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Integrating EVs into the grid: A global review of promising practices

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Summary

The electrification of road transport is at the beginning of a market transformation that offers significant opportunities to cut emissions in both the transport and energy sectors while generating wider benefits for society. The key condition for mass market take-up is to integrate EVs into the grid cost-effectively to benefit consumers, the power sector, and the environment. This paper identifies three policy strategies—smart pricing, smart technology, and smart infrastructure—needed to unlock the environmental and economic opportunities. It also discusses promising practices in each area based on a qualitative review in the EU and U.S. markets, and implications for policymakers and regulators in the EU.

Keywords: BEV, utility, electricity, smart charging, smart meter

1 Introduction

The number of electric vehicles (EVs) [1] has increased exponentially to more than 1 million passenger EVs on the road in Europe at the end of 2018 [2]. EVs are inextricably entwined with the power sector and its decarbonisation. By charging when the costs for producing and delivering electricity are low, EVs can help to integrate and absorb variable renewable generation, smooth the power load curve, contain overall grid costs, and make better use of existing assets. This brings down the costs for all electricity consumers, not just EV drivers. At the same time, it delivers significant further environmental and economic benefits [3].

EVs constitute a flexible load that can be drawn from or fed into the grid at any point during the hours when the vehicle is not being driven. Under the prevailing private ownership model, this constitutes about 90 to 95 percent of the hours in a day [4]. But even in the event of increasing vehicle use through growing shared-mobility services, there is likely to be some flexibility for optimising charging hours, and the incentive to minimise the cost of charging is high.

The opportunity for smart EV integration is to charge EVs when and where it is most beneficial for the power system while meeting consumers' mobility needs at an affordable cost. Integrating EVs optimally into the grid means doing so at least cost and using the flexibility potential that EVs provide to maximise environmental, consumer, and grid benefits.

This paper reviews promising practices for achieving such smart integration of EVs, drawing on examples from around the world. Our analysis is deliberately not comprehensive but instead uses illustrative case studies to demonstrate the opportunities and benefits of a variety of approaches. We identify three particularly important ingredients: smart pricing (the “software”), smart technology (the “apps”), and smart infrastructure (the “hardware”), which build on each other:

- Smart pricing uses retail electricity prices (both for energy and the network) that vary across the day to provide an economic incentive to consumers for adapting their charging behaviour. If done well, this aligns the choices that consumers make to minimise their own bills with the choices that also minimise overall system costs.
- Smart technology, coupled with smart pricing, can help leverage the inherent flexibility of EVs. In a more advanced form, it can automate the charging process by responding to price signals or other information. It also takes the burden off EV drivers of identifying and following the charging pattern that is most cost-effective for them.
- Smart infrastructure places the EV charging infrastructure needed to meet mobility demand in public or private locations that are best suited to use existing power network capacities and provide balancing services, thus reducing the cost of EV grid integration. This is important to address, as the type and location of charging infrastructure determines not only where and how, but also when EVs are charged.

The paper is structured as follows: First, we provide the context and background for smart EV integration. Second, we present the three strategies we identified for smart EV integration. Finally, we share conclusions and provide a number of policy recommendations based on our analysis.

2 Background

Smart integration of EVs can deliver significant power system benefits. For example, when there is a substantial amount of renewable energy on the grid relative to “business as usual” demand, wholesale market prices may be quite low. Shifting EV charging to such periods can mitigate uneconomic curtailment, or output reduction, of renewable energy. For instance, in California the traditional midday peak has, on many days, become a valley, creating the opportunity to charge EVs at low cost and improve the utilisation of increasing solar production in the middle of the day. Similarly, charging could occur when ample grid capacity is available to deliver the required electricity, usually during nighttime hours.

Figure 1 shows the electricity load curve for three European countries on a typical day. It shows that electricity demand is at its lowest levels during the nighttime hours and starts increasing in the early morning. It peaks in the evening, before dropping toward midnight.

