capacity reinforcement

Network capacity upgrade is often wrongly identified as one of the main barriers to the roll-out of EV charging infrastructure in a timely manner. For this reason, network planning is key to support the deployment and integration of EV charging infrastructure in the distribution network. This is a regular exercise conducted by DSOs as part of network development and is not specific to integrating EV charging infrastructure since other requirements also need to be considered.

Uncertainty remains the main challenge for DSOs regarding the network planning for charging infrastructure, especially in the mechanisms for forecasting future load capacity and the location of charging points as explained in chapter 4.1. For this reason, the implementation of flexibility markets for distribution networks can represent an opportunity to face these uncertainties, activating flexibility from electromobility to solve unforeseen congestions or voltage problems. Nevertheless, electromobility policies and strategies in different countries, both locally and regionally, have yet to define the final scenarios, for instance, the role of mobility in cities or the lack of a joint overall strategy for electrification. In this sense, a more coordinated approach is essential to allow DSOs to perform grid planning, and the subsequent development process, which will facilitate the adoption and expansion of electric mobility in a more optimal way. Moreover, DSOs needs a comprehensive and integrated vision of the electrification plan from both the demand and production perspectives. For the DSO's perspective, electromobility works in parallel with the increase in distributed renewable capacity and works in synergy with it to support electrification.

The challenge is not the extra energy demand, but the simultaneous power demand on low-voltage networks. In addition to doubling the yearly electricity consumption of a household, EVs can increase (peak) power demand five times when many electric cars plug in at the same time (after arriving at home) in one street. The result is that DSOs will need to expand or reinforce their networks. But networks might not have the dimension to manage the peak demand happening at short timeframes, which implies that DSOs' networks should be used as efficiently as possible; for instance, by charging the EV in the afternoon with solar power connected to a parking (or charging) spot, or slowly at night. Here the car battery's flexibility (smart charging) comes into play to complement the necessary grid reinforcements.

Grid reinforcement requires an assessment consolidated with other upstream load increases to evaluate the overall impact on the network. These parameters relate to the characteristics of the distribution network in areas under consideration, and the expected future load requirements (accounting for both the location and power capacity requirements of the chargers). DSOs are evaluating all these factors to analyse the network status and develop various EV charging scenarios, thus allowing them to identify the available capacity and connection cost at different grid connection points. In this regard, different situations can be considered, and a distinction should be made between network planning performed for a specific connection requirement (e.g., integration of a known number of EV chargers in a specific area) and overall network planning. In both cases, the task of DSOs is to identify if congestions could happen and their exact location, assessing a wide set of parameters related to the characteristics of the distribution network in the considered area and therefore propose solutions for the different timeframes. According to the Eurelectric position paper, "*Debunking the myth of the grid as a barrier to e-mobility", 2021*[13], the following factors can be considered for that purpose:

- The exact location of the public, and eventually private, charging stations, and number of charging points.
- The technical features of the chargers such as the type of connection (1 phase vs 3 phases), the charging speed (slow or fast charger), power quality use (mainly harmonics from rectifiers or the existence of power input into the grid (V2G technology).
- The requested power capacity for the charger or set of chargers and the simultaneity factor.
- The use of smart charging solutions, e.g., controllability of the EV charging point(s) via load shifting, energy management of the charging station.
- The capacity of power lines and power transformers in the considered area and at the connection point.

Using different methodologies and processes, DSOs should play an active role and identify the areas where customers install private EV charging points behind their meters to analyse the potential impacts of such charging infrastructures on the peak power demand and thus evaluate the network situation, which can help to identify the best suited grid connection point with the chargers. For this purpose, the benefits of extended smart grids and the granularity of data that they provide are key to have a valid visibility of the different parts of the grid. As a result of the previous process, DSOs can determine if grid reinforcement is necessary in that case or alternative solutions can be proposed, such as the procurement of short-term flexibility services.

In the case of mid- to long-term network planning, the goal is to address the impact of additional future loads, including EV charging infrastructure, on the distribution grid. This is a forward-looking exercise where access to reliable and accurate forecasts of future electrification trends is key. This is in line with Article 32.3 of the Electricity Directive (EU) 2019/944 which states that DSO should develop this kind of plans at least every two years and they should have a particular emphasis on the main distribution infrastructure, which is required in order to connect new loads, including recharging points for electric vehicles. However, it should be noted that not all Member States have implemented this obligation in their national legislative framework. The European regulatory framework is also evolving and could also have further developments, as in the case of sector integration.

Nevertheless, the network planning should consider the total number of EVs already in use and their type, what should be in close connection with the forecasted density of charging points and their power requirements, ultrafast/fast/slow charging combined with the expected EV charging simultaneity factor and the utilisation rates of charging stations, taking into account behavioural patterns of the drivers such as charging location (e.g. home charging or public charging) and use of smart charging solutions and dynamic electricity prices. Other relevant factors are the timing and magnitude of EV charging power. Moreover, additional electrification trends and their evolution should also be considered (e.g., integration of heat pumps).

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[13] https://cdn.eurelectric.org/media/5275/debunking_the_myth_of_the_grid_as_a_barrier_to_e-mobility_-_final-2021-030-0145-01-e-h-2DEE801C.pdf

Two use cases are presented to illustrate how DSOs are dealing with the increasing penetration of EVs:

Use case of i-DE

An example of how DSOs use these parameters to develop various EV charging scenarios and predict future load profile is provided by i-DE, the DSO of Iberdrola Group in Spain, which conducted a study to assess how the incorporation of the EVs and heat pumps will mainly impact the LV network in the short term, while in the medium and long term the impact will extend to the rest of voltage levels. The report provided detailed a bottom-up network impact assessment to determine the reinforcements in the LV network and secondary substations ahead of needs, based on smart grids information and data analytics. The impact study developed a set of realistic scenarios based on socio demographic data and the National Energy and Climate Plan electrification goals and also uses a fleet distribution model (see Figure 28).

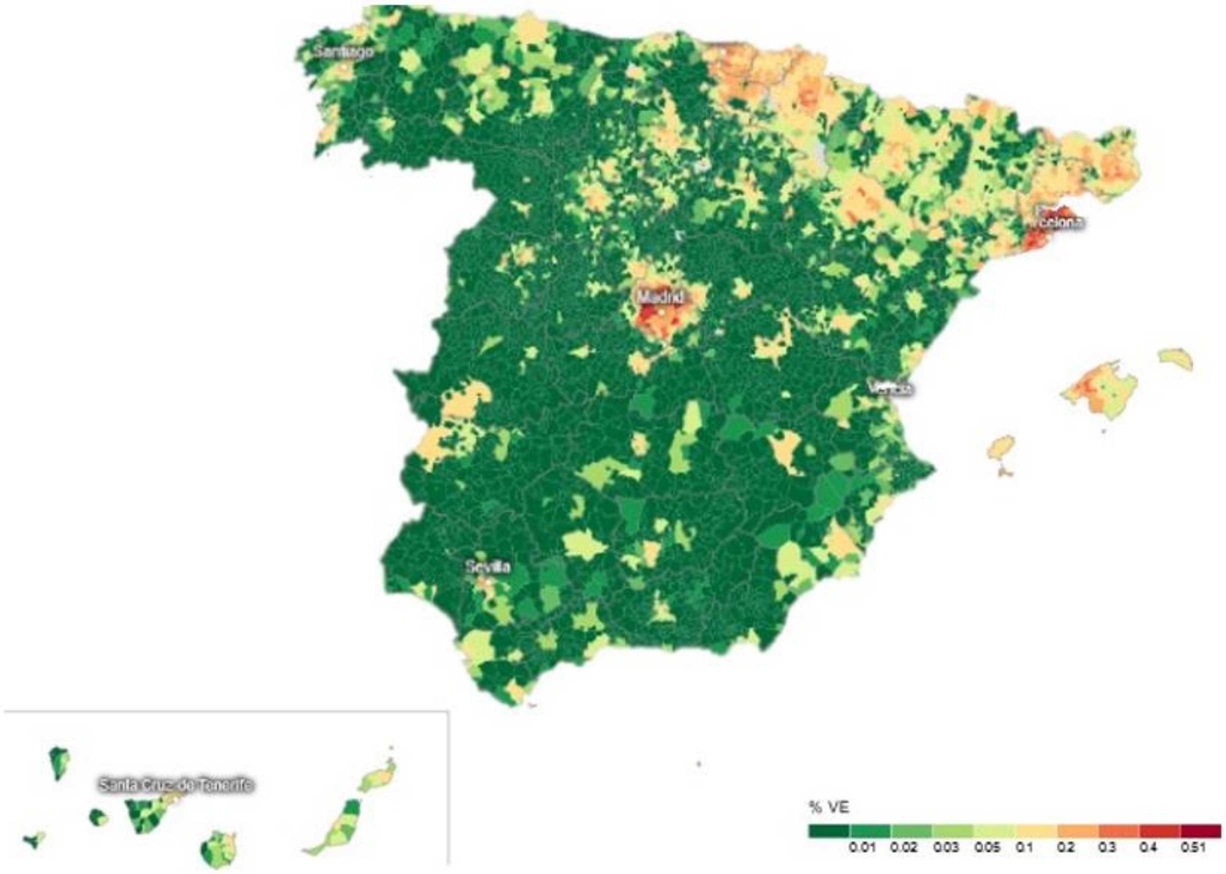

Figure 28 Relative number of EVs (Source: i-DE).

Once the model was established, the next step was to assign the calculated number of EVs (and eventually heat pumps) for each census section to individual connection points before performing a LV simulation. The model is prepared to perform hourly simulations of different scenarios, and, under these circumstances, the profile of the average load curve for EVs can be obtained from a group of existing charging points (Figure 29). Such profiles are then used to analyse the voltage and current load on network components to ensure that the network can satisfy all future loads (Figure 30).

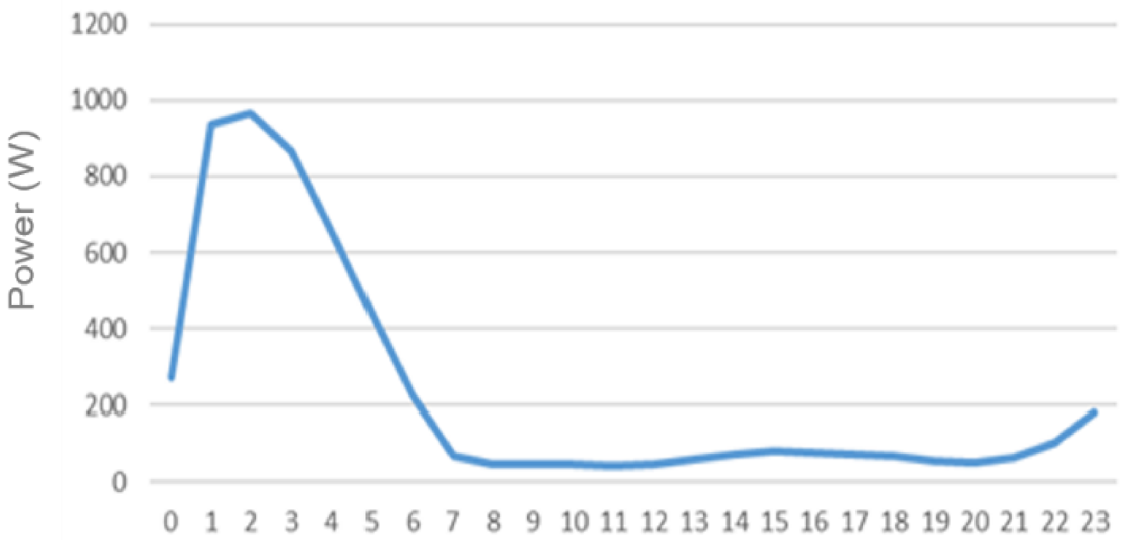

Figure 29 The average EV charging profile (Source: i-DE).

