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ELECTRIC VEHICLES ROLLOUT IN EUROPE TOWARDS AN IMPROVED REGULATORY REGIME





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Executive summary

Our aim with this report is to provide a timely contribution to the search for concrete responses on how to successfully complete and manage the rollout of electric vehicles in Europe. For this purpose, the report presents case studies of three countries: Norway and the Netherlands – where market penetration of electric vehicles is already relatively high – as well as Luxembourg, which is an interesting case from a regulatory perspective.

The three case studies

Norway has some unique characteristics that are important for the study of how electric vehicles affect the electricity system. On the one hand, the penetration of electric vehicles is higher in Norway than anywhere else in Europe. On the other hand, thanks to the availability of cheap hydro power, the Norwegian electricity system has been designed to support electric space heating in a cold climate. Hence, it has been able to accommodate high levels of electric vehicle penetration, even with relatively light-handed regulation on location and capacity of charging infrastructure.

The unique characteristics of Norway make it difficult to generalise its experience. Nevertheless, it does suggest that electric vehicles can be accommodated by electricity systems, given reasonable levels of penetration and sufficient time to respond to the resulting demand for electricity.

The Netherlands already has a well-developed network of charging points. The base for charging is provided by private charging points either at home or at work. Semi-public¹ chargers with limited access are also an important category that is growing quickly. Public chargers are often deployed through a demand-driven approach, and this method of providing charging infrastructure where there is not enough private parking – and therefore a lack of private charging – is an option used particularly in cities.

The Grand Duchy of Luxembourg has a small, still developing system in terms of the number of electric vehicles. Luxembourg has organised the development of its charging infrastructure centrally and the main public charging network is owned by distribution companies. Due to its location, the Grand Duchy cooperates with the Netherlands and Belgium to facilitate the usage of electric vehicles in the region so that users of electric vehicles can charge their cars in any station belonging to any of the three networks.

Looking at the three cases, Luxembourg has taken a somewhat different approach regarding the creation of a charging infrastructure for electric vehicles. There, responsibility for ensuring the deployment of the necessary infrastructure has been vested with the distribution system operators, who have produced a comprehensive national scheme based on public tenders, to ensure a timely rollout. Given the relatively low numbers of both electric vehicles and charging points in the country to date, it is however not yet clear how well this approach is working, especially compared to the alternative pursued in the Netherlands and Norway.

Both the Netherlands and Norway have adopted more decentralised approaches to charging infrastructure. However, in both countries, such infrastructure has developed in line with the fleet of electric vehicles and charging facilities do not seem to be an obstacle to further growth of the fleet. The Norwegian experience is perhaps of particular interest, given the unusually high penetration of electric vehicles there. The fact that distribution networks are guaranteed financing of necessary upgrades from users has clearly played a part in facilitating the connection of charging points. The Netherlands has developed more of a bottom-up approach to account for the fact that a large proportion of people live in multi-home dwellings without access to a garage or a private parking space.

¹ According to the Dutch definition



Policy implications

For the rise of electric vehicles to go smoothly, it is crucial that the right incentives and market structures be in place. One of the challenges for distribution system operators is to ensure that charging mostly takes place during off-peak hours. Time-of-use pricing is a possible option for shifting general demand for charging at or near homes from peak to off-peak hours. However, this may not suffice to solve the localised problems in distribution networks. A change in regulation, e.g. on when and where charging can take place, rather than a change in the tariff and pricing structure, could be more appropriate in certain cases.

Based on our case studies, it is possible to identify different options for organising the electric vehicle “ecosystem” in which multiple actors (i.e. charging point operators, DSOs, platforms, mobility service providers and users of electric vehicles) operate and interact. Irrespective of the regulatory arrangement, a more centralised model (e.g. Luxembourg) highlights the possibility of defining pre-existing roles for most of the actors. While this model could better apply to local and regional realities, more decentralised models (e.g. The Netherlands) may also proliferate and coexist across Europe.

Electric vehicles, or rather their batteries, could also potentially provide important storage and flexibility in a de-carbonised energy system based in large part on renewable energy sources. While time-of-use tariffs and pricing or command-and-control regulation would be the appropriate tools to shift charging demand to off-peak hours, they will not be sufficient to exploit the full potential of electric vehicles as storage. One challenge in this regard is simply having enough charging (or de-charging) points for parked vehicles.

01

INTRODUCTION





1. Introduction

The European drive to decarbonise is now firmly part of the policy agenda. It is underpinned by the Energy Union proposals and the well-known target to cut carbon emissions by 40 per cent by 2030. However, whilst industrial emissions show a 37 per cent drop since 1990, transport emissions have gone up by 16 per cent in the same period (European Environment Agency, 2019). Added to this, concerns about particulate pollution in major urban areas across Europe are increasing.

Against this backdrop, major deployment of electric vehicles (EVs) in the 2020s – concurrent with the expansion of electricity generation from renewable sources – is widely regarded as a prerequisite for meeting the decarbonisation and sustainability goals.²

While there are varying views on how fast the share of electric vehicles will grow, 2018 saw the number of electric passenger cars pass 5.1 million worldwide, with 90 per cent of these being accounted for by China, the US and European countries. Norway, Germany, the UK, France, the Netherlands and Sweden are the countries in Europe with the highest number of electric vehicles.³ While the global electric vehicle stock is only 0.4 per cent of the total number of motor vehicles worldwide, some projections envisage almost full market penetration of battery electric vehicles by mid-century (e.g. Cherif et al., 2017). Recent cost developments support such projections: battery costs have fallen by 85 per cent since 2010 and the downward trend is expected to continue (BloombergNEF, 2019).⁴

Backed by an attractive subsidy scheme, Norway leads the way in Europe in electric vehicle sales, with a 46 per cent share of new registrations in 2018. Iceland and Sweden follow, in terms of market share, with 17 per cent and 8 per cent, respectively.⁵ The Netherlands has seen fluctuations in the market share of electric vehicles due to changes to its subsidy scheme, but is still at 6.6 per cent. Several other European countries, including the UK, France and Germany reached a 2 per cent market share in 2018. Norway was also the global leader in terms of share of electric cars in the total car stock in 2018, with a 10 per cent share. Even with the fast growth in electric car sales, only four European countries had an electric car stock share higher than 1 per cent in 2018: Norway, Iceland (3.3%), The Netherlands (1.9%) and Sweden (1.6%).⁶

In Europe, with mandatory CO₂ emission reduction targets for new cars, and as concerns regarding particulate pollution grow, with major cities proposing penalties or bans on older petrol and diesel vehicles, it seems credible that significant growth in electric vehicles could be observed in the 2020s. As countries such as France and the UK have now proposed bans on sales of petrol and diesel cars by 2040, the momentum driving significant growth in electric vehicles seems clear. This raises the question of the ability of the energy and mobility sectors to manage a major shift to electric vehicles.

The relative increase in electric energy demand due to increased numbers of electric vehicles, and the associated impact on the grid and the overall power system will vary by country depending on a number of factors including electricity consumption, car ownership and driving habits. In Norway, where annual electricity consumption per capita is 24 MWh, existing reports indicate that by 2030, the overall increase in energy demand resulting from a 50 per cent stock share of electric cars will

² In this report, the term 'electric vehicle' includes both plug-in hybrid vehicles (PHEVs) and those that run only on battery power (BEVs).

³ If not otherwise stated, data in this section are sourced from IEA (2019).

⁴ Opinions vary about the pace of change; e.g., IRENA (2017) predicts a slower drop in prices than has been observed over the last decade.

⁵ It is probably not coincidental that these countries also generate most of their electricity from renewable energy sources (including large scale hydro) so the full potential reduction in fuel emissions from the shift to electric vehicles is realised. Other factors, including urban development features, may also play a role.

⁶ China had a stock share of 1.1% in 2018. It accounts for almost half of the absolute number of electric vehicles in the world.



be 3 per cent of present demand. In other words, the relative increase is quite modest and should be easily accommodated within this timeframe (see Section 2). In the Netherlands, where electricity consumption per capita is only a little over a quarter of the Norwegian number, or 6.3 MWh, and the incidence of car ownership is slightly lower than in Norway, a corresponding increase in the number of electric vehicles would lead to a substantially greater proportional increase in overall electricity demand (see Section 3).⁷ Still, the impact seems likely to be manageable.

The table below gives some indication, for a selection of countries, of the potential impact on the power system of full penetration of battery electric vehicles.⁸ The impact on the power system as a whole would lie in the range of 23-35 per cent for most of the countries, although it would be substantially lower for Norway (8%) and markedly higher for Italy (48%). Since most charging at present takes place in residential areas, the relative impact on household consumption may be a better indicator of the challenges faced by distribution systems. This indicator lies in the range of 100-150 per cent for most countries. Again, Norway has the lowest impact (25%) while the impact in Italy would be almost double that in countries like the UK or Belgium.

Indicators of the potential impact of electric vehicles in a selection of countries

	Total electricity consumption MWh/cap p.a.	Household electricity consumption Mwh/cap p.a.	Passengers cars per 1,000 inhabitants	Consumption of EVs with 100% stock share*	Share of current total consumption	Share of current household consumption	Proportional impact of EVs compared to NO
NO	24.0	7.5	514	1.9	8%	25%	1.0
LUX	10.6	1.6	670	2.4	23%	153%	2.9
BE	7.1	1.6	508	1.8	26%	115%	3.3
FR	6.4	2.4	478	1.7	27%	72%	3.5
DE	6.6	1.6	561	2.0	31%	130%	4.0
NL	6.3	1.3	556	2.0	32%	151%	4.1
UK	4.8	1.6	471	1.7	35%	106%	4.6
IT	4.7	1.1	625	2.3	48%	208%	6.2

* based on 0.2 kWh/km and 18,000 km/p.a.

When considering the indicators above, we should keep in mind that full electrification of the car fleet would take place over decades. In other words, there is time for countries to respond. However, if consumer charging behaviour does not change,⁹ peak demand in these – and other – projections could rise considerably more than energy demand; for example, approximately 12 per cent in the Norwegian scenarios for 2030 (see Section 2). In the Netherlands, the proportional impact would be considerably larger (see Section 3). This could put a strain on electricity infrastructure, from generation to networks. Depending on how charging infrastructure develops,

⁷ Globally, the growth is projected to be modest: in its “New Policies” scenario for 2040, the IEA (2018) predicts a 3% rise from present levels of world electric energy demand due to electric vehicles. Other developments consistent with limiting greenhouse gas emissions – especially electrification in the industrial, commercial and residential sectors – will place far greater demands on increased electricity supply worldwide.

⁸ The impact of a lower than full share can of course be calculated *pro rata*.

⁹ As discussed later in this report, smart charging technology offers opportunities to change charging behaviour; see e.g. IRENA (2019).



local effects could be even stronger, leading to an overloading of distribution infrastructure in certain locations at specific times.

The rise in EV-based electricity demand also needs to be considered in the context of increased electricity generation from renewables. In particular, generation of solar power falls and ultimately evaporates during the time the typical electric vehicle owner charges the vehicle at home, starting in the late afternoon. The net peak power drawn from the grid is increased even more when these two effects are combined. If left unmanaged, the prosumer – who could in principle reduce the load on the distribution network by generating electricity locally to charge the car, if it happened at the right time – would place an even greater strain on the network.

Hence, if the opportunities offered by smart technologies are not widely utilised, the rollout of electric vehicles may necessitate considerable investments at substantial cost in distribution networks and other power system infrastructure. At the same time, the prospects of such costs could slow down the electrification of transport, resulting in increased emissions of greenhouse gases and missed opportunities for limiting climate change.