This pattern is typical among EU Member States and beyond, although variations have started to appear in recent years due to increases in the use of distributed energy resources. The significant valley that occurs during nighttime hours could be used to take up new electricity loads. EVs are ideally suited to take advantage of it because they are normally parked during these hours.

Moving EV demand from the peaks to the valleys in the demand curve also delivers benefits for system operators. It reduces the need to add more costly supply-side flexibility (i.e., additional power generation) for meeting ramping requirements. This will be one of the key challenges to address in a power system dominated by variable renewables, a challenge that is likely to extend beyond the daytime and nighttime load differences. Power plant producers can also benefit from this shift in load through the resulting higher load factors, which minimise the costs of starting and stopping their facilities.

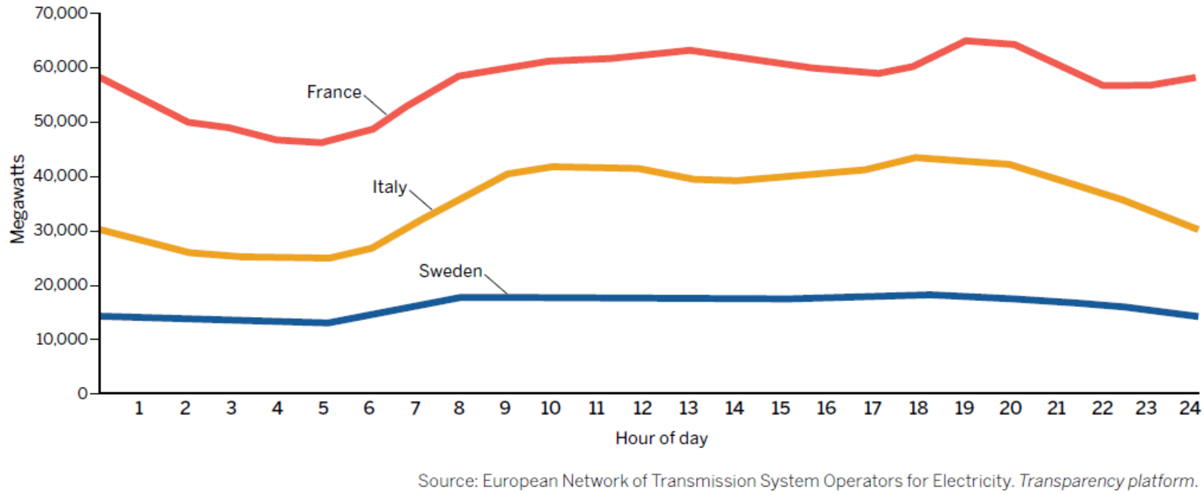

Fig. 1: Electricity demand curve on a typical day in selected European countries (7 Nov. 2018)

Currently, the limited number of EVs on the road doesn't pose any significant concerns for the electric grid [5]. Even increasing numbers of vehicles need not give rise to concerns about integrating this resource into the grid if it's done smartly. The real challenge is about the instantaneous power demand on the grid [6]. Several analyses demonstrate that electrifying road transportation would require minimal incremental costs if we most effectively utilise existing assets. The European Association of the Electricity Industry, Eurelectric, concludes that the overall electricity peak increase would be negligible and that grid utilisation rates could be improved with smart charging, even if some local grid reinforcement might be required [7]. Our own analysis shows that existing distribution network grids are largely underutilised and that the unused network capacity could be used for charging EVs with little or no need for additional capacity [8].

If the number of EVs increases without smart charging of those vehicles, the costs for meeting the power and delivery needs would increase exponentially. Peak demand could double if EVs are charged during peak periods [9][10]. This would needlessly result in significant investment in new generation and network capacity that would operate at very low load factors simply to serve this exacerbated peak. To avoid this threat and to reap the benefits of smart charging and optimal EV grid integration as described above, three strategies for beneficial EV grid integration have been identified which are presented in the following section.

3 Methods

The promising practice examples were selected based on qualitative research of available material, interviews with various stakeholders [11] involved in the practices, and intelligence gathered at various informal exchanges. We also incorporated feedback from external expert reviewers (see acknowledgements). The research was conducted between June 2018 and March 2019.

