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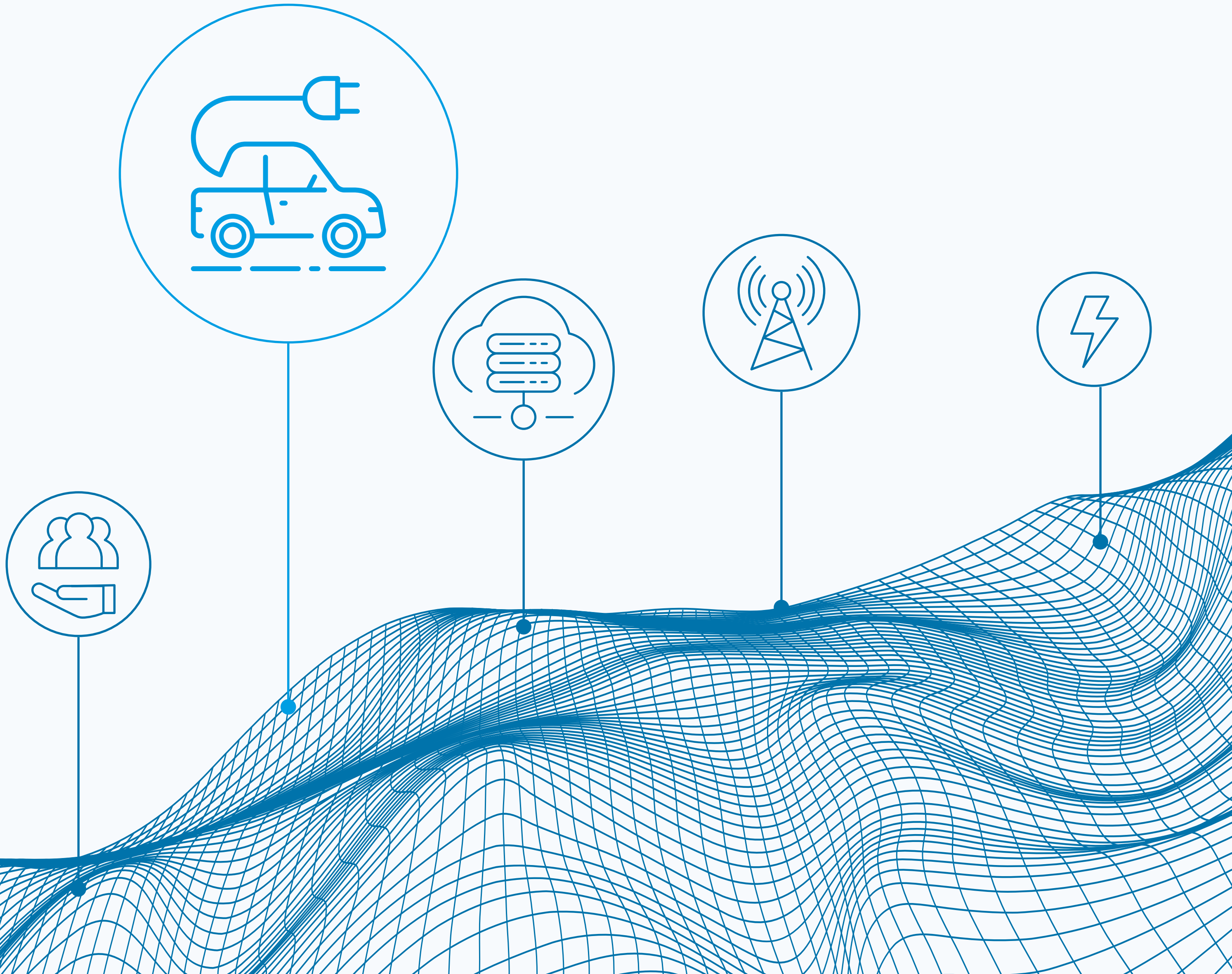
ELECTRIC-VEHICLE SMART CHARGING

INNOVATION LANDSCAPE BRIEF



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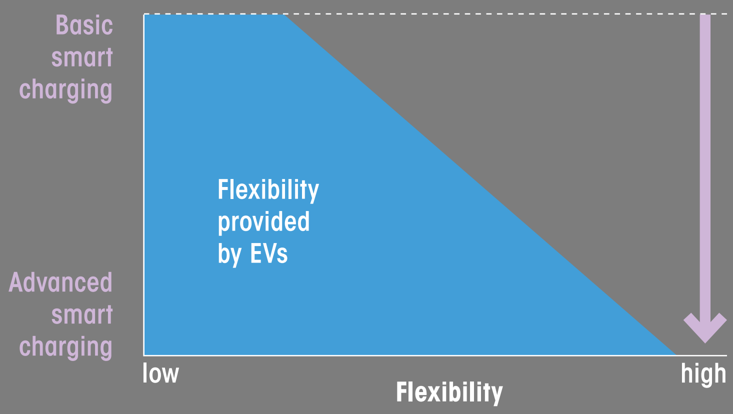
1 BENEFITS

Smart charging of EVs enables:

- Reduce grid infrastructure investments
- Network congestion management
- Peak shaving
- Provision of ancillary services



2 KEY ENABLING FACTORS

- Charging infrastructure development and deployment
- ICT control and communication protocols
- Define roles and responsibilities of stakeholders
- Design regulation for vehicle-grid integration
- Big data and artificial intelligence for smart charging

3 SNAPSHOT

- → 5.6 million EVs on the world's roads as of the beginning of 2019
- → 5.2 million EV chargers in 2018 (540 000 publicly available)
- → Smart charging of EVs can significantly reduce the peak load and avoid grid reinforcements, at a cost of 10% of the total cost of reinforcing the grid

WHAT IS SMART CHARGING?

Smart charging means adapting the charging cycle of EVs to both the conditions of the power system and the needs of vehicle users. This facilitates the integration of EVs while meeting mobility needs.

ELECTRIC-VEHICLE SMART CHARGING

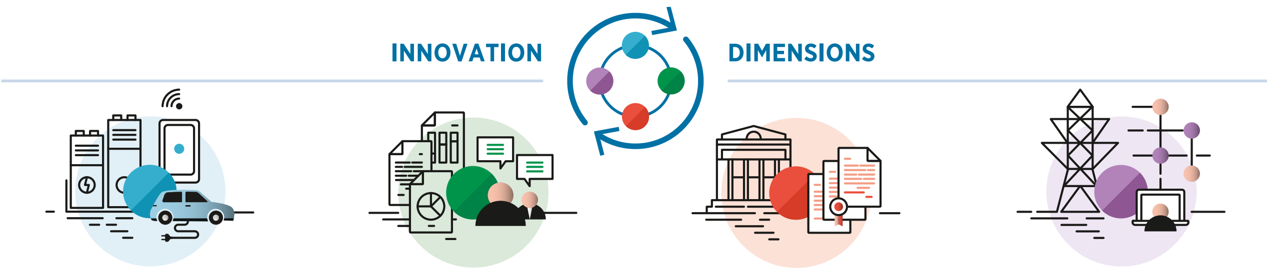
Smart charging for electric vehicles (EVs) holds the key to unleash **synergies between clean transport** sector and **low-carbon electricity.** It minimises the load impact from EVs and unlocks the flexibility to use more **solar and wind power.**

ABOUT THIS BRIEF

This brief is part of the IRENA project "Innovation landscape for a renewable-powered future", which maps the relevant innovations, identifies the synergies and formulates solutions for integrating high shares of variable renewable energy (VRE) into power systems.