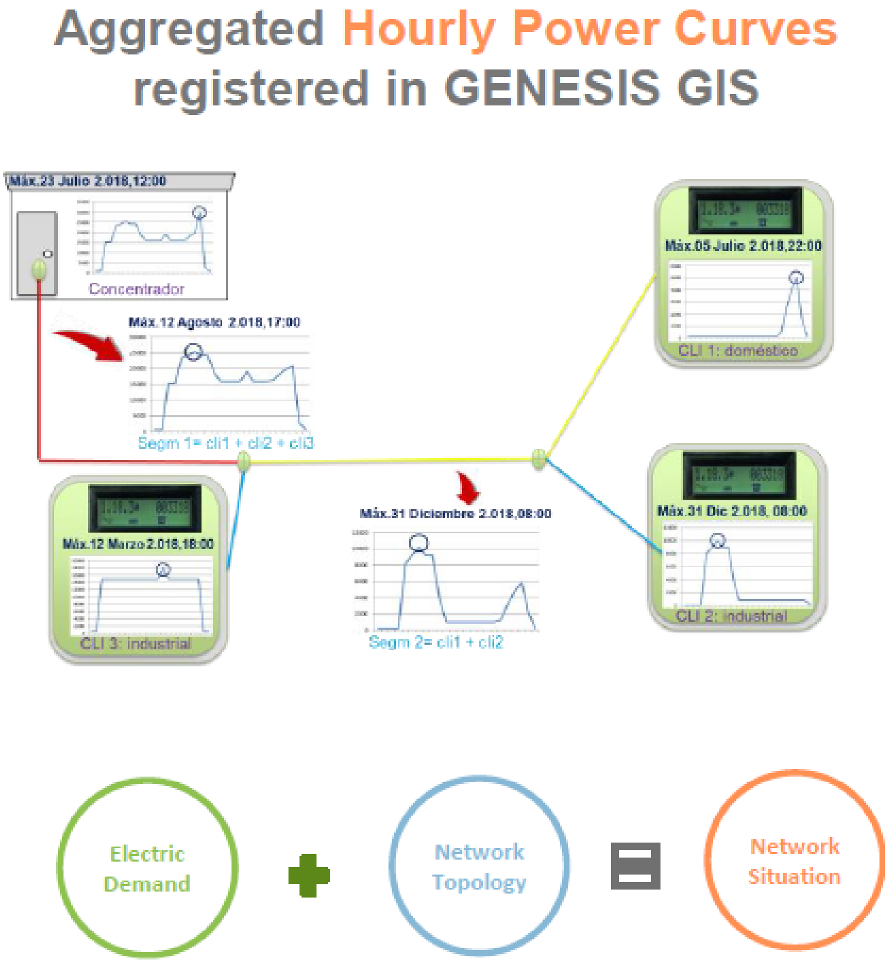

Figure 30 The model performs hourly simulations of different scenarios (Source: i-DE).

In the following step, a power flow simulation model was applied to 110.000 MV-LV transformers and to 150.000 km of the low voltage network. The simulation used data from the i-DE GIS with a very high level of granularity, which made it possible to analyse a wide spectrum of cases for the entire i-DE LV network. Finally, for each individual solution, the calculation included different parameters, such as transformers and lines load ratios, forecast demand and the possibility of connecting a new transformer.

The analysis showed that only 1% of LV lines will have overloads and voltage problems by 2030 in i-DE area. The simulation also concluded that smart charging could potentially reduce network investments by up to 40% (considering 100% of smart charging adoption) in massive adoption scenarios.

The most relevant outcome of this study is that the adoption of EVs is not a problem in the short and medium term since the most significant impact will occur mainly in very specific areas until 2030. In the short term, the incorporation of the EVs will particularly impact the LV network. In the long term, it will be extended to all voltage levels where new substations and transmission lines will have to be planned to support the existing medium and high voltage grids. The combined impact of electrification in the medium term is lower than the average peak demand increases between 2000-2005 of i DE in Spain (e.g., In the first half of the 2000s, with a high economic growth, demand increase was approximately 2.8% per year). Distribution companies have successfully faced similar challenges in the past and thus the necessary reinforcements in LV and Secondary substations in the most stressed areas can be adequately addressed with the investment plans.

It can be concluded, as a general principle for grid reinforcement, that the anticipation to the impact of increased load on the network is crucial to ensure that the network will continue within standard operation (power quality, reliability). Likewise, the low voltage network can also be overloaded in certain circumstances/scenarios where the capacity of the electrical equipment is nearly reached because of an accumulation of small increases in demand of from customers connected to the network. It is also interesting to point out that when home charging stations are installed gradually, in small increments, DSOs can monitor the load development, and therefore, reinforce network components as they become overburdened. In this sense, the more usual analyses consider the network situation in normal conditions (i.e., all elements are in service) and simultaneity factors are taken into account to detect when the network can be overloaded (i.e., the requested capacity is higher than the current installed network capacity).

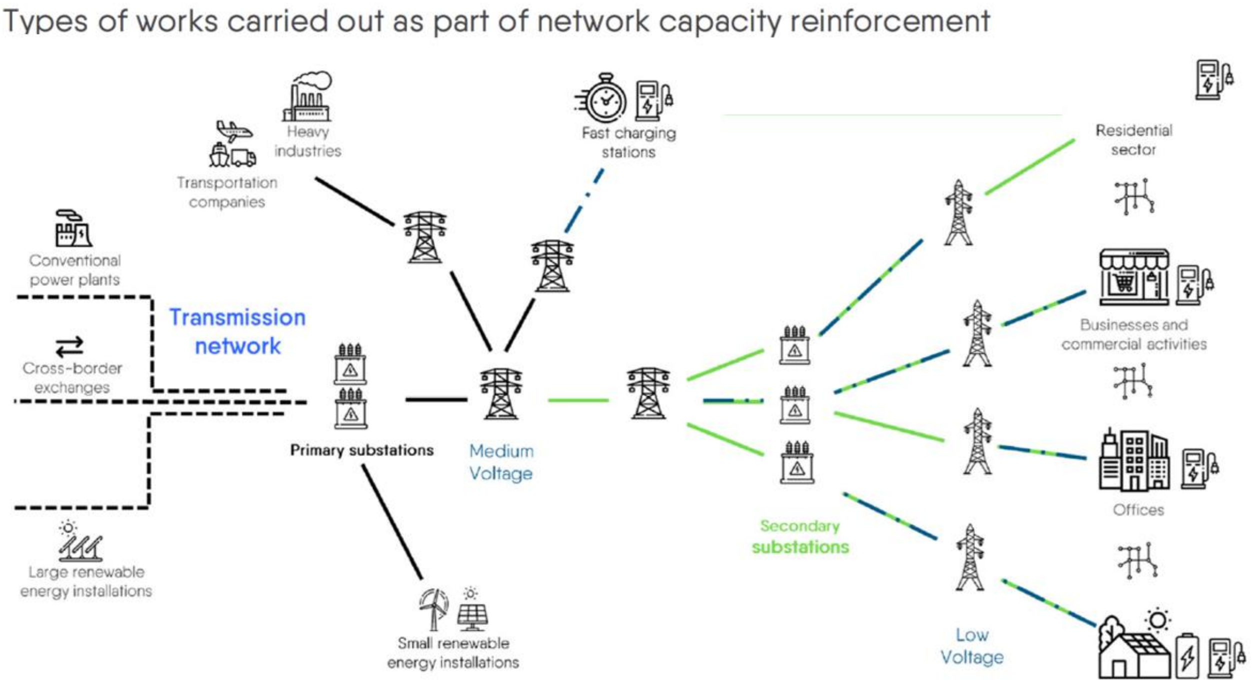

Figure 31 From the Eurelectric position paper “Debunking the myth of the grid as a barrier to e-mobility"[14]

As previously emphasized, it is important to adopt a coordinated approach for network planning. In fact, if other customers request additional capacity at the same point of the distribution grid, it is important that these requests are coordinated in order to optimise network investments and adequately dimension grid reinforcement.

Use case of Enel Global Infrastructure and Networks

Enel Global Infrastructure and Networks is facing several planning and operational challenges posed to the distribution network by the rapid uptake of EVs. In addition to the already mentioned forecasting uncertainties, the group faces increasing complexities caused by wide differences in the network design, electrical infrastructures, regulatory frameworks, and macroeconomic scenarios of the eight different countries where the company operates.

In this uncertain and complex future scenario, the time and resources required by traditional network planning methods are often too high, especially considering that rapidly changing planning parameters, including demand growth, EVs and DER penetration levels or evolving electricity markets would require continuous adjustments of the network analyses. The need for a fast and effective method to perform long-term distribution planning analyses for EVs integration has led Enel Global Infrastructure and Networks to develop an innovative network planning methodology, able to run multiple simulations in a short time and easily scalable to different networks. This is achieved by implementing a preliminary screening analysis to identify the most critical network elements in future scenarios. Only the higher-priority

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[14] Eurelectric, 2021, “Debunking the myth of the grid as a barrier to e-mobility”.

circuits undergo more detailed power flow studies to identify network constraints and grid needs. The introduction of a preliminary screening stage allows to limit the effort of detailed power flow analyses and therefore significantly reduce the computational burden for planning engineers, without compromising the accuracy of results. The new grid planning methodology proposed by Enel Global Infrastructure and Networks uses a four-step, needs-based approach (see Figure 32) to identify the amount of EVs and DER that can be accommodated on a distribution network before adverse impacts occur (commonly termed as hosting capacity).