In light of the above, the objectives of this report are the following:

- a) to provide a thorough understanding of the consequences of the ongoing rollout of electric vehicles in Europe on the energy systems and markets, and also;
- b) to highlight what needs to be done – and by whom – about market models, incentives and regulatory regimes and tools, in order to manage the rollout in an optimal way.

Our aim with this report and the completion of the above objectives has been to provide a timely contribution to the current efforts developed by the various stakeholders involved in the electric vehicle and electricity markets, who are looking for concrete responses on how to successfully complete and manage electric vehicle rollout.

The structure of the report is as follows: the next two sections present case studies of two countries where market penetration of electric vehicles is already comparatively high, viz. Norway (Section 2) and the Netherlands (Section 3). A study of electric vehicle policies in Luxembourg follows (Section 4). Luxembourg does not yet have a particularly high penetration of electric vehicles, but has somewhat different electric vehicle policies – especially concerning charging initiatives, which are more centralised than in other countries.

The case studies build on existing data and reports, with an emphasis on challenges faced by DSOs as a result of the increase in electric vehicles as well as on the responses made to address those challenges specifically. The aim is to draw lessons learned from these responses and to discuss their wider application.

The analysis then proceeds to a more fundamental investigation of the options available (Section 5) with reference to the case studies. The underlying issue is the lack of a market signal which directs consumers and suppliers in a more efficient direction, e.g. incentivising suppliers to locate charging stations in places where the grid is strong, or consumers to use smart technologies for charging at times and at locations where it is efficient to do so. Price-based mechanisms are a standard approach to address such issues. This last section looks into whether and how price-based mechanisms have been employed in the setting of electric vehicle charging – at home or publicly – or, if this is not possible, whether command-and-control instruments may be appropriate.

02

**CASE STUDY I:
NORWAY**



2. Case Study I: Norway

2.1. Introduction

The Norwegian government has an unusually ambitious policy to promote electric vehicles, providing a combination of tax exemptions and benefits that make such vehicles very attractive. As a result, the fleet of electric vehicles has increased rapidly, and Norway now has the highest penetration of electric vehicles in the world.

The rapid increase in the number of electric vehicles – and the associated expansion of charging infrastructure – seems so far to have been handled quite well by the electricity system, including the network. This seems to be explained mainly by the fact that, due to the prevalence of electric space heating, network connections to homes – where most charging takes place – have a capacity that can accommodate the power required to charge an electric vehicle. Moreover, while the number of electric vehicles has become substantial, charging of such vehicles still represents only a fraction of the total demand for electricity.

2.2. Policy drivers

The development of electric vehicles in Norway is driven by policies laid out in the Norwegian government's National Transport Plan (Meld St 33 – 2016-2017). The overall objective is to achieve "a transport system that is safe, enhances value creation and contributes to a low-carbon society". Norway is committed to a reduction target of at least 40 per cent in greenhouse gas emissions by 2030 compared to 1990 levels. Around 50 per cent of Norway's emissions are covered by the EU's Emissions Trading System (ETS). The transport sector accounts for approximately 60 per cent of emissions outside of the ETS in Norway, and a large part of the domestic emission reductions from the non-ETS sectors must therefore be achieved in the transport sector.

As part of the plan to reduce emissions from transport, the Norwegian government has established targets for new zero-emission vehicles:

- all new passenger vehicles and light vans sold in 2025 shall be zero-emission vehicles;
- all new urban buses sold in 2025 shall be zero emitters or use biogas, and;
- by 2030, all new heavy-duty vehicles, 75 per cent of new long-distance coaches and 50 per cent of new trucks shall be zero emission vehicles.

Furthermore, the distribution of freight in the largest urban centres shall have almost zero emissions by 2030.

A number of local governments – especially in major cities – have developed their own policies with regard to electrification of the transport sector, including a shift of local transport from conventional to electric vehicles, introduction of electric buses and onshore charging of ships in ports.

2.3. Current status of electric vehicles

Table 1 shows the stock of electric private vehicles in Norway during the period 2010 to 2018. The stock of battery electric vehicles has increased rapidly and by larger numbers each year. Between 2017 and 2018, it increased by almost 60,000 to a total of 195,000 vehicles. The increase in hybrid vehicles started later, but follows a similar pattern: between 2017 and 2018, it increased by almost 30,000 to a total of 96,000 vehicles.



Table 1: Stock of private battery electric and chargeable private vehicles (*thousands*) in Norway

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Battery Electric	3.3	5.4	9.6	19.7	42.4	73.3	101.1	138.5	194.9
Plug-in hybrid				0.7	2.4	12.1	34.4	67.2	96.0

Source: Norsk elbilforening (elbil.no)

The most popular battery electric vehicle models are the Nissan Leaf (25% of the fleet at the end of 2017), Volkswagen e-Golf (17%) and Tesla Models S (11%) (Figenbaum, 2018).

The rapid increase in stocks is reflected in an increase of electric vehicles in the share of new vehicles. Table 2 hereunder shows the shares of battery electric and hybrid vehicles in total sales of new private vehicles in the period 2010-2018. The shares have been steadily increasing and in 2018, 31 per cent of all new private vehicles were battery electric while 17 per cent were plug-in hybrids, in total making up 48 per cent of all new vehicles. The remainder consisted of petrol (22%), diesel (18%) and non-chargeable hybrids (11%) (elbil.no).

Table 2: Share of total sales of new private vehicles (*per cent*) in Norway

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Battery Electric	0	1	3	6	13	17	16	20	31
Plug-in hybrid				0	1	5	13	18	17

Source: Norsk elbilforening (elbil.no)

At the end of 2018, 7.2 per cent of all private vehicles were battery electric, while 3.5 per cent were plug-in hybrids (elbil.no). The rest were mainly diesel (46.4%) and petrol vehicles (39.5%).

Electric vehicles tend to be concentrated in central areas, around major cities. Table 3 shows the share of battery electric vehicles by region (county) for both stock and new sales. The highest numbers are found around Oslo (Akershus and Oslo), Bergen (Hordaland), Stavanger (Rogaland), Kristiansand (Vest-Agder) and Trondheim (Trøndelag), while the numbers are lowest in more sparsely populated areas in Northern Norway (Nordland, Troms and Finnmark).

Table 3: Battery electric vehicles as share of total vehicles by Norwegian region (31.12.18)

	Akershus, Oslo, Hordaland	Vest-Agder, Rogaland	Buskerud, Telemark, Vestfold, Østfold, Aust-Agder	Møre og Romsdal, Sogn og Fjordane, Oppland, Hedmark	Trøndelag	Nordland, Troms, Finnmark
Share of stock	11.5-12.5	7.8-8.6	4.6-5.7	2.4-3.3	6.0	0.7-3.3
Share of new*	36.4-42.4	26.4-38.2	20.8-26.1	19.7-22.7	30.4	7.2-23.9

* Private vehicles only.

Source: Norsk elbilforening (elbil.no)

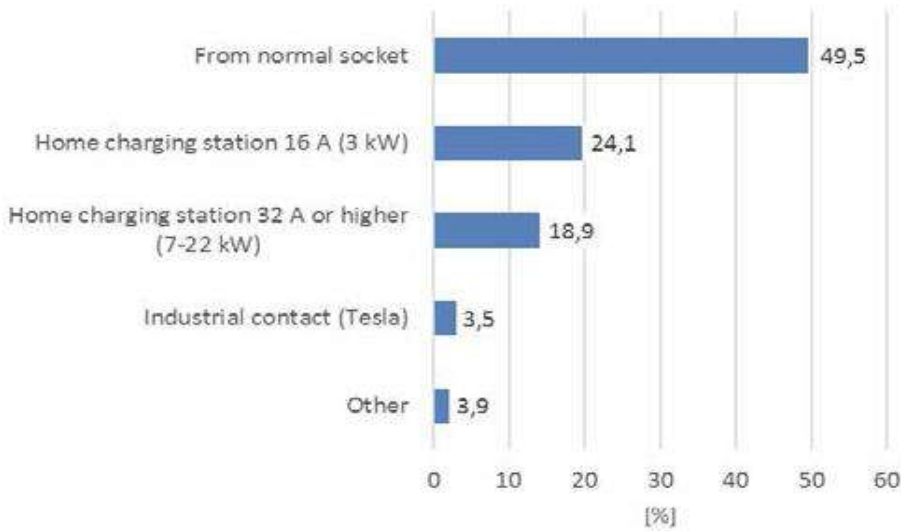


Norway is probably one of the countries in Europe where establishing a basic charging infrastructure for electric vehicles is least challenging (Figenbaum, 2018). 75 per cent of all households can park a vehicle directly on their own land, and a further 12-13 per cent can park in their own parking space less than 100 meters from home. Most households in Norway rely on electricity for space heating and with 10A or 16A connections have sufficient capacity to handle a 2-3 kW electric-vehicle charger. Newer houses with a 32A or 64A three-phase connection can handle a 7-11 kW charger. Most electric vehicles and chargers can be programmed to charge at night in low-cost and low-demand periods and to reduce peak loads.

Home charging in apartment buildings and other types of houses where parking is in shared facilities has proved more difficult (Figenbaum, 2018). Dedicated electricity outlets may not be available and the electrical system may not be able to handle the increase in power demand. There have also been conflicts between those sharing parking facilities about who should bear the cost of installing and using chargers, and how allocation of available power between users should be undertaken when the capacity of the charging station is reached (see below on government initiatives to overcome such difficulties). By the beginning of 2018, electric vehicle chargers were installed in only 18 per cent of housing cooperatives and condominiums. Neighbourhood on-street home-charging is even less common and very few electric-vehicle owners rely on such charging (Figenbaum and Kolbenstvedt, 2016).

According to survey results presented in Sæle and Petersen (2018), 50 per cent of respondents use a normal socket (typically 10A) when charging at home, while the rest have some type of charging station or industrial contact (16A, 32A or higher), as shown in Figure 1 hereunder.

Figure 1: Different home charging types available in Norway



Source: Sæle and Petersen (2018)

Many employers offer charging at the work place. According to Figenbaum and Kolbenstvedt (2016), 28 per cent of electric-vehicle owners use such charging facilities on a daily basis and a further 10 per cent on a weekly basis (see also below).

Electric vehicle charging stations have been built rapidly over recent years. By February 22, 2019, there were a total of 12,464 charging points in Norway, spread over 2,462 charging stations. Of these charging points, 11,139 were public, i.e. available to anybody. Fast chargers intended for vehicles from Japanese manufacturers (CHAdeMO) and European manufacturers (CCS) are about



equal in numbers, having grown in parallel in recent years. Tesla has built its own proprietary network of charging stations, covering essentially all main routes in Norway.

Table 4: Public charging points by type (Norway)

	2011	2012	2013	2014	2015	2016	2017	2018
Normal	3 105	3 688	4 511	5 471	6 253	6 413	7 141	7 910
CHAdeMO 50 kW+	18	58	83	140	284	516	843	1 103
CCS 50 kW+			4	76	224	477	796	1 087
Type 2 43 kW				40	104	65	48	49
Tesla super charger			44	132	190	228	338	562

Source: Norsk elbilforening (elbil.no)

Charging stations are built and operated by both public authorities (mostly municipalities) and private companies including electricity retailers (distribution companies are barred from this competitive business). Stations typically offer a range of chargers (normal, CHAdeMO and CCS), different payment schemes and various payment methods, including via SMS and freely available apps. Fortum Charge & Drive – a subsidiary of the electricity company Fortum – is the largest operator of fast-charging stations in Norway. It runs around 300 stations. Charging is paid for by the minute and depends on payment method (app, chip or SMS) and charging speed/power. Customers with electricity supply contracts with Fortum are offered a rebate on charging. The other operators offer similar payment schemes, although not all offer different payment methods or a range of charging speeds. Grønn Kontakt, the second largest operator with around 200 charging stations, has introduced a rebate scheme, with up to 40 per cent reduction in price depending on the size of the customer’s total monthly electricity bill.