4 Strategies for smart EV integration

This section presents the three fundamental strategies for smart EV integration that we identified during the research.

4.1 Smart pricing

Smart pricing encourages customers to shift their electricity use from periods with high electricity prices to periods with lower prices. That is, smart tariffs help ensure that the choices consumers make to minimise their own utility bills are consistent with choices that also minimise overall system costs. Electricity tariffs can be designed in such a way to make optimal use of existing power system infrastructure while limiting future system costs. To the extent additional demand can be accommodated with existing infrastructure, grid costs can be spread over a larger volume of consumption, thus reducing electricity prices for all customers instead of driving unneeded new investment and higher costs.

The simplest and predominant form of pricing across Europe consists of flat, non-variable tariffs. This type of tariff, often called a standard tariff, offers a uniform volumetric price across the entire day, week, or even year — that is, a charge for every kWh of electricity consumed. These tariffs do not send signals to consumers to use electricity when the associated costs are lower and to avoid consuming electricity when it is most expensive. In other words, consumers cannot save on their electricity bills by flexing their consumption toward times of low electricity costs.

Smart, time-varying pricing designs are available across most of Europe. However, their adoption by consumers is limited overall. Examples of such pricing range from time-of-use (TOU) tariffs — in which the consumer pays a variable, predetermined fee for specific blocks of time based on historical usage patterns (such as a day and night, or a weekday and weekend tariff) — to the most granular real-time pricing, in which the price is determined by actual conditions on the system from one interval to the next. In between the two, critical peak pricing sets significantly higher prices for a limited number of pre-notified “critical peak” periods. Another emerging tariff form is the peak-time rebate. Consumers on such a tariff receive a partial refund if they avoid using electricity during peak hours but face the same charge if they consume electricity during these hours, as with any other time of the day.

The most common option of time-varying pricing is simple TOU tariffs, with different day and night charges. Many of these tariffs were established in the 1970s and 1980s and do not require any type of advanced metering technology. According to a study by the European Commission, the way these tariffs are set varies considerably among Member States. Oftentimes the price differential between the day and night charge can be insignificant, not reflecting the associated costs for producing and delivering electricity to consumers. Real-time price tariffs are increasingly offered in European countries, while critical peak pricing is offered only in France. Real-time price tariffs require the installation of smart metering, which is one of the key obstacles to their implementation, as the smart meter rollout is far short of targets in several Member States.

The smarter a price, the greater the reward and risk associated with it, meaning that consumers can save more if they use the tariff to their full advantage, or pay more if they use it wrongly. It is therefore important that consumers understand the benefits and risks of a tariff and how to make best use of it. This can be achieved, among other ways, through pilot projects that aim at identifying what works best for consumers and educational programmes that explain whether a certain tariff is a good fit for a consumer and how to best make use of it.

In the short to medium term, as the number of EVs on the road remains relatively low and the power system continues transitioning, simple forms of dynamic tariffs such as TOU can achieve the desired outcome of integrating EVs cost-effectively. In the longer term and as EVs and renewable energy dominate the transport and power systems, respectively, more sophisticated tariff designs will maximise the potential benefits of EV integration. A game changer in this direction is smart technology that enables the collection and communication of information to the consumer. More advanced technology that can automate consumers’ energy consumption in response to signals, most often prices, offers the highest potential to achieve smart charging in the longer term. Automation and smart technology can also mitigate the risks associated with the incorrect use of a tariff.

The following examples illustrate lessons from the EU and the United States on how tariffs can be designed to help beneficial EV integration, starting with simple examples and progressively describing more complex ones.