The synthesis report, *Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables* (IRENA, 2019a), illustrates the need for synergies between different innovations to create actual solutions. Solutions to drive the uptake of solar and wind power span four broad dimensions of innovation: enabling technologies, business models, market design and system operation.

Along with the synthesis report, the project includes a series of innovation landscape briefs, each covering one of 30 key innovations identified across those four dimensions. The 30 innovations are listed in the figure below.



ENABLING TECHNOLOGIES

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2 Behind-the-meter batteries

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4 Renewable power-to-heat
5 Renewable power-to-hydrogen

6 Internet of Things
7 Artificial intelligence and big data
8 Blockchain

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This brief provides an overview of the services that electric vehicles (EVs) can provide to the power system through smart charging, and of the importance of such charging schemes for the smooth integration of EVs in the grid. This brief looks into unidirectional (V1G) and bidirectional vehicle-to-grid (V2G) technologies and on their role in integrating higher renewable energy shares, while providing services to the grid.

For a more in-depth study of all these aspects, together with business models and regulatory framework analysis, projections of the flexibility provided by EVs to the system and the possible impact of the expected mobility disruptions, please read IRENA's report *'Innovation outlook: Smart charging for electric vehicles'* (IRENA, 2019c).

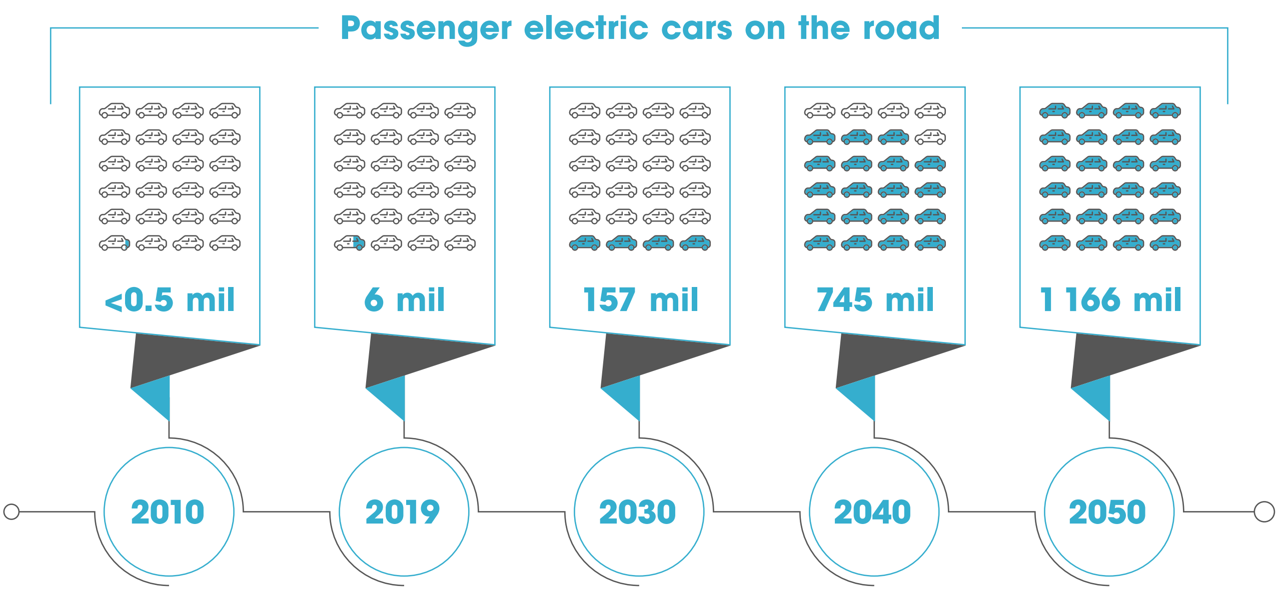
The brief is structured as follows:

I. DESCRIPTION

EVs represent a paradigm shift for both the transport and power sectors, with the potential to advance the decarbonisation of both sectors by coupling them. Although the transport sector currently has a very low share of renewable energy, it is undergoing a fundamental change, particularly in the passenger road vehicle segment where EVs are emerging.

According to Germany's Centre for Solar Energy and Hydrogen Research (ZSW), 5.6 million EVs were on the world's roads as of the beginning of 2019. China and the United States were the largest markets, with 2.6 million and 1.1 million EVs, respectively. If most of the passenger vehicles sold from 2040 onwards were electric, more than 1 billion EVs could be on the road by 2050 (see Figure 1). IRENA analysis indicates that future EV battery capacity may dwarf stationary battery capacity. In 2050, around 14 terawatt-hours (TWh) of EV batteries would be available to provide grid services, compared to 9 TWh of stationary batteries (IRENA, 2019b).

Figure 1: Growth in EV deployment between 2010 and 2050 in Paris Agreement-aligned scenario



Source: IRENA, 2019b

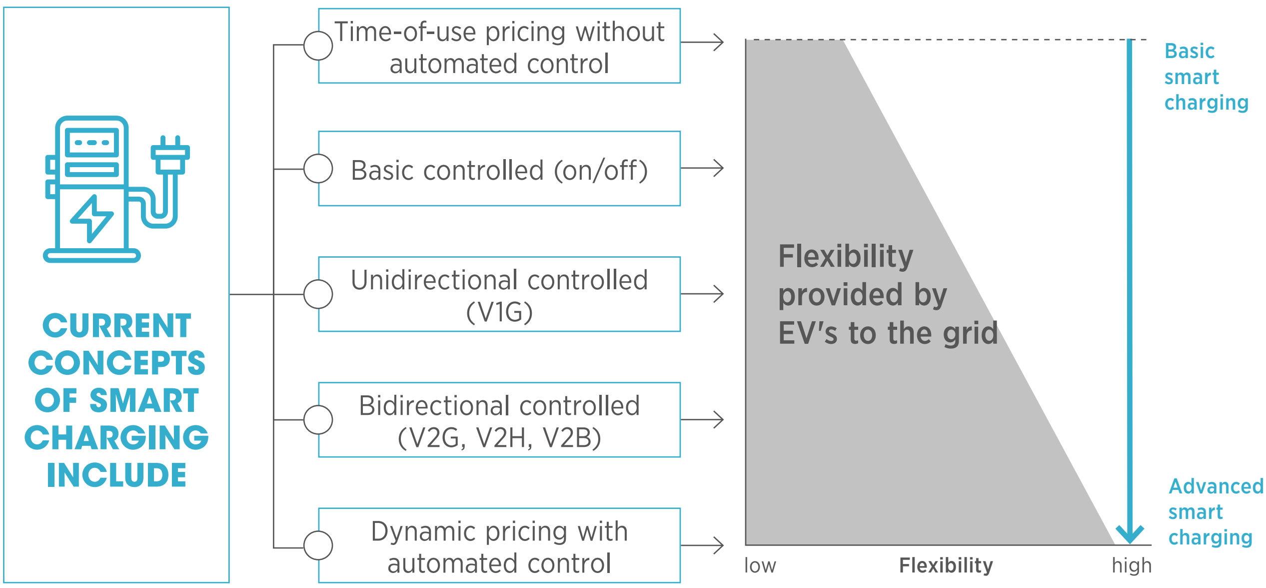
The cost reductions in renewable power generation make electricity an attractive low-cost fuel for the transport sector in many countries. A significant scaling up in EV deployment represents an opportunity for the power sector as well. EV fleets can create vast electricity storage capacity. They can act as flexible loads and as decentralised storage resources, capable of providing additional flexibility to support power system operations. With smart charging, EVs could adapt their charging patterns to flatten peak demand, fill load valleys and support real-time balancing of the grids by adjusting their charging levels. The use of EVs as a flexibility resource via smart charging approaches would reduce the need for investment in flexible, but carbon-intensive, fossil fuel power plants to balance renewables.