2.4. Policies supporting the adoption of electric vehicles

To achieve its target to promote low- and zero-emissions vehicles, the National Transport Plan outlines the following principles:

- The purchase cost of low- and zero-emissions vehicles should be competitive compared to the cost of conventional vehicles.
- The user cost of low- and zero-emissions vehicles should be less than that for conventional vehicles.
- When there is lack of road capacity (queuing) or space (parking) zero-emissions vehicles should be prioritised.
- Power-charging facilities or fuel supply for zero-emissions vehicles should be easily available to facilitate long-distance trips and to avoid unacceptable waiting times.

The above principles are already embedded in national transport policies. Initiatives to promote zero-emissions vehicles – especially electric vehicles – were first introduced in the 1990s. A wide range of electric vehicle friendly policies have been added in subsequent years. Table 5, which with slight modifications is adopted from Figenbaum (2018)¹⁰ summarises the policy instruments in place to promote electric vehicles in Norway.

From an economic point of view, the most important policies are the fiscal incentives associated with exemptions from registration and value added taxes (VAT) (Fridstrøm and Østli, 2017). Battery electric and hydrogen vehicles are exempt from vehicle registration tax. Plug-in hybrids are

¹⁰ See also Figenbaum, Assum, and Kolbenstvedt, 2015.



not included in this scheme, but as the tax is based on engine power as well as CO₂ and NO_x emissions, the total tax is also low for this type of vehicle. In addition, battery electric vehicles are exempted from the 25 per cent VAT. According to figures referred to in Bjerkan, Nørbech and Nordtømme (2016), battery electric vehicles would have been between 30 and 100 per cent more expensive without these policies, depending upon their overall cost. In other words, these policies tend to reduce the price of a battery electric vehicle by between a fifth and a half.¹¹ As a result, battery electric vehicles' prices are competitive, when compared with prices of corresponding vehicles running on traditional fuels (Figenbaum, 2018).¹²

The high taxes on fossil fuels, in combination with the relatively low electricity prices in Norway, provide further economic incentives for the adoption of electric vehicles; according to Figenbaum and Kolbenstvedt (2015), the energy cost saving of running a vehicle on electricity instead of fossil fuels in Norway is the largest in Europe (e.g. twice that of Germany).

Some of the subsidy schemes – such as toll road exemptions, reduced rates on ferries and free parking – are at the discretion of local authorities, albeit with government limits. Since 2017, electric vehicles pay a maximum of 50 per cent of the rates paid by conventional vehicles on toll roads, ferries and municipal parking spaces. Furthermore, local governments may put restrictions on access to bus lanes when these become congested. For example, in Oslo, there is a requirement that electric vehicles must carry one passenger (in addition to the driver) in order to use bus lanes during rush hours.

Table 5: Policies to promote electric vehicles in Norway

YEAR OF INTRODUCTION	POLICY INSTRUMENT
FISCAL INCENTIVES	
1990	Registration tax exemption
2001	VAT exemption
1996/2004	Reduced annual vehicle license fee
2000	Reduced company car tax
2018	Re-registration tax exemption
DIRECT SUBSIDIES	
1997	Toll road exemption (max 50% of rate for conventional cars)
2009	Reduced rates on ferries (max 50% of rate for conventional cars)
2009	Financial support for charging stations
2011	Financial support for fast-charging stations
ACCESSIBILITY	
1999	Free parking (max 50% of rate for conventional cars)
2003/2005	Access to bus lanes (restrictions if buses are delayed)

Source: Figenbaum (2018)

¹¹ For example, the price of a Tesla S is reduced by 50 per cent, while that of a Nissan Leaf is reduced by 20 per cent.
¹² Figenbaum (2108) presents calculations suggesting that ownership costs (incl. financial costs and depreciation) are also lower for electric vehicles than for conventional vehicles.



Bjerkan, Nørbech and Nordtømme (2016) investigate the role of seven different incentives to promote electric vehicles based on a membership survey by the Norwegian Electric Vehicles Association (Elbilforeningen). They find that exemptions from purchase tax and VAT are critical for more than 80 per cent of the respondents. However, to a substantial number of electric-vehicle owners (mostly residing in the suburbs of main cities), exemption from road tolls or bus lane access is the only decisive factor.

Based on survey data, Figenbaum and Kolbenstvedt (2016) estimate the value of local incentives for the average electric-vehicle owner to be €1,500 per year, of which toll roads accounted for 50 per cent, time savings in bus lanes for about 30 per cent, free parking for another 16 per cent and ferry rates for about 4 per cent. Around 10 per cent of respondents claimed to receive no benefits from these incentives, whereas a similarly sized group valued the benefits at more than €5,000 per year. The higher values were found around the largest cities, providing a plausible explanation for why take-up rates of electric vehicles have been particularly high there (cf. Table 3 above).

There is no specific regulation or public support for installations of chargers in private homes in Norway (Figenbaum, 2018). There are, however, a number of local-authority programmes to support chargers in apartment buildings. These programmes differ across municipalities but, typically, they are based on application and provide financial support for charging infrastructure investment.¹³ The government recently introduced regulations stating that, in co-owned housing facilities, owners may require that charging stations be put in place. The government has also suggested that this regulation be extended to include housing co-operatives.

Parking regulations require that 6 per cent of the total number of parking spaces in private and public parking lots be supplied with charging infrastructure.

The government has had support programs for fast-charging stations since 2011 (Figenbaum, 2018). In the beginning, there were no restrictions on the geographical placing of charging stations. This policy has gradually evolved due to the development of deployment strategies, now mainly aimed at ensuring sufficient coverage on all main routes. Several rounds of public tenders have resulted in a basic network of chargers every 50 km along all major transport corridors from the south of Norway to Tromsø in the north. The northernmost region of the country did not attract bidders and has no fast-charging stations, but Enova – the government entity running the electrification support programmes – is opening new tenders in 2019 and 2020 to cover this region and others with little or no availability of charging infrastructure (enova.no). Further support is provided by local authorities. However, a considerable number of charging stations have been set up without any public support, especially in cities (where such support is not available).

Charging stations are connected to the electricity grid at the distribution level, which in Norway is defined to be that part of the grid carrying a voltage of up to 22 kV (see also below). Network owners are obliged to accept requests for connection of charging stations on the same terms as those offered to commercial (or non-household) users. Users are required to cover all connection costs, including upgrades of the network that are triggered by the connection. The so-called "anleggsbidrag" (investment contribution) allows the network company to impose on a user the actual cost of a new connection to the network. This is also the case for an increase in the capacity or in the quality of an existing connection.¹⁴ There is no regulation concerning where charging stations may be placed – they may be placed anywhere the owner of the connection station can obtain the right to place them, including on public parking spaces – but the economic incentive

¹³ For example, the municipality of Oslo finances up to 20 % of investment costs (max NOK 2,000 (≈ EUR 200) per charging point and NOK 1,000,000 (≈ EUR 100,000) per applicant) in existing buildings (buildings under construction are not covered).

¹⁴ The regulation of the investment contribution has recently been revised, making the contribution mandatory and extending its use also to regional and transmission networks, cf. NVE (2018a, b).



arising from connection charges encourages placing them where the costs imposed on the network are relatively small.

Bjerkan, Nørbech and Nordtømme (2016) do not include charging infrastructure in their formal analysis of the role of different incentives to promote electric vehicles. Their data does, however, indicate that charging infrastructure has a lower importance for purchase decisions than other incentives. This may be explained by the fact that a majority of Norwegians live in row houses, family homes and detached and semi-detached houses, where in-house charging is normally available and, hence, access to public infrastructure for normal charging is not crucial.

Figenbaum and Kolbenstvedt (2016) report that the availability and quality of charging infrastructure appears to be only a small problem. 83 per cent of the respondents in their study have never had to avoid a trip due to insufficient charging infrastructure or because the range of the vehicle was too short. Only 6 per cent have had to abort a trip due to such problems. This may not only be due to the availability of charging stations, but also to self-selection (one only buys an electric vehicle when their driving pattern is compatible with the capabilities of such vehicles) and to the fact that people carefully plan their trips and switch mode of transport when necessary (in multi-vehicle households, by using a conventionally-fuelled vehicle).

2.5. Consumer response

Electric vehicles tend to be driven as much as vehicles running on conventional fuels. In 2017, diesel vehicles were on average driven 15,100 km and petrol vehicles 9,100 km, while electric vehicles were driven 11,800 km over the year.¹⁵ The figure for electric vehicles is affected by the strong growth in the number of such vehicles, meaning that many were only used for part of the year. 11,800km is hence an underestimation of the typical annual use of electric vehicles. Survey results among car owners confirm the similarity in driving patterns across different types of vehicles, although electric vehicles tend to be used more in everyday traffic than other types of vehicles (Figenbaum and Kolbenstvedt, 2016).

Figenbaum (2018) argues that electric vehicles are typically used for local transport, often as the "secondary" vehicle in multi-vehicle households (according to Figenbaum and Kolbenstvedt, 2016, 79% of electric-vehicle owners have more than one vehicle at their disposal; the additional vehicles are typically conventionally-fuelled).¹⁶ By studying toll road data, he presents evidence supporting the view that electric vehicles are mostly used locally. In particular, within a given region, the share of electric vehicles passing a toll station is higher for stations located in urban areas than for stations located in rural areas. These results are supported by survey evidence, showing that electric vehicles are used more frequently than conventional vehicles for commuting, as well as for local visits, shopping and leisure and when transporting children, but less for vacations and longer trips (Figenbaum and Kolbenstvedt, 2016).