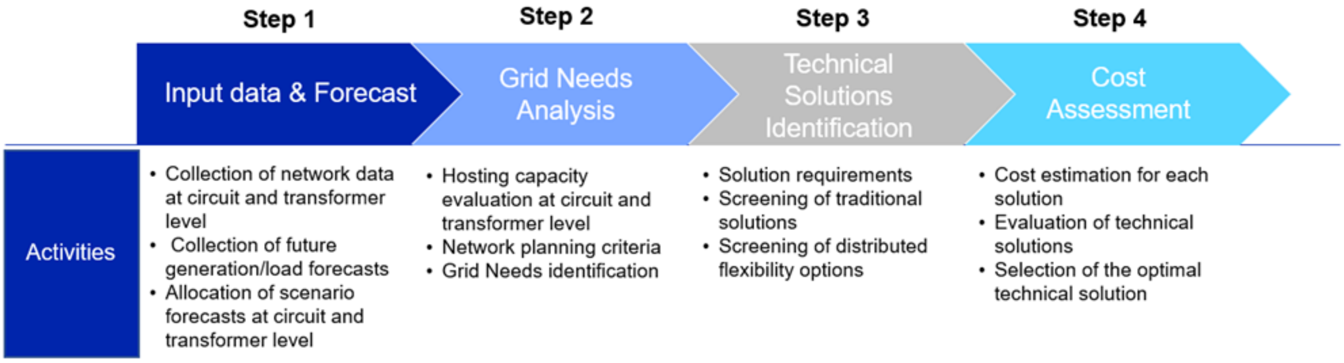

Figure 32 Stages of the Distribution Planning Process (Source: Enel Global Infrastructure and Networks)

First, the tool adds the future needs forecasted by Enel's proprietary and long-term energy scenarios to the current needs imposed on the existing network. While network data are available at circuit and transformer level, generation and load forecasts must be furtherly modelled to provide the same data granularity. For this reason, the grid planning tool employs multiple statistical methods (macro-economic, customer-level and geographical modelling) to allocate scenarios data to the circuit and transformer level and increase the accuracy of results. EVs represent the largest driver of the future grid needs and can be modelled both as loads and as generation resources to account for vehicle-to-grid applications.

The Grid Needs Analysis stage assesses the hosting capacity for every line and transformer of the network. If the network component has reached or exceeded its hosting capacity threshold, the tool triggers an intervention request. The output of this stage is a comprehensive map of all the hosting capacity grid needs at the end of the study period, in the selected concession area. In the Technical Solution Identification stage, requirements to meet the grid needs through traditional (network refurbishment, replacements…) as well as distributed flexibility (storage, demand side management…) options are considered. Lastly, using component-level cost data, the Cost Assessment stage estimates the investments needed to implement the optimal solution. Simulation results of the new grid planning tool applied to Enel's network use cases, show that the new methodology provides a quick, flexible, and effective solution to the challenges of distribution planning in the context of high EVs and renewables penetration, forecasts uncertainties and network complexities.

4.3 Demand side flexibility from electromobility

Demand-side flexibility is crucial to maintain security of energy supply and a stable network. Since the more relevant changes such as massive development of variable and renewable distributed generation and the expected growth of the electric vehicles charging will happen at distribution level, the role and the responsibilities of the DSOs is to evolve into an active system operator and a neutral market facilitator while maintaining security of energy supply and a more reliable network.

Additionally, demand-side flexibility assumes that consumers are willing to engage in demand response activities. Engaging consumers will require incentives and technologies for demand-side flexibility to work and deliver its full benefits. In the case of electric vehicles, incentives could be for example based on price signals, dynamic tariffs for charging vehicles or incentive-based demand response allowing the consumer to make savings by offering controllable charging to market and network operators.

In the planning phase, demand side flexibility can help to delay investments when the grid capacity is close to reaching its limit. Using flexibility from the demand-side thus avoiding or delaying an extension of the physical distribution grid can lead to significant savings for the DSO, for both consumers and society. It can also give the DSO time to assess other options, such as network reinforcement and smart grids, to ensure grid stability. In the operational phase, it can be a useful way to solve local congestion by influencing the consumption patterns of consumers, the charging patterns of electric vehicles and other appliances that are consuming significant amounts of electricity. Demand-side flexibility can be developed together with well-identified large users (using an important capacity during their business), and with residential users that opted for charging their electric vehicles, which also represent an important electricity use when aggregated. Demand-side flexibility can also be a tool to bring additional balancing capabilities; even if these services are useful for TSO, it is important to implement new procedures and processes able in collaboration.

In order to reap these benefits, DSOs should become the neutral market facilitator: gathering, managing and sharing data with retailers, aggregators and other authorised third parties, easing entrance of new players in the market, measuring and validating the use of demand-side resources connected to the distribution grid. But to be successful, appropriate incentives should be set up in order for the customer to reap benefits. For instance, some DSOs are currently using and investigating solutions like incentive-based demand response (reduced tariffs or lump-sum payments that provide the DSO with limited, but clearly defined access to demand-side flexibility) which enable consumers to make savings by voluntarily adapting their electricity consumption to grid needs. Again, it is crucial that DSOs cooperate with

TSOs, being able to identify the resources which are directly connected to the distribution grid and at the same time involved in ancillary services for TSOs.

In this respect electric vehicles connected to the distribution grids can be a huge opportunity to avoid network overloads. The issue is the long period of time that cars, on average, are not used during the day. They spend most of the day as a "stationary vehicle" in the parking lot of the employer, in front of the supermarket or at home and therefore as electric vehicles could offer significant flexibility potential to the energy system. During this idle period, the charging process can be adjusted according to various parameters such as electricity supply and grid utilization. The EV could, for example, charge preferably during a period of high injection of photovoltaic and wind energy and thus make efficient use of surplus renewable electricity. Furthermore, charging can be done at times of low network utilization, optimizing the grid use and reducing the need of further expansion of the distribution network.

Other solutions whereby flexibility is extracted without a connection contract are also explored. Examples of market-based solutions include the possibility of a ‘flexibility marketplace’ where customers can offer their flexibility through a third-party, usually an aggregator’s or single EV charging point offer (depending on the lower bid size allowed for demand response). In this case, the contract is between the DSO and the aggregator, an option which can also allow to solve a specific local need. Unlike for the TSO and BRPs, the congestion in the distribution network is a very local challenge (but a crucial one). Given the local nature of the DSOs’ challenge, EV charging stations have a high potential for these new flexibility markets (provided by consumers/connections with flexible loads under a specific MV/LV substation). Nevertheless, liquidity in the local flexibility market could be too limited to create a marketplace for managing DSOs congestions (e.g., in rural grids).

Where the regulation allows it, direct dynamic smart charging using a variable capacity contract combined with the right tariff can represent a viable and cost-efficient form of local load management. The dynamic smart charging option (within the limits of the contract) in order to be effective and efficient should be effectuated through the use of standardised ICT protocols (from the DSO to the CPO, and to the charging station).

4.4 Managing the integration of electric vehicles in the distribution grid

The additional demand from EVs in terms of total consumption of energy over time (kWh) will not represent a critical factor for the DSOs, as this can be handled with the existing grid and generation capacity. However, in terms of power demand (kW) the additional loads can cause a significant higher peak load (i.e., in case of charging resulting in simultaneous power demand on distribution networks).
The impact on the peak load will be critically dependent on the charging behaviour of users: if all EVs start to charge at the same hour (i.e., cars charge as soon as the drivers plug in on arrival at their destination or at a specified timeframe in case of large differences in the cost of energy at night), the impact will be much higher than in cases where the charge is spread more evenly on the low demand period.

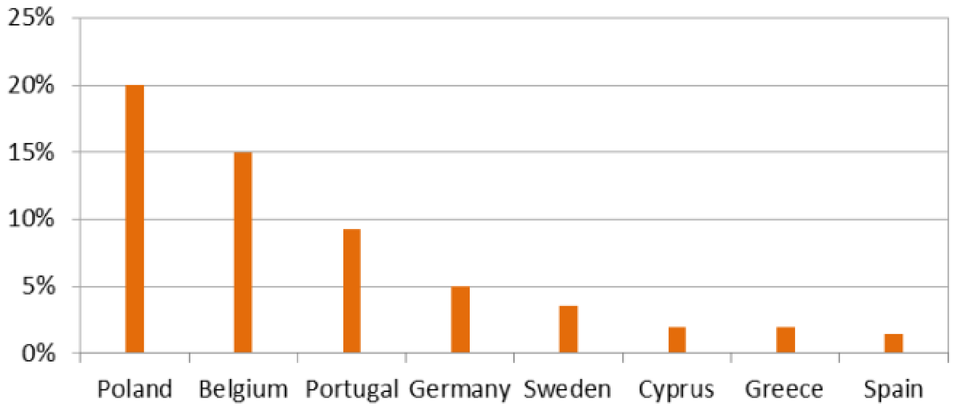

Figure 33 Estimated EV peak demand vs. overall country peak demand in 2030 (%), EDSO 2018.

Higher peak loads can cause (relatively short time) congestions on distribution grids, adversely impacting on voltage and network capacity. Overloads of network equipment can reduce the life expectancy of grid components. These can also lead to voltage fluctuations outside their designated margins causing consumers’ devices failures. From the balance responsible party point of view, a significant number of new quick start power plants might need to be ramped up to provide ancillary services, but the challenge of congestion is not so direct/obvious. The case of (ultra) fast chargers can illustrate the challenges that DSOs could face in the coming years, since it is the most extreme situation. They are usually connected to the MV grid which, in normal situations, has enough capacity. The costs of these connections are based on the actual costs of making the connection. Thus, grid connections/extensions to facilitate (ultra) fast chargers are, in most countries, fully paid by the requesters of the connection. Since (ultra) fast chargers will in most cases have their own transformer, there are no other users that will be negatively affected by possible voltage fluctuations when charging starts at full capacity. The impact on the other side of the transformer (MV side) will be limited. Nevertheless, DSOs will need to be properly engaged and consulted to coordinate and facilitate the connection of (ultra) fast charging stations to the MV grids (e.g., managing smoother upward load ramps). Depending on the specific grid conditions, an impact might be considerable if there are several ultra-fast chargers with dedicated transformers close to each other and attached to the same MV connection/or in case of powering multiple electric buses at around the same time. This can also be an issue in networks where gas stations on the roads and motorways are connected to low-powered transformers (up to 250 kVA). In these cases, DSOs will have to upgrade transformers or even the whole MV feeder (in some cases also

HV/MV substation and/or HV network could be involved, depending on total power of installed fast chargers) to handle the additional power.

In a more general situation, smart charging, also known as V1G charging, enables to control the charging of electric cars in a way that allows the charging power to be increased and decreased when needed (in this case, the power flow is mono-directional). V2G goes one step further and enables the charged power also to be momentarily pushed back to the grid from car batteries to balance variations in energy production and consumption. Cars can be charged smartly only if they are connected to charging stations that are smart charging ready. It should then be recommended to equip both existing and new charging stations with smart charging devices. Developments of interoperable communication protocols (IEC 61850 family Standard could be a reference basis) are equally important[15]. Interoperability of data, commands/settings and information is essential to communicate with all parties, including aggregators among others, in the smart charging process – from the grid to the charging station and the car itself.