Smart charging means adapting the charging cycle of EVs to both the conditions of the power system and the needs of vehicle users. This facilitates the integration of EVs while meeting mobility needs (IRENA, 2019c). Smart charging therefore is a way of optimising the charging process according to distribution grid constraints, the availability of local renewable energy sources and customers' preferences.

Smart charging allows a certain level of control over the charging process. It includes different pricing and technical charging options. The simplest form of incentive – time-of-use pricing – encourages consumers to move their charging from peak to off-peak periods. More advanced smart charging approaches, such as direct control mechanisms, will be necessary as a long-term solution at higher penetration levels and for the delivery of close-to-real-time balancing and ancillary services, as illustrated in Figure 2.

Such mechanisms range from simply switching on and off the charging, to unidirectional control of vehicles (V1G) that allows for increasing or decreasing the rate of charging, to the technically challenging bidirectional vehicle-to-grid (V2G), which allows the EV to provide services to the grid in the discharge mode. In addition, vehicle-to-home (V2H) and vehicle-to-building (V2B) are forms of bidirectional charging where EVs are used as a residential back-up power supply during periods of power outage or for increasing self-consumption of energy produced on-site (demand charge avoidance).

Figure 2: Smart charging enables EVs to provide flexibility



Source: IRENA, 2019c

II. CONTRIBUTION TO POWER SECTOR TRANSFORMATION

Reduced investments in grid infrastructure

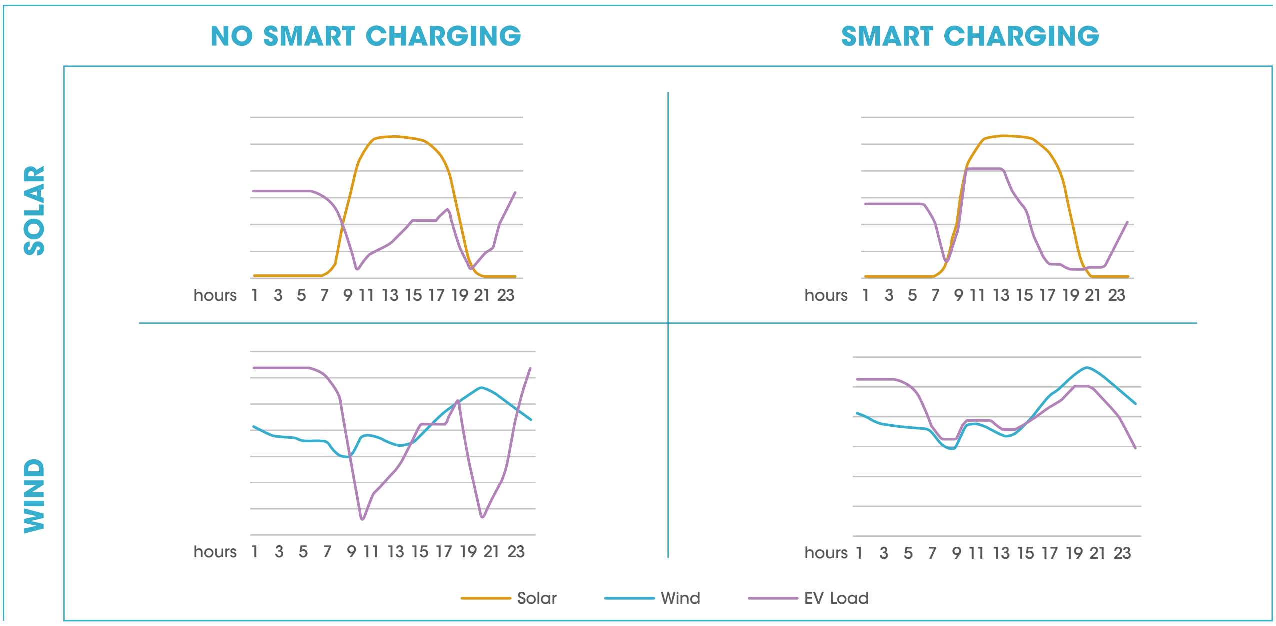
If EVs were charged in an uncontrolled way, they could increase the peak on the grid since charging trends could match existing load peaks and thus contribute to overloading and the need for upgrades at the distribution and transmission levels. Additionally, this extra load would result in upgrade needs in the generation capacity. However, the uptake of smart charging for electric mobility is expected to establish a positive feedback loop with renewables integration, given that e-mobility is a power-dense, mobile and controllable load.

Cars, including EVs, are currently parked on average over 90% of their lifetime (Barter, 2013). This, combined with their storage capacity, could make EVs an attractive flexibility solution to support system operations. The vehicles can become grid-connected storage units with a potential to provide a broad range of services to the system. Smart charging not only mitigates EV-caused demand peaks (mainly at the local grid level), but also can adjust the load curve to better integrate VRE.

Figure 3 illustrates how smart charging can integrate solar and wind generation in the grid by adjusting the charging profile of the EV to resource availability. As observed, smart charging strategies would differ according to the power system's conditions, including the renewable energy generation mix, load profile and interconnections available.

Smart charging reduces the costs associated with reinforcing local electricity grids. Unlike uncontrolled charging, it decreases simultaneity and lowers peaks in demand.

Figure 3: Smart charging for solar and wind generation profiles



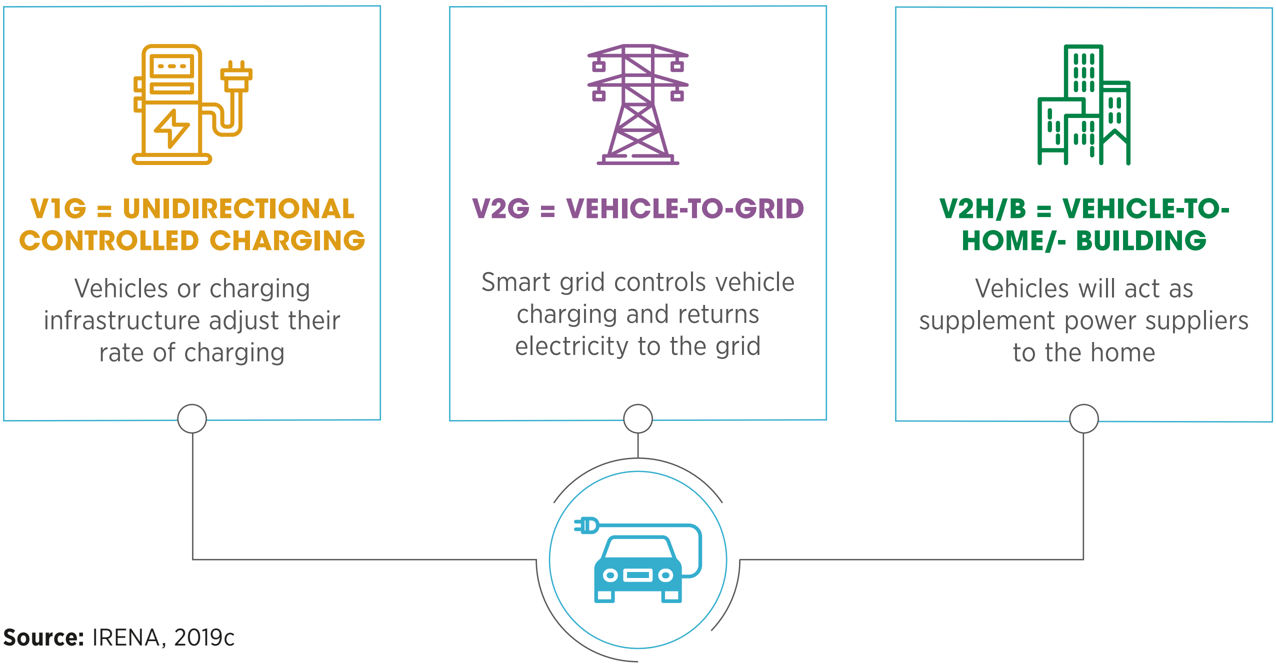
Source: IRENA, 2019c

Provision of services to the power system

Smartly charged EVs can help reduce VRE curtailment, improve local consumption of VRE production, avoid investment in peaking generation capacity and mitigate grid reinforcement needs.