Table 1: Examples of smart tariffs

Tariff Design	Main Features	Prerequisites	User Experience
Two-period TOU tariff for energy (Spain)	80 percent discount for EV drivers charging during predefined night period charged at 0.03 €/kWh, compared to a day charge of around 0.16 €/kWh.	Simple binary meter	A Nissan Leaf owner will save approx. 167 euros per year charging the EV on the night tariff compared to standard rate. [12]
Octopus Agile (UK)	Tied to half-hourly day-ahead market, promotes renewable energy use and flexibility	Smart meter/phone app, active participation of customers	Saves 150 euros per year compared to standard tariff. Energy consumption shifted to low-demand hours.
Radius (Denmark)	TOU-based network tariff, adding a surcharge of 0.09 €/kWh to winter peak hours (5 to 8 p.m.), compared to standard rate of 0.035 €/kWh.	None, standard rate applicable to customers connected to low- (households) and medium-voltage grid (commercial)	

An alternative to steering smart charging via pricing models is active control of charging, as is practiced by some suppliers in Germany. German energy legislation allows classification of EVs as a controllable end use (the same classification applies for heat pumps) and enables distribution system operators (DSOs) and suppliers to put in place discounted network charges for EV charging. In return, DSOs are granted the right to adjust the consumers' demand from controllable loads during predetermined on-peak hours, if the distribution network is stressed. In effect, these tariffs permit DSOs to interrupt EV charging during peak hours if necessary to retain secure supplies. Several German DSOs offer specific EV network tariffs on this legal basis.

4.2 Smart Technology

The previous section demonstrated the potential that electricity pricing offers to encourage beneficial EV integration. While smart pricing is an essential factor for supporting smart charging, its effectiveness will be limited if it is not accompanied by customer means to easily and efficiently respond to that pricing. The effectiveness of pricing can be maximised with the use of smart technology, such as automated systems of load control. The reverse is also true: The deployment of smart technologies will have limited benefits without smart tariffs.

In particular, the combination of smart pricing and smart technology deployment will drive demand response (and by extension smart charging), promoting the best use of existing assets and helping to minimise the costs of the energy transition. Figure 2 illustrates this by showing the levels of peak demand reductions achieved for a number of pilot programs with different forms of smart pricing, and both with and without smart technology. The levels of peak demand reductions achieved were generally higher when smart pricing was accompanied with smart technology.