Smart charging can help to streamline demand for energy (and thus capacity) by adjusting the charging profiles with the supply for energy and grid capacity. This means that the power level to charge an electric vehicle can be reduced at times when there is high demand for energy and/or less available grid capacity. Energy stored in car batteries can even be used to feed electricity back to the distribution network (V2G technology) or lower demand from the customer's side (vehicle to home or V2H). Smart charging could be done directly by the DSOs if there is a communication channel available from the DSO to the charging station. DSOs can communicate directly with the CPO or an aggregator and, depending on the technical architecture, the site owner through an energy management system. The CPO then delivers the requested smart charging profile on the charge stations managed by that CPO, within the predefined contractual settings between the DSO and the customer.

The smart charging process could also follow a route via a centralised system – in that case the local nature of the congestion challenge should be considered. A straightforward aspect is to include mandatory registration of charging stations (also behind the household connection) to have a good visibility on them. In this case the ICT-route is different but smart charging is performed within the contract between the DSO and customer. The aim is also to match the needs of these different stakeholders for an optimal management of EVs. In such a multi-player market the DSOs will be enablers for the uptake of interoperable services for smart charging. There is thus a need to adopt the regulatory framework regarding the role of DSOs in demand response and by deploying specific flexibility markets in distribution networks. At least in the early adopters' phase of introducing demand response technology, it should be necessary to consider the very local nature of congestion challenges and the lack of liquidity to solve the challenge in a market-oriented approach. In enabling direct dynamic smart charging, DSOs will need more investments in smart grids and enhanced supervision to reach visibility of the status of LV grids, where smart meters can play a major role to monitor the grid in real time and identify the need to procure flexibility services. Investments in new methodology and grid tools will also be needed to assess the potential of congestion management, peak shaving, and the value of smart charging. It is crucial that DSOs have a smart grid in place where most of the LV/MV networks are remotely monitored and controlled to detect potential congestions in real time and avoid network constraints.

In general, it is essential for DSOs that the smart charging infrastructure is equipped with all the necessary technology to manage the charging process. This must include both a communication and a control link, but not only. In fact, V2G will act as generators and the EC request is that reference standards will mirror the principles defined by family Standard EN 50549. The charging process should be controlled according to trade-offs between DSOs' constraints and customers' needs. Smart charging will ultimately depend on meeting customers' needs so DSOs and CPOs should first better understand the charging processes and customers' behaviour when developing charge management strategies tools and methods. This will help raise customers' acceptance and awareness of related benefits and risks, including overcoming anxiety concerns of losing control over their car. In doing so, DSOs will contribute to achieving more sustainable transport and green energy goals.

As said, in the future, not only smart charging will play an important role for the energy system and new business models, but also the Vehicle-to-grid (V2G). This concept aims to optimise the way we transport, use and produce electricity by turning electric cars into 'virtual power plants. Under this concept, electric cars would store and dispatch electrical energy stored in networked vehicle batteries which together act as one collective battery fleet for 'peak shaving' (sending power back to the grid when demand is high) and 'valley filling' (charging at night when demand is low). Energy can be sent to the distribution network by using bidirectional charging solutions. Possible applications include for example the provision of many system services. Possible applications include for example the provision of many system services such as balancing to support frequency control, reactive power, or the use of the EV battery as a source of providing flexibility to the grid. In fact, there are ongoing work to identify new possibilities of V2G acting as generators (e.g., as in the European Stakeholder Committee Expert Group of ENTSO-E which has currently an expert group discussing the advanced capabilities for grids with high shares of power park modules, which can provide, among others, support to systems in cases of low frequency disconnection, system inertia, system voltage, short circuit power, etc.).

It is important to consider the V2G concept in order to use this flexibility effectively in the future, and thus, to develop the correct regulatory framework. DSOs will finally deepen their role as active system operators, in addition to their role as network operators.

4.5 Deployment of charging points

DSOs play a key role in the deployment and integration of EV charging infrastructure in the electricity network and much experience has been gained by connecting thousands of charging points to the power system across Europe. The participation of DSOs in the deployment of charging infrastructure for EVs can be explained from two angles: planning of the grid considering the needs of present and future

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[15] European Commission, "Draft standardisation request as regards communication exchange, electricity and hydrogen supply for road, maritime transport and inland navigation in support of Directive 2014/94/EU and its planned revision under the 'Fit for 55' package".

charging points and stations, as explained in the previous chapters, and the role that DSOs themselves play as charging infrastructure promoters.

When DSOs act as the closest network operators to the charging infrastructure, the approach to network planning for the roll-out of charging stations from their perspective is similar across geographies in Europe and comparable with other new network accesses. However, network planning remains a local exercise that depends on a wide set of parameters. Furthermore, a distinction should be made between network planning performed for a specific connection requirement (e.g., integration of a known number of EV chargers in a specific area) and overall network planning, which should be based on a network development plan to be published by the DSO at least every two years according to Article 32.3 of the Electricity Directive (EU) 2019/944.
But on another perspective, the role of DSOs in the context of the deployment of electric vehicle charging infrastructure is defined under Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 concerning common rules for the internal market in electricity and amending Directive 2012/27/EU. Article 33, entitled “Integration of electromobility into the electricity grid”, states that Member States shall provide the necessary regulatory framework to facilitate the connection of publicly accessible and private recharging points to the distribution networks. Moreover, Member States shall ensure that distribution system operators cooperate on a non-discriminatory basis with any undertaking owning or developing or operating recharging points for electric vehicles, including their connection to the grid. Article 33 (2) of the Directive states that distribution system operators must not own, manage or operate recharging points for electric vehicles unless the distribution system operators have private recharging points for their own use only.

Furthermore, paragraph 3 of the same article sets out the conditions under which it is possible to derogate from paragraph 2 if it is established that there is no interest of other operators to perform that activity. If such a derogation is applied, it is necessary to verify the existence of interests of other entities on a regular basis and, in case it is reported, Member States shall ensure that distribution system operators’ activities in this regard are phased out.

Although the Directive clearly establishes that the DSO should not be involved in the development, installation, and management of charging stations in the more general situation, the role of the DSO must be seen in the context of planning the installation and connection of charging points to the distribution network to have a coordinated approach with distribution network long-term planning and scenario improvement. Moreover, and when conditions are met under the consideration of Article 33 of the Directive (EU) 2019/944 for DSOs to install, operate and manage charging points, the possibility of DSO performing the installation and running operations, either in a public or private area, presents a cost-efficient solution, accelerating deployment of charging spots and guaranteeing open access and support standardisation, and avoiding heterogeneous technologies at the same time. Not currently being a specific objective for DSOs, the above considerations must be considered for those national cases in which they are called upon to contribute to promoting the deployment of charging points.

5. USER PERSPECTIVE

EV users have specific needs and expectations and their interaction with electrical infrastructures at home, work or other places must be also analysed, understood, and satisfied. In fact, EV users set the conditions for having their vehicles charged. Their direct involvement is the basis upon which to make the charging process a success and their behaviour drives the subsequent impact on the electricity grids and thus the way that system operators must manage them. The user perspective is crucial to understand the whole picture of the integration of electromobility.

5.1 User typologies and their behaviours

Based on their behaviour, users can be classified in several typologies:

- Domestic user for private use: generally speaking, this consists of a daily use of an EV for less than 60 km during the working days and occasionally at the weekends for less than 150 km. Charging at home every day by night in a private slow charging point. Occasionally, the domestic user needs to connect to fast and ultra-fast charging points during long distance (more that 500 km) journeys.
- Domestic user for professional use: daily use of the car during the working days for up to 300 km. Occasionally at the weekends for less than 150 km. Charging at home by night in a private slow charging point and many days charging in a public fast charging point. Occasionally, the domestic user needs to connect to fast and ultra-fast charging points during long distance (more that 500 km.) journeys.
- Commercial user light: daily use of the car during the working days for up to 300 km. Occasionally, this user needs to connect to fast and ultra-fast charging points during long distance (more that 500 km.) journeys.
- Commercial user heavy: daily use of a big van or small truck during the working days for up to 300 km. Occasionally, this user needs to connect to fast and ultra-fast charging points during long distance (more that 500 km.) journeys.
- Public user light: daily use of a car for public transport during more than 300 km. Usually in the city but occasionally long distance.
- Public user heavy: daily use of a bus for public transport during more than 300 km.

5.2 User needs and their satisfaction

Another step forward in understanding the customer experience and interactions with the charging infrastructure is to consider their real needs, which can be different considering the existing types of users. Another classification can be proposed to structure the different needs of users:

Needs for domestic users:
- Slow private charging point at home
- Slow private charging point at the working place
- Fast public charging points in the cities, malls, or any other public places
- Fast and ultra-fast charging points every X kilometre of the highways and main roads

Needs for the light commercial vehicle user:
- Slow private charging point at home
- Slow private charging point at the working place
- Fast public charging points in the cities, malls, or any other public places.
- Fast and ultra-fast charging points every X kilometre of the highways and main roads

Needs for the heavy commercial vehicle user:
- Slow private charging point at the working place
- Fast public charging points in the cities, malls, or any other public places.
- Fast and ultra-fast charging points every X kilometre of the highways and main roads

Needs for the light public vehicle user:
- Slow private charging point at home
- Slow private charging point at the working place
- Fast public charging points in the cities, malls, or any other public places.
- Fast and ultra-fast charging points every X kilometre of the highways and main roads

Needs for the heavy public vehicle user:
- Slow private charging point at the working place
- Fast public charging points in the cities, malls, or any other public places.

To streamline the user experience and increase the broad acceptance of EVs and their benefits for the energy system, it is necessary to deal with the current electromobility hurdles[16], namely the following:

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[16] SmartEn White Paper - Making electric vehicles integral parts of the power system (2019) - https://smarten.eu/wp-content/uploads/2019/07/FINAL-smartEn-White-Paper-E-Mobility.pdf

1. *Interoperable and broad range mobility payment methods*

Currently there are two payment options for electromobility: ad hoc and contract-based charging. In ad hoc payment, the EV drivers must sign up for each charging provider system, using an APP and a Radio Frequency Identification (RFID) card. Regarding data privacy, current payment systems in public chargers, require confidential Personally Identifiable Information (PII) associated to their APP accounts, unlike gas stations, where people only use their credit card or physical money.

EU open payment protocols and standards would improve the public chargers user's experience, further promoting EV adoption. Moreover, EV drivers should be able to choose the payment method that meets their personal preferences. This is possible by ensuring that public charging points also offer ad hoc charging solutions and not only contract-based charging. And, by ensuring ad hoc payments methods that are universally accessible and that comply with GDPR, public charging payments would be simpler as paying for gasoline or diesel.