Standing idle while parked for most of the time, EVs could provide a range of services to the power system, depending on the smart charging approach: unidirectional controlled charging (V1G), vehicle-to-grid (V2G) or vehicle-to-home/-building (V2H/B), as illustrated in Figure 4.

Figure 4: Forms of smart charging



Source: IRENA, 2019c

Adjusting their charging patterns, given that EVs currently are idle in parking for most of the time (90–95% of the time for most cars), could contribute to both system and local flexibility, as Figure 5 illustrates.

Figure 5: Services EVs can provide to the power system

SYSTEM FLEXIBILITY		LOCAL FLEXIBILITY	
Wholesale market	**Transmission System Operator**	**Distribution System Operator**	**Behind-the-meter**
• Peak-shaving • Portfolio balancing	• Frequency control • (primary, secondaryand tertiary reserve) • Other ancillary services (*e.g.*, voltage management, emergency power during outages)	• Voltage control • Local congestion and capacity management	• Increasing the rate of Renewable Energy self-consumption • Arbitrage between locally produced electricity and electricity from the grid • Back-up power

Peak shaving (system level/wholesale market): This involves flattening the peak demand and filling the "valley" of demand by incentivising late morning/afternoon charging in systems with large penetration of solar, and nighttime charging that could be adjusted following nighttime wind production, as cars are parked for a longer time than they need to fully charge. Early-evening charging that may otherwise increase peak demand would be deferred in this way. Consequently, this would defer investments for building additional peak capacity (Weiller and Sioshansi, 2016).

Ancillary services (system and local levels/ transmission and distribution system operators): This involves supporting real-time balancing of grids by adjusting the EV charging levels to maintain steady voltage and frequency. While flexibility has been well-developed at the system level by transmission system operators, distribution system operators are mostly not yet equipped with flexibility from distributed energy resources for operating their grids, despite the high number of demonstration projects that have been conducted and the intense regulatory discussions in several countries (mainly in Europe and the US).

Behind-the-meter optimisation and "back-up power" (local level/consumers and prosumers): This includes increasing self-consumption of locally produced renewable electricity as well as lowering dependence on the electricity grid and reducing the energy bill by buying low-cost electricity from the grid at off-peak hours and using it to supply homes when the electricity tariff is higher (during evenings).

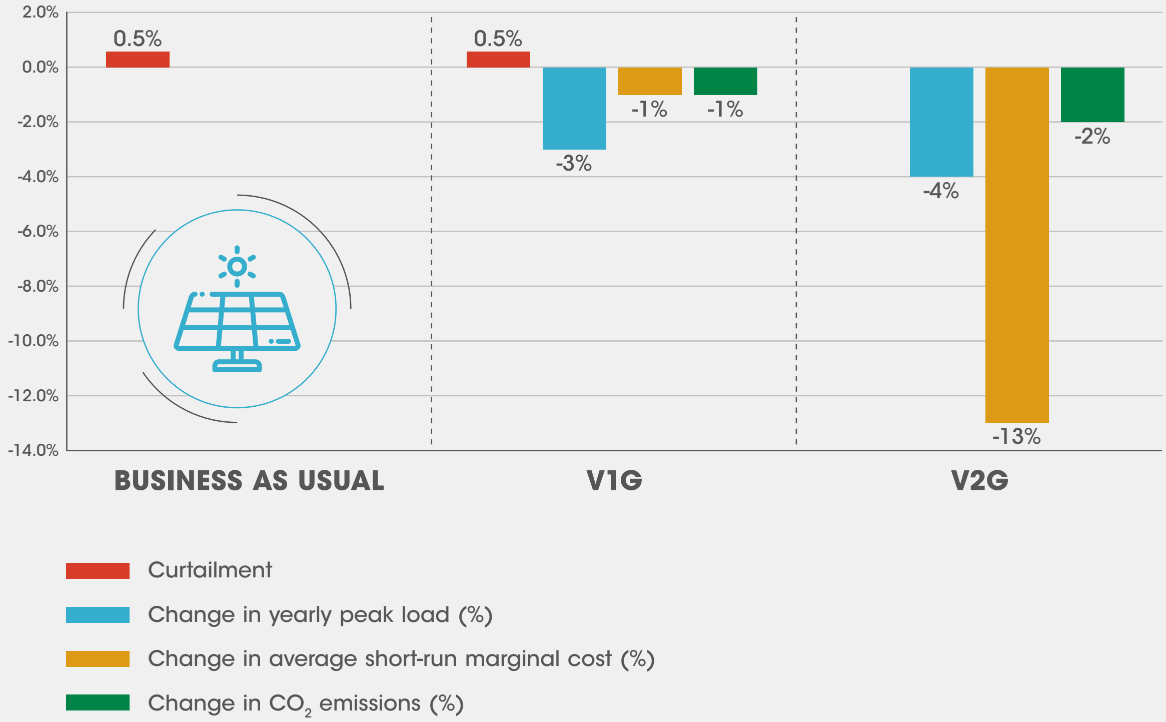
In addition, the EV battery can be used after it has been removed from the vehicle. An EV battery typically will be replaced when the capacity declines to 70–80% (that is, when it may no longer be sufficient for daily mileage); however, the performance is still sufficient for energy storage systems. This offers a lifetime extension of the battery of up to 10 years (Reid and Julve, 2016). With rising EV stocks, the number of potentially available second-use batteries will increase. Acting as stationary storage appliances after being removed from the vehicles, the batteries can further contribute to power system transformation (see the Innovation Landscape brief *Behind-the-meter batteries* [IRENA, 2019d]).

Potential impact on power sector transformation

Smart charging of EVs could have a great impact on the integration of VRE, both in system operation and in long-term expansion plans.

An IRENA study analysed the impact of V1G and V2G charging in comparison to no smart charging in an isolated solar-based system (IRENA, 2019c). In Figure 6, different indicators illustrate the impact of smart charging services in a solar-based system in 2030. **Smart charging cuts peak load, reduces curtailment and allows higher integration of low-cost PV electricity.** This can help displace more expensive generation and can lower electricity prices.

Figure 6: Short-term impact of EV charging



Other recent studies have explored the potential of smart charging and its contribution to power sector transformation, for example:

- Modelling of EVs in New England in the US showed that a 25% EV share in the system charged in an uncontrolled fashion would **increase peak demand by 19%**, requiring significant investment in grid and generation capacities. However, spreading the load over the evening hours could **cut the increase in peak demand to between 0% and 6%**. Charging only at off-peak hours could avoid any increase at all in peak demand (RMI, 2016a).