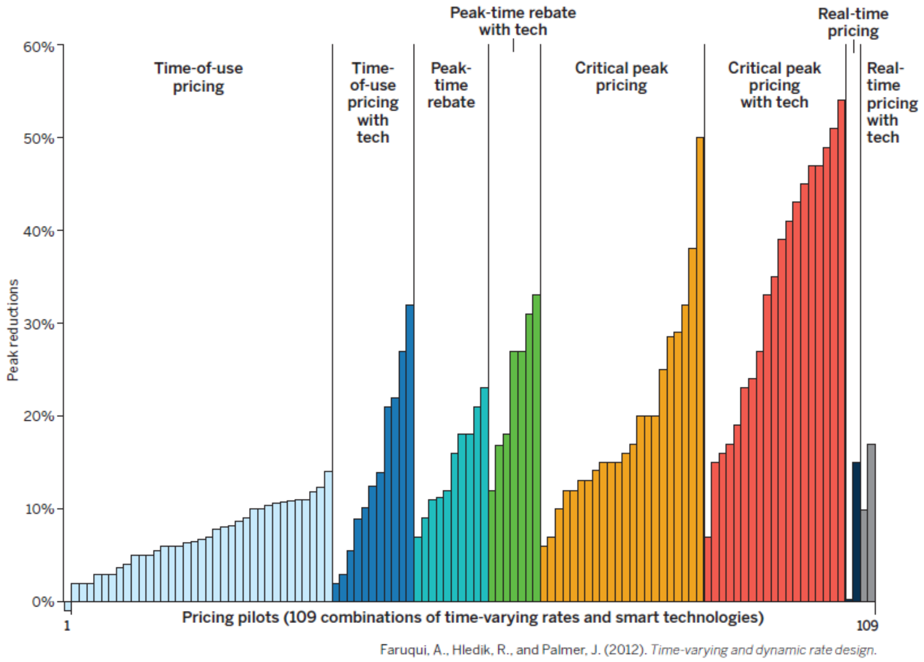

Fig. 2. Average peak reduction from time-varying tariff pilots

Smart technology can be defined as any type of technology that, among other things, can monitor a customer's real-time (or close to real-time) consumption, communicate this information to the consumer and others, and automatically control consumption. In its simplest form this includes smart meters or other type of devices that are able to measure and communicate the real-time consumption of a customer, and in-house displays and mobile applications that can communicate this information to consumers in an easy and accessible way. Although this type of technology provides information to customers, it still requires them or a third party (such as an aggregator) to take action in order to optimise consumption, either through direct interaction with appliances or remotely.

More advanced smart technologies include those that can automatically respond to prices or other signals. This includes, for example, smart chargers that can adjust the level of charging in response to the situation on the grid. Other examples include technology that can optimise the charging of EVs according to cost—that is, minimise the cost of charging based on predetermined or real-time pricing—and technology that can recognise the fuel source of the supply and limit the source of charging to renewable energy.

Smart technology is developing rapidly, and it is uncertain which business models will prevail or which technologies will be available for the medium term. For example, the "intelligence" (e.g., real-time metering) can reside in the charging station itself, the cable that connects the EV to the charging station, or the vehicle itself. It is possible that in the future EV drivers will be able to select different levels of smart technology depending on relative costs as well as on the preferences and needs of individual drivers. The following examples illustrate how different smart technologies can enhance smart charging.

Table 2: Examples for smart technology deployment

Technology	Main Features	Level of Consumer Intervention required
Green Mountain Power (Vermont, US)	Technology and price package; charging controlled by utility and shifted to off-peak hours, with opt-out option	None. The utility offers a 7-kW charger for free to consumers who buy a new electric vehicle and for a $10 monthly payment to consumers who already own an EV. EV owner indicates when EV is available
Jedlix (Netherlands)	App assesses optimal charging profile - including grid capacity, sustainable energy availability, and energy prices - to shift charging to preferential hours	Very low. Consumer indicates time of travel
Maxem (Netherlands)	Wall box/app to integrate EV charging station, own generation units (e.g., solar photovoltaic), and other uses and appliances (e.g., electric heating) into a smart home or office building	None / very low. App monitors the electricity withdrawals and injections of the different applications and implements smart EV charging (e.g., decreases EV charging if the home's demand is greater than its own production and network connection) to ensure its safety
MyEnergi	Meter with app able to recognise the fuel source and direct it to EV charging, e.g., in connection with domestic solar energy production	Very low. Option to manually determine charging time and mode

Load balancing solutions, whereby technology manages the load of charging, can ensure that a large number of users can utilise the charging facilities and avoid stress on the grid, as well as resulting higher charging costs. In multi-unit buildings and large offices, charging several EVs in shared garages can affect a building's electricity system. Load balancing solutions, available to building owners, enable the charging of more EVs overnight, while avoiding an increase of the peak demand of the building (and by consequence the related costs). Load management will also be crucial for integrating larger loads, such as electric buses in depots, to avoid costs of using the grid at peak times and reduce the need for building more capacity. For example, by optimising load management at a bus depot in a large European city, ChargePoint, an electric vehicle supply equipment provider, was able to reduce peak power demand for charging about 130 buses from five megawatts to two, implying considerable savings [13].

4.3 Smart Infrastructure

In addition to smart tariffs and technology, the third ingredient needed to integrate EVs beneficially into the grid is smartly located charging infrastructure. Thoughtful siting encourages EV drivers to charge when optimal for the grid and without compromising their mobility needs. Governments and planners need to answer these questions in pursuing grid-friendly infrastructure location: Which kind of infrastructure is needed to allow for optimised charging? Where should this infrastructure be located, and how can and should grid characteristics be considered when deciding the location of new infrastructure?

