

Start with smart

Promising practices for integrating electric vehicles into the grid

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Abbreviations and acronyms

BGE.	Baltimore Gas and Electric Co.	kWh	kilowatt-hour
CE4All	Clean Energy for All Europeans	PG&E	Pacific Gas & Electric Co.
DSO	distribution system operator	TEN-T	Trans-European Network Transport
EV	electric vehicle	TOU	time of use
EVSE.	electric vehicle supply equipment	V2G.	vehicle to grid
kW.	kilowatt		

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Executive summary

Driven by climate policy, by economics, or by consumer preferences, electric vehicles (EVs) are coming. What makes that both exciting and challenging is that EVs form the nexus between two revolutions: the replacement of coal, oil, and natural gas with zero-carbon energy in the electricity sector, and the replacement of petroleum-based fuels with electricity in the transport sector. The good news is that there are clear opportunities to harness each of these epochal transformations to make the other easier, faster, and more affordable. This paper explores what those opportunities are and how we might take advantage of them.

The key lies in leveraging the potential for complementarity between the needs of electricity decarbonisation and the needs of transport electrification. Electricity grids are looking for ways to make productive use of large volumes of low-cost, zero-carbon energy that will be available at times when it may not have been needed to meet traditional demands for electricity. One such use is the shifting of flexible loads from times when variable production or grid capacity is scarce. At the same time, EVs represent large, inherently flexible loads, the growth of which would benefit greatly from opportunities to lower operating costs to offset higher upfront costs, and from opportunities to minimise the need to build and recover the costs of new grid infrastructure.

Unlocking these opportunities means being smart in ways that are rapidly becoming feasible, convenient, and affordable thanks to ongoing advances in the cost and performance of digital technologies. It begins with **smart pricing** to encourage and properly reward smart charging. There are two pieces to the smart pricing strategy. The first is improving the way real-time energy prices reflect the full value of demand-side flexibility. The second is applying retail tariff structures for both energy and network charges for EV charging customers that would 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 non-responsive charging. The reform of real-time energy price formation

Unlocking opportunities means being smart in ways that are rapidly becoming feasible, convenient, and affordable thanks to advances in digital technologies.

is a topic that's covered extensively in other RAP work; this report delves into the related and equally important topic of tariff design.

Smart tariff design means pricing both energy and network services to serve EV customers in a manner that reflects as closely as practical and equitable the time- and location-specific conditions of supply of and demand for both services. This is critical; energy charges constitute an average of only 33 percent of the customer bill in Europe, whereas network charges represent 27 percent. Together they represent 60 percent of the bill, almost doubling the benefits (or costs) to EV customers of different charging behaviours. This paper offers several promising cases of experience with smart tariffs.

The second strategy is **smart technology**. Smart pricing is necessary but not sufficient to realise the potential for beneficial electrification of transport. Actively managing electricity usage is a low priority for most consumers, even EV customers, so convenience and ease of use will continue to be crucial to harvesting the customer and system benefits of smart pricing. This means more than just smart meters, and indeed meters don't need to be all that smart. Rapid innovation is emerging in products and services that communicate real-time information to consumers and enable automation of responses to that information, sometimes as a byproduct of adoption for reasons other than energy management. This paper offers promising examples of technology innovation and adoption that demonstrate the potential for a combination of smart pricing and smart technology to drive beneficial EV charging behaviour.

The third strategy is **smart infrastructure**. Effort invested in smart pricing and technology can be squandered without

smart deployment of the charging and grid infrastructure on which they must operate. Smart infrastructure involves two aspects: making best use of existing grid and transport infrastructure, and choosing and deploying EV charging infrastructure with a view both to grid topography and to evolving EV usage and mobility patterns. The first aspect recognises that many grid and transport system assets currently experience low utilisation by design or can be repurposed for transport charging. The second aspect recognises that charging needs and preferences are likely to evolve and change as EV penetration grows beyond early adopters. It also recognises that as charging behaviour evolves, the costs and public acceptance of adapting the grid can vary widely depending on where and what kind of charging infrastructure is deployed and how it's connected to the grid. We offer several promising examples of practices that can leverage both aspects of this strategy.

These three strategies—smart pricing (the “software”), smart technology (the “apps”), and smart infrastructure (the “hardware”)—form the strategic triad needed to access the potential complementarity between the power and transport transitions. The beginning of a new legislative period in the European Union offers the opportunity to enact a smart, integrated policy framework that will optimally meet Europeans' needs for clean and affordable electricity and mobility. This

paper concludes with a number of specific recommendations for policymakers and regulators. These include:

1. For smart pricing, use the implementation of the Clean Energy for All Europeans package to:
 - a. Adopt and apply dedicated tariff structures for EV charging;
 - b. Require time-varying (and ultimately locational) tariffs; and
 - c. Monitor the effectiveness of retail markets in grid integration of EVs.
2. For smart technology, update regulatory frameworks to drive deployment of appropriate technologies—for example, through requiring smart functionality in all electric charging solutions.
3. For smart infrastructure, ambitiously implement public EV charging and building legislation by:
 - a. Making good use of existing transport and grid assets—for example, through joint energy and mobility planning;
 - b. Providing funding to phase in a functioning, innovative market for interoperability among e-mobility charging services; and
 - c. Setting criteria and ambitious targets, including developing future use cases such as heavy-duty transport, and increasing the use of renewables.

Chapter 1

Introduction

The electric vehicle revolution offers tremendous opportunity to benefit consumers, the power system, and the environment.

There is no doubt that the electric vehicle (EV) revolution is underway. The number of EVs has increased exponentially since the early 2010s.

At the end of 2017, the global EV stock reached almost 4 million. Growth to 125 million is expected by 2030, if existing and planned policies are continued.¹ In Europe, more than 1 million passenger EVs were on the road at the end of 2018.^{2,3}

EVs are inextricably entwined with the power sector. Because of the momentum gathering behind EVs, we are at a critical juncture in the coordination of both power and transport sector decarbonisation. European policymakers, stakeholders, and companies from the energy and transport sectors will make crucial decisions about how to integrate EVs into the power sector over the next decade. To make the most of the significant opportunity e-mobility offers and to ensure that the electrification of road transportation happens cost-effectively, this paper looks at promising practices for optimal integration of EVs and the power system from Europe and beyond.

Beneficial electric vehicle integration

Decarbonising the transport and power sectors at the same time has wider benefits for society.

Power system: 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,⁴ 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 environmental and economic benefits.⁵

Energy efficiency: EVs consume roughly one-third the amount of energy of conventional vehicles.⁶ Even well-to-wheels (i.e., taking the carbon profile of the transport fuel into account), the energy consumption of a battery electric vehicle running on renewable electricity is about half that of the most energy-efficient combustion alternative.⁷ Transitioning to EVs would therefore reduce overall energy consumption in transport (assuming comparable vehicle weight, vehicle power, and vehicle-kilometres driven).

Carbon emissions reduction: From a well-to-wheels perspective, EVs emit less carbon than diesel or petrol alternatives, even with the current electricity mix in the EU. Over the entire life cycle, the emissions of EVs are already half to two-thirds those of equivalent petrol and diesel cars.⁸ This higher carbon reduction potential will increase as the power sector integrates higher levels of renewable energy.⁹

1 International Energy Agency. (2018). *Global EV outlook 2018*. Paris, France: Author. Retrieved from <https://webstore.iea.org/global-ev-outlook-2018>

2 This includes European Free Trade Association countries and Turkey. European Commission. (2019a). *European alternative fuels observatory* [Database]. Retrieved from <https://www.eafo.eu/vehicles-and-fleet/ml>

3 Across the road transport sector, passenger cars represent the majority of the electrified vehicle fleet. However, sales of electric models in light commercial vehicles (such as delivery vans), smaller two-, three-, and four-wheelers (Category L), as well as electric buses and trucks are growing substantially, albeit starting from a low baseline.

4 The load curve charts the electrical demand and energy requirements of a generator's end-use customers over a defined time period, typically a day. "Smoothing the load curve" means reducing the difference between the minimum and maximum demands during that period, generally for the purpose of reducing overall cost and improving reliability. The means of doing so include price-induced shifting of consumers' demand (demand response), investments in end-use energy efficiency measures, and effective utilisation of customer-sited energy resources.

5 The environmental, economic and power sector benefits of electrification of transport and EV grid integration are discussed in detail in Farnsworth, D., Shipley, J., Sliger, J., and Lazar, J. (2019). *Beneficial electrification of transportation*. Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raponline.org/knowledge-center/beneficial-electrification-of-transportation/>

6 United States Department of Energy, Office of Energy Efficiency & Renewable Energy. *Where the energy goes: Electric cars* [Webpage]. Retrieved from <https://fueleconomy.gov/feg/atv-ev.shtml>. And United States Department of Energy, Office of Energy Efficiency & Renewable Energy. *Where the energy goes: Gasoline cars* [Webpage]. Retrieved from <https://fueleconomy.gov/feg/atv.shtml>

7 Agora Verkehrswende. (2017). *Mit der Verkehrswende die Mobilität von morgen sichern: 12 Thesen zur Verkehrswende* [Transforming transport to ensure tomorrow's mobility: 12 insights into the transport sector transition], p. 60. Berlin, Germany: Author. Retrieved from https://www.agora-verkehrswende.de/fileadmin/Projekte/2017/12_Thesen/Agora-Verkehrswende-12-Thesen_WEB.pdf

8 Modelled against the 2017 baseline for EU average. The study also finds that, on EU average in 2030, the carbon footprint of a battery electric vehicle will be 60 percent less than that of a 2017 internal combustion engine vehicle. European Climate Foundation. (2018). *From cradle to grave: E-mobility and the energy transition*. Retrieved from https://europeanclimate.org/wp-content/uploads/2018/09/From-cradle-to-grave-e-mobility-and-the-energy-transition_IT_SP_UK_EU.pdf

9 As the carbon intensity of the EU energy mix is projected to decrease, the life cycle emissions of a typical electric vehicle could be cut by at least 73 percent by 2050. European Environment Agency. (2018). *Electric vehicles from life cycle and circular economy perspectives*. Copenhagen, Denmark: Author. Retrieved from <https://www.eea.europa.eu/publications/electric-vehicles-from-life-cycle>

Smart is key

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.¹⁰ 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 sweet spot 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. Smart EV integration includes three particularly important ingredients: smart pricing (the “software”), smart technology (the “apps”), and smart infrastructure (the “hardware”). The three components 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 as well as 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.

All of these strategies serve the goal of smart charging.

These three elements guide our discussion on EV integration in the following pages. In Chapter 2, we set out the context in which EV integration takes place and demonstrate why smart integration is key. Chapter 3 provides examples of promising practices for optimal EV integration for each of the three ingredients—smart pricing, smart technology, and smart infrastructure. We show that there is ample experience with all three approaches from which Europe can learn. In Chapter 4, we present recommendations that can accelerate the adoption of EVs in the current EU policy context and further explore future opportunities to advance the clean energy transition through electrification.

¹⁰ This opens up ample opportunities for use of EVs for the grid. They are parked on average 95 percent of the time and are charging only 10 percent of the time. This flexibility allows drivers to shift charging to different times of the day to minimise their costs and maximise benefits to the grid. See Langton, A., and Crisostomo, N. (2013). *Vehicle-grid*

integration: A vision for zero-emission transportation interconnected throughout California's electricity system. San Francisco, CA: California Public Utilities Commission, Energy Division. Retrieved from <http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M081/K975/81975482.pdf>

Chapter 2

Opportunities for smart electric vehicle integration

It's important to recognize the value of this flexible resource to the power sector and consumers.

This chapter demonstrates that the EV revolution offers significant opportunities to the power sector and can play an important role in its decarbonisation. There is a strong case for the smart integration of EVs that ensures the process maximises the benefits for consumers, the energy system, and society as a whole.

EV revolution in Europe is underway

The European EV¹¹ market has grown significantly, in particular the market for passenger cars. This segment developed from hardly any at the start of the decade to around 2.2 percent of new sales today.¹²

The penetration of EVs differs across European countries but is principally concentrated in the Nordic countries and northwest Europe. It is changing faster in some places than in others. The highest share of new electric vehicle sales is in Norway,¹³ where passenger EVs accounted for around 49 percent of new registrations in 2018 (with all-electric vehicles representing 31 percent)¹⁴ and 1 out of 16 cars is already electric.¹⁵ A few countries (e.g., Denmark, Sweden, France, Germany, and the United Kingdom) had a 2018 share of new EV sales of between 2 and 8 percent.¹⁶

Recently adopted European legislation¹⁷ sets benchmarks, or voluntary targets, for EV sales at 15 percent of a manufacturer's passenger car sales in 2025 and 35 percent in 2030 (30 percent for electric vans), and incentives for increased sales of electric trucks. Coupled with stricter carbon dioxide reduction targets for cars, vans, and trucks, this legislation provides a significant incentive to auto manufacturers for greater EV deployment and more certainty

about the timing of an increasing EV market share. By 2030, roughly 10 million battery electric vehicles and 18 million plug-in hybrids are expected to be on the road in the EU.¹⁸ Although it is hard to predict exactly how many EVs there will be, figures strongly suggest that the EV revolution is well underway.

The growing numbers of electrified light vehicles, passenger cars, vans, buses, and trucks—combined with sustainable transport policies to reduce congestion and promote more efficient and shared mobility—are widely recognised as keys for reducing carbon emissions and cutting air and noise pollution, particularly in cities.

But the electrification of the transport sector offers another opportunity: to take advantage of EVs as a flexible load for power sector transformation. This offers a double benefit. First, it is widely recognised that flexibility of electricity demand is an important prerequisite for a clean energy system. And, although less commonly known outside the power sector, making EV charging more responsive to power market conditions can dramatically reduce the cost of electrification without impairing enjoyment of transport services.

A flexible power system resource

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. Managed smartly, EV charging can integrate increasing amounts of renewable energy resources, increase utilisation of the existing network infrastructure, lower the

11 With the term "EVs," we refer to plug-in electric vehicles, which include both battery electric vehicles and plug-in hybrids. For the sake of simplicity, we use "EVs" throughout. This report mainly focuses on passenger cars but also takes other vehicle segments into account in our examples.

12 This includes both battery electric vehicles and plug-in hybrid EVs, each with a share of around 1.1 percent (excluding Norway). European Commission, 2019a.

13 International Energy Agency, 2018.

14 Lambert, F. (2019, 2 January). *Electric car sales grew by 40% in Norway this year*. Electrek. Retrieved from <https://electrek.co/2019/01/02/electric-car-sales-norway-2018/>

15 These are 2017 figures. International Energy Agency. (2018). *Nordic EV outlook 2018*. Paris, France: Author. Retrieved from <https://webstore.iea.org/nordic-ev-outlook-2018>

16 European Commission, 2019a.

17 The formal adoption of the laws is expected before summer 2019. European Council. (2019, 16 January). *CO₂ emission standards for cars and vans: Council confirms agreement on stricter limits* [Press release]. Retrieved from <https://www.consilium.europa.eu/en/press/press-releases/2019/01/16/co2-emission-standards-for-cars-and-vans-council-confirms-agreement-on-stricter-limits/>. See also Transport & Environment. (2019, 19 February). *EU target to cut truck CO₂ and boost zero-emission truck sales must only be the start*. Retrieved from <https://www.transportenvironment.org/press/eu-target-cut-truck-co2-and-boost-zero-emission-truck-sales-must-only-be-start>

18 European Commission. (2018). *Cars/Vans CO₂ Regulation proposal: Additional assessment of higher ambition levels for the targets and ZLEV benchmarks* [Non-paper]. Brussels, Belgium: Author. Retrieved from https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/docs/co2_cars_vans_non_paper_technical_update_en.pdf

operating cost of EVs,¹⁹ and minimise the need for new investment.

Smart charging means that charging can be shifted to times when the costs for producing and delivering electricity are lower, without compromising the vehicle owner's needs.

For example, when there is a significant amount of renewable energy on the grid relative to “business as usual” demand, wholesale market prices may be quite low.²⁰ 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.^{21, 22}

Figure 1 on the next page shows the electricity load curve for three countries on a typical day.²³ 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

Smart charging means that charging can be shifted to times when the costs for electricity are lower, without compromising the vehicle owner's needs.

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.²⁴ 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.²⁵ 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.²⁶ Power plant producers can also benefit from this shift in load through the resulting higher

19 This applies, in particular, in regions such as the United States, where the price of gasoline is comparatively low. Smart charging helps to make the total cost of ownership of EVs more competitive.

20 The subject of wholesale price formation is a complex one covered extensively elsewhere. However, suffice it to say that demand on grid resources, which drives clearing prices, includes not only the demand for energy but also the demand for various categories of grid services required to maintain reliability. Demand for these services can increase dramatically at times of very high renewables production and, in so doing, may stabilise prices. Hogan, M. (2016). *Hitting the mark on missing money: How to ensure reliability at least cost to consumers*. Brussels, Belgium: Regulatory Assistance Project. Retrieved from <https://www.raonline.org/knowledge-center/hitting-mark-missing-money-ensure-reliability-least-cost-consumers/>

21 In the future and as the deployment of generation connected to the distribution network increases, EVs could help relieve congestion on the distribution network when there is an excess of local generation (e.g., through solar photovoltaics) and when an increase in demand is required to avoid reverse flows. This is already happening in places with significant penetration of distributed generation, like Hawaii. For more information, see Kolokathis, C., Hogan, M., and Jahn, A. (2018). *Cleaner, smarter, cheaper: Network tariff design for a smart future*. Brussels, Belgium: Regulatory Assistance Project. Retrieved from <https://www.raonline.org/knowledge-center/cleaner-smarter-cheaper-network-tariff-design-for-a-smart-future/>

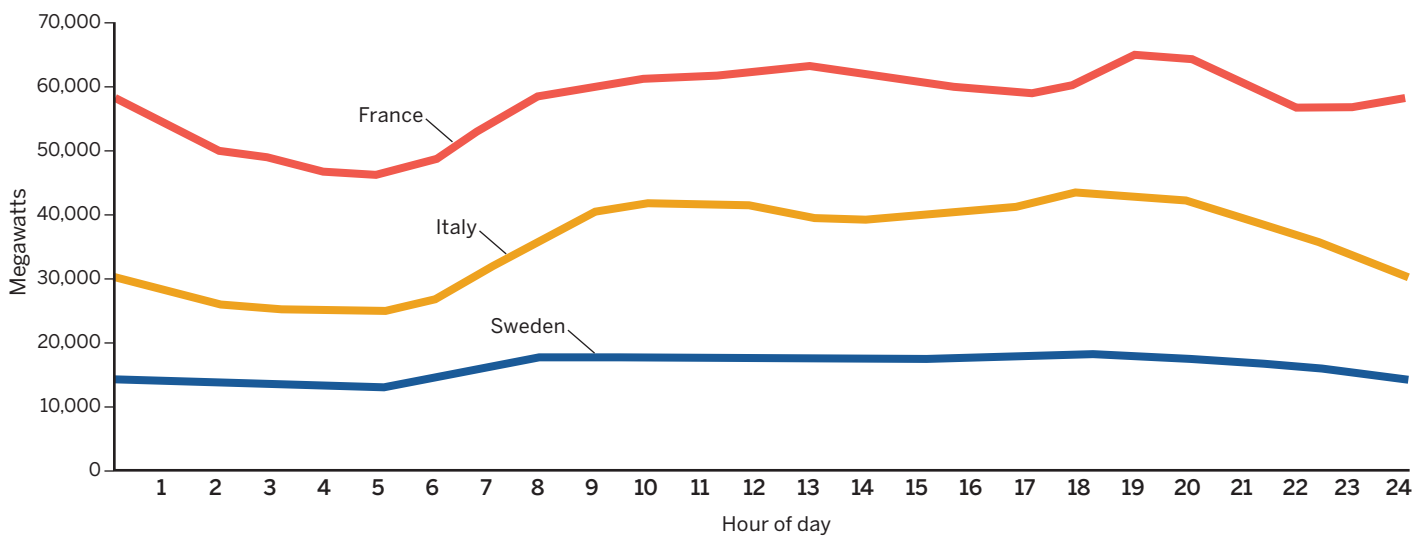
22 Another practice offering substantial potential is vehicle-to-grid (V2G) or reverse charging technology, defined as all services that a vehicle can deliver to the grid as a “battery on wheels”—for example, storage or grid balancing. V2G is not part of this paper's analysis, as most European V2G demonstration projects are small-scale, and promising practices of larger-scale projects are mainly found in the U.S. Potential and emerging promising practices in the U.S. are discussed in Farnsworth et al., 2019, pp. 41-43.

23 European Network of Transmission System Operators for Electricity. (2018, 21 November). *Transparency platform* [Database]. Retrieved from <https://transparency.entsoe.eu/>

24 The electricity demand illustrated in Figure 1 is demand on the transmission network. Any generation on the distribution network (e.g., solar photovoltaic on residential buildings) that is consumed locally affects the profile by lowering the demand seen at the transmission network level. The proliferation of distributed generation has changed the shape of the profile to a greater or lesser extent, depending on the degree of deployment in a given country. The best-known example of this is the California “duck curve.” See Lazar, J. (2016). *Teaching the “duck” to fly* (2nd edition). Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raonline.org/knowledge-center/teaching-the-duck-to-fly-second-edition/>

25 System operators are responsible for matching demand and supply on a second-by-second basis. This can be particularly challenging when demand is increasing or decreasing rapidly over a short period of time, because the amount by which power plants can increase or decrease their output is limited. Ramping requirements refer to the rate by which supply needs to change to meet demand on a second-by-second basis to ensure the reliability of the system. Ramping requirements have traditionally been met by power generation, although demand response is expected to play an increasing role in meeting them. By filling in the nighttime valley in the example above—in other words, increasing the nighttime load—the ramping requirements in the early morning are reduced as the difference between the nighttime and early morning load decreases.

26 For information about the challenges associated with the integration of increasing levels of variable renewable energy and recommended solutions, see Lazar, 2016.

Figure 1. Electricity demand curve on typical day in selected European countries (7 November 2018)

Source: European Network of Transmission System Operators for Electricity. *Transparency platform*.

load factors,²⁷ which minimise the costs of starting and stopping their facilities.