- Another study simulates the impact of 23% EV penetration in the fleet in 2030 in California (US), with both controlled and optimised charging modes. A big difference in peak load is found in the two scenarios. While all EVs in uncontrolled charging mode would **increase the peak load by 11.14%,** with **smart charging,** EVs would **increase the peak load by only 1.33%** (RMI, 2016b).

- With 100% EV penetration in 2050 in Denmark, Germany, Norway and Sweden, if no V2G is applied, the peak of the **net load curve would increase by 20%** in Scandinavia and Germany (from 127 GW to 152 GW). However, if V2G is applied, passenger EVs will smoothen the net load curve in the Scandinavian and German electricity system so that the hour with **maximum net load is reduced by 7%** (from 127 GW to 118 GW) (Taljegard, 2017).

- A study done for the island of Barbados, with solar and wind supply covering 64% of demand and more than 26 000 EVs by 2030, demonstrates a **five-times increase in production costs** with uncontrolled charging compared to the most efficient smart charging strategy (Taibi and Fernández, 2017).

- A study from 50Hertz, one of Germany's transmission system operators, concludes that the number of EVs in the country in 2035 would have a limited impact on peak demand (approximately 8%) if smart charging is in place. The study also concludes that distribution grid infrastructure might limit high EV penetration rates in residential areas, if distribution system operators do not identify shortages in their grid and **implement smart charging also considering location constraints, not only time constraints** (Schucht, 2017).

- A McKinsey study on EV integration in Germany concludes that when local EV penetration hits 25%, peak load can grow by 30% in the absence of smart charging. Using a V1G strategy and time-of-use tariffs, the **peak load increase can be reduced by 16%** (McKinsey & Company, 2018).

- A Dutch field test showed that uncontrolled charging might lead to local black-outs and imbalance between the three phases in a low-voltage grid. Thus, **smart charging is required to avoid expensive reinforcement costs** for seldom but high peaks resulting from uncontrolled or market-based steering of EVs (Hoogsteen *et al.*, 2017).

- One million EVs in the Guanzhou region in China will increase the peak load of the grid by 15% without any charging control. However, the difference between peak and valley load will be reduced by 43% without V2G technology, while **it can be reduced by 50% if V2G is available** (Chen and Wu, 2018).

- Stromnetz Hamburg, the distribution system operator in Hamburg, Germany, partnered with Siemens to install 30 control units and to monitor the private EV-charging infrastructure loads. This will help the operator anticipate congestion issues and plan the network based on the load profiles. The estimated cost of this solution is around EUR 2 million, which is **just 10% of the cost of reinforcing the cables** in a conventional solution (Pfarrherr, 2018).

- A study that assessed the impact of introducing 2.5 million EVs in Turkey, reaching a penetration level of 10% in the total stock, concluded that this would **increase the peak load by 12.5% with uncontrolled charging**. However, with **smart charging, the peak load would increase only by 3.5%** (Saygin *et al.*, forthcoming).

III. KEY FACTORS TO ENABLE DEPLOYMENT

An intelligent exchange of information, standardised communication protocols as well as connecting EVs and charging points with the help of smart meters and other intelligent infrastructure are needed to optimise the system.

Charging infrastructure

Developing charging infrastructure requires major investments, and currently there are limited business models for private investment. Governments can incentivise the installation of charging stations either at residential or public access locations. The support for the development of charging infrastructure can be first based on ambitious EVs targets and then focused on specific funding for implementation projects.

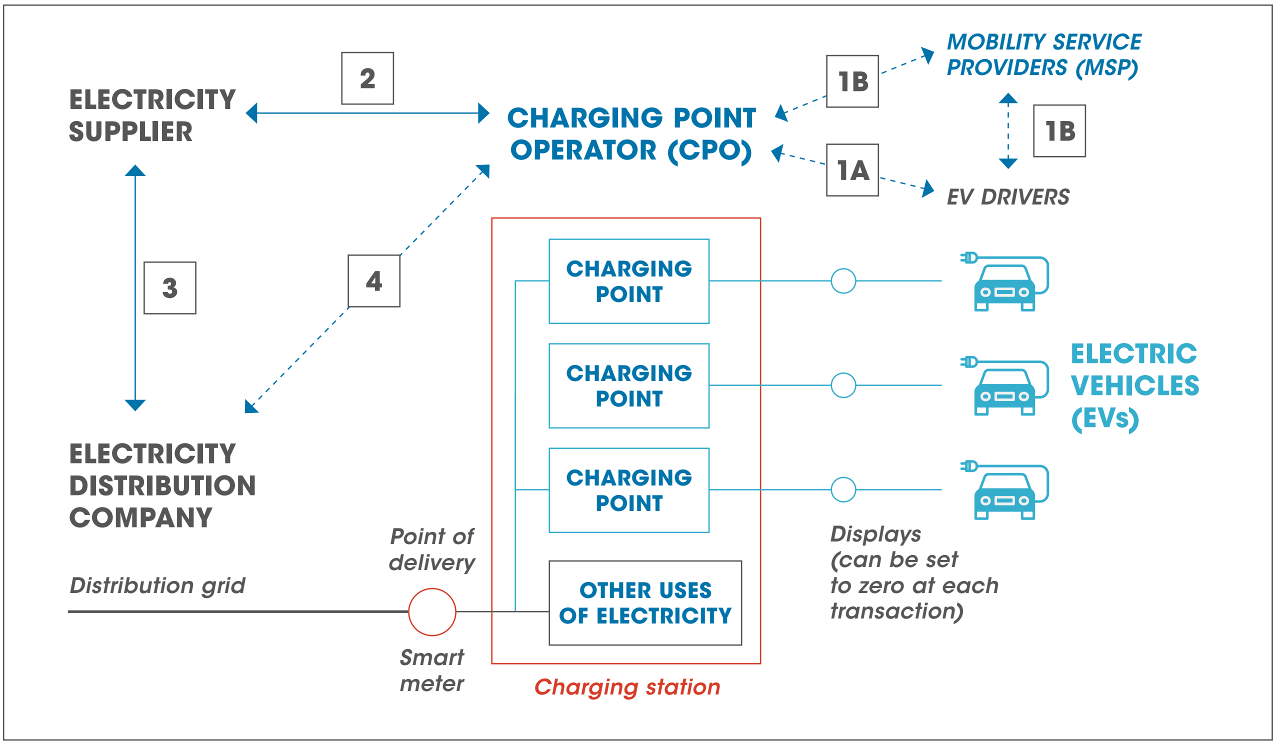
In addition, the need to understand how to best charge, aggregate and control the EV load on the grid is a fundamental and ongoing issue. This would impact important decisions in the development of charging infrastructure – such as where to best place the charging points, which technology to use and how to combine slow smart chargers with fast chargers, to best meet consumer's immediate needs.

In the UK, the Office of Low Emission Vehicles provides grant schemes to cover part of the cost associated with installing EV charging infrastructure. The Electric Vehicle Homecharge Scheme provides residential customers grants that can cover up to 75% of the total procurement and installation costs. From July 2019, only home charging points using "smart" technology will be eligible for this government funding. Smart charging points are defined as charging points that can receive, understand and respond to signals sent by energy system operators or third parties to indicate when is a good time to charge or discharge in relation to overall energy supply and demand (RECC, 2019). A similar scheme is designed for local authorities that wish to install on-street residential charging points. Under the Working Charging Scheme, businesses, charities and public sector organisations can apply for a voucher of GBP 300 per socket up to a limit of 20 sockets (UK Government, 2016).