Early developments in the market for installation of charging points and charging services in the EU have revealed uncertainties as to siting, accessibility, grid integration and return on investments. Where EV charging occurs will vary greatly depending on increasingly differentiated user groups and on the penetration of EVs in the future. In the short term, most of the charging of electric passenger cars is likely to remain in private settings at homes or in office parking facilities. In the medium and long term, however, the ratio of private vs. public charging may change. This depends on how quickly private car ownership and use are replaced by sharing and how soon transport shifts to other modes.

Workplace charging services, including normal and fast charging offers and rates, are developing rapidly. First, existing network infrastructure can be used. Many office buildings are in city centres or dense urban areas, where significant network capacity is available and can readily be exploited. Second, encouraging employees to park and charge EVs during office hours provides an opportunity to increase load when solar power production is high and can be absorbed. This kind of smart charging behaviour can be enhanced when coupled with a time-varying electricity tariff reflecting the cheaper renewable energy available.

Integrated energy and mobility planning should start by effectively utilising existing infrastructure to reduce costs and unlock EVs' full benefits. The promising practices described below illustrate a growing number of diverse use cases for EV charging, summarized below illustrate how to make the most beneficial use of EV grid integration while addressing some of the challenges.

Table 3: Examples for smart infrastructure deployment

Infrastructure solution	Main features	Advantages for grid integration
Public park&charge (London)	Convert street infrastructure such as light-poles into 3-5kW charging points	Uses existing (electrified) infrastructure, reduces cost of installation from 8000 to 1000 £[14], encourages off-peak use by parked cars, additional efficiency gains through shared infrastructure
Study- public fast charging points along existing grid (San Francisco) [15]	Utility mapping tool identified more than 14,000 locations where fast chargers could be installed to provide every EV driver with a fast charger within a one-mile (1.6 kilometre) radius, identifying upgrade costs	Joint energy and transport planning, use of existing infrastructure

TSO Mapping tool for highway fast-charging stations (UK) [16]	UK's transmission system operator National Grid studied 50 optimal locations for fast chargers (up to 350 kWs) along highways, allowing 90 percent of UK motorists to reach a charging point within 50 miles.	With an estimated cost of 1 billion pounds, is also an opportunity to avoid costs for building new grid infrastructure by linking these locations to the high-voltage grid.
Battery-assisted charging for cars (Greenlots / Hawaii) [17]; for ferries (Ampera Electric Ferry / Norway) [18]	Battery-electric ferry operating between two fjords in Norway that runs based on a fast charging system at each quay. Two battery buffers allow fast charging when the ship is ashore, for about 10 minutes, which avoids overloading the grid. The batteries replenish from the grid in slower mode while the ferry is not "plugged' in.	Fast charging stations equipped with batteries could offer electric charging at any time regardless of peak prices due to the ability to charge the stations' batteries off peak, and can be used where using existing capacity is not an option.

Conclusion: Policy Implications

The electrification of road transport is at the beginning of a market transformation that offers significant opportunities to cut emissions in both the transport and energy sectors while generating wider benefits for society. The key condition for mass market take-up is to integrate EVs into the grid cost-effectively to benefit consumers, the power sector, and the environment. With a new legislative period beginning in the EU, policymakers can seize the opportunity to work toward a needed holistic regulatory framework for e-mobility, based on the main ingredients: smart pricing (the "software"), smart technology (the "apps"), and smart infrastructure (the "hardware"). Accordingly, our review of EV integration practices yielded three primary conclusions:

First, electricity pricing has proven effective at encouraging EV drivers to shift their charging to times when it makes more sense for the power system. The implementation of the Clean Energy for all Europeans package will create an enhanced framework for smart pricing in the European Union, which then needs to achieve two goals. The first is to improve the degree to which real-time energy prices reflect the full value of demand-side flexibility. The second is to ensure that retail tariff structures for both energy and network charges are applied in a fair manner for EV charging customers. In other words, the tariff structures must make available to them a fair share of the true value of smart charging or, conversely, ensure they bear a fair share of the true cost of nonresponsive charging. Member States should seek to establish open and competitive retail markets that are going to deliver innovative products such as dedicated EV tariffs that follow as closely as possible the costs of delivering the service. For EVs and other controllable loads with significant potential to shift consumption, we recommend volumetric TOU tariffs as the default option, preferably with locational signals. As EV deployment increases, along with the higher share of renewables that they can absorb, smarter tariffs will likely be necessary. This paper illustrates how different smart pricing practices create benefits for all electricity users, not just EV drivers, as the same cost is spread across higher usage.