None of this happens automatically, however. We must put the right strategies in place to facilitate smart integration of EVs.

Smart integration and the grid

Currently, the limited number of EVs on the road doesn't pose any significant concerns for the electric grid.²⁸ Even increasing numbers of vehicles need not give rise to concerns about integrating this resource into the grid if it's done smartly.²⁹ The real challenge is about the instantaneous power demand on the grid. Several analyses demonstrate that electrifying road transportation would require minimal incremental costs if we most effectively utilise existing assets. 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.³⁰ 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.³¹

This requires smart charging. If EV drivers do not receive appropriate pricing signals through electricity tariffs, or if charging is automated without regard to grid conditions, it is likely that charging would occur without the desired control. Uncontrolled EV charging exacerbates existing demand peaks, typically when people return home from work.³² The placement of EV charging infrastructure at workplaces and in public areas enables both smart charging and the ability to charge outside of peak periods in places where people would commonly park during the day. (We define this as smart infrastructure and discuss promising practices in Chapter 3.)

Overall, the current electricity tariff structure in most cases does not provide sufficient incentive for EV owners to charge during the hours that are most beneficial for the power system.³³ Instead, retail tariffs that vary little by time

27 The load factor indicates the level of utilisation of a power plant. It is defined as the ratio of the actual amount of energy generated to the maximum amount of electricity that could be generated by a plant over the course of a year.

28 Wargers, A., Kula, J., Ortiz de Obregon, F., and Rubio, D. (2018). *Smart charging: Integrating a large widespread of electric cars in electricity distribution grids*. Brussels, Belgium: European Distribution System Operators for Smart Grids. Retrieved from <https://www.edsoforsmartgrids.eu/wp-content/uploads/EDSO-paper-on-electromobility-2.pdf>

29 The energy requirements due to the mass rollout of EVs are expected to be modest. Wargers et al., 2018.

30 Sanchez Duran, R. (2015). *Smart charging: Steering the charge, driving the change* [Presentation]. Eurelectric. Retrieved from <https://cdn.eurelectric.org/media/2705/sanchez-duran-h-A10FF6D7.pdf>

31 Hogan, M., Kolokathis, C., and Jahn, A. (2018). *Treasure hiding in plain sight: Launching electric transport with the grid we already have*. Brussels, Belgium: Regulatory Assistance Project. Retrieved from <https://www.raponline.org/knowledge-center/treasure-hiding-in-plain-sight-launching-electric-transport-with-the-grid-we-already-have/>

32 In many European cities, EV users do not have access to off-street parking and need to use on-street parking overnight. Charging infrastructure solutions for this user group are discussed in Chapter 3.

33 For more information, see the section on smart pricing in Chapter 3.

A short explanation of electricity bills

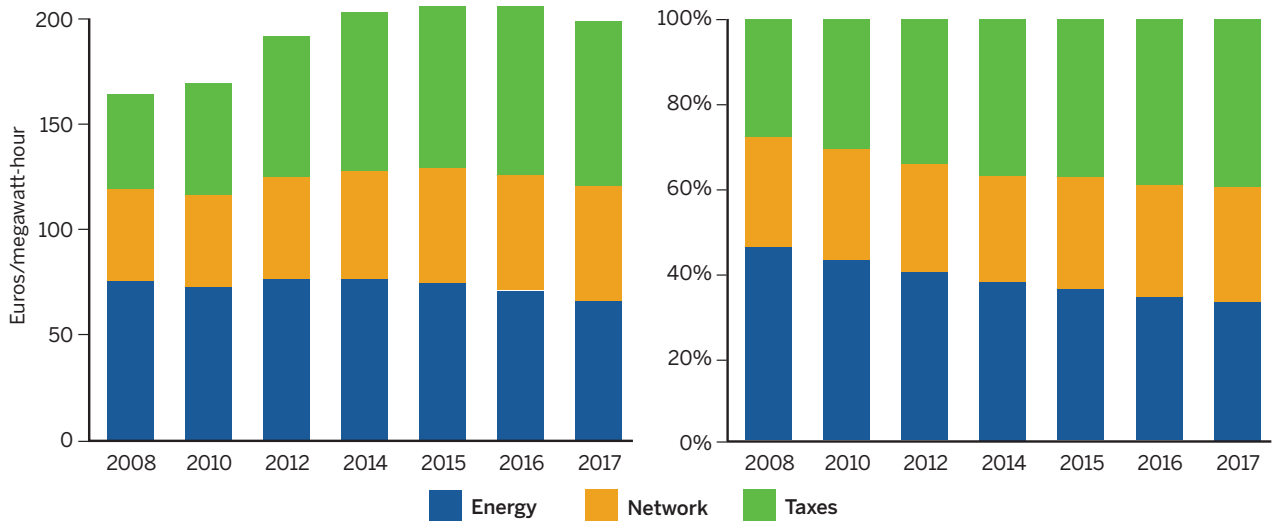
The electricity price or tariff consists of three main components for all types of consumers: the energy component, the network component, and the taxes and levies. The first component relates to the cost of electricity production and the second to the delivery of this electricity to the final consumer. Taxes and levies are effectively the costs for specific policies and fiscal instruments. These include the value-added tax collected by the government, subsidies for the support of renewable generation as Europe decarbonises its power sector, and subsidies primarily granted to thermal generation for mitigating the risks to security of supply.

The focus of this paper is on the energy and network components, while the taxes and levies are outside its scope.³⁴

As of 2017, the shares of the energy and network components were about 33 percent and 27 percent of the total bill, respectively (these refer to the representative household, as defined by the European Commission).³⁵

The energy component has been on a declining trend for the past 10 years, both in absolute and relative terms, as depicted in Figure 2.³⁶ The network component has increased in absolute terms over the same period, but its share remained constant. The taxes and levies currently constitute the greatest part of the bill, around 40 percent. The above values apply for all of Europe, although there is significant variance on the share of the three components across Member States.

Figure 2. Evolution and composition of EU household electricity prices



Source: European Commission. (2019). *Energy prices and costs in Europe*.

or location or not at all, especially those that include large non-time-varying fixed charges, encourage demand to be indifferent to real-time conditions of supply and demand on the power grid. As a result, the majority of EV drivers are likely to charge their cars during on-peak hours—those that should be avoided for the cost-efficient integration of EVs.

The behavioural response to non-time-varying tariffs can already be seen in Norway, the country with the highest EV penetration in the world (see the text box on the next page).

The impact of this charging behaviour on Norway’s electricity grid has caused negligible problems thus far, due to the still relatively limited number of EVs on the road and the

34 For more information on electricity prices, see European Commission, Directorate-General for Energy. *Energy prices and costs in Europe* [Webpage]. Retrieved from <https://ec.europa.eu/energy/en/data-analysis/energy-prices-and-costs>.

35 European Commission. (2019b). *Energy prices and costs in Europe. Report from the Commission to the European Parliament, the Council,*

the European Economic and Social Committee and the Committee of the Regions [Staff working document]. Brussels, Belgium: Author. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/swd_2019_0015_text_6_-_part_1_of_4.pdf

36 European Commission, 2019b.

Impact of electricity pricing on vehicle charging in Norway

Norway's power sector is unique in Europe, with significant resources of hydropower (installed hydro accounts for around 96 percent of total capacity, and its share in total production is close to 100 percent)³⁷ and an electrified heating sector, meaning that its network is already sized for high consumption.³⁸

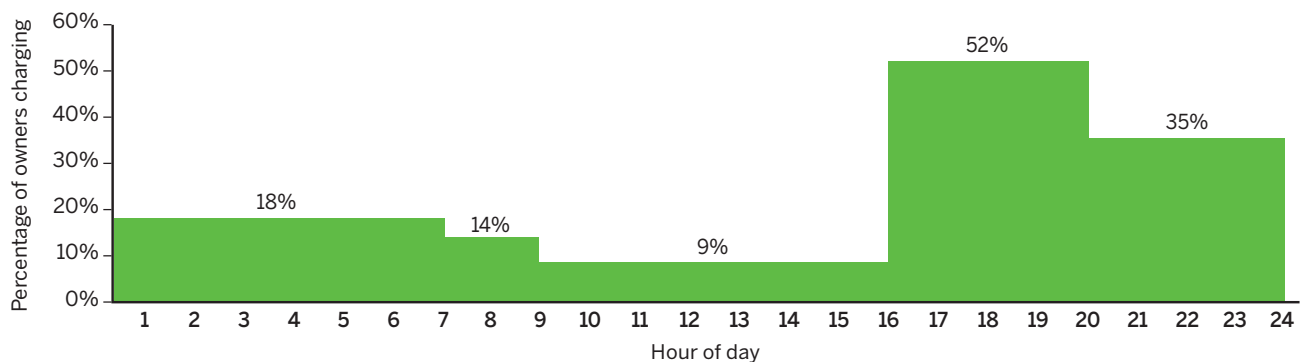
The majority of households have contracts tied to the hourly spot prices from the Nord Pool day-ahead market, affecting the energy component of the bill.^{39, 40} However, electricity prices in Norway are rather low and their variation limited, largely due to the country's hydropower-dominated production.^{41, 42}

On the network side, households pay a yearly fixed charge,

paired with an energy charge per kilowatt-hour (kWh).⁴³ The volumetric part of the network tariff is uniform across the day and year. As a result, consumers do not receive any price signals about when to charge their EVs.⁴⁴ The fixed charge makes up 30 percent of the network component in the bill on average.

Overall, the electricity price varies little with time and provides a weak incentive for smart charging. This is confirmed by the charging habits of owners. Figure 3 shows the times when drivers normally charge their EVs, based on a survey by the Norwegian Electric Vehicle Association.⁴⁵ According to the results, the majority of drivers (around half) tend to charge their EVs during on-peak hours, between 4 and 8 p.m.

Figure 3. Charging habits of electric vehicle owners in Norway



Source: Norwegian Electric Vehicle Association. *Norwegian battery electric vehicle owner survey 2018*.

37 Norwegian Ministry of Petroleum and Energy. *Electricity production* [Webpage]. Retrieved from <https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon/>

38 The average Norwegian household consumes 15,000 kWhs per year, which is more than triple the demand in the majority of other European countries, while natural gas is hardly used. For example, the average household in Germany consumes around 3,000 kWhs per year, in France around 5,000 kWhs per year, and in Romania around 1,700 (data as of 2014). See World Energy Council. *Energy efficiency indicators* [Database]. Retrieved from <https://wec-indicators.enerdata.net/household-electricity-use.html>, data accessed on 22 November 2018.

39 In the absence of smart meters, the energy prices have been historically based on standardised consumption profiles. Recent market developments are toward real, spot-price contracts based on consumers' actual consumption. Andreas Bjelland Eriksen, Norwegian Water Resources and Energy Directorate, personal communication, 27 November 2018.

40 Aanensen, T. (2018, 29 May). *Higher electricity prices for households*. Statistics Norway. Retrieved from <https://www.ssb.no/en/energi-og-industri/artikler-og-publikasjoner/higher-electricity-prices-for-households--351026>

41 Norway, and the Nordic region more generally, has some of the lowest wholesale electricity prices across Europe. See European Commission. (2016a). *Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions* (final) [Working document]. Retrieved from <https://ec.europa.eu/energy/sites/ener/files/documents/swd2.pdf>

42 Average electricity price for households in the second quarter of 2018 was 0.45 Norwegian kroner/kWh (or around 0.045 euros/kWh), excluding taxes; 1.1 Norwegian kroner/kWh (or around 0.11 euros/kWh), including taxes and network tariffs. See Statistics Norway. *Electricity prices* [Webpage]. Retrieved from <https://www.ssb.no/en/elkraftpris>. Norwegian consumers faced a significant increase in electricity prices in the autumn of 2018, which can be largely attributed to unusually low hydro-reserve levels in the beginning of the season as a result of a hotter than average summer. Electricity prices were up 66 percent in the third quarter of 2018 compared with the prior year. The hydro-reserve levels were close to historic levels in late November. Bjelland Eriksen, 2018.

43 The average network tariff for households in the second quarter of 2018 was 0.29 Norwegian kroner/kWh (or around 0.029 euros/kWh). See Statistics Norway.

characteristics of the country's power system (e.g., a network sized for high power consumption).⁴⁶ However, in areas with low network capacity, a high share of EVs charging at the same time could create a risk of overloading substations and cables in the distribution network. This risk is expected to be significant in the future as the total number of EVs increases. A case study from the Norwegian Water Resources and Energy Directorate (Norges vassdrags- og energidirektorat, or NVE) looking at the city of Drammen estimates that, with smart charging behaviour, the city's current grid capacity could handle future charging. On the other hand, uncontrolled charging could require grid investments of 1 billion to 2 billion Norwegian kroner—or around 100 million to 200 million euros—related to on-peak EV charging.⁴⁷

With increasing EV penetration and uncontrolled charging of electric vehicles, the costs for meeting the power and delivery needs would increase exponentially. Peak demand could double if EVs are charged during peak periods.^{48, 49} 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.

Thankfully, there are promising strategies for avoiding this and making the most of the opportunity afforded by EVs. In the next chapter, we illustrate how to reap the substantial benefits of EVs for the power system through a combination of smart pricing, smart technology, and smart infrastructure.

44 Norwegian regulators are working on a proposal for changes to the network tariff regulation in the electricity distribution system for customers connected to the grid with a voltage of 22 kilovolts or lower, favoring a tariff based primarily on subscribed capacity, which in turn is proposed to be based on the customer's highest past consumption over a given time frame. For more information, see Norwegian Water Resources and Energy Directorate. (2017, 16 February). *Network tariffs*. Retrieved from <https://www.nve.no/energy-market-and-regulation/network-regulation/network-tariffs/>. See also Bjelland Eriksen, A. (2018, 19 October). *Regulatory experiences: From volumetric- to capacity-based tariffs* [Presentation]. Retrieved from <https://www.ceer.eu/documents/104400/-/-/9ad78f1a-c528-289a-a213-6a8f95c9d51f>

45 Norwegian Electric Vehicle Association. *Norwegian battery electric vehicle owner survey 2018* [Unpublished research].

46 In some ways, Norway's case is unusual. While time-varying retail energy charges are common, the dominance of hydroelectric supply means there is less need for variable renewables and the variability of the renewables can be largely offset by hydro storage. As a result, regardless of the energy

charge structure, the cost of energy is not likely to vary significantly in real time, and the value of shifting energy consumption is likely to remain modest. However, as in many cases across Europe, the dominant network charge structure does not vary with time. In Norway, this is compounded by the fact that 30 percent of the network charge is not volumetric. The combination of a low, stable energy charge, a flat volumetric network charge component, and a large fixed network charge component creates perverse incentives for EV charging behaviour that is already in evidence. Without appropriate measures (as described later in this paper), it is likely that the same pattern will emerge in other countries.

47 Bjelland Eriksen, 2018, 19 October.

48 See, for example, Wargers et al., 2018.

49 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.

Chapter 3

Solutions for smart electric vehicle integration

Numerous examples of effective practices give policymakers options for reaping the benefits of EVs at least cost.

Three ingredients are critical for the cost-effective integration of EVs: smart pricing (the “software”), smart technology (the “apps”), and smart placement of infrastructure (the “hardware”). For each of those there are promising practices from Europe and beyond that offer important lessons for a policy framework supporting the beneficial integration of EVs.

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 the choices that also minimise overall system costs.⁵⁰ Electricity tariffs can be designed in such a way to make optimal use of existing power system infrastructure while limiting future system costs. They also offer opportunities for customers and empower EV adopters to save on the costs of charging, while reducing system costs and thus benefitting all consumers. 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.⁵¹ 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 don’t send any signal to consumers to use electricity when the associated costs are lower and to avoid consuming electricity when it is most expensive. In other words,

Three ingredients are critical for the cost-effective integration of EVs: smart pricing, smart technology, and smart placement of infrastructure.

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.⁵² However, their adoption by consumers is limited overall.⁵³ 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.⁵⁴ 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 they are charged a uniform price for electricity regardless of whether it is consumed during a peak period or any other time of day.

The most common time-varying pricing options are simple TOU tariffs with different day and night charges.⁵⁵ Many of these tariffs were established in the 1970s and 1980s and do not require any advanced type of 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

50 Farnsworth et al., 2019.

51 European Commission, 2019b.

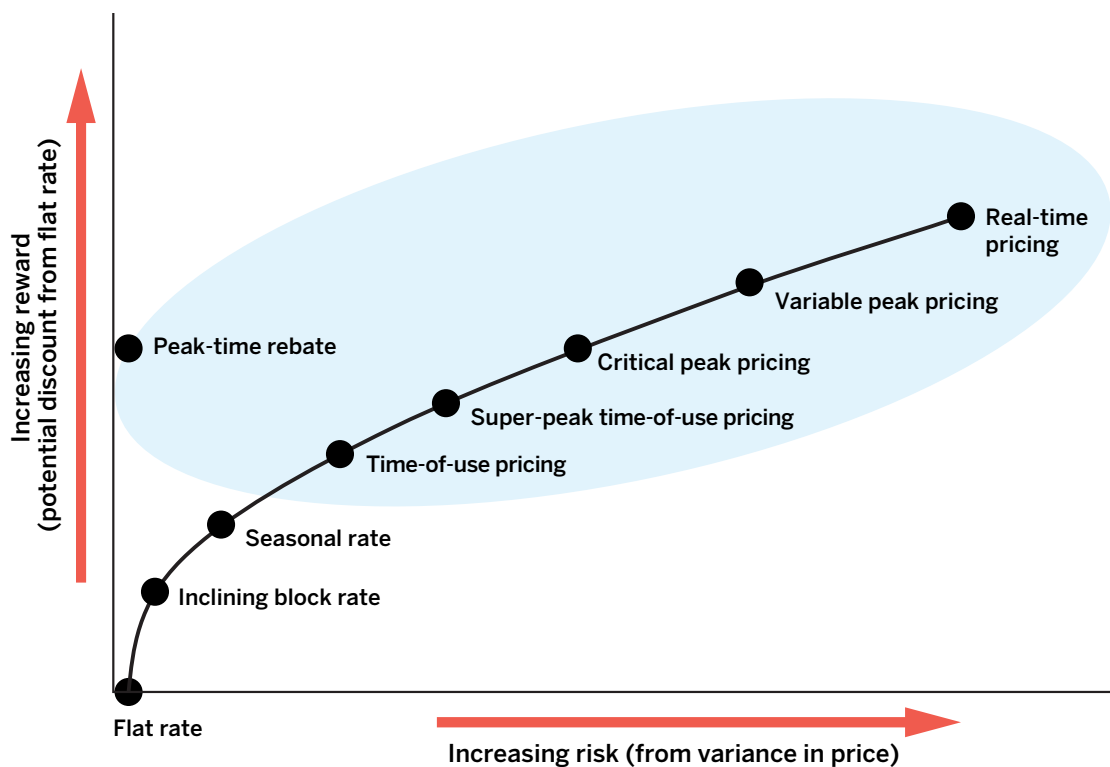
52 Just over half of the 28 EU countries have access to some form of time-varying tariffs. Agency for the Cooperation of Energy Regulators and Council of European Energy Regulators. (2018). *Annual report on the results of monitoring the internal electricity and natural gas markets in 2017—Consumer empowerment volume*. Ljubljana, Slovenia, and Brussels, Belgium: Authors. Retrieved from https://acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/MMR%202017%20-%20CONSUMER%20PROTECTION.pdf

53 The picture varies across Europe, although available information suggests that the overall number of consumers on time-varying tariffs is limited. For example, around 13 percent of UK residential consumers were subscribed to a time-of-use tariff in 2015. On the other hand, such tariffs are common in Finland, especially for consumers with electric heating (often combined with heating storage). European Commission. (2016b). *Impact assessment study on downstream flexibility, price flexibility, demand response and smart metering*. Brussels, Belgium: Author. Retrieved from <https://ec.europa.eu/energy/en/studies/impact-assessment-study-downstream-flexibility-price-flexibility-demand-response-smart>

54 For an example of critical peak pricing, see the Tempo tariff in France. A brief description of the tariff is available in Kolokathis et al., 2018.

55 European Commission, 2016b.

Figure 4. Representation of customer risk-reward trade-off in smart, time-varying tariffs



Source: Faruqi, A., Hledik, R., and Palmer, J. (2012). *Time-varying and dynamic rate design*.

associated costs for producing and delivering electricity to consumers.⁵⁶ Real-time price tariffs are increasingly offered in European countries,⁵⁷ 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 (see Page 53).⁵⁸

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 (see Figure 4).⁵⁹ 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 make best 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 will be 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 from the EU and the United States show how tariffs can be designed to help beneficial

56 European Commission, 2016b.

57 Real-time pricing is currently available in seven EU countries and Norway and is gradually becoming available in Member States that have phased out, or are in the process of phasing out, regulated prices. There is no real-time pricing in countries where the majority of households are under regulated prices. European Commission, 2019b.

58 Agency for the Cooperation of Energy Regulators and Council of European Energy Regulators, 2018.

59 Faruqi, A., Hledik, R., and Palmer, J. (2012). *Time-varying and dynamic rate design*. Montpelier, VT: Regulatory Assistance Project and The Brattle Group. Retrieved from <https://www.raonline.org/knowledge-center/time-varying-and-dynamic-rate-design>

EV integration, starting with simple examples and describing progressively more complex ones (see Appendix A for more).

Two-period TOU tariff for energy (Spain)

Day/night tariffs, where consumers pay a higher charge for electricity use during the day than during nighttime hours,⁶⁰ are the simplest form of a TOU tariff. They have been in place across Europe and elsewhere for decades and can be a simple first step to incentivise smart charging.