Define stakeholders' roles and responsibilities

Another important and defining characteristic of smart charging is that it finds itself at the junction between the electricity market and e-mobility. Unlike "traditional" charging, where the e-mobility market (EV drivers, charging point operators, mobile service providers) acts independently of the electricity market, smart charging requires a close co-ordination between the two in order to both accommodate e-mobility requirements in the power system and provide the power system with the needed flexibility. Figure 7 illustrates the relationship between the actors in the two markets, where clear roles and responsibilities need to be defined for each of them.

Figure 7: Contractual relationship between actors involved in electric mobility



Legend: *1A: EV Driver – Chargning Point Operator (directly); 1B: EV Driver - Charging Point Operator (intermediated by Mobility Service Provider); 2: Charging Point Operator – Electricity Supplier; 3: Electricity supplier – Electricity distribution company; 4 Electricity distribution company – Charging Point Operator (only for connection)*

a: Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure.

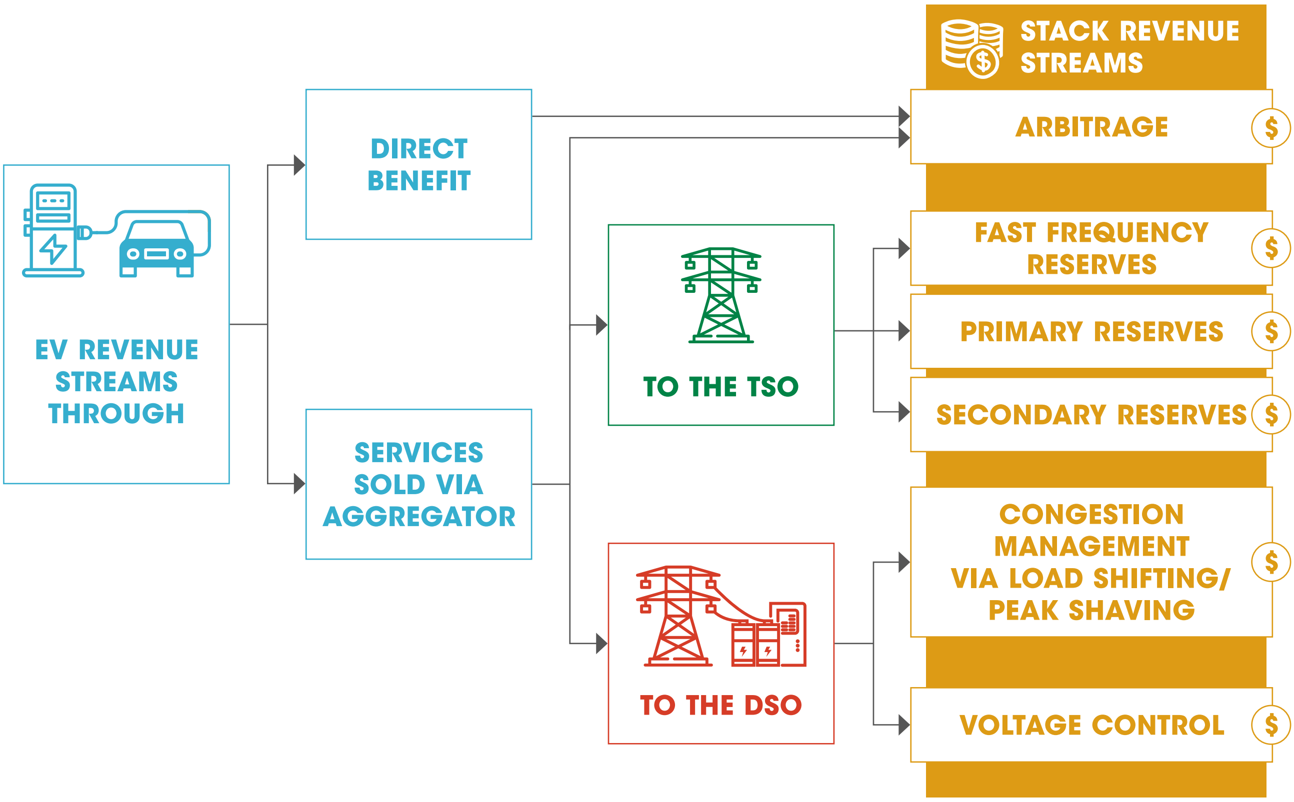
Note: TSO = Transmission System Operator; DSO = Distribution System Operator
Source: IRENA, 2017

Key roles here are the "charging point operator" (CPO) and the "mobility service provider" (MSP). On the one hand, to unlock the potential of smart charging schemes and V2G use cases, charging a fleet of EVs could be controlled by a CPO. The role of the CPO can be taken by the utility itself, the electricity supplier, an e-mobility organisation or even a company that is specialised in demand response services. On the other hand, the MSP could act as an intermediary between the CPO and EV drivers.

Design regulation for vehicle-grid integration

Smart charging will not "just happen" without the right incentives in the form of dynamic price signals. In a similar vein, V2G will not materialise without the possibility to "stack revenue" from multiple revenue streams, providing flexibility at both the system and local levels. Figure 8 depicts the possible revenue streams for EVs, which need to be enabled to incentivise smart charging.

Figure 8: Possible EV revenue streams that can be stacked



Note: TSO = Transmission System Operator; DSO = Distribution System Operator
Source: IRENA, 2019c

This will not happen without well-functioning electricity markets. Competitive wholesale and retail markets are not always in place today, even in the emerging e-mobility markets. In most countries, wholesale electricity markets exist, but competitive balancing/ancillary service markets and retail markets are often missing – that is, they are still regulated services executed centrally by a transmission system operator.

Even where such markets are in place, their design will need to develop, and regulations will need to be adjusted to provide incentives for the valuation of EV grid services, including:

- Adjustment of market thresholds and access conditions for different wholesale segments. Even in markets that explicitly allow aggregation access, minimum capacity and availability requirements for major grid services remain designed for large-scale power plants.
- Avoiding double charging of storage for the grid that penalises V2G as well as second-life batteries.
- Updating outdated regulations prohibiting the resale of electricity from the grid without a supplier, in order to account for EVs.

Aggregators

EV batteries can provide the fast response needed for some ancillary services, but their power capacity is limited; thus a single EV cannot provide these services for the period of time needed by the power system. However, when EVs are aggregated they can complement one other, resulting in a virtual power plant with a fast response and the ability to provide services for the needed period of time.

Aggregator business models facilitate the use of EVs as a source of flexibility. At least 1–2 MW capacity must be traded to make EV power provision viable at the wholesale level. This requires the aggregation of around 500 vehicles and their charging points.

Virtual Power Plant operator Next Kraftwerke, and Jedlix, an electric vehicle (EV) aggregator and smart charging platform provider, have launched an international pilot project which uses EV batteries to deliver secondary control reserve to TenneT, the transmission system operator in Netherlands. Jedlix will be able to combine user preferences, car data, and charging station information to provide a continuous forecast of the available capacity. This is then used by Next Kraftwerke in the bidding process of TenneT for procuring grid services (NextKraftwerke, 2018).

ICT control and communication protocols

In addition, in order to optimise the system and facilitate information sharing among all actors, communication protocols need to be developed. Smart charging involves the charging of an EV controlled by bidirectional communication between two or more actors to optimise all customer requirements, as well as grid management, and energy production including renewables with respect to system costs, limitations, reliability, security and safety.