2. *Ensure price transparency for public charging points*

Currently, in public charging points, there is still great price uncertainty for the consumer, particularly when roaming, since he is often not aware of the exact price before charging or has unexpected costs on his bills.
As stated in chapter 2.2, there is the need to revise the Alternative Fuels Infrastructure Directive (AFID), to make EV charging tariffs transparent and comparable. For example:

- provide a transparent price/kWh to end-users before charging instead of using the amount of power to charge an EV.
- encourage smart applications or websites for price comparison and real-time pricing that could also display pricing adjustments for flexibility services provided.

3. *Consider charging point operators as service providers.*

AFID should emphasize that CPOs must be considered as service providers of EV charging, and not as energy suppliers. This would prevent additional supplier-related requirements for CPOs. There is no need for a legal separation between CPOs and suppliers, only for a clarification of roles.

4. *Common requirements for smart meters in the charging infrastructure.*

Imposing separate and specific metering requirements for the EV charging infrastructure (CPOs, EVs, etc) would differentiate loads, harming local energy resources optimization. It would create useless complexity in metering and billing, creating barriers to smart meter deployment and slowing the electrification of the transport sector.
Any limiting requirements to alternative innovations in this field must be avoided, for both private and public charging stations. Charging stations should be designed to provide various services (as smart charging, V2G, V2H, etc.) avoiding obsolete infrastructure deployment.

5. *Common registration processes for EVs as service providers*.

The registration process is a key first step to provide energy services. Harmonisation across Europe is important to avoid mixed requirements regarding regional variations of the countries' registration models since this would limit possible economies of scale from the automotive manufacturers to its consumers.

The registration process to provide services, using an EV, should be easy, to facilitate consumer engagement with the electricity system. A specific EU regulatory framework could anticipate that an EV and its services would be registered at the same time of the usual car registration. No further steps should be required. This registration should provide clear information on the flexibility capabilities of each EV and its V1G/V2G capabilities. This information must be transparent and accessible to consumers, prior to purchase.

Taking the case of Germany as an example, we can see that this country has the biggest national passenger car market measured in sales in Europe (ACAE 2019). Despite this, its current market shares for PEV are around the European average and lacking behind Nordic countries. One of the discussed and possible reasons for this is the lack of social acceptance of this new kind of technologies[17].
As this example shows, socio-political acceptance is paramount to understand the development of electric mobility. Relatively low number of academic publications investigates general attitudes towards electric vehicles. One the studies by Kühl et al. (2019) analysed current English and German literature and compared them with German statements in Twitter. This comparison is supposed to intertwine user statements with more general discussions happening in the literature. They found out the 60% of content are discussion about price and car characteristics while the rest of the discussions vary more in scope, with infrastructure and societal issues as the next strongest categories at 40% of the content. Another study by Zaunbrecher et al. (2015) explored the attitudes and opinions of non PEV users in focus-groups.

The perceived main benefit of PEVs seems to be environmental advantages and concerns raised were about price, infrastructure, security of the technology and practicalities (some of these partly guided by misconceptions). In 2015 Mazur et al. compared the policy strategies of the UK and Germany, outlining differences that are relevant for policy makers. The study observed that in Germany the policy makers were much more reluctant to increase regulative pressure; however, this didn't mean that the country was against the electric mobility transition but that it was much more economically dependent on the current automotive industry. A more recent study by Burghard et al. (2019) set out to analyse the activities of German municipalities around electric mobility. It used a survey study that found out that 80% of municipalities are already active and representatives from municipal administration regard electric transportation as highly relevant and promising. This study

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[17] Fraunhofer ISI - Social acceptance of electric mobility in Germany - https://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-6086626.pdf

was considered a good indicator for acceptance in this socio-political dimension. However, the research in this domain is still limited to certain niches and needs further investigation.

Market acceptance is another relevant factor that must be conveniently studied. One of the actor groups with great leverage on market development and diffusion of EVs are car manufacturers when the supportive policies are technology neutral. For this group the acceptance of electric mobility varies. There are many different portfolios, business models and different strategies. Wesseling et al. (2015) found out that the manufacturers that sold more were the ones with a greater incentive and opportunity to innovate and that these innovations came especially from less profitable firms. This might explain some of the differences between manufacturers' success with PEV sales.

The group of intermediaries between supply and demand also play an important role in spreading these technologies. Such actors are car dealers, leasing companies and other actors that deal with infrastructure, repair & maintenance. The level of acceptance by these groups is directly related to whether clients are hindered or enabled when purchasing PEVs. There is no specific literature for the German case but for the overall European sales landscape the main central barriers identified was lack of PEV availability and visibility, and both dealers and the public being subject to misinformation and misconceptions.

In Germany 64% of newly registered passenger cars (2019) are from company fleet and company cars and this follows the trend that car sharing fleets have an above-average share of electric vehicles. These fleets are a good way for users to test out electric vehicles at a lower cost. These fleets are also resold more quickly than privately owned cars and permeate through the second-hand car market. This points to commercial adoption helping to trigger private adoption.

A study in 2015 by Kawgan-Kagan found out that carsharing-users tend to hold more positive opinions regarding the environmental impact of PEVs. Other studies also found that these kinds of users give less importance to owning a car than nonusers. Generally, these users feel less restricted using PEVs and even when compared to private PEV users they perceive the usefulness of PEVs more positively and have a higher interest in buying a PEV than non-users. In the case of public bodies as operators and users of PEVs, German municipalities are already active with 86% of them developing or planning this conversion to electric mobility.

Finally, for private users it was found out that range satisfaction plays an essential role for this user group's acceptance. Predictors like the regularity or predictability of mobility patterns, the share of journeys not coverable because of range issues and the individual comfortable range of the users influence their satisfaction. These are coupled together with indicators like charging time and charging locations. The trip purpose is also considered, and leisure and business trips are perceived higher than shopping trips or trips to work. Overall, study results show an heterogenous a not discrete perception of PEVs.

The last dimension of acceptance deals with the local and community aspect. Even though there is no literature on this aspect it is possible to look at some non-academic articles. The first point to consider is the deployment of public charging infrastructures, which faces some public opposition since this roll-out inevitably takes away public space (in many cases parking spots are reserved exclusively for charging, converted from formerly available spots for all vehicles). Another point that experiences opposition are the special rights sometimes given to drivers to electric drives (for example the use bus lanes and free parking in certain areas). This last one can be seen as an advantage for current and future electric drivers boosting their acceptance but as a disadvantage for drivers of fossil-fuel powered vehicles lowering their acceptance. Finally, other aspect that usually boosts acceptance levels is that in normally busy streets electric vehicles are experienced as more pleasant by bikers and pedestrians as well as inhabitants since they have no local emissions and reduced noise generation. This dimension still has many open questions, and more research is needed.

5.3 Advanced active customers role

Active customers – whether as individual citizens living in homes or apartments or organized through neighbour or virtual communities - will end up forming a central focal point of the energy system cross sectorial integration selecting their best financial options to lower their energy costs and decarbonize their lifestyles and so minimize their impact to the planet.
As a result of their growing implication into the energy and climate change debate their investments and strategies will evolve towards net zero living environments simultaneously investing into to housing insulation, renewable self-consumption to mitigate their exposure to the energy crisis, switching to EVs to decarbonize their transportation and minimize their fuel cost as well as replace their boilers with smarter electrical heat pump for their heating. These new developments will naturally lead to further technology integration across their distributed energy resources as well as new building energy optimization taking best advantage of new dynamic tariffs as well as analysing in real-time the carbon footprint of the electrons, they consume through the data published by TSOs & DSOs.

The EV is representing a significant game changer in this environment opening opportunities to manage bilateral energy exchanges (V1G, V2G, V2H). EVs will in some cases be complemented with supplementary batteries to maximise local PV self-consumption benefits.
Beyond their individual home environments, active consumers also represent early adopters of new low carbon living styles becoming strong advocates of their experience and best practises across their neighbour and peer communities, naturally organising into self-administered communities of early adopters. This trend is further accelerated through the new Clean Energy package regulations opening new regulatory regimes enabling new peer to peer exchange models at the edge of the electricity system – whether for energy or carbon emission savings used through gamification – and so leveraging the potential of blockchain technologies and 24/7 carbon origin tracking. V2H and V2G are expected to accelerate these community effect facilitating such exchanges.

The European framework for energy communities

As part of the Clean Energy Package, the EU has defined two types of energy communities that can act as new players on the energy market.

In accordance with its basis in the Internal Electricity Market Directive (Citizens Energy Communities) or the Renewable Energy Directive (Renewable Energy Communities), they deal with renewable energy or electricity. While renewable energy communities focus on the expansion, local use and promotion of renewable energy, energy communities are creating new market players with a focus on electricity, which enables a wide range of activities and services and is not limited to a local area. What both approaches have in common is that they represent a separate legal entity, where the community is enabled to produce, store, use and sell energy. This includes the use of the public network or the operation of own network infrastructure.

The activities listed in this context already result in several use cases for digital solutions. This ranges from the optimization of self-consumption and the internal allocation and billing of jointly produced energy to the integration into the energy markets, which among other things requires a suitable data exchange and the mapping of corresponding business processes.

Table 4 Energy community activities referred to by the guidelines.

Energy community activities	REC	CEC
Production (REC: Renewable Energy, CEC: Electricity)	Yes	Yes
Consumption	Yes	Yes
Storage	Yes	Yes
Sale, e.g. through:	Yes	Not mentioned explicitly
Contracts for the purchase of renewable electricity (power purchase agreements, PPAs)	Yes	Not mentioned explicitly
Suppliers	Yes	Not mentioned explicitly
Peer-to-peer trading	Not mentioned explicitly	Not mentioned explicitly
Sharing	Yes	Yes
Delivery	Yes	Yes
Aggregation	Yes	Yes
Energy efficiency services		Yes
Electric vehicle charging services		Yes
Other (commercial) energy services	Yes	Yes

All EU member states are currently developing a national framework for the implementation of energy communities or have already created one. This is linked to the implementation of the relevant EU directives in national law. The deadline for this was the end of December 2020 for the “Internal Electricity Market Directive” (citizens' energy communities) and the end of June 2021 for the “Renewable Energy Directive”. Two main opportunities have been identified regarding the interaction of electric mobility and the role of energy communities:

1. *Preparation of forecasts based on community-internal level data.*

The existing data about consumers can be used to generate forecasts for individual data series using new (e.g., self-learning methods, big data methods). Technical solutions are algorithms or software solutions that create forecasts based on the data collected. Behavioural analysis (e-mobility behaviour, consumption behaviour) concerns the development of consumer behaviour based on the measured and recorded values. This application is very specific about the specific application for which it is used, e.g., the charging behaviour or the consumption behaviour of the members. In this use case, gamification approaches can also be used to compare user / internal behaviour. This would result in software products, methods and algorithms that are able to extract consumer behaviour from the measured data.