The usage pattern may go a long way in explaining why charging of electric vehicles mostly occurs at home. Based on surveys among members of the Norwegian Electric Vehicles Association conducted in 2017 and 2018, Sæle and Petersen (2018) found that owners tend to charge their vehicles at home.¹⁷ As seen in Figure 2, 59 per cent of respondents living in single-family houses, row houses or similar accommodations charge at home on a daily basis, while 25 per cent do so on a weekly basis. The numbers are considerably lower for respondents living in housing cooperatives (78% of these never charge at home), presumably because access to charging is more difficult

¹⁵ <https://www.ssb.no/transport-og-reiseliv/artikler-og-publikasjoner/sterk-vekst-i-kjoringen-med-elbiler-og-hybrid>

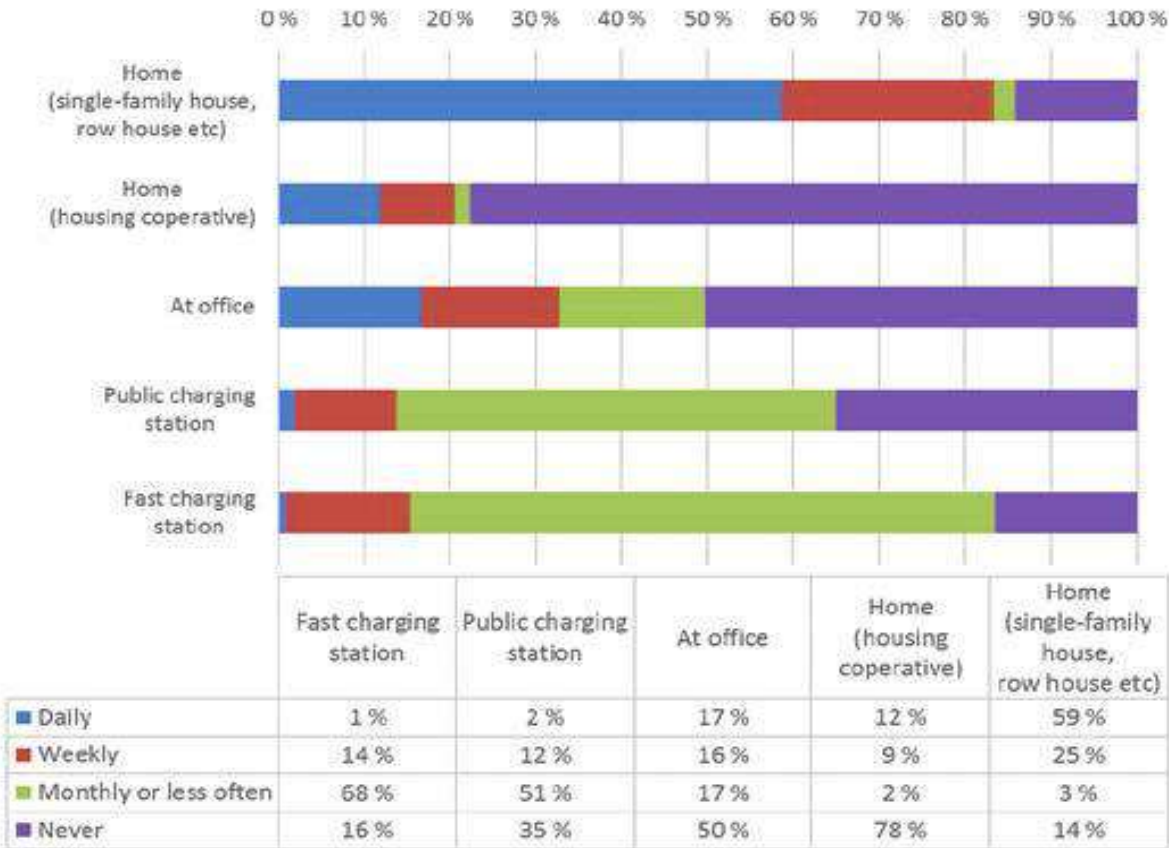
¹⁶ For comparison, in 2018 only 17% of all households had more than one vehicle (of any type), while 26% of all households which owned a vehicle possessed more than one vehicle (Fjørtoft and Piiskog, 2019). Moreover, ownership of electric vehicles is concentrated among the rich: 16% of households in the highest income quartile owned an electric vehicle, compared to 0.6% in the lowest income quartile and an overall average of 6%.

¹⁷ These results are in accordance with those reported by Figenbaum and Kolbenstvedt (2016).



there. Charging at fast and public charging stations is done less frequently, with more than 80 per cent of the respondents doing so only monthly or less often. Such charging – which tends to be about four times as costly as home charging – mostly takes place on longer trips (Figenbaum, 2018). Half of the respondents charge at work, but only 17 per cent on a daily basis. Based on a number of studies, Skotland, Eggum and Spilde (2016) assume that, in Norway, 75 per cent of the energy used to charge electric vehicles is consumed at home, 15 per cent at work and 10 per cent at fast-charging stations.

Figure 2: Charging at different locations (Norway)

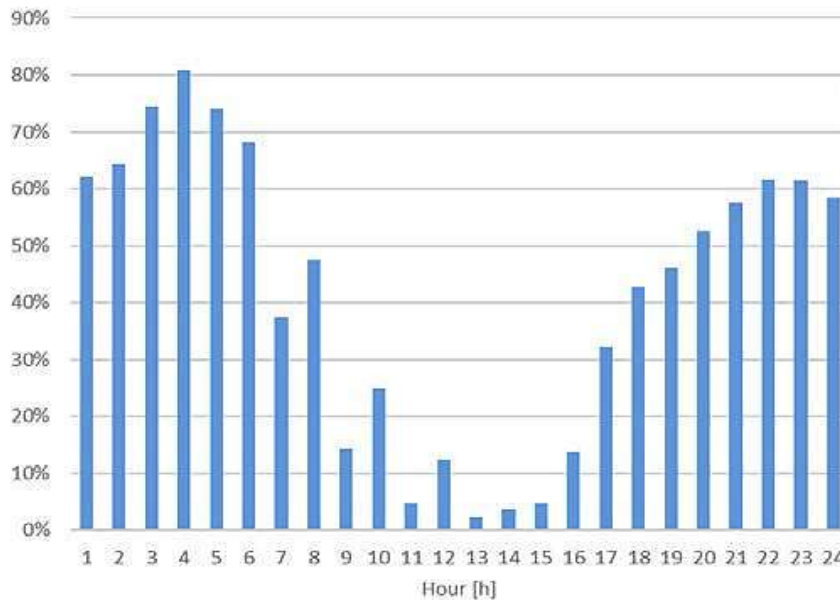


Source: Sæle and Petersen (2018)

Sæle and Petersen also found that home charging tends to take place in the evening and at night. Figure 3 gives the fraction of respondents charging at home at a given time of the day. It shows that 60 per cent or more charge in the late evening or at night and only very few during typical office hours. A considerable share of respondents charge their vehicles during hours when total electricity demand is peaking, i.e. in the morning, afternoon and early evening.



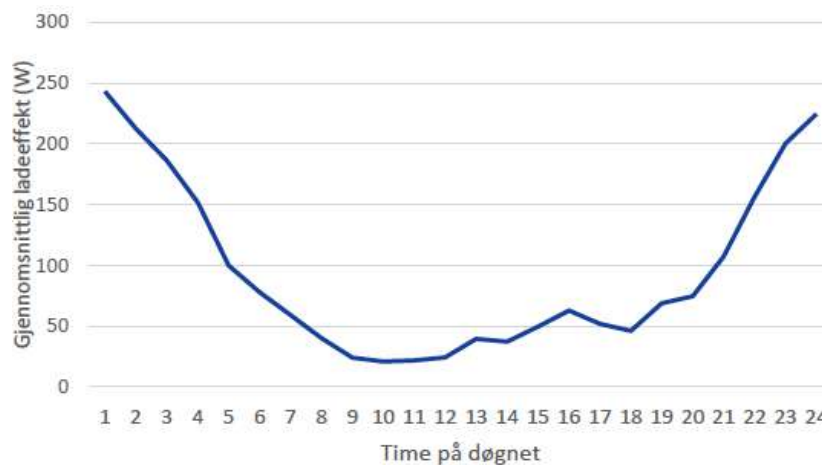
Figure 3: Time of the day home charging in Norway



Source: Sæle and Petersen (2018)

These results conform with profiles based on actual measurement of a group of home chargers (Skotland, Eggum and Spilde, 2016). Figure 4 shows the average power consumed in charging electric vehicles, hour by hour over the day, where the average is taken both over the group of chargers and the days of the measurement period. The figure may thus be interpreted as the average home charging power consumed by an electric vehicle owner on any given day. Again, most charging takes place outside of office hours, with a clear peak around midnight. It may be noted that the average charging power is very low compared to the typical power demand of Norwegian households, which can easily reach 4 kW or more in the cold season. This is due to the fact that charging of vehicles does not take place every day.

Figure 4: Time of day home charging in Norway



Source: Skotland, Eggum and Spilde (2016)

In comparison, the charging pattern at fast-charging stations is very different (Skotland, Eggum and Spilde, 2016), with a peak around 5:00pm. There is little difference in the use of fast chargers



between weekdays and weekends and between seasons. Charging at work starts around 6:00am, increases steadily until 9:00am and then gradually falls off until the end of the workday.

2.6. Impact on the grid

The Norwegian electricity grid is organised around three levels: the transmission grid, the regional grids and the distribution grids (energifaktanorge.no). Both the regional and the distribution grids are distribution systems, as defined by EU legislation. The transmission grid carries a high voltage, of usually 300 to 420 kV, although in certain parts of the country, there are also lines carrying 132 kV. The regional grid carries a voltage of 33 to 132 kV. It often links the transmission grid with the distribution grid and may also include production and consumption radials carrying higher voltages. The distribution grid carries a voltage of up to 22 kV and consists of the local electricity grids that normally supply power to smaller end users – i.e. households –, service industries and small-scale manufacturing. The low-voltage distribution to ordinary customers normally carries 230 or 400 V.

Until now, it would seem that electric vehicles have presented only minor challenges to the electricity grid. Overall, the charging of electric vehicles in Norway has only added a small fraction to the overall electricity demand (less than 1 per cent measured in energy) and hence has only minor effects in the aggregate, i.e. at the regional and transmission levels of the network. Furthermore, since distribution networks are strong – built so as to accommodate electric space heating in homes and offices – both connections and other infrastructure have had sufficient capacity to accommodate the demand from electric vehicle charging. Finally, since network owners are allowed to charge for upgrades associated with new or stronger connections, they have been able to finance new investment where it has been warranted.

So far, due to the ability of the network to accommodate the charging of electric vehicles – as well as the relatively modest short-term (hour to hour) variations in prices in the hydro-dominated Norwegian electricity market – there is little use of "smart" technologies aimed at shifting demand to avoid capacity constraints or high-price periods.

2.7. Future outlook

As set out in the section on policy drivers (Section 2.2), the Norwegian government aims at ensuring that all new passenger vehicles and light vans sold in 2025 be zero-emissions vehicles, that all new urban buses sold in 2025 be zero emitters or use biogas, and that, by 2030, all new heavy-duty vehicles, 75 per cent of new long-distance coaches and 50 per cent of new trucks be zero-emissions vehicles.

According to studies commissioned by the Norwegian Water Resources and Energy Directorate – the regulator – the electrification of the transport sector according to these goals will have little impact on the transmission network with respect to capacity needs, flows or bottlenecks (Skotland and Spilde, 2017). The main reason is that the resulting increase in demand for electricity remains modest relative to the overall consumption.

However, matters may be different at the regional level (where voltage levels are between 33 and 132 kV). Skotland and Spilde (2017) summarise the results of studies conducted by various network companies on how the electrification of the transport sector would affect their grids towards 2030. Those studies were based on the assumptions that the number of electric vehicles (incl. plug-in hybrids) would be quintupled (i.e. 50% of private vehicles would be electric) and that the number of fast-charging stations would be quadrupled. Another assumption was that city busses and two out of three ferries would be electric, while facilities to cover the electricity needs



of ships in ports (incl. for charging) would be installed in all major harbours.¹⁸ The results of the studies showed that the maximum power consumption would increase by between 5 and 15 per cent, depending on the region. Most of the network capacity required due to the electrification of the transport sector would however be met by investment undertaken for other reasons (re-investment, general demand growth and connection of new generation). Where transport electrification itself triggers new investment is mainly in connection with electric facilities for ferries and ships, where power requirements are particularly high and concentrated.

In an earlier study, the impact of transport electrification on distribution networks (voltage levels below 22kV) was considered (Skotland, Eggum and Spilde, 2016). This study is limited to the impact of electric vehicles, based on the same assumption as above, i.e. that half of the fleet of private vehicles will be electric by 2030. Such an increase in the number of electric vehicles is estimated to increase electricity consumption by 4 TWh per year, i.e. about 3 per cent of the total annual consumption. The maximum energy consumption per hour would be 700 MWh and would occur at night. Compared to an average maximum consumption of 4 KWh/h for households on a cold day (with a peak at 7:00pm), the charging of electric vehicles would increase the maximum by approximately 0.5 kW on average. Based on assumptions on the location of electric vehicles and their charging patterns, as well as detailed information on distribution networks, Skotland, Eggum and Spilde found that, in most areas, the distribution network is sufficiently robust to handle the increase in demand from electric vehicles. However, in areas with low network capacity, a high share of electric vehicles and a high correlation in charging behaviour among electric vehicle owners, both transformers and lines may be overloaded. In areas with weak distribution networks, quality of supply (i.e. voltage level stability) may also be challenged.¹⁹ Since much of the distribution network will be replaced in the years up to 2030 due to age, it is argued that the necessary up-grading may be taken care of as part of this process.