For example, the Open Charge Alliance developed the Open Charge Point Protocol (OCPP) as a uniform solution for communication between a charge point and a central system. With this protocol, it allows for connecting any central system with any charge point, regardless of the vendor. The control mechanism can be enabled by the grid, the charging point or the vehicle itself.

Meanwhile, a communication system with the grid allows the charging process to take into account actual grid capabilities (intelligent algorithms can be distributed at all three levels) as well as customers' preferences. Price or control signals can be communicated through an information and communications technology (ICT) infrastructure (for example, intelligent metering system, communication between charging stations and back-end systems) in order to allow algorithms to take into consideration generation and grid constraints, as well as to enable customers to benefit from price opportunities.

Big data and artificial intelligence for smart charging

Smart charging through use of V2G integration technologies is a means of managing EV loads, either by customer response to price signals or by an automated response to control signals reacting to the grid or market situations, or by a combination of the two. This needs to be done while respecting the customer's needs for vehicle availability. It consists of shifting some charging cycles in time or modulating the power in function of some constraints (for example, connection capacity, user needs, real-time local energy production).

Advancements in big data and artificial intelligence could facilitate and optimise the services provided by smart charging solutions. ICT advancements including data management and data analytics from drivers, charging patterns, CPOs and charging stations would enhance smart charging functionalities and atomise the provision of services to the grid. In addition, digital technologies and data analytics will enable mobility demand with power supply patterns to be as compatible as possible and to decide about the most optimal locations for charging points.

If direct control mechanisms enabled by the EV and the charging point are in place, further services could be provided to the grid without affecting consumers' needs. For instance, customers could set the car's departure time and/or the required battery capacity reserve. The charging station then determines the current battery status and calculates the energy necessary to reach the desired state in the most optimal way to improve the power system's economic and environmental performance.

IV. CURRENT STATUS AND EXAMPLES OF ONGOING INITIATIVES

The table below captures useful indicators about EVs and smart charging. Some case studies follow.

Table 1 Key indicators for EVs and smart charging

Number of EVs on the road at the beginning of 2019	Worldwide: 5.6 million China: 2.6 million US: 1.1 million
Compound annual growth rate of EV sales between 2012 and 2017	57%
EV share of total light-duty vehicles (LDVs) sold in 2017	1.3%
Largest EV markets in terms of units sold in 2017	China, Norway, US (Norway has the highest penetration of EVs in overall LDV sales)
LDV chargers in 2018 (globally)	5.2 million
Publicly accessible chargers in 2018 (globally)	540 000
Fast chargers for buses in 2018 (globally)	157 000

Source: IRENA, 2019c; IEA, 2019

Vehicle-grid integration project in San Diego (US)

San Diego Gas & Electric (SDG&E) launched a vehicle-grid integration pilot project that tests making fleets of EVs available as dispatchable distributed energy resources to improve the stability of the grid. SDG&E will install and operate 3 500 charging stations, mainly slow-charging stations, throughout the San Diego region. The programme explores dynamic pricing and, through an app, incentivises charging activities at moments of high renewable energy supply (Turpen, 2016). Dynamic hourly rates are posted on a day-ahead basis, and they reflect both the system and local grid conditions. An app matches customers' preferences with those prices. For simple time-of-use, bigger effects were recorded for customers with separate EV-only meters (RMI, 2016a).

Nuvve the vehicle-to-grid experience (US)

One advanced player in the V2G technology is Nuvve. Nuvve supplies a wide range of services to the power system including frequency and supply reserve capacity in different markets. It has been participating in the PJM (Pennsylvania-Jersey-Maryland) frequency market in the US since 2009. Customers just provide information on when they need the vehicle, and when the battery is charged enough, the optimisation software can choose to supply electricity back to the grid, or provide other services.

Nuvve announced the intention to roll out 1 500 smart chargers in the UK with V2G capability. The idea is to offer the chargers to EDF Energy's business customers that use electric cars. Estimations show that the chargers would be able to supply up to 15 MW of power (assuming that the cars are connected to the chargers and charged sufficiently). On average the resulting power would be some 10 kW per car/charger (Kane, 2018).

Vehicle-to-grid projects in Hamburg (Germany)

In February 2019, the City of Hamburg launched the ELBE project, which focuses on funding the installation of EV charging stations at buildings and on commercial premises. The project includes the application of V2G technology and load-dependent tariffs, where EVs are considered as controllable consumption.

Parker project (Denmark)

The Danish project, Parker, is an example of a V2G project that uses smart charging technology and relies on co-operation between the automotive and power industries to demonstrate the ability of EVs to support and balance power systems based on renewable energy. Grid integration specialists such as Enel, Nuvve and Insero, as well as the auto manufacturers Nissan, Mitsubishi and PSA Groupe, have demonstrated that state-of-the-art vehicles from various auto manufacturers can contribute to supporting the electricity grid, providing services such as frequency and voltage control via V2G technology.

The project shows that V2G has the potential to play a significant role in providing grid flexibility, and increasing the vehicle's revenue, but that technical challenges remain, including uncertainty about degradation of batteries, lack of standardisation of communication and lack of consumer knowledge of the V2G system (Bach Andersen *et al.*, 2019). The yearly revenue per car in Denmark is estimated to be between EUR 1 700 and EUR 2 500, depending on the availability of wind resources (Bach Andersen *et al.*, 2019).

Other examples of smart charging deployment from different parts of the world, listed by the type of smart charging implemented, are provided in Table 2.

Other examples of EV Smart Charging projects

Table 2 Overview of smart charging deployment and pilot projects

Type of charging	Examples of projects
Uncontrolled time-of-use tariffs	China, Germany, Japan, UK, US
Basic control	My Electric Avenue, Scottish and Southern Energy Power Distribution and led by EA Technology, UK (100 households testing Esprit system) Pepco, Maryland, US (200 households) United Energy – Victoria, Australia (2013)
Unidirectional controlled (V1G)	Green eMotion project, EU (2015): reduction of grid reinforcement cost by 50% Sacramento Municipal Utility, US: reduction of grid upgrade expense by over 70%
Bidirectional vehicle-to-grid (V2G)	eVgo and University of Delaware project, US, with transmission system operator PJM Interconnection – commercial operation Nuvve, Nissan and Enel, in England and Wales, with transmission system operator National Grid – operating pre-commercially Nuvve, DTU, Nissan, PSA and Enel project in Denmark, with transmission system operator energinet.dk ("Parker project") – operating trial Nuvve, The New Motion, Mitsubishi project in the Netherlands, with transmission system operator TenneT – commercial trial Jeju, Republic of Korea project developing fast and slow V2G; Toyota city project with 3 100 EVs Renault, Elaad NL and Lombo Xnet project, Utrecht, the Netherlands, AC V2G
Bidirectional vehicle-to-X (*e.g.*, V2H)	ElaadNL and Renault, Utrecht, the Netherlands: 1 000 public solar-powered smart charging stations with battery storage around the region in the largest smart charging demonstration to date, although not all of them are V2X chargers. Increase of self-consumption from 49% to 62–87% and decrease of peak by 27–67%. DENSO and Toyota intelligent V2H (HEMS and V2G integrated model), Nissan (V2B) – all Japan
Dynamic pricing with EVs (controlled)	Nord-Trøndelag Elektrisitetsverk Nett in Norway San Diego Gas & Electric in California, with prices posted one day ahead
Second-life battery	BMWi and PG&E Charge Forward Pilot Program in California

V. IMPLEMENTATION REQUIREMENTS: CHECKLIST

TECHNICAL REQUIREMENTS	**Hardware:** • Widespread adoption of EVs. • Public and private charging infrastructure – smart charging points. • Smart meters – required for supplying interval values for net consumption and net production.
	Software: • Smart charging services such as energy and power flow management systems that allow for optimal EV charging, ICT systems, intelligent charging infrastructure or advanced algorithms for local integration with distributed energy sources.
	ICT structure and development of communication protocols: • Agree and develop common interoperable standards (both at physical and ICT layers) as well as clear definitions and roles for actors and smart charging. • Develop a uniform solution for the method of communication between charge points and the central power system, regardless of the vendor.
POLICIES NEEDED	**Stable, supportive policies for e-mobility and smart charging**
	Strategic policies could include: • Prioritisation of demonstration and commercialisation: Increased co-operation between public and private actors could enable the roll-out of large-scale demonstration and pilot projects. • Win-win synergies and exchanges between the electricity, automotive and manufacturing sectors: the electricity industry should increasingly engage with e-mobility stakeholders in raising awareness and developing best practices with a focus on customer opportunities.