2. *Real-time analysis of energy systems*

As with DSOs, it is possible to focus on processing live data to determine the state of the energy community. Going further, this also allows automatic detection of incorrect measured values in a data series. This is intended, for example, to avoid accounting errors and to detect data manipulation, as the collected and evaluated data must be prepared and visualized for different stakeholders (energy community members, charging operators, external third parties, etc.).

5.4 Charging operators: profiles and business model

Another crucial role in the customer involvement to make the charging process a success is that of charging operators. To understand their interaction with other actors it is important to consider what their main functions are.

There are several profiles for charging operators:

1. Local small business initiatives of slow and/or fast charging
2. Local councils and municipalities infrastructures of slow and/or fast charging
3. Commercial services for slow and/or fast charging
4. Local or regional fast and ultra-fast charging networks
5. National fast and ultra-fast charging networks
6. Fleets and enterprises infrastructures for slow, fast and ultra-fast charging

With reference to Charging Operator’s business model different options exist. Existing solutions to incentivise drivers to shift their consumption to off-peak periods through price incentives (ToU tariffs, critical-peak-pricing) can be applied to EV charging. This is called ‘open loop’ smart charging, where a customer may decide to take the offer or not. In this case, the DSO cannot be sure about the acceptance and effectuation of smart charging beforehand. A ToU tariff implies a basic ‘delayed charging’ strategy to move the charge at a certain timeframe outside the peak. This is a fairly static approach with the drawback that EVs can still cause off-peak sharp demand increases when a large number of EVs will start the charging process simultaneously when the low tariff begins.

While these basic strategies may be effective in the short-term (charging at night to avoid network stress), they might still result in grid reinforcements in networks with large EV shares. In the long-term, full flexibility of EV charging with more dynamic and advanced smart charging strategies is necessary. Grid operators could make offers to EV customers to modulate the power or shift the EV charge (time and power) to avoid high peak load. Such smart charging should be based upon an agreement between DSOs and customers. Even for the dynamic option, there should be a variable capacity contract in place between the DSO and the customer, allowing the DSO to manage the capacity within the limits of the agreed variable capacity.

With the right charging strategy in place, customers' benefits may include an opportunity to reduce their mobility costs by trading time flexibility with service cost savings. This may also reduce the need for increasing the contracted power and related connection costs. Financial benefits such as offering attractive discounts on electricity tariffs and savings on mobility bills will play a clear role. But other factors such as guaranteeing technical reliability and operation, or environmental benefits of load management (i.e., option for a green provider), will also be critical for changing customers' attitudes.

Nevertheless, the decision to participate in load management will ultimately rest with the customers. Charging management must meet customers' preferences about their desired charging schedule and the level of charge. The vehicle can automatically maintain the control by managing the amount of energy and the constant power flow needed throughout the charge. Range anxiety can be further overcome by allowing customers to use a 'direct charging option' overriding 'delayed charging'. For this to happen, charging operators need to work out best strategies to incentivise customers with active (variable capacity agreements) and passive (price signals, critical peak pricing) demand response schemes.
Compounding this trend, smarter regulation will be needed to overcome existing bottlenecks by stimulating the right smart charging strategy, flexible tariff structure and technology adoption. And finally, common interoperable interfaces between the electricity distribution grid, the charging station and the electric vehicle itself will ensure the required safety and security level for the customers.

5.5 New digital services

Technologies and new digital services for electromobility currently still have a need for development. Forecasting methods in complex systems (e.g., energy systems) are currently not yet mature enough to be widely used. In addition to the necessary technological development, there is also the question of how the data generated can be used sensibly. As described in the previous chapters, they could be used to regulate flexibilities. In this context, the ambiguities regarding the use of flexibilities stand in the way of simple applicability. However, this gap is being bridged by current research.

Privacy and data protection

Digital applications such as the IoT lead to a large volume of data, for which it will be essential to determine who the data belongs to and with whom it can be shared, especially in the cases of EVs that can be charged in different points and using many operators. The General Data Protection Regulation (GDPR) (2016/679) regulates the processing of personal data. The Internal Electricity Market Directive emphasizes the relevance of the GDPR also for the energy sector, in particular Article 8 - Right to and protection of personal data. The regulation on the free movement of non-personal data (2018/1807) allows the use of non-personal data across national borders. Another relevant future legislation is the e-privacy regulation, which regulates data protection with a focus on electronic communication. Simple access to precise and timely data is seen as a prerequisite for flexibility services, since both EV users and the CPOs or the energy communities must have a clear understanding of the flexibility potential. Member States should introduce a regulatory framework for a data management concept to enable secure and efficient data access and exchange.

Analytical services

Different software products offer the possibility to use the existing data to create forecasts about the future consumption of EVs. The forecasts can be derived from directly measured data or indirectly via the predicted behaviour of the EV users. The forecasts can be scaled differently, for example at the level of a charging point or in relation to groups of them or entire parts of the energy system. The forecasts made can be short-term or long-term, depending on the application and needs.

Besides, software products and services in this area have a wide range of uses. Short-term forecasts could be used for deployment planning, sales, trading, but also for controlling the charging status, for example. There are similar use cases for the occupancy of charging stations, although the forecasting methods in this area are currently less developed than the forecasts for renewable generation. The use of such technical solutions requires appropriate hardware (computer or server) on which the software can be operated, or which is the interface to a cloud on which the calculations are carried out. In addition, it is necessary to carry out corresponding measurements in the energy system and to operate the necessary measuring devices. In the case of the analysis of the EV users' behaviour, it can be assumed that accompanying measures are also to be carried out in addition to the necessary components. If the forecasts are used to control the charging processes, it is also necessary to operate a corresponding control and the associated components.

The main benefit of these software products is that information about future consumption values is available. This enables better planning to be carried out, which can lead to savings in resources and effort. In addition, certain strategies for controlling charging processes are only made possible by forecasting methods (model predictive control).

Recommendations for implementation

The use of this group of technologies (software products) requires that the generated forecasts are put to a meaningful purpose. Since the software products require comprehensive data for use and, in the case of behavioural analyses and prognoses, also require accompanying measures, a corresponding effort is associated with their use. Since, under the current framework conditions, the use of these technologies primarily makes sense in the context of creating the basis for a model predictive control, the available feed-in capacities (V2G) and the flexibilities to be adapted to them must also be ascertained and a need for flexibility to be clarified.

As an example of projects, it is worth mentioning the project of tokenisation of electric vehicles in Vienna. The use case comes from a start-up with a small initial fleet of vehicles and the goal of increasing the fleet of vehicles in the next two years, which seemed quite unrealistic with the funds they have available. As a matter of fact, they decided to tokenise the vehicles and share the ownership with a large community of retail token buyers. Interested token buyers can register on the dedicated web-based asset tokenisation dashboard, providing their contact information, and are then redirected to go through the identity verification process conducted by the Austrian State Printing House (Staatsdruckerei) in accordance with stringent federal and local regulations. Once the verification process is completed, users can get access to the token purchasing webpage, as well as to reports on the vehicle fleet and the financials. Important to note is that all the data is recorded in a fully GDPR-compliant process, with no identifiable personal information ever stored in a publicly accessible way.

Possible barriers and recommendations include access to (almost) real-time data (e.g., smart meters) with clear regulation of data protection requirements and if necessary, specification of technical requirements for hardware and software with regard to data protection and privacy by design.

6. ENABLERS

6.1 Technological advancements

In 2020 close to 200.000 normal power public charging points, up to 22 kW, and other 25.000 high-power public recharging points (> 22KW) were available in the EU. This achievement has been held thanks to the implication of the European regulatory authorities and the Member States Governments as well as public-private collaboration participations. Connecting Europe Facility (CEF) for Transport programme funded projects per amount of €24.05 billion for the 2014-2020 period, making possible the deployment of this network.
The Trans-European Transport Network (TEN-T) policy addresses the implementation and development of a Europe-wide network of all kinds of transports including roads. Besides the construction of new physical infrastructure, the TEN-T policy supports the application of innovation, new technologies and digital solutions to all modes of transports, and the objective is improved use of infrastructure, reduce environmental impact of transport, enhance energy efficiency, and increase safety. The objectives foreseen by 2030 is the completion of the Core Network, structured around nine multimodal Core Network Corridors, and the Comprehensive Network to cover all European regions to be completed by 2050.

Vehicle to Grid technology

A further technological advance is that of the Vehicle to Grid (V2G) technology (see for reference "The Drive Towards a Low-Carbon Grid", a collaboration involving carmaker Nissan, E.ON Drive and Imperial College London[18]). As explained in previous chapters, V2G technology allows electricity to flow in both directions to and from electric vehicle batteries, allowing energy stored in the battery to be sold back to the grid when demand for power is high. Vehicles can then charge when demand is lower or renewable generation is high, reducing reliance on fossil-fuelled generation and giving V2G a role in carbon reduction efforts. It can also release capacity on the electricity networks which distribute power around the country. Given that many vehicles spend a high percentage of time idle, both during the working day and overnight, vehicle-to-grid (V2G) technology offers an ideal solution to ease grid capacity constraints and provide flexibility to the power system. V2G enables energy to be discharged from EV batteries to power buildings or the electricity network during peak periods. Batteries can be recharged when demand is lower, and renewable energy is in greater abundance. In doing so, V2G-enabled EVs can limit the need for expensive investments in additional generation capacity and grid reinforcement, while providing the necessary flexibility to support a smarter, more sustainable energy system.

Given expectations that V2G-enabled EV fleets can have an integral role to play in the future electric ecosystem, it is imperative that appropriate market and regulatory conditions are in place to ensure there is sufficient value available for all stakeholders involved to make V2G a commercially viable proposition.
The V2G technology has been found to hold significant benefits, following the results of an analysis conducted in the British power system for the years 2025 and 2030 over 1 million commercial EVs. Specifically, these benefits can be categorized as follows.

Whole-system economic benefits

Modelling results show V2G can unlock substantial whole-system cost savings in the range of £412-883m/year. Also, the additional cost associated with meeting the electricity demand of a million fleet EVs can be offset by the value of flexibility from V2G in the form of:

- Avoided capital expenditure in generation;
- Reduced need for distribution network reinforcement;
- More efficient provision of balancing services, with reduced curtailment of renewable energy.

In contrast, unmanaged and smart charging scenarios are shown to result in increased system costs of £567-773m/year and £102-150m/year respectively, due to the higher demand placed upon the power system by these vehicles, and the limited flexibility they offer.
Note also that V2G flexibility can be utilised in various ways to create financial benefits. Certain V2G use cases lead to cost savings when compared to a standard unidirectional charging solution. Alternatively, revenues can be directly generated from trading in energy markets or offering specific flexibility products. In general, these use cases can be marketed simultaneously to boost overall economic benefits. This is known as revenue stacking.