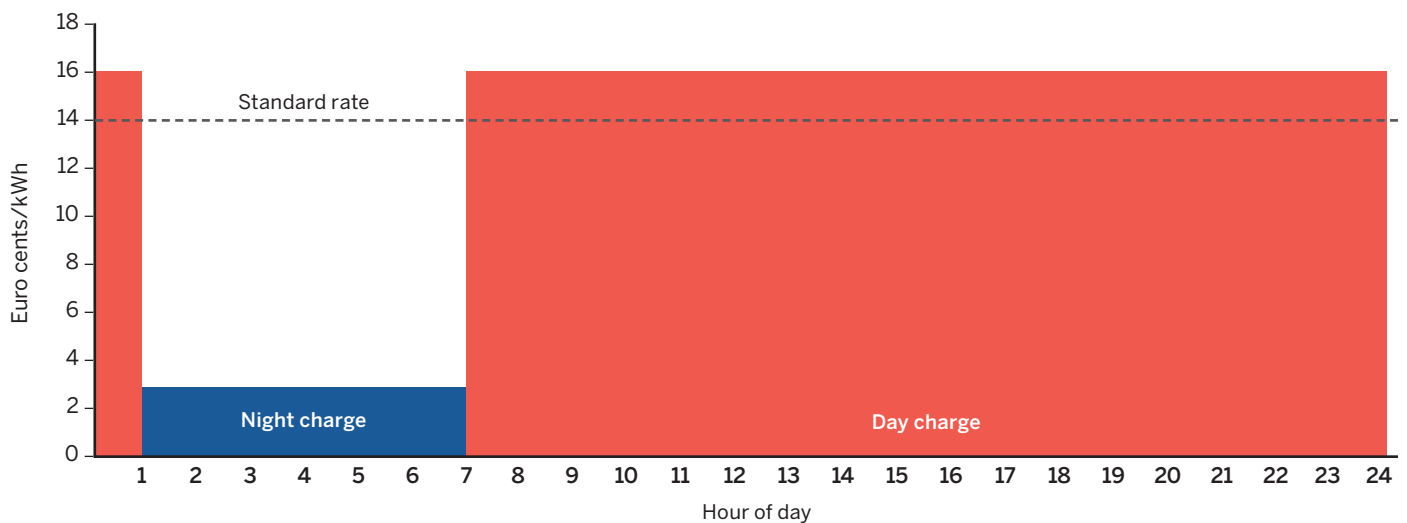
In Spain, Iberdrola has introduced a day/night TOU tariff for the energy component of the electricity bill specifically for EV owners (see Figure 5).⁶¹ The tariff is split into a day charge, which is around 0.16 euros/kWh, and a night charge, which is 0.03 euros/kWh.⁶² The night period lasts from 1 to 7 a.m., and the charges are the same throughout the year (i.e., no seasonal differentiation).

The night charge represents a discount of more than 80 percent and sends a strong signal to EV adopters on the

tariff to charge at night, when demand on the system is lowest and so, by extension, are production costs.⁶³ This can be seen in Figure 6 on the next page, which depicts the load curves for Spain on the highest demand days for the summer and winter of 2017.⁶⁴ The figure shows that nighttime demand was roughly two-thirds the highest demand observed on the two days.

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 price 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. At the standard price, the cost to fully charge the vehicle would be 3.40 euros, almost five times the cost under the EV-dedicated tariff.⁶⁵

Figure 5. Iberdrola EV-dedicated tariff



Source: Based on Iberdrola. *Electric vehicle plan*.

60 There is no universal definition of the day and night hours, but rather these depend on the individual system in question. In the two following examples, the day hours are 7 a.m. to 1 a.m. in the case of Iberdrola and 9 a.m. to 9 p.m. in the case of Xcel Energy.

61 Iberdrola. *Electric vehicle plan* [Webpage]. Retrieved from <https://www.iberdrola.es/en/movilidad-electrica/electric-vehicle-plan>. Spain also has a regulated EV tariff in place, which is described on Page 44.

62 On top of these rates, the utility is charging an annual fee for the network costs, the amount of which depends on the size of the customer's connection to the grid. This is equal to around 42 euros per kW per year. A household with a connection of 10 kW (e.g., a 7-kW Level 2 home charger and other loads) would pay a total of 420 euros per year, which can dilute the price signal sent by the energy component. It would have

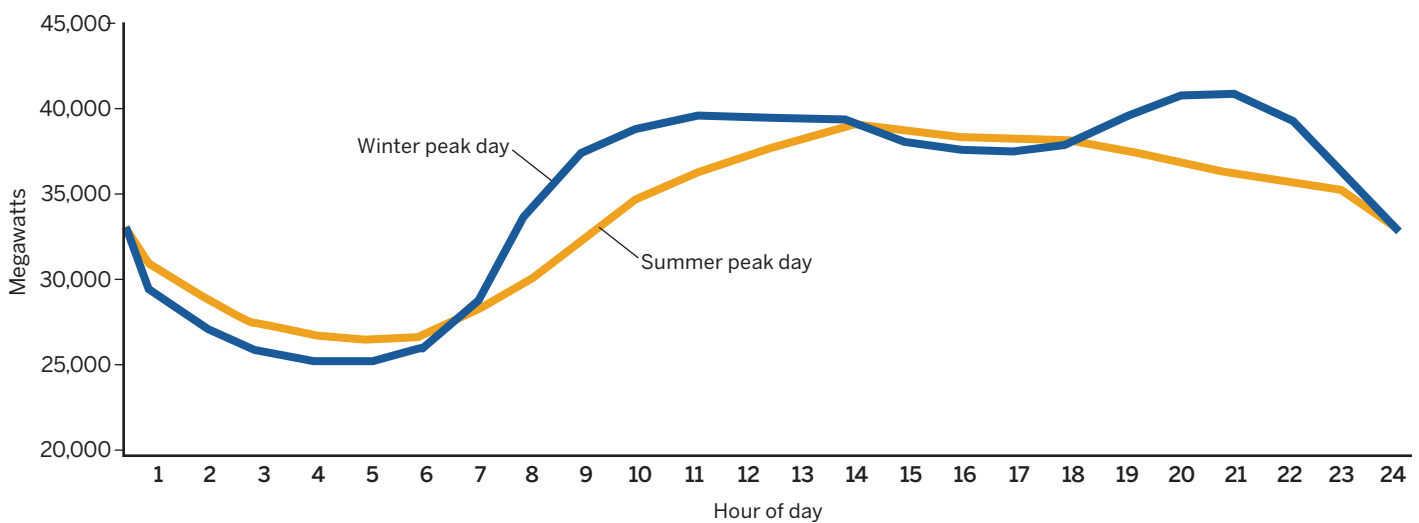
been preferable to also recover the network costs at a volumetric rate, ideally with a TOU charge for the same hours as the energy costs.

63 For illustration, a Nissan Leaf with a battery size of 24 kWhs requires around three to four hours for a full charge with a 7-kW household charger, or eight to nine hours with a 3-kW charger.

64 European Network of Transmission System Operators for Electricity. *Power statistics* [Database]. Retrieved from <https://www.entsoe.eu/data/power-stats/>

65 For a driver covering a distance of 10,000 kilometres per year, this equates to a savings of 167.50 euros for the entire year, assuming that all charging is taking place during the nighttime (off-peak) hours.

Figure 6. Load curves on peak demand days for Spain (2017)



Source: European Network of Transmission System Operators for Electricity. *Power statistics*.

The EV-dedicated tariff has been introduced only recently, and there isn't enough evidence yet to assess its effect on consumer behaviour. Experience from other jurisdictions, however, provides evidence that consumers respond to this kind of tariff. Under a similar tariff in Minnesota, the share of charging done during off-peak hours has ranged from 90 to 95 percent on a monthly basis and averaged 92 percent during a two-year period when the utility monitored customer behaviour (see Page 45).⁶⁶

Two-period TOU tariff for energy and network (Maryland)

Although the majority of TOU tariffs for EVs focus on the energy component of the bill, it is equally important that the network component be time-varying. Network costs are expected to grow and could become an even more dominant part of the bill as networks are modernised. Varying prices only for the energy component does not send a strong

enough signal to encourage beneficial charging and ignores the equally variable nature of the utilisation of the grid. The following example presents a tariff with varying charges for both the energy and network components.

Since the beginning of 2018, Baltimore Gas and Electric Co. (BGE) of Maryland⁶⁷ has had a TOU tariff for residential customers with electric vehicles (see Figure 7 on the next page).⁶⁸ All residential consumers who use BGE's distribution network to charge their EVs are eligible for the tariff.⁶⁹ A prerequisite is the installation of a smart meter at the consumer's home that is capable of taking half-hourly consumption measurements.

BGE splits the year into two seasons: summer (June through September) and non-summer (for the remainder of the year). The non-summer season features higher charges, as the utility experiences higher demand during this time. Each season is further split into an on-peak and an off-peak segment. For the summer season, the peak segment lasts

66 Xcel Energy. (2018, 1 June). Compliance filing, residential electric vehicle charging tariff, Docket No. E002/M-15-111. Retrieved from <https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId={60A5CA63-0000-C11E-9F24-C36F15592A04}&documentTitle=20186-143541-01>

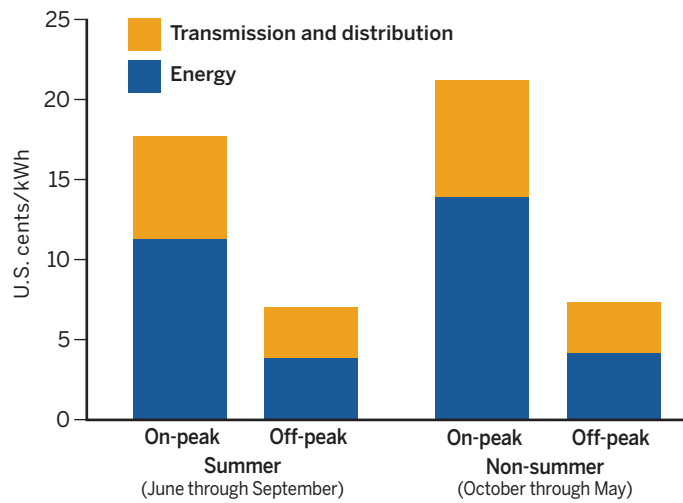
67 BGE is a bundled, or vertically integrated, U.S. utility. This means it is responsible for the distribution network as well as generation and supply. In the U.S., while much of the wholesale power market is competitive, the retail market remains mostly regulated (through either bundled utilities or, where retail competition is allowed, through oversight of default service). This is different than in Europe, where European and subsequently national legislation obliges distribution system operators to unbundle (accounting, functional, legal, and ownership separation) from any generation and supply (or retail) activities. (There is an exemption for those with fewer than 100,000 customers.) In both

regions and elsewhere, distribution system operators have the same high-level responsibilities, and the regulatory frameworks governing their functioning needn't be different due to their unbundling status. For more information on the recent status of unbundling across Europe, see Council of Energy Regulators (2016). *Status review on the implementation of distribution system operators' unbundling provisions of the 3rd energy package*. Brussels, Belgium: Author. Retrieved from <https://www.ceer.eu/documents/104400/-/-/882514d5-c57f-86f8-50a3-90185e270f15>

68 Baltimore Gas and Electric Co. (2018). *Residential electric vehicle time-of-use—electric: Schedule EV*. Retrieved from <https://www.bge.com/MyAccount/MyBillUsage/Documents/Electric/ScheduleEV.pdf>

69 The BGE tariff is a whole-house tariff, meaning it applies for the entire consumption of a household and not just the electricity used to charge the EV.

Figure 7. Baltimore Gas and Electric's residential time-of-use EV tariff



Source: Based on Baltimore Gas and Electric Co. (2018). Residential electric vehicle time-of-use—electric: Schedule EV.

from 10 a.m. to 8 p.m. on weekdays only, excluding public holidays. The peak period of the non-summer season is between 7 and 11 a.m. and 5 and 9 p.m. on weekdays, or in other words during the morning and evening peaks.

The tariff features a dynamic component for the energy and network costs. Overall, the on-peak charge is about three times the off-peak one. This sends a strong signal to EV owners to charge their vehicles outside the on-peak hours, during which the costs of providing the service are higher.

Time-varying tariffs for the network component of the electricity bill are in place in some European countries, although current trends are toward more fixed charges that discourage smart charging.⁷⁰

While the above example is for households, similar designs can be applied for non-household charging—such as at multi-family, commercial, and industrial sites and fast charging stations—to incentivise charging at beneficial times for the power system.⁷¹ California offers promising examples.⁷²

The previous two examples focused on the simplest form of TOU tariffs. More sophisticated TOU tariffs with three or four time periods⁷³ coupled with seasonal differences can better reflect the actual costs for the production and delivery of electricity. They can, therefore, be a preferable option to simple day/night TOU tariffs and will incentivise EV charging at beneficial times for the power system and the avoidance of the costliest hours. In any case, the tariff design should be based on the nature of the system in question and the likely impact. For example, a system with spiky peak demand might well justify the use of a three-period TOU tariff with a significant super-peak charge that lasts for a short time. An example of such a tariff comes from the Sacramento Municipal Utility District in California.⁷⁴

Half-hourly dynamic pricing (United Kingdom)

The tariffs explained in the previous sections of this chapter offer predetermined prices for predetermined periods. Given the still relatively low to moderate level of renewable energy deployment in the power system, this can be considered a good approximation of the costs related to the delivery of the service to electric vehicles and electricity consumers more broadly. However, as the power system is changing quickly, new challenges and opportunities arise. These include using cheap excess renewable energy rather than curtailing it, and vice versa: flexing demand when there is insufficient renewable energy generation available. The following example of dynamic half-hourly pricing offers a potential blueprint for tariffs in a system dominated by renewable energy resources.

A small energy supplier in the UK, Octopus Energy, has recently launched a smart tariff designed primarily for electric vehicles and storage heaters, but also more broadly for consumers who can flex their consumption. It is the

70 For more information see Kolokathis et al., 2018. We also describe a promising example of a time-varying network tariff from Denmark on Page 45.

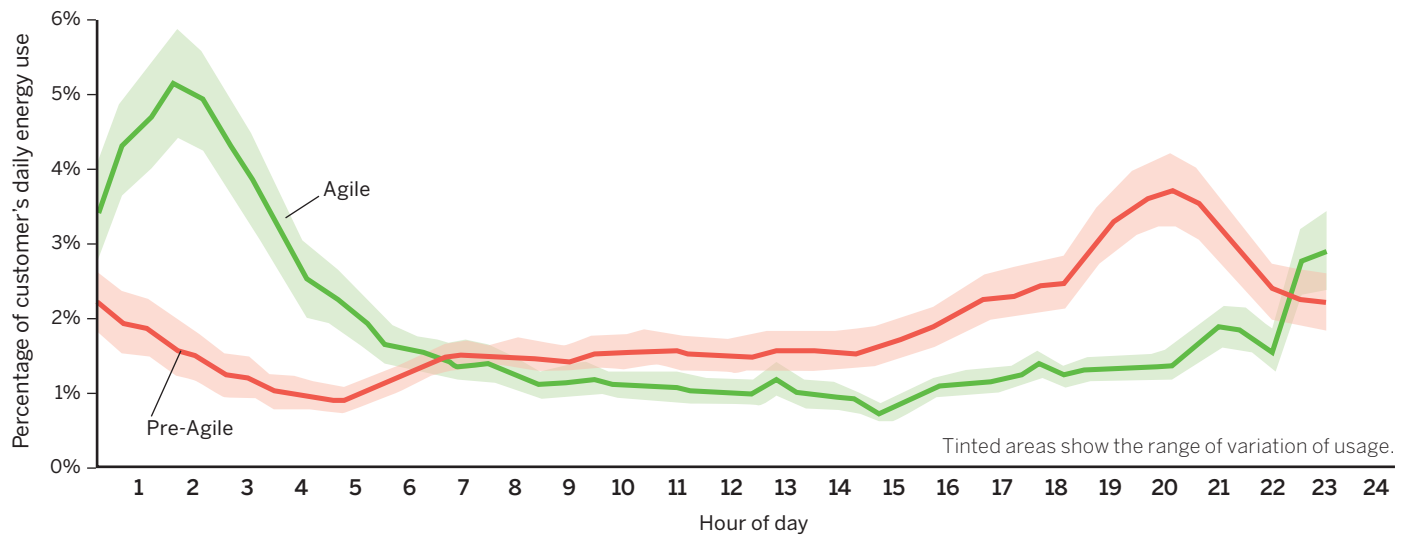
71 These kinds of sites tend to face significant fixed charges through non-coincident peak demand charges. These charges are based on the highest demand, usually defined with regard to the individual site's peak demand without taking into consideration whether it occurred at the time of system peak demand. Such charges do not incentivise shifting EV charging away from peak hours. They also are detrimental to the

economic viability of these types of charging stations, especially in the early stages of e-mobility when their utilisation is more likely to be low and as a consequence the charges to individual EV owners too high.

72 We describe these beginning on Page 47 in Appendix A.

73 Although, in theory, a TOU tariff could be divided into more than four time periods, we are not aware of any such example in practice.

74 For the details of this tariff, see Page 46 in Appendix A.

Figure 8. Electric vehicle owners' charging habits change on time-of-use tariff

Source: Octopus Energy. (2018). *Agile Octopus: A consumer-led shift to a low carbon future.*

Agile Octopus tariff.⁷⁵ The tariff offers half-hourly prices that are linked to the half-hourly wholesale market prices. More specifically, the supplier determines on a daily basis the rates that apply to the customers, based on a formula that is tied to the day-ahead half-hourly wholesale price. The company then communicates the applicable rates to the final consumers at 4 p.m. every day through its smartphone application, giving them sufficient time to adapt their consumption for the following day. A prerequisite to signing up for this tariff is the possession of a smart meter that can take half-hourly consumption measurements and send them to the supplier for billing purposes. An additional feature of the tariff is that it can inform consumers when wholesale prices drop below zero and pay them if they consume electricity during those times. This information can either be shared via text message alerts, allowing consumers to manually change their consumption, or be communicated directly

Initial results from one smart tariff programme show that electric vehicle drivers shifted their charging almost entirely away from the peak hours.

to the consumer's pre-programmed smart appliances.

The initial results, according to Octopus Energy, show that EV drivers shifted their charging almost entirely away from the peak hours, which tend to be between 4 and 7 p.m. in Great Britain (see Figure 8).⁷⁶ Out of all the customers signed up to the tariff, EV drivers changed their behaviour the most and achieved the greatest savings, with the average EV driver saving around 132 pounds per year (or around 150 euros) compared with the Octopus Energy fixed tariff contract.⁷⁷

75 See Octopus Energy. *Introducing Agile Octopus* [Webpage]. Retrieved from <https://octopus.energy/agile/>

76 It is not clear from the report whether this conclusion is statistically significant. Octopus Energy. (2018). *Agile Octopus: A consumer-led shift to a low carbon future.* Retrieved from <https://octopus.energy/static/consumer/documents/agile-report.pdf>

77 Overall, experience so far shows that customers with EVs shifted their total household consumption by 47 percent from the on-peak to the off-peak hours. Octopus Energy, 2018.

Alternative to dynamic tariffs: Active control of charging (Germany)

German energy legislation allows classification of EVs as a controllable end use (the same classification applies for heat pumps)⁷⁸ 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 ensure sufficient supply.

A typical network tariff in Germany makes up 25 percent of the average consumer's electricity bill and consists of three elements: a fixed annual fee ("Grundpreis"), a volumetric fee ("Arbeitspreis"), and a metering fee. The structure of the controllable load tariffs differs from a standard tariff in two ways: The EV owner doesn't pay an annual fixed fee, and pays a highly discounted volumetric charge throughout the day. If a DSO interrupts the charging of EVs due to reliability reasons, it resumes during off-peak hours. A prerequisite

for an EV owner to choose such a tariff is the possession of a meter that can communicate with the DSO and has a function allowing interruption of charging. The original objective of the law when first implemented in the 1980s was to utilise nuclear power plants more effectively by filling in the night demand troughs.⁷⁹ The power market, since its liberalisation, only operates the distribution network. Non-discrimination rules allow new technologies such as heat pumps and EVs to benefit from the price reduction in the same way as the initial night storage space heating systems.

Several German DSOs offer specific EV network tariffs on this legal basis. Each DSO may define the peak period according to the characteristics of its territory. For example, the DSO Edis defines the interruptible hours as 10:45 a.m. to 12:15 p.m. and 5:15 to 6:45 p.m. (a total of three hours per day). An EV owner on the network tariff pays only a discounted charge of 0.24 euros/kWh compared with 0.75 euros/kWh for standard consumers, a discount of 67 percent.⁸⁰

Smart technology

The previous section demonstrated the potential that electricity pricing offers to encourage beneficial EV integration. Although 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 9 on the next page illustrates this by showing the levels of peak demand reductions achieved for a number of pilot programmes with different forms of smart pricing, both with and without smart technology.⁸¹ The peak demand reductions achieved were generally higher when smart pricing was accompanied with smart technology.