Both Skotland, Eggum and Spilde (2016) and Skotland and Spilde (2017) argue that the impact on networks may be mitigated by exploiting new technology, allowing for more sophisticated tariffing and shifts or reductions in (power) demand.

Figenbaum (2018) questions the realism of the Norwegian transport electrification policy. He argues that the penetration of electric vehicles is the result of strong incentives and of a stable long-term policy, but that this is not enough to meet the target of only selling zero-emissions vehicles by 2025. Until now, the main electric vehicle user group has been multi-vehicle households that have replaced one conventional vehicle with an electric vehicle. After 2025, all single-vehicle households must buy electric vehicles, and electric vehicles must replace all vehicles in multi-vehicle households. New electric vehicles with longer range coming on the market may help, but traffic on peak travel days could become a major barrier. As it may not be economically sensible to build charging infrastructure capacity to absorb these peaks, users will be confronted with a trade-off between daily cost and time savings on the one hand, and longer stops and charging queues on long distances, on the other.

Wangsnæs, Proost and Rødseth (2018) argue that current policies may lead to a massive penetration of electric vehicles but also to much more congestion and a decrease in the use of public transport.²⁰ Better policies require an efficient pricing of road congestion, a greater use of

¹⁸ Due to considerable uncertainty about likely developments, the electrification of commercial vehicles, long-distance busses, construction equipment and machinery, trains, airplanes and high-speed passenger ferries is not taken into account.

¹⁹ Electrical equipment such as electric vehicle chargers represents more of a challenge for supply quality in Norway than in other European countries (Skotland, Eggum and Spilde, 2016) due to the fact that about 70% of the distribution network in Norway is of the 230 V IT type, as opposed to the 400 V TN type that is common in other countries, and which most electrical equipment, including chargers, is built for.

²⁰ Fridstrøm and Østli (2017) undertake a cost-benefit analysis of the Norwegian electric vehicles policy, concluding that the cost per tonne CO₂ is moderate to high.



public transport and incentives for consumers to choose the most efficient combination of vehicles. Such policies may result in a less extreme penetration of electric vehicles, but will achieve a better transport equilibrium and substantial resource cost savings, leading to higher welfare levels.

In sum, irrespective of exactly how policies will develop, it would seem that, over the foreseeable future, electric vehicles will not pose a serious threat to the Norwegian electricity system.

2.8. Conclusion

Norway possesses some unique characteristics that are important to account for in a study on how electric vehicles may affect the electricity system there. On the one hand, the penetration of electric vehicles is higher than anywhere else. Almost one out of ten of all vehicles – and almost half of all new vehicles – are now electric. On the other hand, thanks to the availability of cheap hydro power, the electricity system has been designed to be able to support electric space heating in a cold climate. While the first characteristic implies that electric vehicles may become a challenge for the electricity system, the second one entails that the electricity system has been able to accommodate high levels of electric vehicle penetration – even with relatively light-handed regulation on location and capacity of charging infrastructure. Furthermore, due to the relatively modest short-term variations in electricity prices, there is little use of "smart" technology to shift demand to avoid capacity constraints or high-price periods so far.

The unique characteristics of Norway make it difficult to generalise its experience. Nevertheless, the latter does suggest that electric vehicles may be well accommodated by electricity systems, given reasonable levels of penetration and sufficient time to respond to the resulting demand for electricity. In particular, we point to the following insights:

- In the aggregate, the electricity demand from the charging of electric vehicles is modest, even at high penetration rates. As a consequence, electric vehicles pose limited challenges for the high-voltage parts of the electricity network.
- The charging of electric vehicles mostly occurs at home and outside of office hours and periods of peak demand. With "smart" technologies, the scope for moving charging to periods when overall demand on the network is relatively small will increase further.
- Robust distribution networks can accommodate even quite high numbers of electric vehicles without capacity expansion. In weaker parts of such networks, upgrading will be necessary to accommodate the increased demand from electric vehicles.
- Connection charges may be designed so as to cover the costs of connecting chargers for electric vehicles and hence finance the necessary network upgrades.

03

**CASE STUDY II:
THE NETHERLANDS**

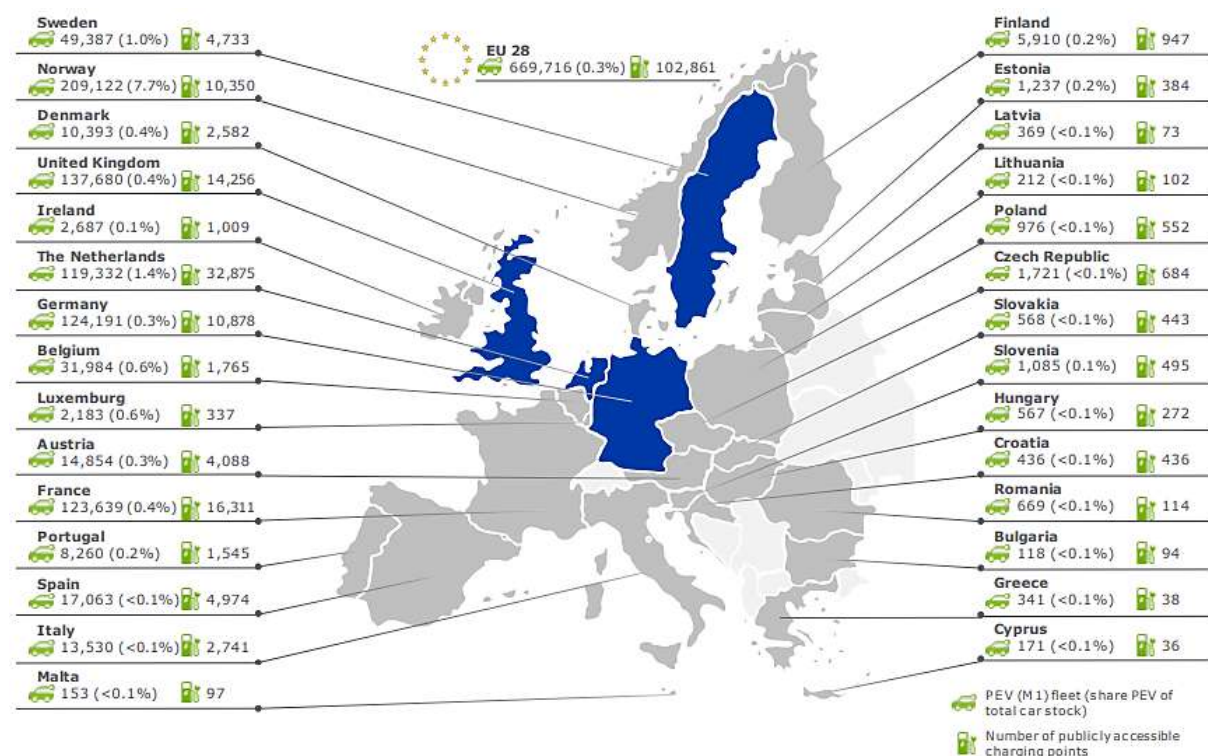
3. Case Study II: the Netherlands

3.1. Introduction

One of the front runners in electric vehicles deployment is the Netherlands where, according to 2017 data (Figure 5), the share of plug-in electric vehicles over the total stock of registered passenger vehicles was 1.4 per cent (Ecofys and Navigant Research, 2018).

In 2018, electric vehicle sales (including battery electric vehicles, plug-in electric vehicles and fuel cell electric vehicles) constituted 6.5 per cent of all new registrations in the Netherlands. The Tesla Model S and Mitsubishi Outlander were the two most popular models, with 12,646 registered Tesla S and 23,592 Mitsubishi Outlander in April 2019 (NEA, 2019). The country has set a goal of having 1 million electric vehicles on the roads by 2025 (Longo et al., 2015) and an ambition that, by 2030, only zero-emissions cars will be sold (NEA, 2018). In 2018, battery electric vehicles constituted 5.6 per cent of all new registrations (NEA, 2019).

Figure 5: Number of private electric vehicles and publicly accessible charging points in Europe (EU28 and Norway) 2017



Source: Ecofys and Navigant Research, 2018

There is a clear idea for the development of e-mobility in the Netherlands since 2016, when a vision for charging infrastructure was made public.²¹ This vision was based on a study prepared by Ecofys and the Eindhoven University of Technology. It proposed developing the charging infrastructure and making the business case viable through cost reduction achieved thanks to innovation and efficiency improvements (NEA, 2017).

²¹ In November 2016, the Minister of Economic Affairs informed the Dutch House of Representatives by letter about the cabinet’s vision for the charging infrastructure for electric transport (NEA, 2017).

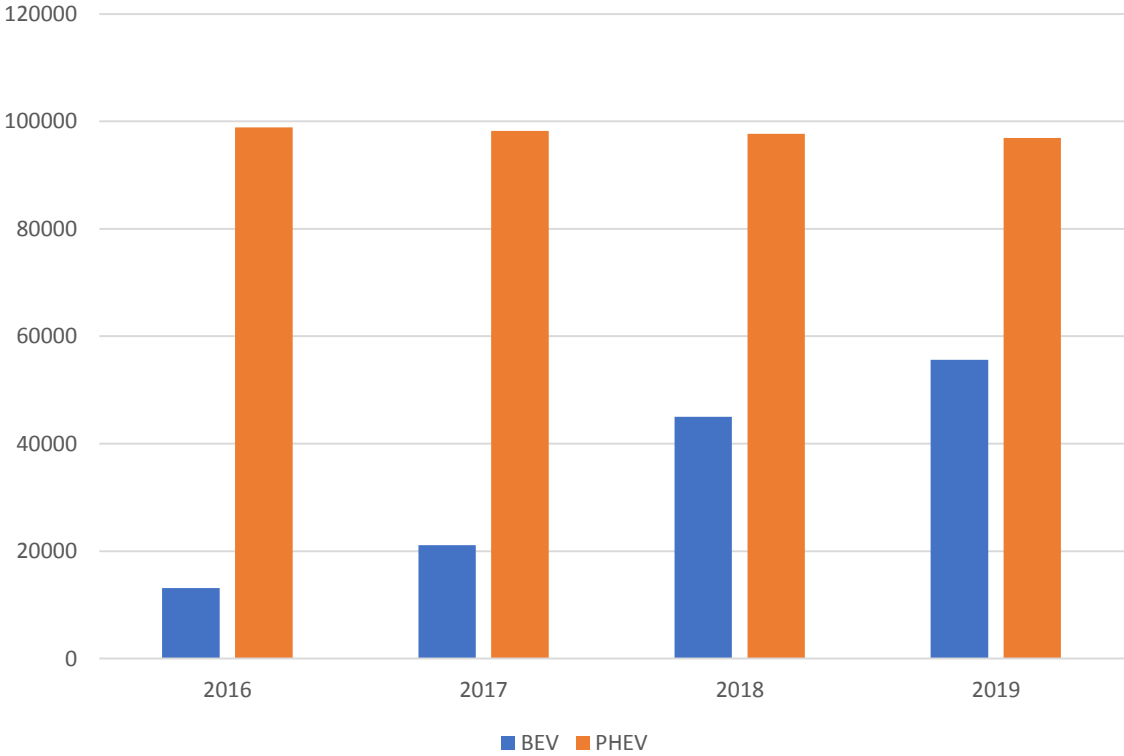


In accordance with the EU objectives to reduce CO₂ emissions in the transport sector, the goal of the Netherlands is to decrease its carbon dioxide emissions by 17 per cent by 2030 as compared with 1990 and by up to 60 per cent by 2050. The Dutch mobility and transport sector agreement is part of the Energy Agreement signed by forty-seven organisations in 2014.²²

3.2. Current status

In the first half of 2019, the Netherlands reached the milestone of more than 150,000 registered electric vehicles (see Figure 6). Out of these, around two-thirds are plug-in hybrid electric vehicles. The initial increase in the number of plug-in electric vehicles between 2012 and 2014 is linked with tax incentives successfully targeted towards company cars. Dimitropoulos (2016) indeed reports that 95 per cent of the total number of plug-in electric vehicles registered in the Netherlands in 2013 were company and fleet cars. After an initial fast growth, the number of plug-in electric vehicles has remained approximately constant since the end of 2016 (NEA, 2019).