Carbon benefits

Results show V2G-enabled EV fleets can have a significant negative carbon impact, i.e., reduce overall power system CO_2 emissions. Also, incremental carbon emissions of fleet EVs with V2G can be as low as -243gCO2 /km. In contrast, unmanaged or smart charging regimes are shown to trigger additional power system emissions in the range of 36-52gCO 2 /km, as a result of the additional power demand created by EV fleets.

The benefits of V2G are highest in scenarios with high renewable penetration and low uptake of other flexible options. Carbon savings from V2G fleets would make it possible to install lower volumes of low-carbon generation capacity while still meeting current system-level decarbonisation targets.
Note that these benefits are significantly important given that transport is the UK's most polluting sector with the majority of greenhouse gas emissions coming from road transport.

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[18] https://www.eonenergy.com/content/dam/eon-energy-com/Files/vehicle-to-grid/The%20Drive%20Towards%20A%20Low-Carbon%20Grid%20Whitepaper.pdf

Value of V2G for electricity system operation

Analysis also suggests that with a lower penetration of 50,000 V2G-enabled EVs, each EV could reduce system operation costs by approximately £12,000 per annum and CO2 emissions by around 60 tonnes per annum.
Reduced wind curtailment and more efficient frequency response provision through V2G are the main drivers of these cost and emission savings.
The value offered by V2G EVs for system operation falls with larger fleet sizes. With 150,000 EVs on the system, the marginal value per EV is approximately £600. Competing flexibility sources could also diminish overall operational cost savings from V2G.

6.2 Interoperability and standards

Different standards and protocols are used to solve the same issues throughout the e-mobility ecosystem. We can find different physical connectors with which to plug an EV to the charging point, different battery management strategies to optimize the use and the longevity of the batteries, different communication protocols between the EV and the charging station, also between the charging station and the Charging Point Operator, and more. And as more EVs are introduced in the market, the relevant interactions will grow in complexity.
In the case of smart charging technology, the starting point is that the charging station must be 'connected' to be able to communicate and be managed by a back-end system (of the Charge Point Operator (CPO)). This communication should include smart charging messages to be exchanged through standardised communication protocols. For example, the OCPP, in addition to other standards (IEC 63310), forms the basis for this communication between the charging stations and their back-end systems. But to fully enable smart charging, standardisation of data and coordination between all charging infrastructure and electromobility management systems is needed beyond those requirements set in the OCPP. The whole electromobility 'chain' – starting from the electric vehicle itself, the charging station and the grid should seamlessly communicate with each other.
Several aspects have been addressed in the regulation within the EU in this matter but there still work to do on setting standards for operations that ensure interoperability between equipment, users, service providers and back-end systems. There are multiple available options in the industry, therefore, standardized unique identifiers, data models, attribute lists and common data structures should be specified to enable a whole interoperability.
The main standardized aspects of electromobility so far are:
IEC 62196 plugs, socket-outlets, vehicle connectors and vehicle inlets (CCS and Type 2 are the two standard vehicle connectors to be used within Europe).

- IEC 61851 Electric vehicle conductive charging system
- IEC 61980 Electric vehicle wireless power transfer (WPT) systems
- ISO 15118 Road vehicles - Vehicle to grid communication interface

On the one hand, European institutions have addressed important aspects that enables the interoperability and that responds to Directive AFI 2014/94/UE, and Directive ITS 2010/40/EU with regard the information exchange between Charging Point Operators (CPOs) and National Access Points (NAPs). This work was carried out within the framework of the IDACS project (ID and Data Collection for Sustainable fuels in Europe.
On the other hand, the Sub-Group to foster the creation of an electric mobility Market of Services of the Sustainable Transport Forum (STF-SGEMS) set the foundations of data models, and common data structures the electric vehicle ecosystem.

There are still challenges to be addressed:

- The existence of a widespread used communication protocol between charging points and CPOs. One of the most extended is OCPP which offers a uniform solution for the method of communication between charge point and central system. With this protocol it is possible to connect any central system with any charge point, regardless of the vendor.
- The existence of a widespread used communication protocol between the CPOs and other players. The Open Charge Point Interface protocol (OCPI) supports connections between electric mobility Service Providers (eMSP) who have EV drivers as customers, and CPOs who manage charge stations. Nevertheless, DATEX II is the electronic language used in Europe for the exchange of traffic information and traffic data that CPOs has to implement to send information to the NAPs.

It is expected that other actors in the energy sector, such as demand and storage aggregators, will enable EVs to participate in the energy markets, which will have specific needs, different from those addressed to the transport sector, that must be considered. This protocol will also need in the future to interface the data exchange protocols historically developed in the grid industry and referred through the SmartGrid architecture model and so ensure a seamless integration of data from TSO-DSO down to BSP & CPOs.

6.3 Regulatory framework and cross-sector cooperation

The regulatory framework should include the possibility for the DSOs use smart charging (signals), since EVs are connected directly to their grids. It is important that they take part in dynamic network control as part of their responsibility for maintaining a stable and efficient network operation.
As current possibilities to apply flexibility in this type of contracts differ from country to country, a higher degree of comparability of the different experiences would be useful. Considering the diverse regulatory starting points across EU member states, and customers' experience with different tariff schemes, a potential comparison should not too straightforwardly neglect commonalities.
In this sense, 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 5). 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).

Table 5 Stakeholders and actions (X = relevant; XX = very relevant; XXX = extremely relevant).

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

7. R&D AND INNOVATION NEEDS

7.1 Where to concentrate R&I efforts

The new European framework programme for research and innovation, Horizon Europe, covers the period from 2021 to 2027 (European Union, 2019), with an important aim to be dedicated to R&D activities supporting the delivery of scientific, technological, economic, and societal impact. It is framed into three Pillars (Excellent Science, Global Challenges and European Industrial Competitiveness, Innovative Europe) with a specific mission area committed to "Adaptation to climate change including societal transformation". According to the European Commission, the focus "will be on solutions and preparedness for the impact of climate change to protect lives and assets. It will include behavioural changes and social aspects by addressing new communities beyond usual stakeholders, which help lead to a societal transformation" (European Commission, 2020d).

Electrification of transport (electromobility) is a priority for the European Commission and for this reason is high in the priority list of its research programme. Consistently, Cluster 5 of Horizon Europe on Climate, Energy and Mobility envisages energy and mobility systems that are "climate and environment-friendly, smarter, safer, more resilient, inclusive, competitive and efficient" (European Commission, 2019). The expected impact with further Research, Development and Innovation, in line with the Strategic Plan, is to contribute "Towards climate neutral and environmentally friendly mobility through clean solutions across all transport modes while increasing global competitiveness of the EU transport sector".

In what concerns road transport, which is the scope of this document that should be done through transforming road transport to zero-emission mobility through a world-class European research and innovation and industrial system, ensuring that Europe remains world leader in innovation, production, and services in relation to road transport.

With the aim of accelerating the development and deployment of zero tailpipe emission road transport with a system approach in Europe, the European Partnership "Towards zero emission road transport" (2Zero) is working towards a common vision and delivering a multi stakeholders roadmap for a climate neutral and clean road transport system that improves mobility and safety of people and goods and ensures future European leadership in innovation, production, and services. Relying on the success of the Green Cars and Green Vehicles initiatives, the 2Zero partnership is organising constant exchange between the EC services and the stakeholders gather in the non-for-profit association EGVIAfor2Zero to identify research and innovation priorities in Horizon Europe. A total budget of up to 615 million euros will be dedicated to four pillars covered by the partnership:

1. Vehicle technologies and vehicle propulsion solutions for BEV and FCEV
2. Integration of the battery electric vehicles into the energy system and related charging infrastructure
3. Innovative concepts, solutions, and services for the zero-emission mobility of people and goods
4. Life cycle assessment and circular economy approaches for the sustainable and innovative road mobility solutions.

ETIP-SNET being one of the five technology platform supporting the 2Zero partnership, its activities, and priorities identified in this paper, will be an important input for the future identification of research and innovation priorities.
Within the context of ETIP-SNET "Smart Network for Energy Transition" and in particular WG1 "Reliable, Economic and Efficient Energy System", there are two relevant aspects to consider:

- Affordable, user-friendly charging infrastructure concepts and technologies that include vehicle-grid-interactions
- Innovative use cases for the integration of zero tailpipe emission vehicles, and infrastructure concepts for the road mobility of people and goods.

For this purpose, the following R&D&I efforts could be identified based on the main ETIP SNET Research Areas, as shown in Table 6

Table 6 Different support measure types for EVs.

ETIP SNET Research Area	Topics
SYSTEM OPERATION	Charging Strategies
PLANNING and HOLISTIC ARCHITECTURE	System integration
FLEXIBILITY	Storage Usage
	Flexibility in networks
	Renewables Integration
SYSTEM ECONOMICS	Market Implications
	Economic Assessment
	Regulatory Aspects
CONSUMER	User Experience
	EV Owner Compensation Model
DIGITALIZATION	Data Flows

<u>On Charging Strategies (mainly related to ETIP-SNET Research Area SYSTEM OPERATION):</u>

- Definition of the optimal smart charging concepts able to cope with mass deployment of Electric Vehicles (EV) deployed in different environments, avoiding uncontrolled charging (i.e., maximum available power from the moment the vehicle is plugged in), that, when scaled to a mass-market-level, could contribute to create an extra burden on the power system.

- Innovative concepts and technologies performances to create affordable, user-friendly smart and bidirectional (V2X, where X can be G for Grid, H for Home and B for Business) charging solutions, co-optimising the needs of EV users, of the house/building and of the supplying grid.
- Research on pros and cons, under different scenarios (geographical, topological, penetration, etc), under a different mix of slow, quick, fast, and ultra-fast charging, under a mix of AC and DC solutions and, eventually, under additional inductive solutions (besides the traditional conductive). Clarify and understand "grid impact use cases".

On overall System Integration (mainly related to ETIP-SNET Research Area PLANNING – HOLISTIC ARCHITECTURE):

- Development of smart charging strategies and control mechanisms that maximise the efficiency of the whole energy system, increasing the use of renewable electricity harnessing unused EV storage capacity, whilst minimising grid reinforcements and energy generation needs.
- Contribution to the integrated planning process of systems aimed at exploiting cross-sector mutual benefits (G2X and V2X).
- Implement an open architecture (i.e., not proprietary) concerning smart and bidirectional charging solutions, as key success factors to build a mutually beneficial charging experience for the user and for the grid.
- Implement a holistic technical architecture and restructure of the market for its harmonisation with the power grid. Promotion of the local market for effective participation and role of distributed energy resources (including e-mobility) in providing flexibility while being economically and commercially viable.
- Optimizing the specific charging infrastructures for logistics hubs and/or TEN-T urban nodes.
- Establishment of quantitative parametric and probabilistic models for assessing the impact of progressive, massive EV penetration on the electricity system.
- Explore how TSO–DSO cooperation should be enhanced, being essential to favourably managing EV charging.
- Research with system integrated control to enable experiments for AC grid dynamics from DC charging of EVs so researchers can emulate grid response for evaluating how charging equipment controls impact the grid.