REGULATORY REQUIREMENTS	**Wholesale market:** • Allow EVs, through aggregators or individually, to provide services in the ancillary service market and wholesale market. • Enable revenue streams to incentivise smart charging of EVs.
	Distribution system: • Innovative grid fees for distribution networks (possibly special tariffs for transport) given a suitable framework for smart meters.
	Retail market: • Efficient price signals (such as time-of-use tariffs) or other load management schemes to incentivise smart charging. • Understand customer behaviour and create awareness of the possibilities to use load management.
STAKEHOLDER ROLES AND RESPONSIBILITIES	**State institutions:** • National governments could sponsor the projects and provide subsidies for deployment of charging points. • Local and regional authorities could co-finance the project.
	Electricity market: • Distribution system operators can seek support from e-mobility service providers and/or ICT companies in the delivery of smart charging services through their customers to ease the cost of technology adoption and to delay/avoid grid reinforcements. • Energy retailers can develop smart charging as a measure to support their power plants portfolio strategy, particularly at the local level, and as a possible revenue stream coming from ancillary services sold to the transmission system operators.
	E-mobility market: • Incentivise electric mobility market participants to invest in smart charging solutions and services. • Provide incentives to e-mobility customers, via contractual benefits (*e.g.*, price signals), to access smart charging services. • Charging spot operators need to fulfil their contractual commitments while considering charging requests from consumers and optimising their costs based on electricity market signals. • E-mobility service providers request charging access following the demand from their e-mobility customers. The charging requests might be executed either on a charging infrastructure owned by a third party, the charging spot operators, or owned by the e-mobility service provider itself, in the case when it also plays the role of charging spot operator.

ACRONYMS AND ABBREVIATIONS

BMWi	Germany Federal Ministry for Economic Affairs and Energy
CO_2	carbon dioxide
CPO	charging point operator
DSO	distribution system operator
EU	European Union
EUR	Euro
EV	electric vehicle
GBP	British pound
ICT	information and communications technology
KPI	key performance indicator
LDV	light-duty vehicle
MSP	mobility service provider
OCPP	Open Charge Point Protocol
PG&E	Pacific Gas & Electric
SDG&E	San Diego Gas & Electric
UK	United Kingdom
US	United States
V1G	unidirectional vehicle-to-grid
V2B	vehicle-to-building
V2G	bidirectional vehicle-to-grid
V2H	vehicle-to-home
V2X	vehicle-to-X
VRE	variable renewable energy

UNITS OF MEASUREMENT

GW	gigawatt
kW	kilowatt
MW	megawatt
TWh	terawatt-hour

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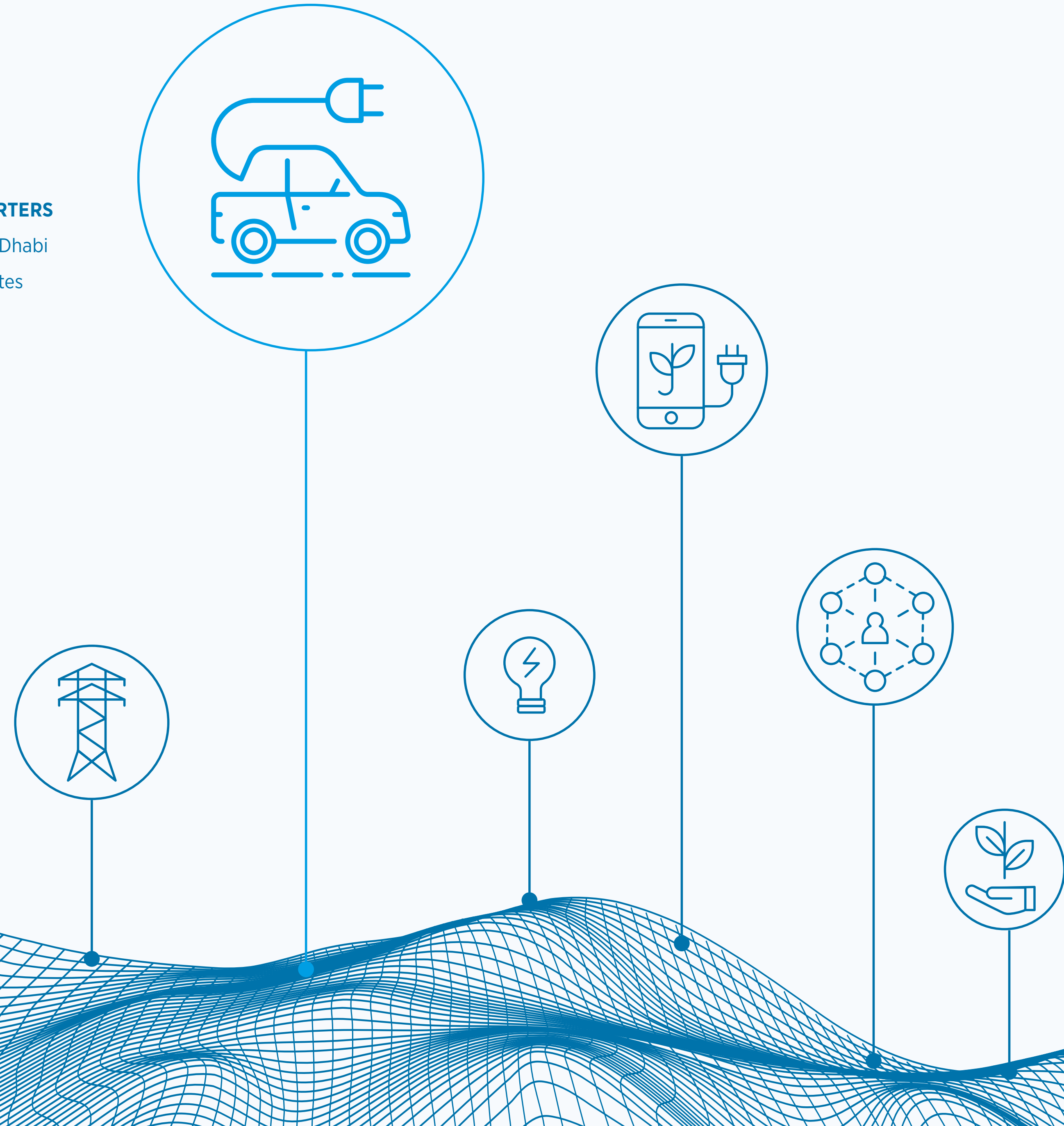

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