Smart technology can be defined as any type of technology that 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.⁸² In its simplest form this includes smart meters

78 Bundesministerium für Justiz und Verbraucherschutz [German Federal Ministry of Justice and Consumer Protection]. (2005). Gesetz über die Elektrizitäts- und Gasversorgung (EnWG) [Energy Industry Act]. Para. 14a. Retrieved from https://www.gesetze-im-internet.de/enwg_2005/BJNR197010005.html

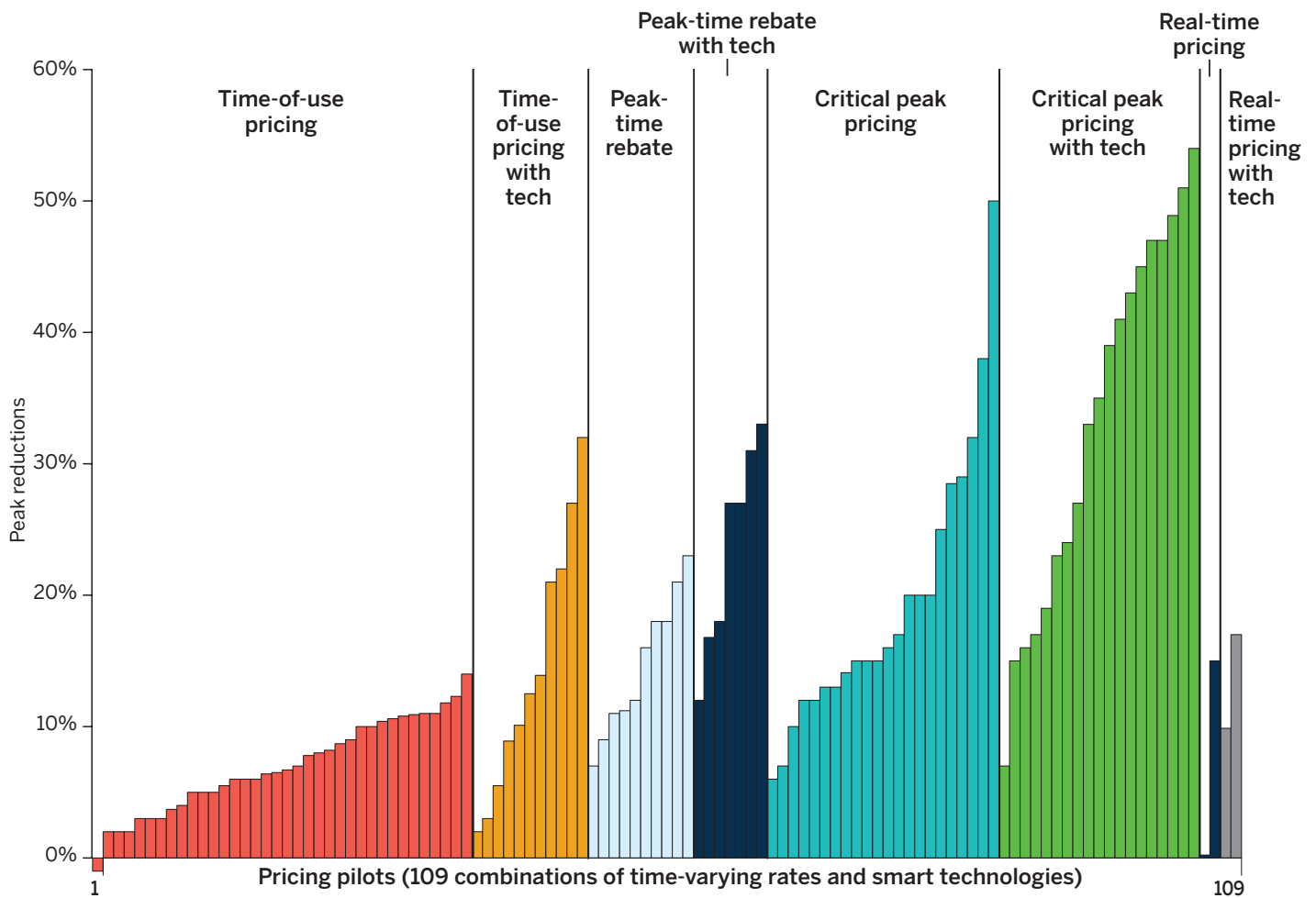
79 Our analysis shows that German networks are underutilised when looking across the entire year and there is significant spare network capacity during the evening hours even in the highest demand years. Hogan et al., 2018.

80 e.dis Netz GmbH. (2018). *Preisblätter Netzentgelte Strom der E.DIS Netz GmbH*. Fürstenwalde/Spree, Germany: Author. Retrieved from https://www.e-dis-netz.de/content/dam/revu-global/e-dis-netz/dokumente/Preisblaetter_Netzentgelte_Strom_20180101.pdf

81 Faruqi et al., 2012.

82 Other technologies, such as timers that allow the user to start an action at a predetermined time, can also be considered smart technology. Timers are a common feature of modern appliances (e.g., dishwashers and laundry machines) and can be used to prearrange when the charging of an EV takes place. This technology can be particularly useful for owners who want charging to begin even if they aren't available to initiate it (e.g., during sleeping hours).

Figure 9. Average peak reduction under time-varying tariff pilot programmes



Source: Faruqui, A., Hledik, R., and Palmer, J. (2012). *Time-varying and dynamic rate design*.

and other types 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.⁸³

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, the cable that connects the EV to the charging station (see the Ubitricity example on Page 27), or the vehicle itself.⁸⁴ It is possible that in the future EV drivers

83 See, for example, the zappi EV charge point from Myenergi, which can use one’s own solar generation to charge an EV: <https://myenergi.uk/product/zappi-product/>.

84 A prominent example is BMW’s i ChargeForward Project developed in California. In the first project phase, 2015-2016, the carmaker aggregated via proprietary software the load of electric vehicles to participate in California’s demand response market. By default, EVs were available

to participate in managed charging when plugged in. Users received notifications when their car was selected to participate in a demand response event, allowing them to opt out if they needed to use the car. Kaluza, S., Almeida, D., and Mullen, P. *BMW i ChargeForward: PG&E’s electric vehicle smart charging pilot*. Pacific Gas & Electric Co. Retrieved from <http://www.pgecurrents.com/wp-content/uploads/2017/06/PGE-BMWiChargeForward-Final-Report.pdf>

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 provide a sample of how different smart technologies can enhance smart charging.

Technology to boost EV adoption and smart charging (Vermont)

Green Mountain Power, a Vermont utility, has offered a package to incentivise the rollout of electric vehicles.⁸⁵ The package includes smart technology⁸⁶ and a smart tariff.⁸⁷ The smart technology consists of a charger that allows direct communication with the utility and a mobile app that allows consumers to control its operation remotely. The package offers unlimited charging for a monthly fee of \$30, as long as the charging occurs outside the utility's peak events. Such events occur an average of five to 10 times a month and last for two to six hours at a time. The charging is controlled by the utility itself to coincide with off-peak hours, while respecting a driver's needs. At the same time, customers enrolled in the package can always opt to charge their vehicles during a peak event, albeit at a significantly high cost of 0.60 U.S. dollars per kWh (or around 0.52 euros per kWh).

Technology to reduce costs and carbon footprint

Jedlix, a startup based in the Netherlands, has developed a suite consisting of a mobile phone application and smart technology for the smart charging of EVs in multiple use cases.⁸⁸ The application assesses the optimal charging profile for an EV based on the driver's needs (e.g., the time when

the driver needs to begin travel). It takes into account the available capacity on the grid, the availability of sustainable energy, and energy prices. It then uses smart technology to determine the best hours to charge the EV in terms of supply of sustainable electricity and charging costs, while meeting the driver's requirements. In general, the technology aims at shifting charging away from the hours when the grid is stressed and toward times when there is a significant amount of renewable energy generation.

Another startup, Maxem, has developed a control device in the form of a separate wall box, complemented by an application, that can integrate a user's own EV charging station, generation units (e.g., solar photovoltaic), and other uses and appliances (e.g., electrical heating) into a smart home or office building.⁸⁹ The technology's primary objective is to ensure that the grid connection of the smart home is operated safely by avoiding overload in both directions. In other words, the control device helps to manage the size of the connection with the grid and therefore minimises the resulting connection costs.⁹⁰ It 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.⁹¹

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

85 Green Mountain Power is a bundled utility serving the majority of the state's consumers. The utility is responsible for generation, supply, and the distribution network in its jurisdiction.

86 The utility offers a charger (with a capacity of 7 kW) for free to consumers who buy a new electric vehicle and for a \$10 monthly payment to consumers who already own an EV. Green Mountain Power. *In-home Level 2 EV charger* [Webpage]. Retrieved from <https://greenmountainpower.com/product/home-level-2-ev-charger/>

87 Dostis, R. (2019, 1 March). *Green Mountain Power electric vehicle programs & outlook* [Presentation]. Retrieved from <https://legislature.vermont.gov/Documents/2020/WorkGroups/Senate%20Transportation/Electric%20Vehicle%20Charging%20Tariff%20Testimony/W-Robert%20Dostis-Green%20Mountain%20Power%20Electric%20Vehicle%20Programs%20Outlook-3-1-2019.pdf>

88 Examples include optimising charging at home and lowering demand and the resulting costs for fleets. See Jedlix. *The smartest way to power your ride* [Webpage]. Retrieved from <https://www.jedlix.com/en/>. Jedlix

is partnering with companies from the mobility and electricity supply sectors such as Tesla, Renault, and Eneco. It has also engaged with Next Kraftwerke in a potentially larger European V2G trial, aggregating connected EVs into a virtual power plant providing frequency regulation services. See Next Kraftwerke. (2018, 10 September). *Next Kraftwerke and Jedlix launch initiative to use electric car batteries for grid stability*. Retrieved from <https://www.next-kraftwerke.be/en/next-kraftwerke-and-jedlix-launch-initiative-to-use-electric-car-batteries-for-grid-stability/>

89 Maxem. *Your smart energy monitor* [Webpage]. Retrieved from <https://maxem.io/en/>

90 These are the costs for connecting a consumer to the power network and are defined in euros per kW. The lower the size of the connection (the kW), the lower the connection costs.

91 The technology is also available for larger multi-charger stations, with up to 99 chargers, with a similar objective of avoiding overloading one's network connection and, by extension, minimising the connection costs.

the charging of more EVs overnight, while avoiding an increase in 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 the costs of using the grid at peak times and to 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 (EVSE) provider, was able to reduce peak power demand for charging about 130 buses from 5 megawatts to 2, implying considerable savings.⁹²

The examples in this section demonstrate that the use of smart technology is a key enabler for cost-effective EV grid integration with significant contribution to smart charging and therefore to lowering the cost of EV deployment.

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. Unlocking the inherent flexibility of EV loads as a benefit to the grid while reducing costs and carbon emissions requires locating charging infrastructure to meet existing grid requirements and mobility demand. Identifying the best locations for EVSE⁹³ is most effective if the location is considered from both a power market and a transport policy point of view. This requires the combined perspective and collaboration of actors in both domains to fully realise EV benefits. 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

Thoughtful siting of charging infrastructure encourages drivers to charge when optimal for the grid and without compromising their mobility needs.

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.⁹⁴ 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 alternatives based on sharing and how soon transport shifts to other modes.

Workplace charging services, including normal and fast charging⁹⁵ offers and rates, are developing rapidly, driven by two factors. 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.⁹⁶

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

92 ChargePoint, personal communication, 26 November 2018.

93 In Europe, the term "EVSE supplier" is sometimes used interchangeably with "charge point operator." This paper uses "EVSE supplier" to cover all companies involved in providing services related to EV charging.

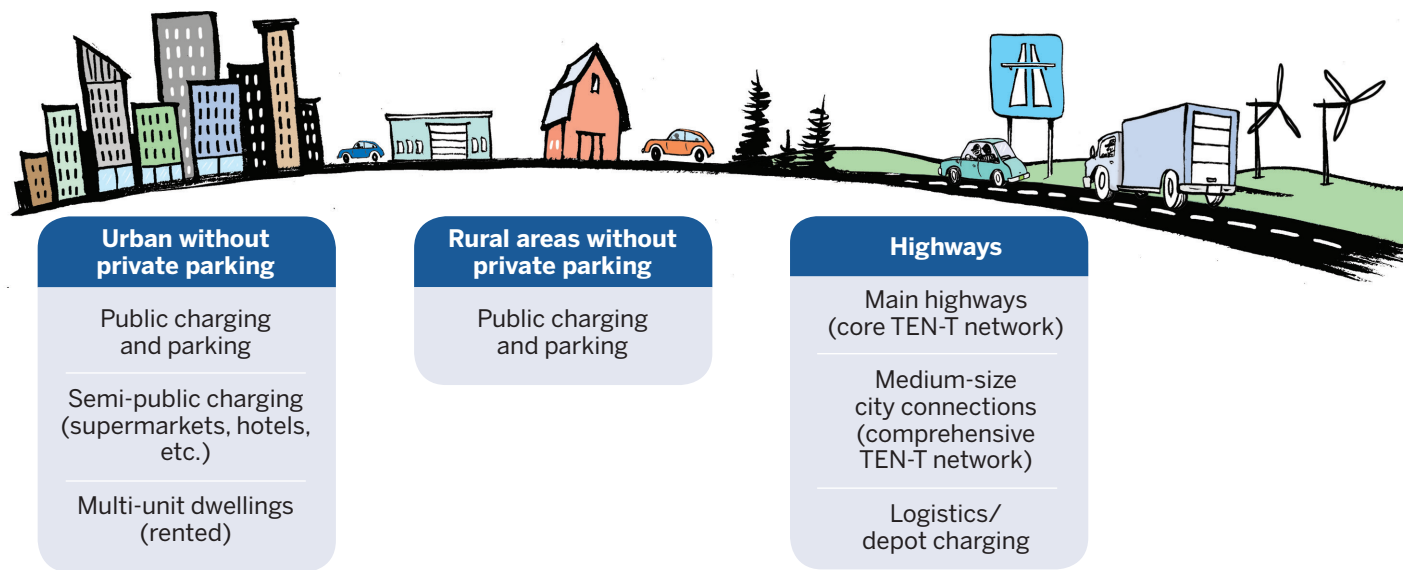
94 The supplier ChargePoint, for example, argues that about 20 percent of the kilowatt-hours will be charged at public sites in and between cities, while 80 percent of kilowatt-hours will be charged at home or at work. This figure is likely to vary by country depending, for example, on the availability of off-street parking. Burghardt, C. (2019, 19 September). Presentation by the EU managing director of ChargePoint at a workshop organised by SolarPowerEurope. For an overview of the charging infrastructure market, see Burghardt, C. (2018, 8 October). *Charge-it:*

e-mobility now! [Presentation]. Retrieved from <https://cdn.eurelectric.org/media/3390/burghardt-h-B71C04CC.pdf>

95 In this paper, we use a simple definition of "normal" charging as up to 22 kW and "fast" charging as more than 22 kW. See European Alternative Fuels Observatory. *Alternative fuels (electricity) charging infrastructure stats* [Webpage]. Retrieved from <https://www.eafo.eu/alternative-fuels/electricity/charging-infra-stats>

96 Opportunities will occur in particular in countries where solar energy generation is available and is currently curtailed or where renewables curtailment could be a risk in the future. Likewise, in countries where wind generation is highest during evening hours, home charging or overnight public charging can enable EVs to absorb peaks in generation.

Figure 10. Use cases for public or semi-public electric vehicle charging



cases for EV charging, summarised in Figure 10, that show how to make the most beneficial use of EV grid integration while addressing some of the challenges.

Overall, evidence from real-world examples in the next section reveals two principles that can help address some of the current barriers to smart, grid-friendly EV infrastructure:

1. Use existing grid and transport infrastructure to reduce costs of EV grid integration.
2. Plan EV infrastructure based on demand, in view of commercial use and by considering mobility and grid aspects.

Use existing grid and transport infrastructure

It's difficult to project demand and optimal locations for public chargers, as the battery ranges of next-generation EVs increase to approximately 400 kilometres and an EV driver can be expected to drive typically 50 to 60 kilometres a day, varying by country.⁹⁷ To integrate the growing number of EVs at lowest cost and respond to a growing variety of charging patterns, planners can exploit existing transport

infrastructure and electricity distribution capacity in cities and along highways, as the practices we review here illustrate.

Public charging using existing urban infrastructure (London)

Necessity is the mother of invention. Lacking the space to equip London's urban sidewalks with separate EV charging infrastructure, EVSE supplier Ubitricity partnered with UK power supplier OVO Energy to convert public light poles into 3- to 5-kilowatt (kW) charge points.

The equipment, located in several London districts, allows for normal charging of parked EVs. The model creates additional efficiency benefits by replacing the traditional inefficient light pole bulbs with an LED light and using the excess power to charge the EV's battery. OVO Energy claims to have reduced the cost for installation of a charge point from an estimated 8,000 pounds to 1,000 pounds.⁹⁸ The solution was adopted rapidly^{99, 100} to a



Photo: Ubitricity. <https://www.ubitricity.com/mobilecharging-system/>

97 Pasaoglu, G., Fiorello, D., Martino, A., Scarcella, G., Alemanno, A., Zubaryeva, A., and Thiel, C. (2012). *Driving and parking patterns of European car drivers—a mobility survey* (Report EUR 25627 EN). Brussels, Belgium: European Commission, Joint Research Centre. Retrieved from http://publications.jrc.ec.europa.eu/repository/bitstream/JRC77079/driving%20and%20parking%20patterns%20-%20final_online.pdf

98 Pakenham, T. (2018, 9 February). If you build it, they will charge. *Utility Week*. Retrieved from <https://utilityweek.co.uk/build-will-charge/>

99 Cuff, M. (2017, 14 November). *Ovo Energy teams up with Kensington & Chelsea and Ubitricity to roll out EV-charging lamp posts*. BusinessGreen. Retrieved from <https://www.businessgreen.com/bg/news/3020960/new-agreement-will-see-50-extra-electric-vehicle-chargers-installed-in-lampposts-across-the-london-borough>

100 One London borough announced a plan for a total of 700. Manthey, N. (2018, 26 February). *London's Wandsworth to install EV charging lampposts*. Electrive.com. Retrieved from <https://www.electrive.com/2018/02/26/londons-wandsworth-install-ev-charging-lampposts/>

network of approximately 290 charging points in London and Oxford by October 2018.^{101, 102} By enabling parking and charging over a longer period of hours, the system encourages overnight charging, shifting it to optimal grid use times. By a similar logic, EVs parked during the day could capitalise on the midday drop-off in electricity demand, encouraged by a time-varying tariff.

Other promising practices of converting urban infrastructure for parking and charging solutions involve repurposing telecommunications infrastructure and exploiting synergies with electrified public transport (see Appendix B).

Urban public fast charging points along existing grid

Existing infrastructure can be more optimally employed for charging purposes by reviewing existing capacity and comparing it with public fast charging needs. Some cities have chosen this approach to explore whether and where upgrades are necessary. A 2016 study found that the city of San Francisco already had half of the needed capacity for a very comprehensive charging network by 2025. Pacific Gas & Electric, a California utility, studied options to provide a selected urban area with 50-kW direct current fast chargers using existing transformer capacity to meet a scenario with over 800,000 EVs by 2025.¹⁰³ With the help of a mapping tool, the utility identified more than 14,000 locations at which fast chargers could be installed to provide every EV driver with a fast charger within a 1-mile (1.6 kilometre) radius. The study found that more than 6,000 of the identified locations for fast charging could host two or more 50-kW charging sites without upgrades, while the remaining

locations would need an upgrade.

A similar study has been performed for Ottawa, Ontario, identifying grid upgrade costs of three representative locations that could be equipped with a variety of fast chargers. It found that distribution grid upgrades are necessary only for multiple high-power charging stations with peak capacities of more than 1,600 kW (for example, four chargers delivering 400 kW each).¹⁰⁴ In yet another example from Germany, Berlin's DSO found that if 1 in 5 cars were electric in 2025 (about 250,000 of today's 1.2 million), the city's high- and medium-voltage grid would not require any "structural extensions"; however, the low-voltage level may need upgrades.¹⁰⁵

Highway charging using high-voltage grid (United Kingdom)

While the market for highway charging technologies and offers evolves quickly, aided by public co-funding, the recommended coverage with charging facilities that informs Member States' infrastructure planning is likely to need refinement. The EU Commission's initially recommended ratio of 10 EVs per charging point and one fast charging site every 60 kilometres on the main highways (the core Trans-European Network Transport [TEN-T] corridors) by 2025 is likely to be met.¹⁰⁶ Further criteria are needed, however, as an EU-wide average density ratio does not guarantee sufficient density at the local level. It is important to plan for extending charging infrastructure to smaller highways and medium-sized cities (the comprehensive TEN-T network) to ensure a larger number of destinations can be reached electrically, in particular covering highly car-dependent

101 Ubitricity. (2018, 11 October). *Zap-Map integrates Ubitricity charge points*. Retrieved from <https://www.ubitricity.co.uk/unternehmen/newsroom/zap-map-integrates-ubitricitys-london-and-oxford-charge-points/>

102 Zap-Map. *Ubitricity network* [Webpage]. Retrieved from <https://www.zap-map.com/charge-points/public-charging-point-networks/ubitricity-network/>

103 Nicholas, M., and Hall, D. (2018, July). *Lessons learned on early electric vehicle fast-charging deployments*. Washington, DC: The International Council on Clean Transportation. Retrieved from https://www.theicct.org/sites/default/files/publications/ZEV_fast_charging_white_paper_final.pdf, citing Pacific Gas & Electric. *Site information for electric vehicle direct current fast chargers*.

104 Nicholas and Hall, 2018, citing Ribberink, H., Wilkens, L., Abdullah, R., McGrath, M., and Wojdan, M. (2017, October). Impact of clusters of DC fast charging stations on the electricity distribution grid in Ottawa, Canada. In *Electric Vehicle Symposium 30*, Stuttgart, Germany.

105 Frese, A. (2018, 4 July). Berliner Stromnetz ist fit für E-Autos [Berlin grid is ready for electric cars]. *Der Tagesspiegel*. Retrieved from <https://www.tagesspiegel.de/wirtschaft/elektromobilitaet-berliner-stromnetz-ist-fit-fuer-e-autos/22768386.html>

106 Platform for Electro-mobility. (2018). *How EU Member States roll-out electro-mobility: Electric charging infrastructure in 2020 and beyond*. Retrieved from <http://www.platformelectromobility.eu/wp-content/uploads/2018/02/Emobility-Platform-AFID-analysis.pdf>. These guidelines were issued as part of the implementation of the Alternative Fuels Infrastructure Directive, based on a model by the European Commission's Joint Research Centre. See Gkatzoflias, D., Drossinos, Y., Zubaryeva, A., Zambelli, P., Dilara, P., and Thiel, C. (2016). *Optimal allocation of electric vehicle charging infrastructure in cities and regions* (EUR 27894 EN). Brussels, Belgium: European Commission, Joint Research Centre. Retrieved from http://publications.jrc.ec.europa.eu/repository/bitstream/JRC101040/alllocatechargingpoints_sciencepolreport_eurreport_online.pdf

Opportunities from battery-based fast charging

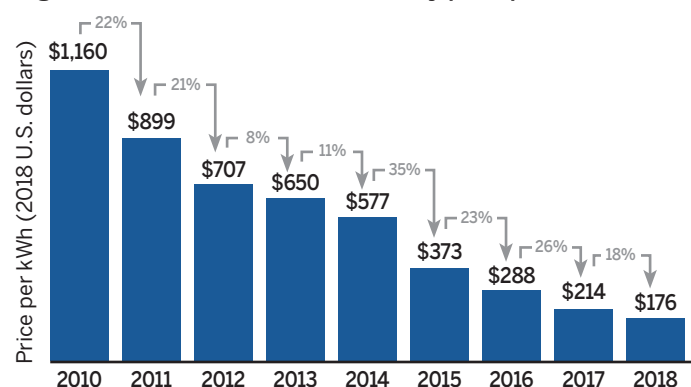
Another option to deliver fast charging without increasing grid costs is to link charging stations with electricity storage. Fast charging stations equipped with batteries, for example, could offer electric charging at any time regardless of peak prices due to the ability to charge the stations' batteries off peak. Battery-based high-power chargers could be used where using existing capacity is not an option. This solution can be used in urban or extra-urban environments. The very sharp decline in the cost of batteries, as shown in Figure 11,¹⁰⁷ makes this combination very attractive in many locations. Having on-site storage means that the charging point operator can forgo the cost of a seldom-used high-capacity grid connection, avoiding both line extension and demand charges.¹⁰⁸ This trend is expected to continue and will likely challenge the ability of DSOs to impose and collect demand charges without triggering on-site shaping of loads to minimise these costs.