On Storage Usage (mainly related to ETIP-SNET Research Area FLEXIBILITY):

- Explore the availability of battery storage, provided by parked EVs (both light and heavy-duty vehicles) to be used as a benefit if an integrated approach is adopted considering the different charging scenarios (public charging, home charging, depot charging, etc.).
- Research on the estimated different bidirectional charging profiles and energy flows with the grid, to provide inputs to other areas related with batteries and electronics lifetime.

On Flexibility (mainly related to ETIP-SNET Research Area FLEXIBILITY):

- Effective exploitation of EV charging flexibility to minimise investments in the electric grids, resulting in reduced system charges for the network users.
- Assessment of EV DR potential and appropriate Integration of the EV sector for DR purposes.

On Market Implications (related to ETIP-SNET Research Area SYSTEM ECONOMICS):

- Research of impact on markets under different scenarios and uses cases.

On Economic Assessment (related to ETIP-SNET Research Area SYSTEM ECONOMICS):

- Increase the understanding of the operational and economic trade-offs for the user and the vehicle (e.g., cost of battery damage, additional cost for electronics to enable V2G), and on the charging (e.g., installation cost, battery damage/degradation) infrastructure of the different smart and bidirectional (V2G) charging approaches and technologies (for instance AC vs DC), as well as the costs for the different actors involved.
- Consider current slow/medium power charging, analyse and develop and demonstrate lower cost alternatives, appropriate for the mass deployment of slow charging, considering both AC and DC V2X solutions, related costs and issues (for instance power quality of AC systems), in view of optimising the cost of on-vehicle and infrastructure side electronics.
- Explore the trade-offs, under different EV penetration scenarios, aiming at defining the optimal balance between the vehicle and infrastructure costs, the location and typology of charging infrastructures, and its interoperability whilst demonstrating the efficiency of V2X centralized and decentralized scenarios and catering for different EV categories, in different environments.

On contribution to Renewables Integration (mainly related to ETIP-SNET Research Area FLEXIBILITY):

- Demonstrate V2X potential in encouraging renewable energy growth through the integration with low power renewable energy sources (e.g., photovoltaics on the roof or in parking lots), by reducing energy exchange with the grid (in both directions).

On User Experience (mainly related to ETIP-SNET Research Area CONSUMER):

- Improve the whole user experience (localization, booking, payment and billing process) when charging EVs under different scenarios (on street and in personal parking, in company and public buildings, etc.) and considering different electric vehicle fleets (passenger cars, light and medium commercial duty vehicles).

On EV Owner Compensation Model (mainly related to ETIP-SNET Research Area CONSUMER):

Research structured in Use Cases approach, namely, individual parking and charging, collective parking and charging and stop-over charging.

On Data Flows (mainly related to ETIP-SNET Research Area DIGITALIZATION):

- Research on the data models and communication requirements between the different actors, promoting interoperability.
- Investigate the framework for use of the necessary personal data and data portability generated by the natural persons making use of vehicle infrastructure pair.
- Research on definition and regulation of access to data and data management as a key enabler to implement new services.
- Research on development and adoption of common standards to guarantee the interoperability of charging networks and to perform V2G.
- Research on cybersecurity threats under different use cases, namely, vulnerability analysis and risk assessment for a smart EV charging system, and development of countermeasures to secure the network.

On Regulatory Aspects (mainly related to ETIP-SNET Research Area SYSTEM ECONOMICS):

- Demonstration of fast charging concepts capable of fitting established regulations and business practices, particularly at load/unload points enabling efficient operations.
- Research on Smart regulation aspects related to tariff in order to incentivize the consumer or, at least, avoid negative tariff or charging structures.

In addition to all the previous topics, the strategy related to battery-powered vehicles should be mainly focused on technological optimisation and market development, including reliability and durability of batteries and new materials, reducing battery weight and volume, safety, cost reduction, charging infrastructure and plug-in solutions and IT interoperability.

An important consideration about the priority and relevance of the different research areas identified above is that the SET Roadmap and Implementation Plan are expected to address the different needs, define timelines and budgets, taking into account the objectives of the Green Deal and Fitfor55 initiatives. One of the goals of this whitepaper is to provide information and guiding in this regard by different stakeholders coming from different fields (System Operators, Customers, Academia, Manufacturers, Service Providers…).

7.2 Where to concentrate incentives for deployment

Two big challenges remain as important barriers for a full deployment of electric mobility: the price of vehicles and the availability of charging infrastructure. The specific objectives of the incentives must be to achieve cost competitiveness and to ensure minimum infrastructure that support the required uptake of electric vehicles across all transport modes and in all Member States to meet the EU's climate objectives.

High prices for electric vehicles, mainly because of the cost of batteries, remain an important barrier for a larger EV uptake. In this framework, it should be highlighted that purchase costs decrease as technology evolves and more models are available on the market and increase competition. Additionally, support policies and incentive schemes could be facilitated to support the transition to low emission mobility. A notable increase in EV demand has been observed in various European countries where incentive schemes were introduced, while countries with low or no incentives present low EV registrations and market shares. Thus, total EV registrations and market shares observed across European countries align well with the levels of financial benefits accompanying the EV market, proving that the form of the incentives and its continuity can play a catalytic role in EV deployment at this stage ("Electric vehicles in Europe from 2010 to 2017: is full-scale commercialisation beginning?[19]", Joint Research Centre, 2018). Table 7 summarizes the types of support measures that could be implemented:

Table 7 Different support measure types for EVs

Impact on	Type of Support
Purchase	Tax reduction/exemption, purchase premium, penalty for polluting cars
Annual tax/cost	Tax reduction/exemption
Privileged access	Free access to bus/taxi lanes, access ban for polluting vehicles, reduction or exemption from road tolls or parking fees
Recharging	Provision of public recharging points (slow/fast), free recharging, condition to use low-carbon electricity
Research, development, and demonstration	Support to R&D projects and field tests

Regarding charging infrastructure, support measures stimulating EV demand are not harmonised in the EU Member States and this has led to a certain market fragmentation both in terms of EVs on the road and availability of publicly accessible recharging infrastructure. Moreover, interoperability and non-discriminatory access to available public recharging points is crucial. Ensuring the infrastructure's full interoperability and full user information and adequate payment options should be a priority goal.

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[19] https://op.europa.eu/en/publication-detail/-/publication/2f0c7419-e890-11e8-b690-01aa75ed71a1/language-en

In this sense, the proposal for a revision of the European Regulation on the deployment of alternative fuels infrastructure (AFID) seeks to ensure the availability and usability of alternative fuel vehicles (including vessels and aircraft), enabling the deployment of key charging infrastructure such as in motorways and other roads.

8. KEY FINDINGS AND MESSAGES

8.1 Key findings

- **The shift to electric transport is likely to accelerate in the EU**, both due to European and national legislation, and the industry involvement. Only in certain niches, such as aviation or maritime transport, green fuels and fuel cells may be more competitive.

- **The impact of electromobility and charging infrastructure on European transmission and distribution grids remains to some extent unquantified,** but studies and forecasts by system operators, industry, academia and European and international bodies presented in this study show a significant impact in the medium and long term, affecting the Medium Voltage (MV) and eventually to the High Voltage networks (DSO-TSO networks), while **in the short term the electric mobility load is expected to impact mainly to the DSO Low Voltage networks**. This white paper showcases some experiences and use cases in this regard.

- **TSOs' interest today is on facilitating the electrification of road transport** (cars and trucks). TSOs position themselves both as grid operator, market facilitator and as electric/energy system manager and supervisor (one system view).

- **DSOs play a key role in managing the impact of electric vehicles in the power system** since much experience has been gained by connecting thousands of charging points to their networks across Europe. By taking advantage of DSOs' in-depth knowledge of the distribution network and planned network development, it is possible to make a more optimal use of the network while maintaining the required levels of quality and security of supply. 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, regulatory authorities and new charging operators.

- While electric mobility users are at the centre of this new ecosystem, **TSO and DSOs, as grid operators, play the role of energy facilitators in the electricity portion of the ecosystem** and they should jointly lead a joint standpoint. 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 in the more difficult to electrify niches 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. The challenge is to do it while maintaining the levels of security of supply.

- **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.

- **A holistic view of the power grid** based on fractal features (e.g., *LINK*-architecture) and market restructuring offers great opportunities for smooth integration of electromobility and enables repeatability and scalability per design.

- **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 previous options.

8.2 Key messages

The main message of this paper is that a proper environment is needed to allow the optimal exploitation of electric vehicles and the opportunities they can offer to electricity networks. 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. System operators have an important role to play, both directly as grid operators and as facilitators (through market services).

a) **Promote integrated planning for charging infrastructure and electric grids**. 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.

b) **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).

c) **DSOs play a key role in the deployment and integration of EV charging infrastructure in the electricity network** as much experience has been gained by connecting thousands of charging points to the power system. Therefore, DSOs should be included in the planning and development process for the deployment of EV charging infrastructure as early as possible, to facilitate grid network connections. Grid reinforcement requires an assessment consolidated with other load increases up stream to evaluate the overall impact on the network. These parameters relate to the characteristics of the distribution network and the expected future load requirements (accounting for both the location and power capacity requirements of the chargers). DSOs evaluate all these factors to analyse the network situation and develop various EV charging scenarios, thus allowing them to identify the available capacity and connection cost at different grid connection points.

d) **System operators 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, DSOs and the hub operators should be pursued. The option of installing stationary storage systems to limit peak power demand should also be considered.

e) **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.

f) **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 electromobility service providers and 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 including 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, etc..). The Internet of Things (IoT) and cloud-based monitoring and control systems will facilitate the adoption of these schemes.

g) **Both private and public charging infrastructure should be equipped with a minimum level of "smartness"** by design, 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-and-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.

h) **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.

i) **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. 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, 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).

j) **Enable a new consumer-oriented ecosystem**. 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.

k) **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.

l) **Restructure market and rules and establish local markets to harmonise with the power grid** (holistic approach) and enable the effective participation of the EV users. 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.

m) **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.

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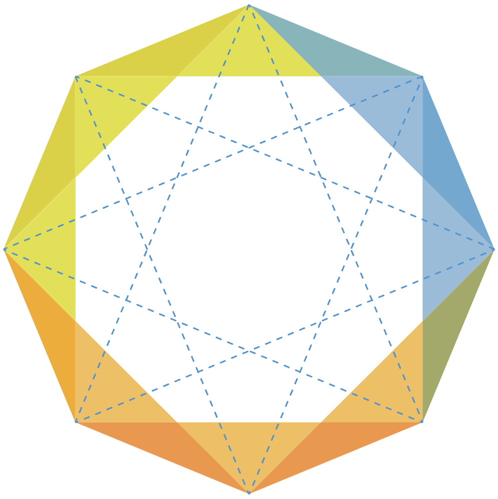

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