Second, combining smart pricing with smart technology delivers maximum benefits. Benefits from smart charging can be maximised if paired with smart technology. Smart technology is not widely in place across all Member States, meaning that EVs connected to chargers have insufficient measurement or communication capabilities. Different smart metering technologies we reviewed allow automation that, combined with smart pricing, optimises charging and delivers the maximum economic benefits for consumers and the grid (assuming that pricing reflects network costs). In the dynamic market for smart charging technologies, business models are evolving to offer this combination. Regulatory frameworks need to allow this market to evolve and address in particular barriers to interoperability of charging services. To ensure this, we recommend mandating that all new EV charging environments include smart functionality and making compulsory the use of technology that enables dynamic tariffs. In addition, legislation should support the deployment of automation technology to support smart charging.

Third, rolling out grid-friendly charging infrastructure is most cost-effective. The type and location of charging infrastructure determines not only where and how but also when EVs are charged. This is critical to enabling beneficial EV grid integration. EV charging infrastructure needs to meet mobility demand in locations that are best suited to use existing power network capacities, thus reducing the cost of EV grid integration. In creating public charging infrastructure, in particular in cities but also along highways, planners should consider using existing transport and energy infrastructure as much as possible. As the EU institutions evaluate the revision of the legal framework underlying public charging infrastructure setup, integrated transport and energy planning will be crucial to ensure meeting future patterns of charging needs across different user groups. To enable promising cases of EV grid integration such as workplace charging and charging in multi-unit dwellings, Member States should also adopt ambitious related provisions in building codes when implementing the European Energy Performance of Buildings Directive. Public co-funding of the maturing EV supply equipment market helps to stimulate innovation and should be designed a view to commercial operation.

Further questions will have to be answered as technology, business models, and the EV market continue to develop. For example, the question of how to adequately design tariffs for accessible public EV charging will become crucial for EV uptake. Also, taxation of EV use will arise in different areas. The next legislative period offers the perfect opportunity to design a comprehensive e-mobility strategy for Europe, ensuring that no single element of EV integration is blocking progress, and that different policy actions are coming together simultaneously and reinforcing each other.

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Responsibility for the information and views set out in this paper lies entirely with the authors.

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[9] See, for example, Wargers et al., 2018. https://www.edsoforsmartgrids.eu/wp-content/uploads/EDSO-paper-on-electro-mobility-2.pdf

[10] Peak periods vary in different countries, based on time of day and seasons. Northern countries face peak demand during the winter, while Southern states may face peak demand in the summer. Generally peak occurs between 5 and 9 p.m.

[11] ChargePoint, Norwegian Electric Vehicle Association, Norwegian Water Resources and Energy Directorate, and the European Platform for Electro-Mobility.

[12] Under this tariff, a customer owning a Nissan Leaf (with a battery size of 24 kWhs, which gives it a maximum range of about 160 kilometres), needs roughly 0.72 euros to charge the vehicle, if the charging occurs during the night period. In this case, the EV-dedicated tariff represents a significant discount compared with the standard tariff. The latter offers a uniform charge of 0.14 euros/kWh throughout the 24 hours. This means that whether a driver charges an EV at night or during the high-demand hours of the day, the cost is the same; the equivalent cost to fully charge the vehicle would be 3.4 euros, which is almost five times as high. Calculated for a driver covering a distance of 10,000 kilometres per year, assuming that all charging is taking place during the nighttime (off-peak) hours.

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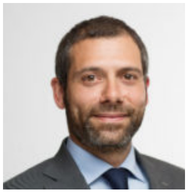

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