Examples suggest that investments into storage-based charging are being made where it is the most cost-effective option. In the U.S. (Hawaii), the charging point firm

Greenlots has equipped one fast charging (high-voltage direct current) station in Honolulu with a battery because the electric infrastructure was not adequate to support fast charging and the cost of expansion was prohibitive.¹⁰⁹ Another example is a 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, without overloading the grid, then replenish themselves from the grid in slower mode while the ferry is not "plugged in."¹¹⁰

These technologies also can be used for depot solutions, in or close to cities, as electric bus technology matures and sales of electric buses grow rapidly. Storage technologies can also support commercial traffic: Drivers of delivery or service fleets, taxis, and the like will have to rely much more on public fast charging infrastructure as the business models rely on optimal use of EVs and a maximum number of kilometres driven per charge.

Figure 11. Downward trend in battery pack prices



Source: BloombergNEF. (2018). *2018 Battery price survey*.

107 BloombergNEF. (2018, 19 December). *Lithium-ion battery price survey results: Volume-weighted average*. Retrieved from <https://www.facebook.com/%20BloombergNEF/videos/our-2018-battery-price-survey-has-found-that-the-volume-weighted-average-price-o/2243145969343197/>. BNEF projects that these costs will continue to decline, estimating prices of \$70 per kWh for lithium-ion batteries by 2030. See Morsey, S. *Electric vehicle outlook: 2018—Global sales outlook*, p. 3. BloombergNEF. Retrieved from <https://bnf.turli.co/story/evo2018>

108 A demand charge is assessed on the basis of metered demand, typically for the highest hour or 15-minute interval during a billing period. Demand charges are usually expressed per watt units—for example, dollars per kW. Demand charges are common for large (and sometimes small) commercial and industrial customers but have not typically been used for residential customers because of the high cost of interval

meters. The widespread deployment of smart meters would enable the use of demand charges for any customer served by those meters. Lazar, J. (2016). *Electricity regulation in the U.S: A guide* (2nd edition). Montpelier, VT: Regulatory Assistance Project. Retrieved from <https://www.raonline.org/knowledge-center/electricity-regulation-in-the-us-a-guide-2/>

109 Greenlots. (2016, 25 February). *Hawaiian Electric & Greenlots test EV charging and energy storage as ideal grid allies*. Retrieved from <https://www.prnewswire.com/news-releases/hawaiian-electric--greenlots-test-ev-charging-and-energy-storage-as-ideal-grid-allies-300225926.html>

110 Paris Process on Mobility and Climate. *Battery electric car ferry in Norway* [Website]. Retrieved from <http://www.ppmc-transport.org/battery-electric-car-ferry-in-norway/>

rural areas.¹¹¹ Grid-based planning approaches can help to avoid investments that don't pay off because they don't meet future needs.

To ensure efficient grid integration, highway charging is best located along existing high-voltage lines, which often run next to motorways. Signaling an effort to make use of existing infrastructure, the UK's transmission system operator National Grid studied 50 optimal locations along highways where sites of fast chargers (up to 350 kW) could be located, allowing 90 percent of UK motorists to reach a charging point within 50 miles.¹¹² The project, with an estimated cost of 1 billion pounds, is also an opportunity to avoid costs for building new infrastructure by linking these locations to the high-voltage grid.

Grid-friendly highway charging will become more relevant with the fast-developing electric trucking sector and electric coaches. In addition to plug-in charging as for smaller vehicles, electric heavy-duty vehicles will come with different charging solutions, such as dynamic electric charging (catenary, on-road, or in-road).¹¹³ Logistical hubs, depots, and parking spaces could be built close to existing infrastructure or by retrofitting abandoned industrial depots with pre-installed infrastructure.

Plan electric vehicle infrastructure based on demand

Public policy plays a crucial role in identifying where EV charging infrastructure could be located and how grid infrastructure should be taken into account. Promising practices from advanced EV markets in Norway, the Netherlands, and California illustrate successful approaches concerning urban siting, financing tools, and building equipment.

Public demand-driven charging infrastructure (Amsterdam)

Amsterdam's demand-driven process of building charging infrastructure has contributed to one of the most ambitious EV charging networks in European cities.¹¹⁴ In this bottom-up approach, EV drivers can request that the municipality install a charging point at a location convenient for them. The public procurer appointed by the city checks whether the user's request can be granted based on criteria such as distance to existing or planned charging points and their occupancy rate, and whether previous requests exist for the same spot. For the installation of a new charging point, the grid operator and city district are consulted, and a grid connection is granted and built as required. The city council adopted this approach in 2009, focusing on charging infrastructure availability to reassure customers while meeting their location needs. It is particularly relevant given the city's low share of off-street parking. From the first public charging point installed in 2009, the city has expanded the network to 3,800 charging points as a result of this policy.¹¹⁵ These have an average occupancy rate of 35 percent (which is high compared with other Dutch cities and other locations in Europe) and use only 20 percent of their connection time for actual charging, which allows for further optimization strategies in terms of grid and street use.¹¹⁶ The demand-based planning approach, seeking to optimise charging infrastructure buildup and use as part of existing transport and energy systems, has been confirmed as an effective means to support early EV market uptake¹¹⁷ and has been replicated in other Dutch cities.¹¹⁸

111 For detailed EU coverage projections and further recommendations, see Transport & Environment. (2018). *Roll-out of public EV charging infrastructure in the EU: Is the chicken and egg dilemma resolved?* Brussels, Belgium: Author. Retrieved from https://www.euractiv.com/wp-content/uploads/sites/2/2018/09/Charging-Infrastructure-Report_September-2018_FINAL.pdf

112 Hanley, S. (2018, 21 February). *National Grid planning fast charging network for UK*. CleanTechnica. Retrieved from <https://cleantechnica.com/2018/02/21/national-grid-planning-fast-charging-network-uk/>

113 Moultak, M., Lutsey, N., and Hall, D. (2017, September). *Transitioning to zero-emission heavy-duty freight vehicles*. Washington, DC: The International Council on Clean Transportation. Retrieved from https://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

114 Fortuna, C. (2018, 21 May). *City policies that can grow electric vehicle adoption*. CleanTechnica. Retrieved from <https://cleantechnica.com/2018/05/21/city-policies-that-can-grow-electric-vehicle-adoption/>. See also Transport & Environment, 2018.

115 Chenadec, J. *Good practice: Amsterdam's demand-driven charging infrastructure*. Interreg Europe. Retrieved from <https://www.interregeurope.eu/policylearning/good-practices/item/1699/amsterdam-s-demand-driven-charging-infrastructure/>

116 Wolbertus, R., van den Hoed, R., and Maase, S. (2016, December). Benchmarking charging infrastructure utilization. *World Electric Vehicle Journal* 8(4), 748-765. Retrieved from https://www.researchgate.net/publication/316561797_Benchmarking_Charging_Infrastructure_Utilization

117 The analysis of more than 1.3 million charging sessions is one of the largest datasets on EV charging currently available. It also finds that, in a more mature EV market, infrastructure planning should be complemented by "strategic" location of charging points near shopping or leisure venues. Amsterdam University of Applied Sciences. (2018, 9 July). *Study reveals optimal charging infrastructure rollout strategy*. Retrieved from <http://www.amsterdamuas.com/content/news/news/2018/07/study-reveals-optimal-charging-infrastructure-rollout-strategy-for-electric-vehicles.html>

118 Wolbertus et al., 2016.

Tools to fund phase-in of commercial fast charging (Norway)

A second example of successful policy support for EVSE development can be found in Norway. There, coherent government policy has actively sought to maximise charging infrastructure utilisation, minimise cost, and phase in a self-sustaining EVSE market while reducing costs of grid integration.

Government support programmes for co-financing publicly accessible fast charging stations along Norway's main roads are limited to installation and do not cover operation costs.¹¹⁹ As a result, all installed fast charging stations today are run commercially. Norway is gradually phasing out public financing for fast charging infrastructure, especially in and around cities as well as along major highways.¹²⁰ At the same time, the number of fast charging stations being installed without public support has been increasing. This suggests that demand is high enough to support a business case for EVSE suppliers. However, phasing in commercial charging in remote rural regions proves more difficult. Despite being offered 100 percent financial support for installation costs, no companies have bid on Enova's fourth call for tenders to build charging stations in the far north of the country.¹²¹ Thus, in order to ensure charging infrastructure in remote areas, there will be continued need for targeted governmental support in these areas. The example also raises the question of how regulated entities should be included in ensuring sufficient charging infrastructure coverage, if no third (commercial) party is interested in investing.

Cost-efficient grid integration of fast charging points was

achieved through making use of an existing policy tool: a Norway-specific grid connection charge that DSOs can claim to cover the costs of connecting new customers to the grid or reinforcing connections for existing customers demanding additional capacity. The one-time charge is paid by the customer that necessitated the investment—for example, the EVSE supplier in the case of fast charging stations.

The grid connection charge can cover up to 100 percent of the necessary investment costs including construction, personnel, and equipment. The necessary investment costs depend on the existing grid infrastructure in a given location. Thus, the charge provides a price signal, reflecting capacity constraints and encouraging customers to consider the investment costs in their decision to connect and demand additional capacity. The price signal intends to influence the decision with respect to location and sizing and the assessment of alternative measures to reduce the final need for grid investments. Thus, the connection charge contributes to a cost-effective expansion of grid infrastructure and, being paid by the customer that prompted the investment, ensures that network tariffs do not increase more than necessary for all other customers.¹²² The charge therefore reflects a demand-based planning tool that also incentivises the use of existing grid infrastructure as a principle for smart infrastructure planning.

Incentives to improve charging facilities at multi-unit dwellings

There is a growing recognition of the need to offer EV charging at multi-unit dwellings, as 41.8 percent of the EU's

119 The first tender was issued for 2010-2014 and since 2015 continued as Enova. The Enova enterprise is owned by the Ministry of Climate and Environment and is responsible for promoting greenhouse gas emissions reductions, developing sustainable energy and climate technology, and strengthening security of supply. The enterprise is financed through government funding and the Enova fee that electricity consumers pay, amounting to 0.01 Norwegian kroner/kWh. For more information, see the Enova website: <https://www.enova.no/>.

120 Although 230 fast charging stations have been covered with up to 100 percent of installation costs until 2016, funding was gradually restricted as infrastructure coverage expanded. Since autumn 2017, only new installations in municipalities with fewer than two installed fast chargers can get investment support, which covers 40 percent of installation costs capped at approximately 20,500 euros. See Enova. (2017, 30 June). *Enova vil hurtiglade distriktene*. Retrieved from <http://presse.enova.no/pressreleases/enova-vil-hurtiglade-distriktene-2036526>

121 According to the Norwegian EV association, this lack of commercial interest occurs because charge point operators, as large electricity

customers, need to pay a capacity charge (per kW) based on used capacity within a certain period and independent of how often the charge point is used in that period, which significantly affects profitability. Norwegian Electric Vehicle Association, personal communication, 11 September 2018.

122 With respect to the installation of fast charging stations, the grid connection charge can vary between around 5,000 and 67,000 euros for the same type of charging station, depending on location. This significant difference illustrates the intended price mechanism of the charge to concentrate new connections where grid investment costs are lowest. The charge furthermore incentivises the utilisation of charging management systems to reduce the total need for additional capacity, as well as the consideration of further alternative measures such as the installation of batteries combined with charging stations. The connection charge has an impact on the profitability of commercial charging stations, which will become even more significant when considering future charging stations providing up to 350 kW. The connection charge is in addition to the monthly capacity charge to be paid by large electricity customers (those using more than 100,000 kWh a year).

population lives in flats.¹²³ Addressing the charging needs of these households in a grid-friendly way will be essential to reduce the cost of EV grid integration as the market evolves. Currently, owners of multi-unit dwellings—who are not likely to be required to provide charging infrastructure through current building codes—lack incentives to equip shared parking for tenants with EV charging facilities as long as there is no additional benefit for them to do so. The recently revised European legal framework for building codes¹²⁴ has the potential to change this, provided Member States implement it in the coming years. (For detailed recommendations, see Chapter 4.)

While uptake of existing incentive programmes in the EU remains slow,¹²⁵ more promising practices can be found in the U.S. in California, where several utilities offer rebates for installing chargers at multi-family housing complexes.¹²⁶ For example, the Sacramento Municipal Utility District offers as much as \$1,500 per charger for up to 20 normal EV charging stations.¹²⁷ Building codes that mandate the installation of a minimum number of charging points, which have also been adopted in several other U.S. jurisdictions, make it difficult for building owners or managers to deny residents' requests to install EV charging stations in their parking spaces without valid reasons.

123 Eurostat. *Housing statistics* [Webpage]. European Union. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php/Housing_statistics#Type_of_dwelling

124 European Parliament and Council of the European Union. Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=EN>

125 For instance, in the UK, fewer than half of households have access to a garage. The UK's Office for Low Emission Vehicles offers city districts co-funding for the construction of charging points; this covers up to 75 percent of installation costs, capped at 7,500 pounds. However, only five local authorities have taken subsidies from the scheme, and only

50 chargers have been built since 2016. See Milligan, B. (2018, 16 February). *Electric cars: What if you live in a flat?* BBC News. Retrieved from <https://www.bbc.com/news/business-42944523>. French government programmes to subsidise charging points found the lowest uptake for residential customers, particularly for collective EV charging. By September 2018, only 23 applications were granted. See Avere-France and EcoC02. *Points de charge finances par Advenir* [Webpage]. Retrieved from <http://advenir.mobi/statistiques/>

126 California Air Resources Board. (2018). *Electric vehicle (EV) charging infrastructure: Multifamily building standards*. Sacramento, CA: Author. Retrieved from <https://arb.ca.gov/cc/greenbuildings/pdf/tcac2018.pdf>

127 Sacramento Municipal Utility District. *Charging forward: Multi-family charging incentive* [Webpage]. Retrieved from <https://www.smutd.org/en/Going-Green/Electric-Vehicles/Business>

Chapter 4

Getting to smart through policy

A comprehensive policy framework for e-mobility complementing current EU legislation will accelerate smart pricing, technology, and infrastructure.

In the previous chapter, we highlighted strategies and practices that can help integrate EVs into the power system in a smart and cost-efficient way while benefitting both the power and transport sectors. Clearly, this is not happening by itself. The implementation of an appropriate set of policies will be critical to accelerating the transition of the two sectors and keeping costs down. In this chapter, we provide policy recommendations for decision-makers focusing on the design of the three dimensions of EV grid integration: smart charging, smart technology, and grid-friendly infrastructure rollout. Together, they can advance the smart integration of EVs in the power sector.

Current policy framework

The policy framework that governs the three dimensions of EV grid integration is set out broadly in European legislation and in further detail in national legislation. Below, we briefly present the most relevant European legislation; more detail is in Appendix C.

The Clean Energy for All Europeans (CE4All) legislative package,¹²⁸ which replaces the Third Energy Package, is currently in the final stages of adoption and is expected to come into force as of 2020. The package sets out the framework for the design and operation of wholesale and retail electricity markets.¹²⁹ It requires the establishment of well-functioning, fast, and close to real-time wholesale markets as the main objective. On the retail side, the European legislation's key objective is the creation of open and competitive markets, where consumers can choose their suppliers and a range of businesses (such as aggregators) can offer services. The package promotes and, depending on conditions, even requires use of dynamic pricing.

The legislative context for rolling out EV charging

infrastructure and the EU's EVSE market consists of several areas of regulation that will require improvement and amendments in order to adequately address current challenges: The current European legal framework covering public EV infrastructure¹³⁰ requires Member States to set up open competition in an emerging market for EV charging services.¹³¹ As a directive, the legislation gives governments some freedom as to how they put this in place—and thus how they define the role of public policy—as well as how they procure both electricity and charging services in charging infrastructure rollout. The EU Commission will evaluate this framework in 2019 and might undertake a review of the legal text. In addition, Member States need to implement minimum infrastructure requirements for buildings and parking as part of the Energy Performance of Buildings Directive, in place since July 2018.¹³²

Policies for smart pricing

The implementation of the CE4All package will create an enhanced framework for smart pricing, and Member States should prioritise its timely implementation. Wholesale electricity prices (in other words, the energy component of a consumer's bill) that are driven by the fundamentals of supply and demand for energy and balancing services will better reflect the value of flexibility (for example, by removing price caps).¹³³ These wholesale energy prices could then be reflected in customers' bills through dynamic pricing contracts.¹³⁴ In addition, the package supports the establishment of dynamic network tariffs and, more broadly, the use of tariff designs that will lead to cost-efficient grid operation and development in the short and long term.

At the same time, more can be done at the national level to support smart pricing and, by extension, the cost-effective

128 European Commission. *Clean energy for all Europeans* [Webpage]. Retrieved from <https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans>

129 The key relevant files are the Electricity Market Regulation, with its main focus on establishing a single wholesale electricity market across Europe with a modern design for a power sector dominated by renewable energy sources, and the Electricity Market Directive, with a key focus on setting the rules for national retail markets. The regulation will apply automatically across all members of the European Union once it comes into force, while the directive will need to be implemented through national legislation.

130 European Parliament and Council of the European Union. Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of the alternative fuels infrastructure. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0094&from=en>

131 The Alternative Fuels Infrastructure Directive (Recital 30) mandates that "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." European Parliament and Council of the European Union, 2014.

132 European Commission. (2018, 19 June). *New Energy Performance in Buildings Directive comes into force on 9 July 2018*. Retrieved from https://ec.europa.eu/info/news/new-energy-performance-buildings-directive-comes-force-9-july-2018-2018-jun-19_en

133 For more information on the benefits of implementing effective price formation in wholesale electricity markets, see Hogan, 2016.

134 More specifically, the legislation establishes the right of suppliers to offer dynamic pricing contracts and of consumers with a smart meter in place to request such a contract from any supplier that has more than 200,000 customers.

integration of EVs. Below, we identify policy recommendations for achieving this objective.

Implement dedicated electric vehicle retail tariffs

Given the low levels of EV penetration across European countries, simple dynamic tariffs—such as day and night tariffs or TOU tariffs with more periods and seasonal differentiation—can already offer significant benefits. Most importantly, EV-dedicated tariffs should follow as closely as possible the associated costs. As the power system continues to transition and variable renewable energy sources become the predominant form of power generation, it will be important that tariffs also evolve to keep pace.

It is important to differentiate between countries with regulated prices and those without.

Member States with regulated prices: A minimum of 11 Member States had some form of price regulation in place as of 2016, with some offering regulated prices in addition to market offers.¹³⁵ In those countries, regulated EV tariffs could be implemented as a transitional measure until an open and competitive retail market is in place.¹³⁶ Regulators could implement this through the supplier of last resort, as is the case in Spain (see Page 44).

Member States without regulated prices: Even in the case of markets where electricity prices are not regulated, there might be a need to establish such tariffs if the markets fail to deliver—for example, due to the lack of competition. Theory suggests that an open, competitive retail market should deliver innovative products that meet consumers' needs (and there is evidence supporting this based on experience from European countries that have had deregulated prices for longer).¹³⁷ However, several retail markets across Europe are not competitive enough, and market power could

Given the low levels of EV penetration across Europe, simple dynamic tariffs can already offer significant benefits.

strangle any attempts to introduce innovative ideas. Recent data demonstrate that the majority of national markets in Europe exhibit a high concentration of suppliers in the retail market.¹³⁸ If the market fails to provide such solutions, then it would be prudent for regulators to introduce smart, EV-dedicated tariffs and, more broadly, tariffs for new highly controllable loads (this might be possible to be implemented through the supplier of last resort). Such a solution should be applied as a transitional measure while, in parallel, focusing on removing any obstacles to the creation of an open and competitive retail market.

Require time-varying network tariffs

Although dynamic energy prices are important, they send signals only about the cost of electricity production and not about the state of the network.¹³⁹ Network tariffs should send the right signals to consumers about the use of the network. 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 (see, for example, the BGE tariff in Chapter 3 and the Denmark tariffs in Appendix A).¹⁴⁰ This will help to ensure that these new technologies make the best use of existing networks and hence minimise the need for investment in new infrastructure. Critical peak pricing is also a suitable option, especially where smart technology is available. In the longer term, there might be potential for introducing tariffs closer to real-time pricing. On the other hand, fixed charges, including capacity-based charges, should be avoided.¹⁴¹

135 Council of European Energy Regulators. (2017). *Retail markets monitoring report*. Brussels, Belgium: Author. Retrieved from <https://www.ceer.eu/documents/104400/-/-/56216063-66c8-0469-7aa0-9f321b196f9f>

136 When regulated EV tariffs are implemented in conjunction with an open market, they should not be subsidised. They should reflect actual costs, so that they don't suppress competition in the open market.

137 European Commission, 2019b.

138 Only five out of 21 national markets exhibited low concentration levels in 2016. See Council of European Energy Regulators, 2017.

139 This is demonstrated in Norway (see Page 14), where consumers mainly see a flat volumetric charge for the use of the network. Despite the widespread provision of dynamic contracts for the energy component,

the final prices seen by consumers do not incentivise the charging of EVs during beneficial times for the network, as the energy prices vary little across the day.