Figure 6: Number of battery-only electric vehicles and plug-in hybrid electric vehicles in Netherlands



Source: NEA, 2019

The most popular battery electric vehicle remains Tesla, with 12,646 cars on the roads, and the Nissan LEAF, with 6,611 – the number has doubled since 2018 (see Figure 7 hereafter).

²² <https://www.eesc.europa.eu/ceslink/resources/docs/netherlands---agreement-on-energy-policy-in-practice.pdf>



Figure 7: Top 10 models of battery electric vehicles registered in the Netherlands

Brand/Model	Type of vehicle	Number	Since last month (MtM)	Since the same month in the previous year (YtY)
Tesla Model S	Passenger Car (BEV)	12,646	-73	3,822
Nissan Leaf	Passenger Car (BEV)	6,611	251	3,769
Volkswagen Golf	Passenger Car (BEV)	4,812	229	2,660
Tesla Model X	Passenger Car (BEV)	4,642	2	2,581
Renault Zoe	Passenger Car (BEV)	4,209	123	1,458
BMW i3	Passenger Car (BEV)	4,178	179	1,982
Jaguar I-Pace	Passenger Car (BEV)	3,580	23	3,580
Tesla Model 3	Passenger Car (BEV)	3,173	463	3,173
Hyundai Ioniq	Passenger Car (BEV)	2,810	63	1,210
Hyundai Kona	Passenger Car (BEV)	2,157	370	2,157

Source: NEA, 2019a

3.3. Policies supporting the adoption of electric vehicles

The 2030 target of all new passenger cars being purely electric is aimed at through central government and local government initiatives. In order to encourage electric driving, the Dutch government introduced various tax incentives, such as total exemption from registration fees and road taxes for electric vehicles before 2014, which is to be retained for zero-emissions cars until 2024 (NEA, 2019). Since 2015, plug-in hybrid vehicles have been subject to both registration tax and road tax. However, the value of these taxes depends on the emissions level. In 2016 and 2017, the total exemption from the road tax was retained for vehicles with zero carbon emissions and a 50 per cent exemption was allowed for vehicles with carbon emissions of 1 to 50 grams per kilometre (NEA, 2017; NEA, 2018). The 2016 and 2017 fiscal stimulus package also included an exemption from purchase tax on zero-emissions passenger motor vehicles and motorcycles. Vehicles with carbon emissions of 1 to 79 grams per kilometre were liable to the lowest purchase tax, which started at €175 plus €6 per gram of CO₂ emission (NEA, 2018), which was later amended to include three tax brackets for different levels of carbon emissions, from 1-30 g/km to over 50 g/km²³ (NEA, 2018).

Additionally, drivers of lease battery electric vehicles and plug-in electric vehicles (with carbon emissions of 1 to 50 grams per kilometre) were liable to respectively: 4 and 7 per cent addition to taxable income (NEA, 2016) which in case of plug-in electric vehicles in 2016 increased to 15 per cent (NEA, 2017) and in 2017 became the same as for all other vehicles, i.e. 22 per cent (NEA, 2018). The amendments to these tax incentives targeted towards plug-in company cars were announced in 2015 and led to situations where consumers purchased cars before the new, less beneficial rules came to life, therefore creating a steep increase in the number of plug-in electric vehicles in the Netherlands in 2015.²⁴

The environmental investment rebate (MIA) is another part of the stimulus targeting battery electric vehicles and plug-in electric vehicles with maximal carbon emissions of 30 grams per kilometre. It offers owners of such vehicles an option to deduct up to 36 per cent of the investment

²³ The detailed tax brackets are as follows: tax bracket 1 (1 - 30 g/km): €19 per g of CO₂; tax bracket 2 (31 - 50 g/km): €85 per g of CO₂; tax bracket 3 (> 50 g/km): €282 per g of CO₂.

²⁴ <https://www.cbs.nl/en-gb/news/2018/21/number-of-all-electric-cars-increasing-rapidly>



costs for an environmentally friendly investment on top of their regular tax deductions for investments (NEA, 2018).²⁵ The MIA and Vamil²⁶ (Random Depreciation of Environmental Investments) tax, which are thought to boost investment in environment-friendly operating assets, can also be used in case of constructing private charging points for lease cars on a company's own site (MEA, 2017).

Another initiative that facilitates cooperation between private firms, civil society organisations, and local and regional governments is the concept of "Green Deal", which is a joint initiative set up by the Dutch Ministries of Economic Affairs (EZ), of Infrastructure and the Environment (I&M) and of the Interior and Kingdom Relations (BZK). It is an agreement under private law between various partners who cooperate with the aim to remove barriers encountered during implementation of various innovations (Green Deal, n.d.). Over the years, there have been many Green Deals spanning over 9 themes: among others, energy and biodiversity, mobility, resources and climate. "Between 2011 and 2014, 176 Green Deals were closed involving 1090 participants" (Green Deal, n.d.).

In April 2016, the then Dutch Minister of Economic Affairs, Henk Kamp, signed the Electric Transport Green Deal for 2016-2020 along with 17 other parties. The aim of this cooperation was to smooth the transition to e-mobility (NEA, 2017). A year earlier, with the aim to enable a rollout of public charging stations, the Dutch government had set up a budget of €5.7 million as part of the Publicly Accessible Electric Charging Infrastructure Green Deal. The initiative was successful and the funding was almost used up by the end of 2016, when the Ministry of Economic Affairs announced that the budget would be extended by another €1.5 million (NEA, 2017). The intention of the Deal was to reduce the cost of installation and operation of public charging infrastructure.

The Dutch government has co-founded the installation of public and semi-public charging points including fast-charging points largely through Green Deals. The provinces of Gelderland, North Brabant and Limburg, the cities of Amsterdam and Utrecht, the Amsterdam Metropolitan Area, Rotterdam and The Hague Metropolitan Area have all received government funding (NEA, 2017). All local and regional authorities (municipalities, provinces and regions) in the Netherlands could apply for the funding if they were able to prove that "they themselves are making an equal financial contribution to the rollout by means of invitations to tender (for a contract or concession) or through another channel, and that they are assured of a contribution by private parties".

Another Green Deal relating to the transition to e-mobility in the Netherlands concerns car sharing. The objective of this cooperation is that, by 2021, the Netherlands have 100,000 car-share vehicles on the roads, with 700,000 users of the service (NEA 2018; 2019). Table 6 presents the development of the number of shared cars over the last three years and the share of battery electric vehicle and plug-in electric vehicle in that shared fleet. In 2018, there were 400,000 users of the service.

²⁵ The maximal value of the MIA incentive was 36% for pure electric cars (maximal value – €50,000) and 27% for plug-in hybrids (with maximal value at €35,000) (NEA, 2017). Also, zero-emissions vans were eligible for 36% MIA, but in this case the maximum level of allowance was €75,000 (NEA, 2018).

²⁶ Vamil – an economic incentive targeting Small and Medium Enterprises – has the objective of stimulating the dissemination and market penetration of new environmentally friendly technologies (EC, n.d.).



Table 6: Number of shared cars (2016-2018) in the Netherlands

	2016	2017	2018
Shared cars (all types)	25,128	30,697	41,000
Users	n.a.	n.a.	400,000
Share of electric cars (battery electric vehicle and plug-in electric vehicle)	4.5%	4.1%	6.5%

Source: NEA, 2019b

Box 1: Examples of local stimuli in the Netherlands

The Hague

Since 2016, the city of The Hague has offered subsidies for the purchase of fully electric passenger cars, delivery vans and taxis. In 2016 and 2017, the grant was at €5,000 for new vehicles and €3,000 for second-hand cars (NEA, 2017, 2018). Since 2016, the municipality has also started to facilitate the introduction of fast-charging points in the city centre (NEA, 2017).

North Brabant

In 2016, North Brabant together with the province of Limburg launched a tender for the installation of 2,500 charging points. The aim was to put charging points in places indicated by residents and businesses of the participating municipalities without necessitating any investment from government authorities (NEA 2017). The goal is to, by 2020, install 12,000 public or semi-public charging points capable of offering smart charging standards in order to enable an increase to 100,000 electric vehicles. The province, in cooperation with Enexis – a distribution network operator in the east of the Netherlands – participated in the Smart Charging in North Brabant project, which installed 255 new smart charging stations across 35 municipalities and investigated the potential of smart charging outside of peak hours.

Amsterdam

Amsterdam also offers a range of subsidies for the purchase of electric cars, vans and trucks. (NEA, 2018). Since 1st January 2017, an environmental zone has been established in the city, where pre-2000 delivery vehicles are not permitted to enter, subject to a €90 fine. A study indicates that the creation of the zone has decreased pollution from delivery vehicles by reducing their use by two thirds (NEA, 2018). The city is also greening its taxis and buses fleets – as of 2021, only zero-emission taxis will be allowed to use the taxi rank at Amsterdam Central Station and by 2025, all buses are to be emissions-free (NEA, 2017).

Utrecht

Utrecht was the first municipality in the Netherlands to introduce a zone free of old diesel cars in 2016. The municipality has an ambition to, by 2020, install 1,000 charging points charged with solar power that could also power a battery located at home. However, an obstacle – a double VAT on releasing power back to the grid – must first be resolved. (NEA, 2018). At the beginning of 2019, there were 4,548 normal and 133 fast public charging points in the province.

Rotterdam

The first wireless charging system for electric passenger vehicles using an induction plate was made available for operation in the autumn of 2015 (NEA, 2017). Additional incentives for commercial electric vehicles include extended loading and unloading times and permission for electric taxis, hire coaches and lorries to use bus lanes. The city also has a scrappage scheme for old cars or vans, with a subsidy of up to a maximum of €2,500 per car (NEA, 2018).



Apart from general financial incentives offered by the central government, local governments have also been encouraging the adoption of low emissions vehicles through a number of stimuli (see Box 1 above). Municipalities of big cities – Amsterdam, Rotterdam, The Hague, Utrecht and Tilburg – offer subsidies for the purchase of electric vehicles, including private cars, taxis and lorries. Additionally, some municipalities offer subsidies for the installation of charging stations and the scrapping of polluting passenger and delivery cars (NEA, 2017). A number of tenders have been issued for the installation of charging points, often experimenting with smart charging technology as in the provinces of Gelderland and Overijssel (NEA, 2018).