140 Network tariffs can be defined per DSO area. One of the key questions for further investigation is how granular network tariffs should be in terms of location. For example, could network tariffs be defined at the local feeder level?

141 Fixed charges—whereby a consumer pays a fixed fee per year or month independent of when they use the network—and capacity-based charges—whereby a consumer pays for the use of the grid based on the size of the connection to the grid—do not reflect the costs a consumer imposes on the grid. Such charges don't encourage smart EV charging, because they do not send time-specific pricing signals based on the costs for the delivery of the service to consumers. For more information on the current state of network charges and recommendations for the design of smart network tariffs, see Kolokathis et al., 2018.

National regulators should mandate that network companies implement time-varying network tariffs for EVs and other controllable loads, such as heat pumps.¹⁴² These tariffs should extend beyond households to, for example, charging at multi-family and commercial sites and fast charging stations. In addition, regulators and network companies should develop a monitoring framework for assessing the impact of the tariffs on charging behaviour and grid utilisation.

Last resort: Active charging control by system operators

A less preferable solution to dynamic prices is the option to allow active control of EV charging by system operators. This would give them the right to control and shift EV charging if safe operation of the grid and reliable delivery of electricity to consumers are at stake. This is an inferior solution, as it doesn't incentivise the type of flexible consumer behaviour that is essential for a low-cost, low-emissions power system.¹⁴³ On the other hand, it could be a cautious temporary solution while time-varying network tariffs are being put in place and demand-side flexibility more broadly develops. Where regulators decide to implement this option by granting the right to network companies, EV owners should be remunerated for granting control of their EV charging to system operators (see the example from Germany in the box on Page 23).

Monitor retail markets and EV grid integration

Policymakers and regulators should establish a mechanism to monitor market trends and determine whether these are aligned with the need for smart integration of EVs. While the power and transport systems transition, it is important to understand what is and isn't working. We recommend

that, as a minimum, this includes an assessment of:

- New tariffs designed for EVs (and more broadly for new flexible loads);
- Grid utilisation rates and the impact of network tariffs on charging behaviour;
- Whether suppliers are providing the necessary information to consumers;
- Whether consumers are aware of the opportunities and risks new tariffs provide;
- Whether consumers receive remuneration if system operators actively control their charging; and
- More broadly, which approaches work and which do not deliver.

Policies for smart technology

In the previous chapter, we demonstrated that smart technology, such as automated charging that can be operated in response to price or other signals, is needed to achieve the maximum benefits of EV integration for the power system. This means that the charging technology put in place now and in the years to come must have smart functionality built into it (or an alternative should be available), even if it is not used immediately.¹⁴⁴

Mandate technology supporting dynamic pricing

As mentioned above, EV charging should be subject to time-varying prices that reflect as closely as possible the underlying costs for energy and network usage. It is therefore important that technology is in place to enable suppliers and other parties to offer such tariffs (e.g., technology that can measure the electricity consumption of an EV in the relevant time intervals and communicate it to the consumer or other parties).

142 The methodology used to determine these tariffs should as a minimum be approved by the regulators.

143 It would be important to ensure that system operators are using the active control option only if a real problem occurs and that they do not abuse their authority for their own benefit (i.e., to minimise the costs of running the system). Another disadvantage of this option is that it effectively predetermines the value of the flexibility EVs provide to the system, which could be lower or higher than the actual value.

144 Another fundamental condition for a functioning market for EV charging—one we have not addressed in detail in this paper—is interoperability among EV charging services. The lack of

interoperability is a widely recognised barrier. Addressing it is key to building a common e-mobility market in Europe—that is, enabling EVs to use charging services from different providers. The European Commission has undertaken efforts to establish interoperability within the European EV industry by developing a memorandum of understanding, but further efforts are needed. European Commission, Sub-group to Foster the Creation of an Electromobility Market of Services. (2017). *Memorandum of understanding (MoU) fostering seamless and valuable EV customer experience in Europe*. Brussels, Belgium: Author. Retrieved from <http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetailDoc&id=36206&no=2>

National legislation should make compulsory the use of technology that enables dynamic tariffs. Currently, several Member States lack this type of legislation, and smart technology is not commonly in place. In other words, EVs are connected to chargers that do not have any measurement or communication capabilities. In addition, legislation could support the deployment of automation technology to support smart charging.

One way of achieving this is to simply mandate that all new EV charging environments include this type of smart functionality.¹⁴⁵ A good example of such a mandate can be found in the UK, where a law explicitly grants policymakers the power to specify technical requirements for new charge points (see the box on this page).

Policies to develop smart infrastructure

The guidelines below summarise lessons from current practices in EV charging infrastructure buildup and grid integration to:

- Inform Member States, regions, and cities currently planning and building EV charging infrastructure;
- Inform EU decision-makers and stakeholders improving future guidelines, such as a reviewed Alternative Fuels Infrastructure Directive, and help Member States design national implementation of EU building codes; and
- Build on lessons from today's practices to optimise smart charging infrastructure for tomorrow's markets.

Mandating smart functionality of charge points (United Kingdom)

Smart charging is essential for integrating EVs in the UK. Thirty-two percent of low-voltage feeders (310,000) in the UK will require intervention when EV penetration ranges from 40 to 70 percent.¹⁴⁶ At the highest EV penetration levels, smart charging infrastructure can provide an additional buffer below thermal capacity limits, significantly delaying or removing the need for further expensive reinforcement.¹⁴⁷

The UK took a major step in this direction when the Automated and Electric Vehicles Act passed through Parliament in 2018. The act grants the government the authority to introduce regulations prohibiting the sale or installation of charge points in the UK unless they can meet certain statutory requirements. Those requirements can relate to the smart functionality of the charge point and can include provisions about the ability of the charge point to:

- Send and receive electronic communications to and from a third party;
- React to the information sent or received from the third party and adjust the charge point's charging (or discharging) rate;
- Monitor and record the charge point's own energy usage;
- Work toward energy efficiency standards; and
- Require any protocols to be open.

This measure was included from the outset of the bill and has been deemed essential in making sure that the UK's energy system can cope with the expected uptake of EVs over the coming decades. National Grid's most recent Future Energy Scenarios report suggested that smart charging would enable 11 million EVs to take to UK roads by 2030, with limited impact on the grid.¹⁴⁸

145 This type of smart technology could reside in the charging point, the EV, or the cable connecting it to the charger.

146 EA Technology. (2016). *My electric avenue*. Capenhurst, England: Author. Retrieved from <http://myelectricavenue.info/sites/default/files/documents/Summary%20report.pdf>

147 ICF Consulting Services. (2016). *Overview of the electric vehicle market and the potential of charge points for demand response*. London, England: Author. Retrieved from https://www.nve.no/Media/4053/icf_uk_overview-of-the-electric-vehicle-market_160316.pdf

148 National Grid. (2018). *Future energy scenarios: System operator*. London, England: Author. Retrieved from <http://fes.nationalgrid.com/media/1363/fes-interactive-version-final.pdf>

Make best use of existing grid and transport infrastructure

EVSE builders should be required to use, where possible, existing network assets (e.g., transformer or network line capacity) and existing public transport or street infrastructure¹⁴⁹ to maximise efficiency gains and avoid additional infrastructure costs. As the examples in this paper suggest, this can include:

- Encouraging “park and charge” solutions for EVs that use existing infrastructure (e.g., light poles, telecommunication distribution) but also exploring further synergies with existing electrified public transport lines;
- Mandating that transmission system operators study how existing capacity and high-voltage grids can be used to supply high-powered fast chargers in cities and along highways;
- Locating charging infrastructure where spare network capacity exists and at charging locations that meet demand for driving and parking vehicles¹⁵⁰ and ensuring demand-driven infrastructure rollout reflects different local characteristics, as different use cases require different types of charging;
- Ensuring that the EU cities’ sustainable urban mobility planning tool¹⁵¹ facilitates the building of electric transport infrastructure based on joint transport and energy planning, with a view to most beneficially integrating mobility and grid requirements;
- Linking public funding for EV charging infrastructure to future demand and seeking to phase in commercial operation; and
- Building a commercial EVSE market while ensuring accessibility for different groups of commercial or private EV users. To future-proof investments, policymakers need to strike a balance between the need for competition among market solutions and the objective of

guaranteeing accessible cross-border electric mobility for drivers. This also means carefully evaluating the need for public fast charging in view of expected growth, normal charging coverage at home and work, and infrastructure built on “semi-private” ground, such as supermarkets, sports facilities, and the like. The review of examples suggests that:

- Public entities, such as municipalities, should base the buildup of EV charging infrastructure on existing demand and facilitate a procedure to collect demand requests from citizens.
- Public authorities should aim at simplifying permit procedures for the installation of charging infrastructure for all use cases.
- Public authorities should research, document, and publish detailed data on utilisation of public charging points to allow improvement in the utilisation and commercial operation of charging infrastructure and to ensure network expansion to meet demand. This is particularly important as reliable data on charging infrastructure are often missing.
- Governments should ensure that funding for EV infrastructure includes a gradual phase-in of commercial operations—for example, through an annual reduction of the share of public support. Exceptions for areas with low population density can be considered.
- Financial incentives for EV charging infrastructure developers, such as waiving a connection charge (see the Norway example on Page 31), further encourage EVSE suppliers to use existing grid infrastructure. The tool seems to be effective in early markets, in particular, but may need to be revised for more mature markets.

149 The term “street infrastructure” refers to light poles, bollards, pillars, and other structures installed on the street to designate and limit parking spaces, some of which already contain some electrical infrastructure.

150 To achieve the maximum reductions of emissions in transportation, electrification of road transport must be accompanied by a suite of other, interrelated policies that will reduce traffic generally. Among other things, governments should consider EV charging solutions that discourage increased use of private cars, particularly private passenger

cars carrying only one person. For example, parking regulations can give priority to electric vehicles over non-electric and to shared vehicles over private ones. Insofar as the circumstances and needs of cities vary and innovation will be a key to addressing these challenges, it makes sense to empower municipalities to plan and incentivise these and related traffic reduction measures to enhance clean city transport.

151 European Commission. *Sustainable urban mobility plans* [Webpage]. Retrieved from https://ec.europa.eu/transport/themes/urban/urban_mobility/urban_mobility_actions/sump_en

Set ambitious targets for public charging infrastructure

The spread of public EV infrastructure is very heterogeneous across the EU and will need to meet the requirements of a growing EV market in the next decade to allow beneficial integration of EVs. Member States could benefit from more clearly defined, appropriate, and ambitious target requirements in legislative frameworks, to accelerate public EV charging infrastructure rollout. For example:

- It is important to set minimum requirements for public EV infrastructure coverage with a differentiated set of criteria reflecting main market segments and vehicle types. Indicators could include the setting (urban or rural), level of charging power required, existing grid and mobility infrastructure, and potential to integrate renewable energy.
- Binding minimum requirements for public EV infrastructure density should be set in all Member States.
- Implementing EU-wide interoperability requirements is also crucial.

Ambitiously implement building codes to increase charging points

One of the main challenges that needs addressing is the deployment of incentives to enable access to e-mobility for residents of multi-family dwellings. Workplace charging should also be facilitated by equipping non-residential parking with charging stations, thus encouraging companies to offer employees the chance to park and charge EVs during working hours. Member States can address the current lack of charging points in buildings and parking by ambitiously implementing the recently revised Energy Performance of Buildings Directive and going beyond the legal minimum standards. Examples include:

- Providing “make-ready” ducting infrastructure in parking spaces at residential and non-residential buildings;
- Implementing tenants’ and owners’ “right to charge” by allowing owners of parking spaces in residential

Regulatory frameworks need to specify under what circumstances regulated entities are allowed to operate charging points.

buildings to install a smart charging point, or by granting additional incentive programmes for landlords to set up EV charging in buildings;

- Setting ambitious requirements for the numbers of smart charging points required in newly constructed or substantially refurbished residential and non-residential buildings as soon as possible in the context of the directive; and
- Setting high minimum requirements for equipping existing buildings with EV charging points.¹⁵²

Regulate who can operate charging infrastructure

As the practices we have reviewed show, the emerging market for EVSE services is likely to lead to a shift of traditional market roles between incumbents such as energy suppliers, DSOs, and traditional carmakers on the one hand, and many startups offering innovative EVSE solutions based on smart technology on the other. In view of this development, regulatory frameworks need to specify under what circumstances regulated entities are allowed to operate charging points. Reviewed practices suggest that this should be assigned to third parties. However, should no third party show interest, exceptions can be allowed for DSOs to operate charging points.

Some governments have granted DSOs a partial right to build and operate EV charging points. In Spain, DSO Iberdrola argued that third-party interest was missing and that, to offer EV charging, DSO involvement was needed. A royal decree was passed in October 2018 to allow this as a last-resort option under certain conditions, such as lack of private interest after a competitive tender, and to require review once there is private interest.¹⁵³ The EU’s reviewed

152 Member States have some discretion in choosing their level of ambition for existing buildings with more than 20 parking spaces, as the minimum requirements of pre-cabling and charging infrastructure are to be decided by each Member State. This applies only as of 1 January 2025.

153 Boletín Oficial del Estado [Official State Gazette, Spain]. (2018, 6 October). N242: Real Decreto-ley 15/2018, de 5 de octubre, de medidas urgentes para la transición energética y la protección de los consumidores [Nr. 242: Royal Decree-Law 15/2018, of 5 October, on urgent measures for the energy transition and consumer protection]. Retrieved from <https://www.boe.es/boe/dias/2018/10/06/pdfs/BOE-A-2018-13593.pdf>

electricity market design rules have adopted a similar guidance and stipulate that DSOs cannot own or operate EV recharging points, unless the market can't deliver.¹⁵⁴ Experience from California has also shown that the early market for EV charging services did not evolve with third-party actors alone. In reaction to a lack of investments by EVSE companies, regulation was revised to allow DSOs to offer charging services if it can be demonstrated that no other commercial actor is offering this service. The regulation draws on the DSO's responsibility as a provider of a public good.¹⁵⁵

Anticipate charging infrastructure for electric trucks and buses

As the market for electric trucks and buses develops, solutions for electric logistics will emerge and could be helped by policymakers. For example, it could be useful to anticipate and try grid-friendly charging solutions for electric heavy-duty vehicles. These programmes might include reusing former industrial depots that have grid connections and those close to cities, perhaps for deliveries into the city. Recently suggested legislation on setting mandatory break times for drivers¹⁵⁶ provides some indication of potential charging times for electric heavy-duty traffic along highways and could influence developing business models.

Ensure charging infrastructure increases renewable energy use

Optimal use of existing power network capacities also means locating EV infrastructure so that renewable energy can be the primary resource for charging EVs. To fully reap EVs' potential to help integrate renewable energy production and use, more recommendations can be made that reach beyond the examples reviewed to inspire future promising practices.

- EV charging infrastructure should be coupled with energy efficiency policies and seek to generate additional efficiency gains—for example, by ensuring more efficient shared use of electrified devices and therefore reducing energy consumption overall.
- Developing and piloting use cases for battery-based fast charging could provide grid flexibility and renewables integration.
- Programmes could prioritise and incentivise renewable energy as the primary source for EV charging. For example, they could reward charging points powered with renewable energy—such as via on-site generation—or incentivise smart charging applications that help absorb surplus renewable generation.

Real-world examples of smart, grid-friendly EV charging infrastructure analysed in this paper suggest that the often-cited “chicken and egg” problem can be replaced by a “virtuous circle”—that is, a chain of mutually reinforcing benefits for electricity consumers and transport users, the environment, and the energy transition overall.

154 Council of the European Union. (2017, 15 September). Proposal for a directive of the European Parliament and of the Council on common rules for an internal market in electricity (recast). (No. 10691/17). Retrieved from <http://data.consilium.europa.eu/doc/document/ST-10691-2017-INIT/en/pdf>

155 Melton, M. (2016, 6 April). *Utility involvement in electric vehicle charging infrastructure: California at the vanguard*. Washington, DC: Center for Strategic & International Studies. Retrieved from <https://www.csis.org/>

analysis/utility-involvement-electric-vehicle-charging-infrastructure-california-vanguard

156 European Commission. (2017). Proposal for a regulation of the European Parliament and of the Council amending Regulation (EC) No. 561/2006 as regards on minimum requirements on maximum daily and weekly driving times, minimum breaks, and daily and weekly rest periods. Retrieved from <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52017PC0277>

Chapter 5

Conclusions

Integrating EVs into the grid cost-effectively is key to the goal of decarbonising the power and transport sectors concurrently to benefit consumers and the environment.

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 takeup 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.

1. Smarter electricity tariffs encourage more cost-effective EV charging with wider benefits for all electricity users.

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 CE4All package will create an enhanced framework for smart pricing, 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 customers’ 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 non-responsive 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 likely will 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.

The key condition for mass-market takeup is to integrate EVs into the grid cost-effectively to benefit consumers, the power sector, and the environment.

2. 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 enable smart charging.

3. 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 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 with 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, questions around taxation of EV use will arise in different areas.

EV grid integration helps transport and energy decarbonise and supports the EU in reaching its climate goals. European legislators have recently decided to modernise and to promote flexibility in European electricity markets as well as to stimulate the supply of EVs through setting a sales benchmark for manufacturers, accelerating charging

infrastructure rollout, and incentivising EV procurement. These and other related initiatives are important building blocks for a policy framework for EV market transformation. But they need to be part of a holistic, coherent policy approach including decision-makers, companies, and societal stakeholders from transport, energy, and related sectors. Without this joint effort, the market transformation risks stagnating, producing unnecessary costs for drivers, electricity consumers, and the public sector. It also may miss out on delivering the urgent carbon dioxide emissions and air pollution cuts needed in transport—the only sector where carbon emissions, despite existing efforts, keep growing. 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.

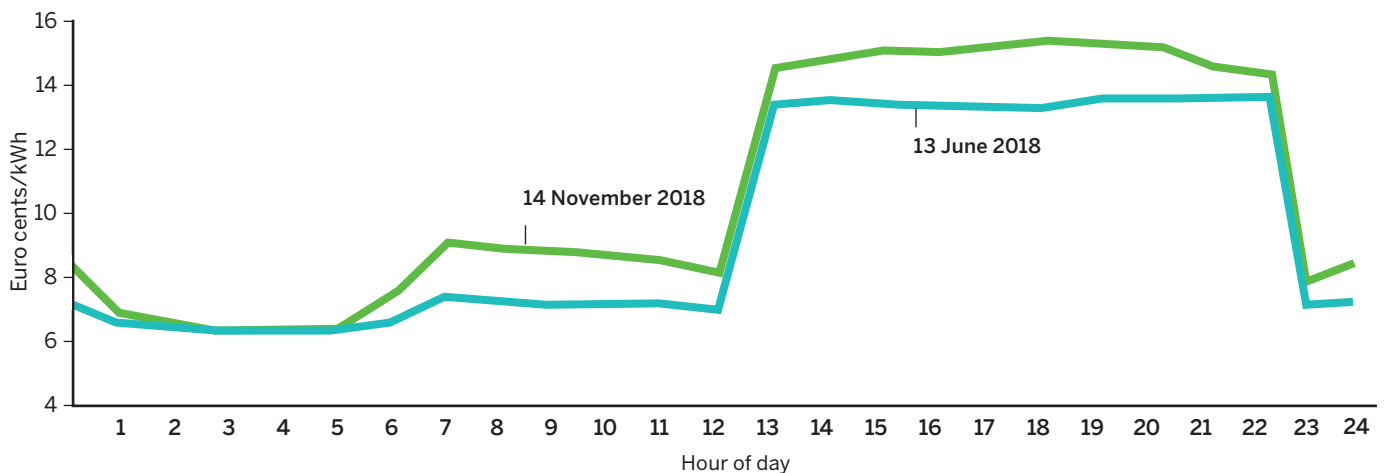
Appendix A: Additional examples of smart pricing

Regulated time-of-use electric vehicle tariff (Spain)

Similar to other European countries, Spain has in place a supply of last resort.¹⁵⁷ A supply of last resort is normally established by the government, and the supplier commonly sets the tariff. This is sometimes based on a predefined framework and may be subject to approval by the national regulator. In Spain, the Ministry of Industry, Energy, and Tourism sets the methodology for determining the energy component of the tariff. Three different contracts are available to consumers, one dedicated to electric vehicles

(EVs).¹⁵⁸ The regulated EV tariff resembles a two-period time-of-use (TOU) tariff, although it is more granular. The hourly prices are linked to wholesale prices and can fluctuate from day to day and hour to hour. Figure 12 illustrates the hourly prices for two random days in 2018, one in summer and the other in early winter.¹⁵⁹ The figure shows that the consumer pays a higher price during the higher-demand periods (on-peak hours) between 1 and 10 p.m. and a lower charge for the rest of the day (off-peak hours). The on-peak price was nearly twice the off-peak charge for these two days.

Figure 12. Hourly prices for regulated electric vehicle tariff in Spain



Source: Red Eléctrica de España. *Active energy invoicing price*.