3.4. Charging infrastructure

According to a report from 2017, there are 7.7 million homes in the Netherlands, out of which 35 per cent are flats (ECORYS 2017). 34 per cent of flat occupants have access to a parking space on a common ground, a small part can park on private parking space – for example in a garage –, others have to park in the public space. Therefore, various cities across the Netherlands have created programs enabling electric-vehicle drivers without access to home or work charging to apply for curb side charging stations. To request the installation of a public charging point in their neighbourhood, owners of electric vehicles must prove that they have no access to private charging. The municipality verifies requests and later monitors the usage of the installed chargers. If usage is very low, unused chargers may be removed (Hall and Lutsey, 2017; City of Amsterdam, n.d.). In order to improve cooperation between the parties involved in the installation and management of demand-driven charging points, the city of Rotterdam has launched the initiative *Laadpaalnodig.nl*, which can be translated into "*Charging station required.nl*". It is a platform that, among other things, enables electric-vehicle drivers to request a public charging station (NEA, 2019).

In order to enable private charging in multi-dwellings complexes, some additional barriers have to be abolished. There have been instances where electric-vehicle owners living in flats belonging to an Owners' Association were prepared to install chargers themselves but did not get permission from the Association. In that context, the introduction of a legal right of every owner to a charging spot, as has been done in Spain or California, is being discussed (MEA, 2017).

The charging needs in the Netherlands are primarily met by private charging at home or at work. The second layer of the charging infrastructure is – according to the Dutch definition – made up of 'semi-public' charging points, installed at shopping malls and on the parking places of private facilities which are accessible to all although access might be restricted due to, for instance, opening hours. Public charging accessible 24 hours a day is seen as "the last resort" alternative, i.e. to be used when other options are not available (MEA, 2017).



Table 7: Number of charging points in the Netherlands (2011-2017)

Charging points	2011	2012	2013	2014	2015	2016	2017
Public (freely accessible 24/7)	1,250	2,782	3,521	5,421	7,395	11,768	15,288
Semi-public (limited public access)	576	829	2,249	6,439	10,391	14,320	17,587
Fast-charging Semi-public	14	63	106	254	465	612	755
Private*	Unknown	4,500- 5,500	18,000	28,000	55,000	72,000	80,000

* Estimation

Source: *Nederlandelektrisch* (n.d)

Table 7 shows that, in the Netherlands, the number of private and semi-public charging points tends to grow faster than public charging points.

Public charging stations have initially been constructed by a consortium of network companies in big cities and along main roads, with the hope that an initial uptake of electric vehicles in the cities will encourage further investment in charging infrastructure in the surrounding municipalities. In its 2018 Highlights Report on electric transport, the Netherlands Enterprise Agency announced its aim to create 1.8 million private and public charging stations by 2030.

The largest manager of public charging stations in the Netherlands is EVnetNL, an initiative set up by the network companies Alliander, Coteq, Enexis, Stedin and Westland infra. Between 2009 and the beginning of 2014, EvnetNL (together with ElaadNL) built a network of around 3,000 public charging points. Local and regional governments had the possibility to apply for a charging point and EVnetNL managed the procedure (Helmus, 2018). These charging points were usually placed in the vicinity of public facilities where occasional use was expected, such as shopping centres and sporting halls (Helmus, 2018). EVnetNL also offered demand-driven rollout: the owner of an electric vehicle could request a charging point near home.

Until 2016, EVnetNL was the primary owner of the charging infrastructure. However, that same year, EvnetNL offered municipalities the possibility to take over charging stations and some of them took the offer.²⁷ At the beginning of 2019, EVnetNL was managing around 1,000 charging stations (out of approximately 1,760), of which 200 were in the transfer process.²⁸ The municipalities that took over charging points have outsourced their management to commercial players (NEA, 2018).

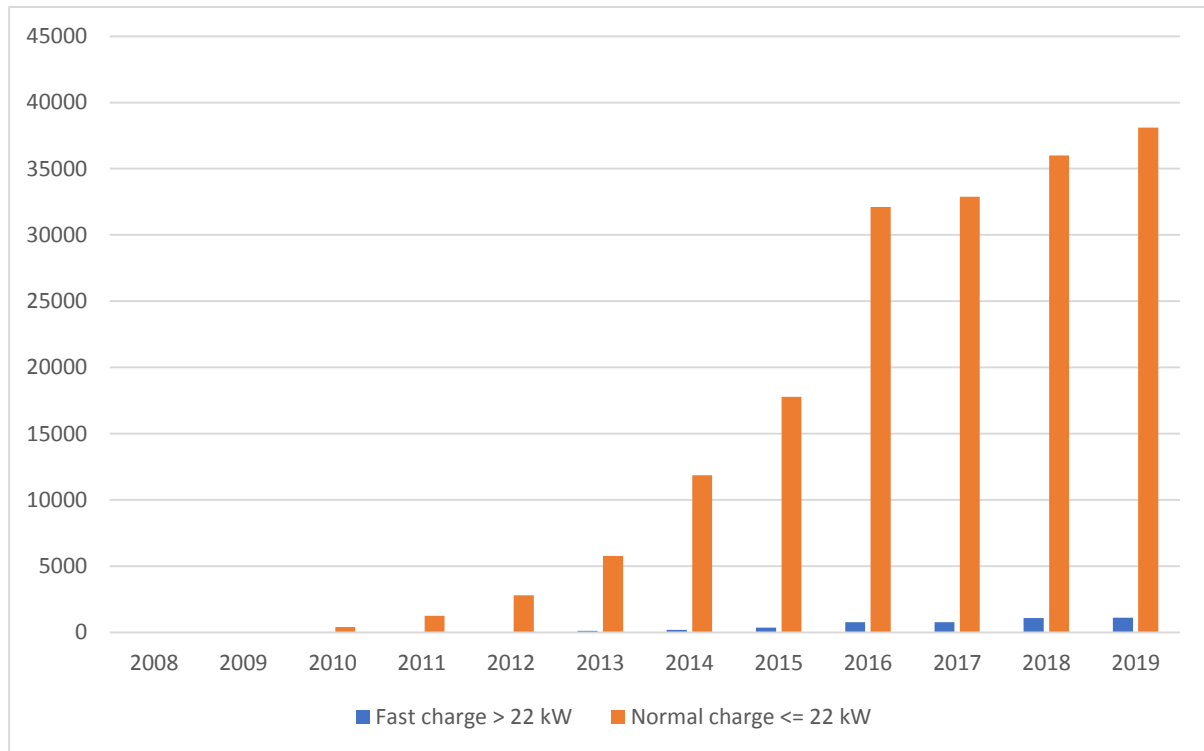
EVnetNL is responsible for the management and maintenance of the network. Although it is the largest manager of public charging stations, it manages only a small fraction of the overall charging infrastructure. According to EAFO data, in 2018 there were around 38,000 public charging points in the Netherlands (see Figure 8 hereafter) offering normal speed connection (i.e. below 22kW).

²⁷ <https://www.evnet.nl/nieuws/helft-laadpalen-evnetnl-volgend-jaar-in-andere-handen/>

²⁸ <https://www.evnet.nl/nieuws/statistieken-2018-qemiddeld-meer-qebruikers-en-hoqer-verbruik-op-laadpalen-evnetnl/>



Figure 8: Normal and fast public charging points in the Netherlands



Source: EAFO

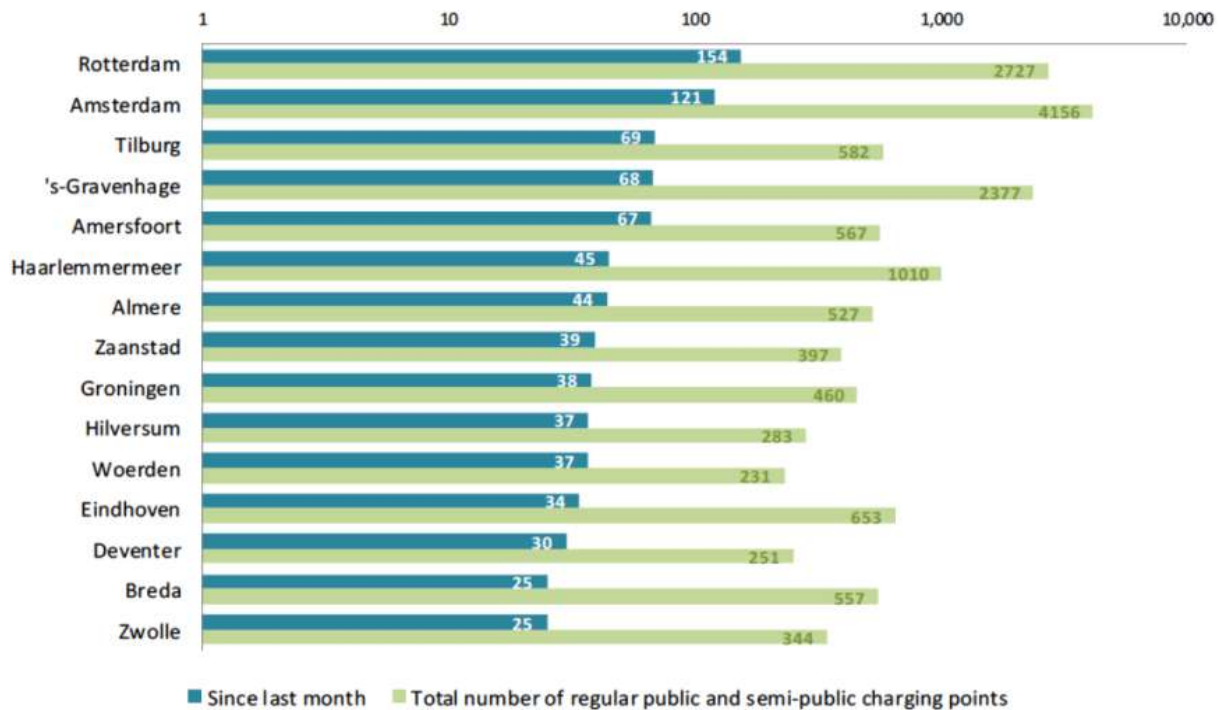
The city with the highest number of public and semi-public charging points is Amsterdam (see Figure 9). In order to promote e-mobility, the city prioritises electric vehicles in applications for city parking. Additionally, in cooperation with Vattenfall, the local network owner Liander, the infrastructure competence centre Elaad and the University of Applied Sciences Amsterdam, the city offers two types of charging points: regular and Flexpower. Flexpower stations offer normal power between 06:30am and 6:00pm, more power between 9:00pm and 6:30am (as well as in sunny weather during day time) and less power between 6:00 and 9:00pm.²⁹ In order to enable faster charging, and when conditions allow, the capacity of Flexpower charging points has been increased by 40 per cent, up to 3x35 A (instead of 3x25 A in the case of regular stations). This allows for up to 2.5 times faster charging (depending on the capacity of the battery).³⁰

²⁹ <https://www.amsterdam.nl/en/parking/electric-charging/>

³⁰ <https://group.vattenfall.com/press-and-media/news--press-releases/pressreleases/2019/largest-smart-electric-vehicle-charging-network-optimizes-use-of-renewable-energy-in-amsterdam>



Figure 9: Dutch municipalities with the largest increase in number of charging points between April and May 2019