157 Under Article 27 of the Electricity Directive, European legislation stipulates that Member States have the right to appoint a supplier of last resort to ensure universal service for household consumers and small enterprises. The directive also stipulates that Member States must obligate distribution system operators to connect consumers to their networks. See European Commission. *Clean energy for all Europeans* [Webpage]. Retrieved from <https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans>. According to the market monitoring report from the Agency for the Cooperation of Energy Regulators and Council of European Energy Regulators, the bulk of Member States have assigned a supplier of last resort. The most common functions of the supplier of last resort are protecting consumers with payment difficulties, protecting inactive consumers, and replacing failing suppliers and distribution system operators. See Agency for the Cooperation of Energy Regulators and Council of European Energy Regulators. (2018). *Annual report on the results of monitoring the internal electricity and natural gas markets*

in 2017—Consumer empowerment volume. Ljubljana, Slovenia, and Brussels, Belgium: Authors. Retrieved from https://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/MMR%202017%20-%20CONSUMER%20PROTECTION.pdf

158 Boletín Oficial del Estado [Official State Gazette, Spain]. (2014, 29 March). N77: Real Decreto 216/2014, de 28 de marzo, por el que se establece la metodología de cálculo de los precios voluntarios para el pequeño consumidor de energía eléctrica y su régimen jurídico de contratación [Nr 77: Royal Decree 216/2014, of 28 March, establishing the methodology for calculating voluntary prices for the small electricity consumer and the legal framework for contracting]. Retrieved from <https://www.boe.es/boe/dias/2014/03/29/pdfs/BOE-A-2014-3376.pdf>

159 Red Eléctrica de España. *Active energy invoicing price* [Webpage]. Retrieved from <https://www.esios.ree.es/en/pvpc?date=09-04-2019>

Two-period residential TOU electric vehicle tariff (Minnesota)

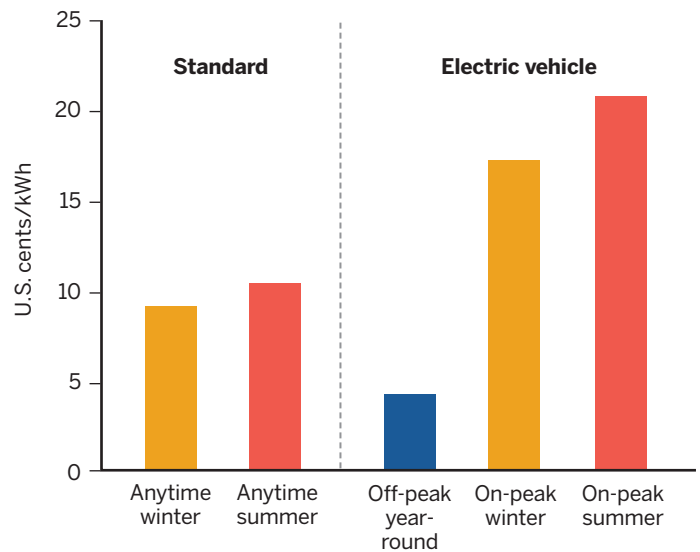
Xcel Energy offers a residential EV tariff in Minnesota for both energy and network charges, which features lower volumetric rates for EV charging during off-peak hours.^{160, 161} Figure 13 shows the standard and EV rates.¹⁶² The standard rate is a flat charge in each of two seasons: summer and winter. The summer charge is higher, as the utility experiences greater demand during summer and therefore higher costs for serving it. For the dedicated EV rate, the utility breaks down pricing into on-peak and off-peak charges. The off-peak charge is uniform across the year, while the on-peak charge differs between summer and winter (and is also higher during the summer for the reasons explained above). At 0.04 U.S. dollars (or 0.36 euros) per kilowatt-hour (kWh), the off-peak charge is about one-quarter of the winter on-peak charge of 0.17 U.S. dollars/kWh (0.15 euros/kWh) and close to one-fifth of the summer on-peak charge, which is 0.21 U.S. dollars/kWh (0.19 euros/kWh). Riders and additional charges add about 0.03 U.S. dollars to these rates.

The utility has monitored charging behaviour over the two years since implementing the tariff, and the results demonstrate that the bulk of EV charging has shifted to off-peak hours. More specifically, the share of charging during off-peak hours has ranged from 90 to 95 percent on a monthly basis and averaged 92 percent over the two-year period.¹⁶³

Volumetric TOU network tariffs (Denmark)

Radius, a distribution system operator (DSO) in Denmark serving about a million customers in Copenhagen and parts of the Zealand area, recently has widely

Figure 13. Standard and EV tariffs for Xcel Energy residential customers



These rates do not include riders, fuel adjustments, etc., which add approximately 3 cents per kWh.

Source: Xcel Energy. (2018, 1 June). Compliance filing, residential electric vehicle charging tariff.

implemented TOU network tariffs to recover the bulk of their costs.¹⁶⁴ The tariffs aim at shifting demand away from the winter peak season, which effectively dictates the size of the grid required. By shifting demand away from these hours, the DSO can avoid or limit expensive grid reinforcements.

The TOU tariffs apply to consumers with smart meters who are connected to the low-voltage and parts of the medium-voltage network.¹⁶⁵ The network charges consist of two elements: a fixed subscription charge and a volumetric TOU charge. For households, the fixed charge is 25 Danish kroner per month (or around 3 euros per month). The volumetric TOU charge is divided into peak and off-peak periods and two seasons: winter (October through March)

160 Minnesota legislation requires utilities operating in the state to offer EV-specific tariffs with discounts for off-peak EV charging. Minnesota Legislature. (2018). 2018 Minnesota Statutes: Electric Vehicle Charging Tariff (216B.1614). Retrieved from <https://www.revisor.mn.gov/statutes/cite/216B.1614>

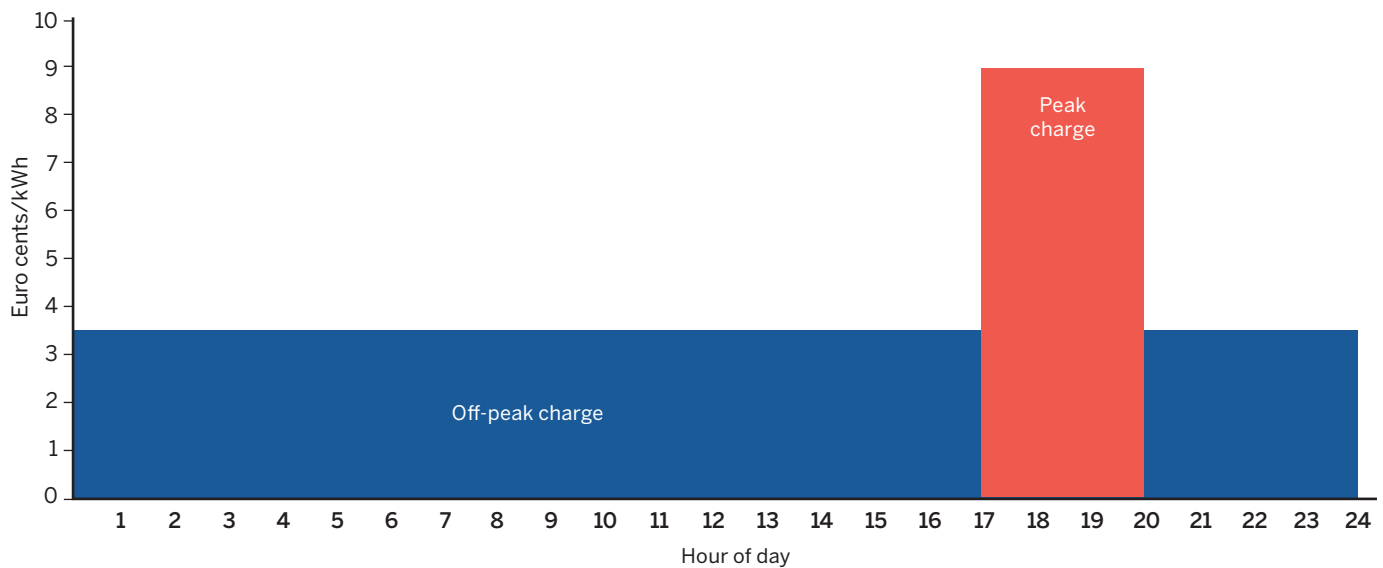
161 M.J. Bradley & Associates. (2018). *Electric vehicle cost-benefit analysis: Plug-in electric vehicle cost-benefit analysis: Minnesota*. Concord, MA: Author. Retrieved from: <https://www.mjbradley.com/sites/default/files/MN%20PEV%20CB%20Analysis%20FINAL%2015aug18.pdf>

162 Xcel Energy. (2018, 1 June). Compliance filing, residential electric vehicle charging tariff, Docket No. E002/M-15-111. Retrieved from <https://www.edockets.state.mn.us/EFiling/edockets/searchDocuments.do?method=showPoup&documentId={60A5CA63-0000-C11E-9F24-C36F15592A04}&documentTitle=20186-143541-01>

163 Xcel Energy, 2018.

164 For several years, Radius has offered TOU tariffs for industrial customers with consumption above 100,000 kWhs. TOU tariffs for households and other non-industrial consumers have been offered since the rollout of smart meters that enable such tariffs. For more information, see Radius. *Tariffer og netabonnement* [Tariffs and network subscriptions] [Webpage]. Retrieved from <https://radiusnet.dk/Elkunder/Priser-og-vilkaar/Tariffer-og-netabonnement>

165 For consumers without a smart meter (applicable only at the low-voltage level), different tariffs apply. These are outside the scope of this example.

Figure 14. Winter time-of-use tariff for Radius customer households

Source: Based on Radius. *Tariffer og netabonnement* [Tariffs and network subscriptions].

and summer (April through September).¹⁶⁶ The peak period is in effect only during winter between 5 and 8 p.m., as shown in Figure 14.¹⁶⁷

Three-period TOU tariff (California)

The Sacramento Municipal Utility District introduced a voluntary TOU tariff for EV owners in recent years.¹⁶⁸ The original goal was to contain demand during the summer peak hours, when the utility needed to bring expensive generation online for only a short period to deal with load increase. The three-period TOU tariff better reflects the underlying costs for the production and delivery of electricity compared with a two-period tariff. It is therefore considered preferable, especially for places with demand characterised by sharp peaks.

The utility divided the day into three periods, as depicted in Figure 15 on the next page.¹⁶⁹ The peak period

lasts from 5 to 8 p.m., when the costs for serving consumers are highest.¹⁷⁰ The mid-peak period flanks the peak period, lasting from noon to 5 p.m. and from 8 p.m. to midnight. The off-peak period covers the rest of the day, from midnight to noon, giving customers significant flexibility to choose when to charge their EVs. The retail price (energy and network cost) for consumers varies from 0.28 U.S. dollars/kWh (or around 0.25 euros/kWh) for the peak period to 0.12 U.S. dollars/kWh (approximately 0.11 euros/kWh) for the off-peak period. EV owners enjoy a rate of 0.10 U.S. dollars/kWh (around 0.09 euros/kWh) from midnight to 6 a.m. The off-peak rate represents a discount of around 60 percent relative to the peak period, while the mid-peak rate is around 40 percent lower than the peak period charge.

Before introducing the tariff, the utility ran a pilot project to test it. The pilot achieved peak demand reductions as high as 13 percent in the first year. The shift represents

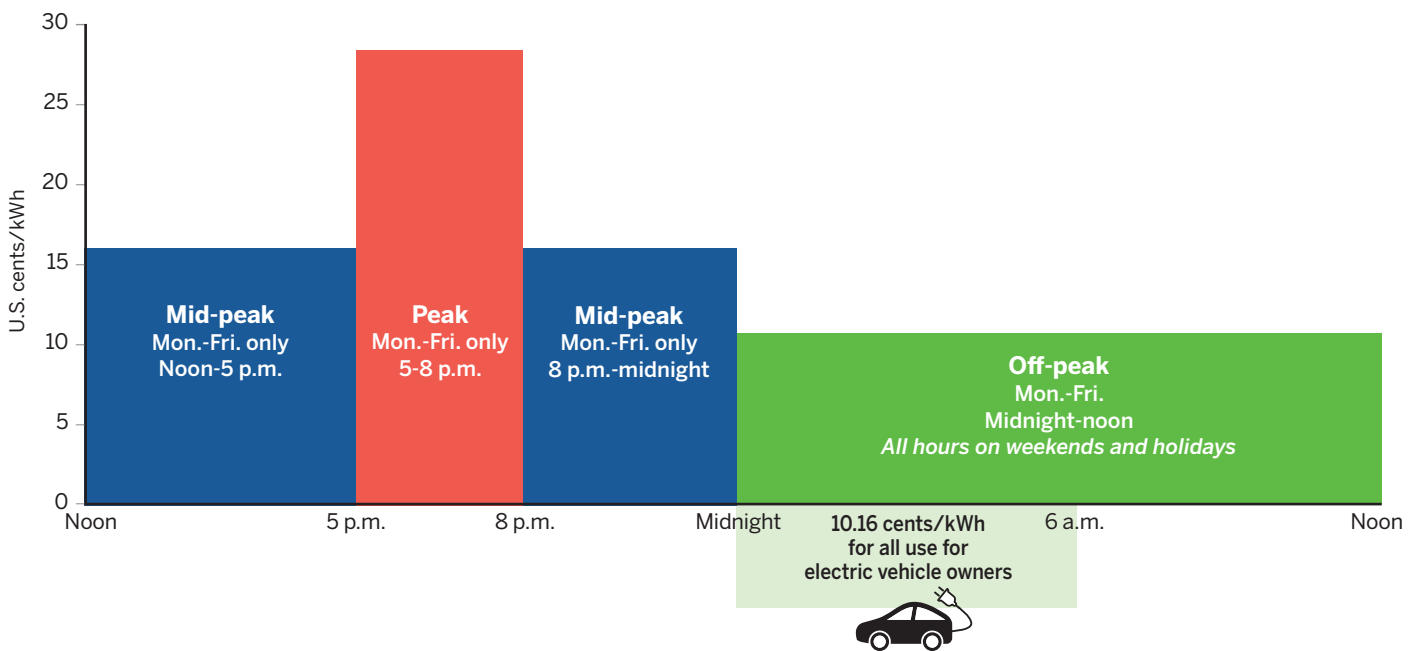
166 For consumers who are connected to any level higher than 240 volts, the TOU element of the tariff consists of three periods: low, high, and peak. The peak period is applicable only in winter and lasts from 7 a.m. to 8 p.m. The low winter period, by contrast, is in effect from midnight to 6 a.m. Different charges apply for consumers, depending on the voltage level at which they are connected. For example, for consumers connected to 400 volts, the peak charge is 0.206 Danish kroner/kWh (or around 0.028 euros/kWh), the high charge is 0.138 kroner/kWh (or around 0.018 euros/kWh), and the low period charge is 0.073 kroner/kWh (or around 0.01 euros/kWh).

167 Radius. *Tariffer og netabonnement* [Tariffs and network subscriptions].

168 The Sacramento Municipal Utility District's TOU tariff is now the standard, mandatory tariff for all residential consumers as of 2019. For more information, see <https://www.smud.org/>.

169 Sacramento Municipal Utility District. *Get to know our time-of-day rates* [Webpage]. Retrieved from <https://www.smud.org/en/Rate-Information/Time-of-Day-Rates/Time-of-Day-5-8pm-Rate>

170 The utility gave EV owners the option to choose their peak period from two ranges: 4 to 7 p.m. and 5 to 8 p.m. The utility's goal was to shift load away from the high-demand hours for the period from 4 to 8 p.m. For customers who choose the 4 to 7 p.m. peak, the mid-peak period is noon to 4 p.m. and 7 p.m. to midnight. For simplicity, we focus on the 5 to 8 p.m. peak period.

Figure 15. Sacramento Municipal Utility District summer residential time-of-use tariff

Source: Sacramento Municipal Utility District. *Get to know our time-of-day rates.*

the entire household consumption, not just EV charging.¹⁷¹ Customer satisfaction with the pricing ranged from 80 percent for those with the default rate to 87 percent for those with the time-varying rates.¹⁷²

TOU tariffs for shared and fast charging stations (California)

Previous examples have focused mainly on tariff designs for home charging or slow charging at the workplace. The tariffs for fast charging stations and for multi-family, commercial, and industrial sites resemble those for commercial and industrial customers, mainly because the chargers draw higher volumes of power instantaneously from the grid. These customers normally pay a volumetric and a demand charge. The latter is dependent on the customer's highest demand during a predetermined period, normally a month or a year, assuming that their

profile is generally relatively stable over the course of the day. The fixed charge often represents the bulk of their electricity bill, giving these customers little incentive to shift consumption.¹⁷³

This type of charging station does not have a stable load profile, especially at low levels of EV penetration. As the deployment of EVs grows, a more stable load profile is expected to become the norm. Currently, high demand charges are spread across a small number of EV customers, meaning high costs for those who use the stations. These high charges to consumers could be a significant obstacle to the use of this type of charging station and could make the business case for fast charging points unfavourable, at least until sufficient EVs are on the road.

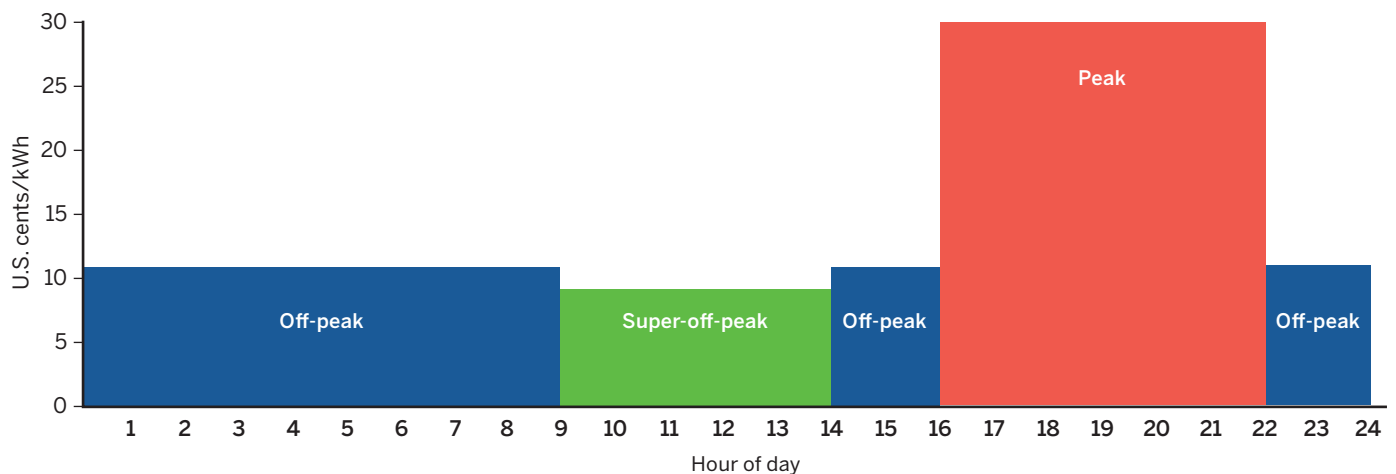
Recognising these concerns, two California utilities, Southern California Edison and Pacific Gas & Electric Co. (PG&E), are planning to implement alternative tariff designs

171 The utility tested the tariff for two different focus groups: one that opted in and another that was assigned the tariff but could opt out. Both focus groups shifted demand during peak hours, but consumers who opted into the tariff reduced peak demand about twice as much as consumers who were assigned the tariff. In addition, analysis of the impacts of the tariff shows that consumers with in-home displays achieved greater demand reductions than consumers without. Parks, J. (2016). *Preparing for the utility of the future*. Washington, DC: American Council for an Energy-Efficient Economy. Retrieved from https://aceee.org/files/proceedings/2016/data/papers/6_823.pdf

172 Among customers told they would be put on TOU pricing, no more

than 8 percent opted out of the pilot before it began. In contrast, the utility had anticipated an acceptance rate of 50 percent. Potter, J., George, S., and Jimenez, L. (2014, 5 September). *SmartPricing Options Final Evaluation*. Sacramento, CA: Sacramento Municipal Utility District. Retrieved from https://www.smartgrid.gov/files/SMUD_SmartPricingOptionPilotEvaluationFinalCombo11_5_2014.pdf

173 Kolokathis, C., Hogan, M., and Jahn, A. (2018). *Cleaner, smarter, cheaper: Network tariff design for a smart future*. Brussels, Belgium: Regulatory Assistance Project. Retrieved from <https://www.raponline.org/knowledge-center/cleaner-smarter-cheaper-network-tariff-design-for-a-smart-future/>

Figure 16. Pacific Gas & Electric's time-of-use proposal for shared and commercial EV charging

Source: Pacific Gas & Electric Co. (2018, 5 November). *Application of Pacific Gas and Electric Company (U 39 E) for approval of its commercial electric vehicle rates.*

to promote the utilisation and development of fast charging stations and workplace EV charging, among other things.¹⁷⁴ Southern California Edison plans to waive the demand charge for at least the next five years, while PG&E intends to significantly reduce the charge permanently. Both utilities are also planning to use TOU tariffs that better reflect the marginal cost of serving EV consumers. Let's look more closely at the PG&E tariff.

PG&E is proposing to replace the current demand charges with a two-element tariff consisting of a subscription fee and a TOU charge. The subscription fee is a fixed monthly charge tied to the expected maximum demand in kilowatts (kW) and is meant to recover customer-specific costs. This type of subscription fee is common in mobile phone service contracts for planned usage levels. For electricity usage, however, it is significantly lower, as a percentage of the total bill, than for mobile phone service.

The subscription fee is equal to \$3.70 (around 3.30 euros) per kW, as opposed to a demand charge of \$11/kW (about 9.80 euros/kW) in the winter and \$19/kW (around 17 euros/kW) for summer in the current general service rate (rate A-10).¹⁷⁵

The second part of PG&E's proposed tariff comprises TOU charges, which are depicted in Figure 16.¹⁷⁶ In addition to the usual on-peak and off-peak (day/night) periods, the tariff includes a super-off-peak period for the five hours between 9 a.m. and 2 p.m. This tariff takes advantage of the high volume of low-cost renewable energy production around midday from solar photovoltaics in the utility region. Conversely, the cost for charging during the peak period, from 4 to 10 p.m., is more than three times as high, as this period coincides with lower output from renewable generation and higher demand. The utility expects that the new tariff design will halve the charging costs for EV owners.

174 The California regulator approved the Southern California Edison tariff design in 2018. PG&E submitted its proposed design in November 2018 to regulators, who are reviewing it. Muller, M. (2018, 18 December). Reforming rates for electric trucks, buses & fast chargers [Blog post]. Natural Resources Defense Council. Retrieved from <https://www.nrdc.org/experts/miles-muller/reforming-rates-electric-trucks-buses-fast-chargers>

175 Pacific Gas & Electric Co. (2018, 5 November). Application of Pacific Gas and Electric Company (U 39 E) for approval of its commercial electric vehicle rates [Application No. 18-11-]. Proceeding A1811003. Retrieved from <http://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M238/K227/238227315.PDF>

176 Pacific Gas & Electric Co., 2018.

Appendix B: Additional examples of smart infrastructure

This section contains further examples of promising practices for smart infrastructure planning and development.

Using existing telecommunications infrastructure for charging

Germany's Deutsche Telekom plans to build a public EV charging network. The firm's plan aligns well with the best practice of leveraging EVs to help with power system optimisation and making best use of existing grid infrastructure. This will also lower the cost of installing network cables for data connection.

The phone and internet service provider has started converting its 12,000 on-street distribution boxes, which are primarily used for phone and internet services, and its former public phone booths into public EV charging outlets. Deutsche Telekom also aims to expand its network by adding 24,000 stations with 22-kW chargers and 500 fast charging stations with 100-kW chargers, using company-owned medium-voltage sites. However, progress slowed over the course of 2018 as local authorities faced difficulties freeing up parking spaces for EVs next to the charging outlets.¹⁷⁷

An EU-funded project explored further benefits of using existing public transport electric infrastructure for EV charging, such as the overhead lines that transmit electricity to trams, trolleybuses, or trains. One project pilot in London set up EV charging points next to a London Underground

metro substation that enabled the transport authority, Transport for London, to charge vehicles in its service fleet (electric cars and vans) without affecting the power network or underground rail operations. Project participants estimate that the use of these charge points will reduce tailpipe carbon dioxide emissions from the Transport for London fleet by more than 13 metric tons annually.¹⁷⁸ Another trial in Oberhausen, Germany, used electricity from catenary tram lines (and from substations at bus stops) to charge electric buses during operation. The project also explored using electricity from tram catenaries for fast charging solutions for EVs outside the station to serve private customers.¹⁷⁹

Using electric public transport infrastructure for electrified passenger vehicles offers an interesting option for "park and ride" stations close to cities, where commuters could park and charge their EVs while taking the bus (or free shuttles) into urban areas. These solutions can be used to complement policies restricting vehicle use in urban areas through, for example, a congestion charge such as the one successfully implemented in London.¹⁸⁰

Developing storage via battery-based fast charging solutions

With regard to fast charging infrastructure in Europe, both energy and automotive players are exploring the market for battery-assisted mobile fast chargers. These projects are prompted by the development of vehicles with

177 Jehle, C. (2018, 1 August). Verteilerkästen als Ladesäulen: Telekom-Projekt lahm [Fixed line and cable infrastructure boxes as charging stations: Telekom project founders]. *bizz energy*. Retrieved from https://bizz-energy.com/verteilerkaesten_als_ladesaeulen_telekom_projekt_kommt_nicht_vom_fleck

178 Talbot, D., and Poulton, M. (2018, June). *London final use case report*. Electrification of Public Transport in Cities (ELIPTIC). Retrieved from <http://www.eliptic-project.eu/sites/default/files/ELIPTIC%20D2.4%20London%20Final%20Use%20Case%20Report.pdf>

179 Thurm, S., Gesing, J., and Berends, H. (2018). *Oberhausen final use case report*. Electrification of Public Transport in Cities (ELIPTIC). Retrieved from <http://www.eliptic-project.eu/sites/default/files/ELIPTIC%20D2.14%20Oberhausen%20Final%20Use%20Case%20Report.pdf>. The main hurdle for operating the fast chargers was a lack of legal clarity

as to which entity was authorised to sell energy to third parties. This is a recurring issue in the emerging e-mobility market. A similar issue arose in the United States, where regulators must consider whether third parties that are engaged in charging services and also sell electricity need to be licensed and regulated as utilities or treated like competitive retail service providers. With a fast-growing EV market, private investors in both regions may look for clarity on these questions as they decide whether and how much to invest in electric vehicle supply equipment. One current practice in the U.S. is charging for the use of the parking space—per minute for high-voltage direct current or per hour for Level 2 chargers—and offering free electricity.

180 Badstuber, N. (2018, 2 March). *London congestion charge: What worked, what didn't, what next*. The Conversation. Retrieved from <http://theconversation.com/london-congestion-charge-what-worked-what-didnt-what-next-92478>

higher-performing batteries. For a trial in 2019, Volkswagen intends to set up mobile battery-based fast charging stations with 360-kW capacity in public parking areas or private non-residential areas.¹⁸¹ The solution offers several advantages. First, it can respond to ad hoc demand for fast charging stations, such as short-term large-scale events, while helping city planners and developers address any remaining uncertainties about siting for fast charging infrastructure. Second, it can provide temporary storage for renewable energy or other grid services. Third, it provides a second life for EV car batteries by using them for stationary charging services.

From a grid perspective, the UK's transmission system operator National Grid is also looking into combining energy storage and EV charging by equipping 45 sites with large battery systems (45 megawatts) that would include 100 EV fast charging points each. The company expects that by drawing energy from those batteries, EVs could be charged more cost-effectively.¹⁸²

Integrating EVs into public fleets via joint procurement

In addition to using existing infrastructure, some cities have also improved their planning tools to integrate electric vehicles.

The region surrounding Copenhagen has actively supported the procurement of EVs in public and private fleets since 2013. Some municipalities in the region have ambitious targets. For example, the municipality of Copenhagen aims to use alternative fuels for 85 percent of municipal vehicles and to make the whole city carbon-neutral by 2025.¹⁸³ In total, 1,660 electric vehicles have been purchased since 2013. The region and the municipality developed a procurement process aimed at electrifying fleets where most combustion-driven kilometres can be replaced. In March 2017, they instituted procurement cooperation among 10 municipalities, three regions, the state-owned network company, and the capital's utility to achieve discounts on the total number of EVs purchased.¹⁸⁴

181 Volkswagen. (2018, 27 December). *Electrifying world premiere: Volkswagen offers first glimpse of mobile charging station* [Press release]. Retrieved from <https://www.volkswagen-newsroom.com/en/press-releases/electrifying-world-premiere-volkswagen-offers-first-glimpse-of-mobile-charging-station-4544>

182 Hanley, S. (2018, 21 February). *National Grid planning fast charging network for UK*. CleanTechnica. Retrieved from <https://cleantechnica.com/2018/02/21/national-grid-planning-fast-charging-network-uk/>

183 Procura+ Network. *Copenhagen* [Webpage]. Retrieved from <http://www.procuraplus.org/public-authorities/copenhagen/>

184 Copenhagen Electric, personal communication, 30 January 2019.

Appendix C: European Union legislation in place

Various European legislation supports smart EV charging through provisions on wholesale and retail markets, dynamic pricing, and technology.

Clean Energy for All Europeans package

Over the past couple of years, the European institutions negotiated the Clean Energy for All Europeans (CE4All) package—new rules that govern the operation of the wholesale and retail power markets and other aspects of the energy sector.¹⁸⁵ One of the key objectives of the package is to empower citizens to participate in the power market, with the goal of minimising the costs of the future decarbonised power system.¹⁸⁶ Citizens and customers of all sizes can participate either directly or indirectly through third parties such as aggregators or suppliers. Aggregators can pool the demand of smaller commercial and domestic customers to participate in the different market segments and to provide services to system operators and other market players.

Demand for electricity has traditionally been inflexible, where generation is scheduled to meet demand. In the future, the reverse will also need to be the case as variable generation from renewable energy sources grows—in other words, demand aligning with generation. EVs and other controllable loads, such as heat pumps, present a valuable

option to achieve this goal.¹⁸⁷

Traditionally, demand response came primarily from large industrial customers that could shift their demand from peak periods to lower-demand periods or would provide ancillary services to system operators. Thus, these customers would play a role in what is known as peak shaving, which has been used increasingly for grid management. As we move toward a power system dominated by renewable energy sources, it will be important that electricity consumption becomes significantly more flexible. This includes, for example, the ability of consumers to shift their usage from high-demand hours to times when there is a surplus of renewable generation. Another option is for consumers to adjust demand dynamically, potentially providing services to system operators such as helping them manage the ramping requirements for the system. This dynamic adjustment varies in duration from only seconds to minutes or hours.¹⁸⁸

European legislation determines the rules for the design of wholesale power markets across Europe, as well as the framework for network regulation and network tariff design (mainly covered in the Electricity Regulation)¹⁸⁹ and the principles for operating retail markets (mainly covered in the Electricity Directive).¹⁹⁰ National legislation, by contrast, sets forth detailed rules and regulations for the wholesale and retail markets and network regulation, such as the

185 The European Commission proposed the CE4All package in November 2016. The package consists of eight legislative files, most of which were agreed upon over the course of 2018. The most relevant files for smart charging are the Electricity Regulation and Electricity Directive. European Commission. *Clean energy for all Europeans*.

186 See, for example, Energy Union Choices. (2017). *Cleaner, smarter, cheaper: Responding to opportunities in Europe's changing energy system*. Brussels, Belgium: Author. Retrieved from <https://www.energyunionchoices.eu/cleanersmartercheaper/>

187 There are two types of demand response: implicit demand response, whereby consumers shift when they use electricity in response to the price at a given time, and explicit demand response, whereby consumers offer their flexible energy consumption as a product to different market segments (e.g., wholesale or balancing markets) and market participants (e.g., system operators or suppliers). Implicit demand response can be managed directly by the consumer or a third party such as an aggregator. Explicit demand response is normally facilitated by an aggregator, which could be an independent service provider or supplier. For more information, see Smart Energy Demand Coalition. (2016).

Explicit and implicit demand-side flexibility: Complementary approaches for an efficient energy system. Brussels, Belgium: Author. Retrieved from <http://www.smart.eu/wp-content/uploads/2016/09/SEDC-Position-paper-Explicit-and-Implicit-DR-September-2016.pdf>

188 Some of these services will require vehicle-to-grid technology, where EVs feed electricity back to the grid. This is still largely in the demonstration phase. The availability of this technology could offer substantial potential to provide flexibility services to system operators and beyond. For more information, see Chapter 2, the section “A flexible power system resource.”

189 The Electricity Regulation will be applied automatically across all Member States once it becomes official legislation. The European institutions have reached a political agreement on the file and are in the process of ratifying it. The legislation is expected to come into force in January 2020.

190 Unlike the Electricity Regulation, the Electricity Directive will need to be transposed into national legislation once it has become official EU legislation.

methodology for estimating network tariffs. The national legislation must comply with the European legislation.

Below we highlight aspects of the European legislation that are important for enabling smart charging.

Wholesale market design: The recently adopted Electricity Regulation aims to create well-functioning wholesale markets that reveal the full value of the energy, balancing, and grid services needed to maintain reliable operation of the power system. For example, the legislation requires the removal of any obstacles to price formation, such as price caps or regulatory distortions. In addition, it sets the objective of moving toward shorter-term markets that will provide more accurate pricing signals. Appropriate price formation will be one of the key elements for incentivising smart charging and the type of flexible services that EVs can provide to the power system.

Retail markets: The main objective of the European legislation on retail markets is to form open and competitive markets where suppliers and other parties compete to meet consumers' needs at the lowest possible cost. EU legislation has already established the right of consumers to choose their supplier. The CE4All package aims to link the wholesale and retail markets more closely compared with previous legislation by providing real-time or near-real-time information to consumers about their consumption and the associated costs of delivering the service to them. Ultimately, the goal is to enable consumers to participate actively in the energy market by establishing appropriate tools for their benefit and for the benefit of the system as a whole.

Treatment of demand response and aggregation: Although demand response is recognised as an important resource, its participation in markets is often obstructed by outdated regulations that give preferential treatment to power generation.¹⁹¹ For example, in several Member States, demand response is precluded or effectively prohibited from participating in the balancing or ancillary services markets due to a minimum bid threshold.¹⁹² The EU legislation

establishes the principle of aggregation (covered, for example, in Article 17 of the Electricity Directive), allowing smaller commercial and domestic customers to participate in the different market segments. This is particularly important as individual EVs are a very small load that cannot participate in different markets.¹⁹³ In addition, the new Electricity Regulation and Electricity Directive remove several obstacles to the participation of demand response—and by extension EVs—in the different markets. One aim of this legislation is to ensure a level playing field between demand response and traditional resources.

Dynamic pricing for energy: The principle of dynamic, or time-varying, pricing for energy is established in the Electricity Directive (Article 11). The legislation states that suppliers are allowed to offer dynamic pricing contracts and that any consumer with a smart meter may request a dynamic pricing contract from any supplier that has more than 200,000 customers. At the same time, the directive allows suppliers to implement regulated prices, primarily for vulnerable consumers. Regulated prices may also be applied to other consumers as an intermediate measure during retail market reforms to achieve competition (Article 5).

Dynamic pricing for networks: European legislation establishes the high-level principles for pricing network usage (mainly Article 16 of the Electricity Regulation). The legislation promotes cost-reflective, non-discriminatory tariffs that aim to minimise the long-term costs of developing networks. Although it doesn't specifically mention e-mobility or other flexible sources of demand, the legislation does promote the use of dynamic network tariffs where smart meters are in place. Individual nations are responsible for determining methodologies, the network tariffs themselves, and related details.

Smart meters and technology: Beginning as early as the Third Energy Package, European legislation has stipulated the rollout of smart meters unless their costs are expected to outweigh the benefits (Articles 19 to 21 of the

191 Baker, P., and Hogan, M. (2016). *The market design initiative: Enabling demand-side markets*. Brussels, Belgium: Regulatory Assistance Project. Retrieved from <https://www.raponline.org/knowledge-center/the-market-design-initiative-enabling-demand-side-markets/>

192 For a review of the status of explicit demand response in Europe, see Smart Energy Demand Coalition. (2017). *Explicit demand response in Europe: Mapping the markets 2017*. Brussels, Belgium: Author. Retrieved from <https://www.smartenergydemand.eu/wp-content/uploads/2017/04/SEDC-Explicit-Demand-Response-in-Europe-Mapping-the-Markets-2017.pdf>

193 For example, an individual EV could not participate in the balancing market, as the minimum threshold is set at hundreds of kilowatts. However, several EVs combined could be treated as one resource. As such, they could reach the threshold, allowing them to participate in the balancing market and provide services controlled by a central entity, such as an aggregator. An aggregator could be a third party or a consumer's electricity supplier.

Electricity Directive). The rules prescribe the minimum technical requirements for smart meters (e.g., the secure and timely delivery of historical, real-time, and near-real-time consumption data that can be used in energy efficiency or

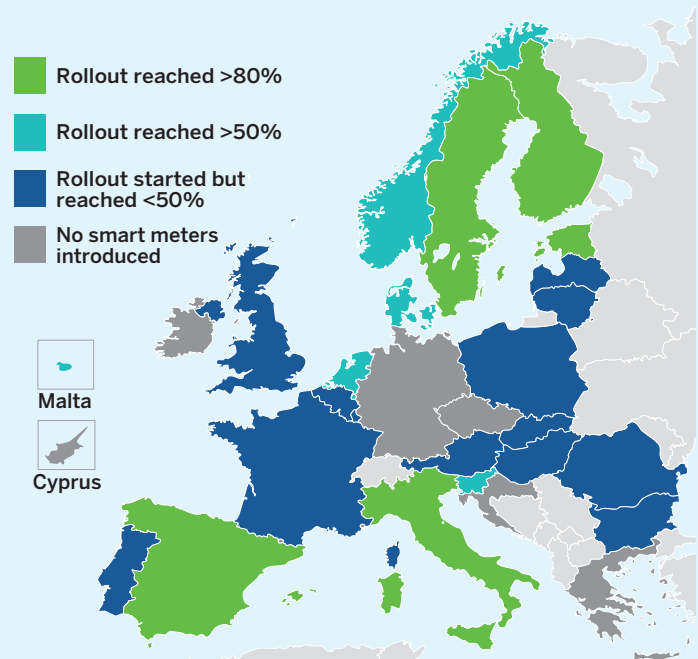
demand response programmes),¹⁹⁴ although the detailed functions required are a matter of national legislation. The text box below provides more information on the status of smart meter rollout across Europe.

Smart meters in Europe

The deployment of smart meters is regulated by EU-wide policy. The Third Energy Package obliged Member States to roll out smart meters to at least 80 percent of their customers by 2020, unless it could be proven that the cost of deploying them outweighs the benefits.¹⁹⁵ The CE4All package, which replaces the Third Energy Package, stipulates that Member States need to have rolled out smart meters within the next 10 years at the latest, subject to a positive cost-benefit analysis (Annex III of the Electricity Directive; the directive also sets more detailed timelines). Currently, some Member States are aiming to achieve this target by 2020, while others have either set a later date or have not set their goal. Of the nine countries that have rolled out smart meters to more than half their consumers, five have already hit the 80 percent mark. Figure 17 shows the Member States' progress as of 2017.¹⁹⁶

The detailed minimum technical functions required for smart meters are defined in national legislation, while European legislation defines the high-level principles to which smart meters must also adhere. Some of the most common functions include remote readability, the measurement of near-real-time electricity consumption, and billing based on actual consumption. In addition, 17 Member States require that smart meters be compatible with advanced dynamic tariff systems. EU countries also

Figure 17. Status of smart meter rollout in 2017



Source: Agency for the Cooperation of Energy Regulators and Council of European Energy Regulators. (2018). *Annual report on the results of monitoring the internal electricity and natural gas markets in 2017*.

set the maximum time interval for measuring consumption. This varies from 15 to 60 minutes across Europe, although the majority of Member States have set it at 15 minutes (14 out of 20 countries). The maximum interval affects the type of tariffs that can be offered to consumers.

194 In conjunction with minimum functionality for smart metering as defined in the Commission Recommendation 2012/148/EU. See European Commission. (2012, 9 March). *Commission recommendation on preparations for the roll-out of smart metering systems*. Brussels, Belgium: Author. Retrieved from <https://publications.europa.eu/en/publication-detail/-/publication/a5daa8c6-8f11-4e5e-9634-3f224af571a6/language-en>

195 European Commission. *Market legislation* [Webpage]. Retrieved from <https://ec.europa.eu/energy/en/topics/markets-and-consumers/market-legislation>

196 Agency for the Cooperation of Energy Regulators and Council of European Energy Regulators, 2018.

Legislation on EV charging infrastructure

Ambition levels and framework conditions for rolling out the current EV charging infrastructure are defined in the Alternative Fuels Infrastructure Directive that all EU Member States and Norway must implement. As part of this process, several national governments have launched public support programmes, which vary in size and ambition, to establish charging infrastructure. However, progress has been heterogeneous,¹⁹⁷ creating the risk of “a market fragmentation at EU level and even within certain Member States” according to the EU Commission.¹⁹⁸ In an official statement on this topic, the European Parliament has already asked Member States to step up efforts, stating that it “regrets that progress regarding the deployment of alternative fuels infrastructure ... is too slow.”¹⁹⁹ The EU Commission has started an evaluation process and is expected to decide in late 2019 whether to open a legislative review process for the current directive.

In the EU, reformed building codes entered into force in July 2018, setting minimum requirements for EV integration on private grounds. The revised Energy Performance of Buildings Directive requires car parks for new or deeply renovated non-residential buildings to be equipped with at least one charging point and at least 20 percent of their parking spaces to be equipped with electric conduits to allow for possible installation of charging points. New and substantially renovated residential buildings with more than 10 parking spaces are required to be equipped with electric conduits. For existing buildings with more than 20 parking spaces, Member States can decide on minimum requirements individually, but these will apply only after 2025.²⁰⁰

During implementation of this EU legal framework, Member States may choose to go beyond the agreed minimum. They might, for example, expand the requirement to install the necessary duct infrastructure for EV charging to all parking spaces (residential or non-residential buildings), as well as ensure smart functionality for all charging infrastructure (see Chapter 4).

197 For a detailed review of Member States' priorities and progress, see Platform for Electro-mobility. (2018). *How EU Member States roll-out electro-mobility: Electric charging infrastructure in 2020 and beyond*. Retrieved from <http://www.platformelectromobility.eu/wp-content/uploads/2018/02/Emobility-Platform-AFID-analysis.pdf>

198 European Commission. (2019). *Report on the assessment of the Member States National Policy Frameworks for the development of the market as regards alternative fuels in the transport sector and the deployment of the relevant infrastructure pursuant to Article 10 (2) of Directive 2014/94/EU*. Brussels, Belgium: Author. Retrieved from <https://ec.europa.eu/transport/sites/transport/files/legislation/swd20190029.pdf>

199 European Parliament. (2018). European Parliament resolution of 25 October 2018 on deployment of infrastructure for alternative fuels in the European Union: time to act! Procedure 2018/2023(INI). Retrieved from <http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P8-TA-2018-0438+0+DOC+XML+V0//>

EN&language=EN. In that resolution, the European Parliament further details its vision of future EV infrastructure rollout and says that it: “Notes that most charging of electric vehicles will occur at home or at work, complemented by charging at public and semi-public places such as supermarkets, train stations or airports; stresses in this regard that a greater focus on smart charging solutions is needed, grid stability must be ensured and self-consumption enabled; underlines that for long-distance electromobility, fast- and ultra-fast charging stations are needed along highways, main road systems, and network nodes; highlights that open access to charging points, interoperability of technology and payments, and the free choice of energy, including renewable energy, and suppliers are key factors for a functioning system.”

200 Platform for Electro-mobility. (2018). *Electro-mobility Platform recommendations on the EPBD [European Performance of Buildings Directive] review guidance note*. Retrieved from https://www.platformelectromobility.eu/wp-content/uploads/2018/02/20180821-EPBD-position-paper_final.pdf

Additional Resources

Related papers, reports, and research from RAP

Beneficial electrification of transportation

<https://www.raonline.org/knowledge-center/beneficial-electrification-of-transportation/>

Farnsworth, D., Shipley, J., Sliger, J., and Lazar, J. (2019)

Treasure hiding in plain sight:

Launching electric transport with the grid we already have

<https://www.raonline.org/knowledge-center/treasure-hiding-in-plain-sight-launching-electric-transport-with-the-grid-we-already-have/>

Hogan, M., Kolokathis, C., and Jahn, A. (2018)

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<https://www.raonline.org/knowledge-center/cleaner-smarter-cheaper-network-tariff-design-for-a-smart-future/>

Kolokathis, C., Hogan, M., and Jahn, A. (2018)

Getting from here to there:

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<https://www.raonline.org/knowledge-center/getting-from-here-to-there-regulatory-considerations-for-transportation-electrification/>

Regulatory Assistance Project. (2017)

Hitting the mark on missing money:

How to ensure reliability at least cost to consumers

<https://www.raonline.org/knowledge-center/hitting-mark-missing-money-ensure-reliability-least-cost-consumers/>

Hogan, M. (2016)



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