Source: NEA, 2019

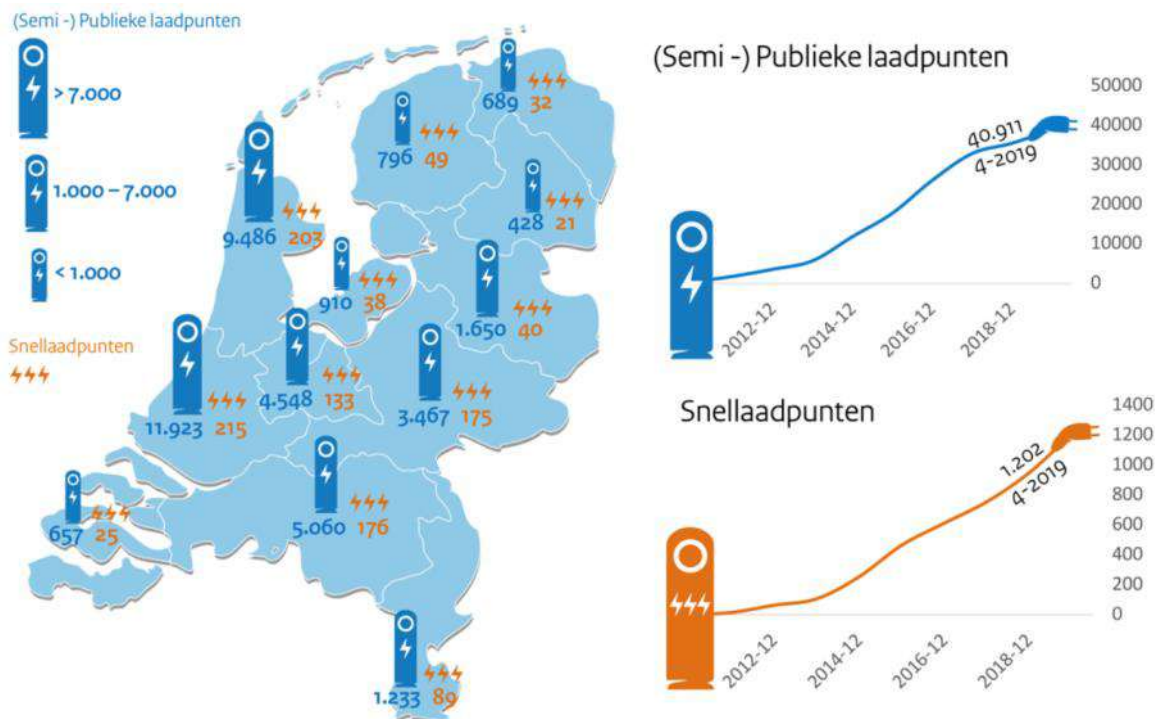
Various partnerships between cities and businesses have emerged in order to support charging infrastructure. PitPoint operates around 230 charging stations in Utrecht, the Nuon-Heijmans partnership is active in Utrecht and Amsterdam, and the Municipality of Rotterdam has chosen ENGIE Services (NEA, 2017).

Together with regular-speed charging points (below 22 kW), the network of fast-charging infrastructure is also developing as cities are investing in fast-charging infrastructure. For example, the city of Amsterdam has installed 52 fast-charging points as a result of agreements between the municipality and the taxi sector (NEA, 2019). There are also numerous other examples of fast chargers being installed throughout the country: all McDrives³¹ will eventually be equipped with a fast-charging station for electric vehicles, Nuon is installing a network of 168 fast chargers, Lidl has installed fast chargers (with no charging fee) at its stores in a partnership with ABB, Fastned is installing some along the roads, and Shell, in cooperation with Allego, has installed and manages fast chargers at Shell service stations (NEA, 2017; 2018; 2019). By April 2019, the number of fast-charging stations throughout the country had reached more than 1,000. The highest number (215) was located in the province of South Holland, while North Brabant had 176 fast-chargers and the province of Gelderland 175 (see Figure 10).

³¹ McDonald's drive-through services.



Figure 10: Number of (semi-) public regular (blue) and fast-charging points (orange)



Source: RVO (n.d)

Fast-charging is developing rapidly, with some chargers offering maximum power connection of 350 kW and used as corridor charging. They are installed at the medium voltage network and are used as fuel stations for regular cars (van Amstel, 2018).

The Netherlands are also active internationally. Luxembourg, Belgium and the Netherlands have signed an agreement that promotes “cross-border access to e-Mobility services in the Benelux countries”, which enables electric-vehicle drivers to charge their vehicle in all three countries using the same access card/app and ensuring transparency of prices (NEA, 2018).

3.5. Consumer response

A typical household in the Netherlands with a three-phase connection of 25A has a connection capacity of 17.3 kW and uses about 3,500 kWh/year. For such a household, the average calculated peak capacity³² is of 4 kW and the average peak power demand is between 0.8 kW and 1.3 kW (EDSO, 2018).

The attitudes of potential users towards proposed technical solutions for smart charging are presented by Hoekstra and Rafa (2017). They report consumers’ thoughts on smart charging based on a focus group and a survey with 286 respondents. According to this study, people agree to make smart charging the default choice at home under the condition that they can control charging and are able to override the smart charging option. Respondents are concerned about grid stability: they do not want to cause outages and grid overload, but these factors do not motivate them to adapt their behaviour. What interested respondents is the possibility to use renewable energy and also the decrease of charging costs thanks to smart charging. Notably, participants in the focus group were more interested in the possibility of a cost reduction than in how big such a

³² Capacity that is calculated for net planning purposes including the coincidence factor is based on 70 households or more (EDSO, 2018).



decrease would be. In other words, the option to be rewarded for offered flexibility was considered as more important than the amount of the savings. The authors conclude that customers “wanted something in return for their flexibility as a matter of principle”. The focus group was also positive about the possibility to charge faster during non-peak hours. However, they were especially interested in larger – i.e. doubling or tripling – increases of charging speed. Hoekstra and Rafa (2017) point this as an important finding as “the electricity grid only has occasional peaks but on average has 81 per cent excess capacity (in the Netherlands)”. Therefore, they conclude that it would be sensible from a cost perspective to set up limits on charging speeds if drivers are offered faster charging speeds during low demand.

A recent survey on electric vehicles drivers’ needs indicated that the majority of respondents would like the price structure to be displayed while charging.³³ This indicates that Dutch electric vehicle drivers might show signs of sensitivity to price signals (price elasticity) and highlights the need for transparency of prices. A price list available on Ido-laad’s webpage (idolaad, 2016) from 2016 indicates that the price of electricity depends not only on the charging point operator but also on the mobility service provider. Sometimes, the cost is based on a volumetric fee, sometimes charging or connection time are also included (this was introduced as cars were found to be plugged in for much longer than necessary for charging). On The Hague city portal, electric vehicle owners are informed that the price depends on the type of pass they own: “With an Ecotap pass it is cheapest to charge your car at an Ecotap charging point.”, “With a Nuon pass it is cheapest to charge your car at an Alfen charging point in The Hague” (denhaag, n.d.).

3.6. Impact on the grid

The total length of the electricity network in the Netherlands is 337.952 km and it has 8.2 million connections. Four DSOs are responsible for the medium and low voltage network which is 288.000 km long.³⁴ The medium voltage network operates 32.500 connections and the low voltage network, consisting of households and small commercial parties, 8.1 million (van Amstel, 2018). In accordance with regulation, network operators are obliged to connect and transport the electricity requested by a customer, and are not to discriminate between customers (van Amstel, 2018).

An assessment of additional peak load in the Dutch electricity grid with a 100 per cent adoption of battery electric vehicles using uncontrolled charging gives an estimation of 7 GW. This is a 42 per cent increase compared to the current peak load levels and a 22 per cent increase of energy consumption (Beltramo et al., 2017; van Amstel, 2018). The traditional approach to increase grid capacity and relieve congestion has been network reinforcement. Today, flexibility on the demand side is seen as one of the solutions for dealing with these problems (van Amstel, 2018).

Smart charging is one of the most influential concepts relating to charging infrastructure in the Netherlands. It implies that a vehicle does not start charging straight after having been plugged in. Instead, charging is adjusted to the period when demand is not too high, i.e. off-peak. This type of charging fits well with home charging, when cars are connected for several hours. The average Dutch car drives 37km per day, meaning that for most of the day, it stays still. If a 37 km trip requires around 8 kWh – which is about 2.5 hours charging with the lowest speed (single phase 16A and 3.7 kW) – the potential for using smart charging and adjusting the starting time of charging and power level to the conditions on the grid seems a plausible option (EDSO, 2018). For shopping centres and office environments, benefits are more limited since charging time on such premises is shorter and there is therefore less room to postpone charging. In the case of fast charging, the potential of smart charging is very low, since customers want their vehicle to be charged as quickly as possible.

³³ <https://www.nklnederland.com/news/exploration-how-transparent-is-the-charging-price-for-ev-drivers/>

³⁴ <https://www.energievergelijken.nl/en/about-energy-in-the-netherlands>



Many projects and initiatives investigate the potential of smart charging. For instance, the province of North Brabant and Enexis have cooperated on a smart charging project including the installation of 255 stations offering smart charging outside of peak hours (NEA, 2017).

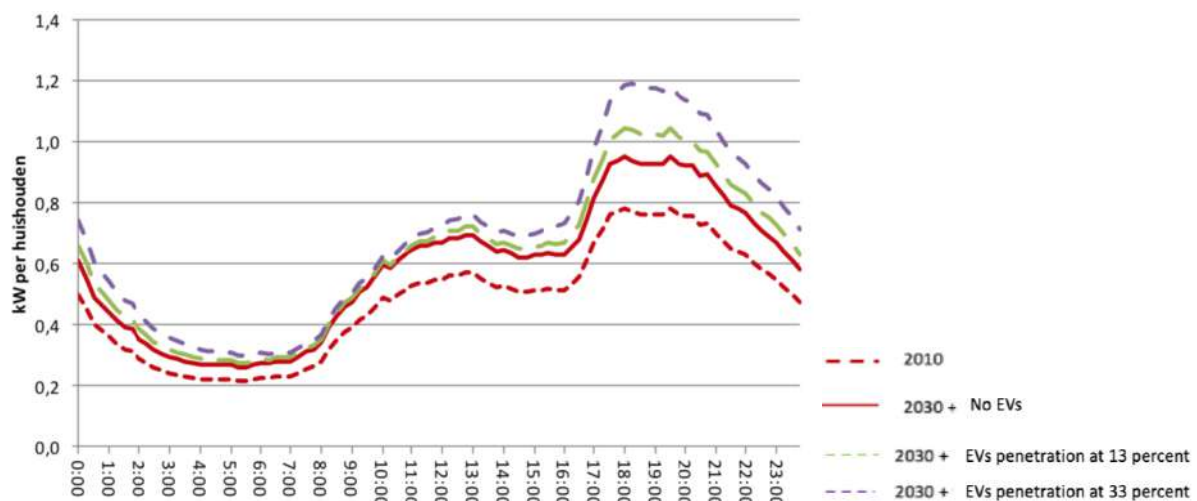
By 2023, the Dutch DSOs want smart charging options to be able to accommodate 1 million cars. In order to facilitate that goal, they are investing in ELaadNL – the Dutch knowledge and innovation centre – which in 2018 opened a new test lab responsible for testing the smart charging solutions currently used in the country (NEA, 2019).

Another envisioned solution is that of charging plazas – a number of charging stations sharing a single connection (NKL, 2019). In 2018, one of the largest charging plazas in the Netherlands was opened at Van der Valk Hotel Eindhoven (Allego, n.d.). The plaza counts 50 Allego charging stations, offering a combination of smart, regular, fast and ultrafast charging (NEA, 2019). The business case of charging plazas has more potential than that of charging stations: the capacity charge must be paid only for a single grid connection and a plaza can accommodate several vehicles at the same time, which is expected to increase the number of transactions. However, at present, grid operator costs remain higher for a charging plaza than for a charging station (NKL, 2019).

3.7. Future outlook

The load profile of a typical Dutch household is changing. In 2013, Movares, an energy consultancy, investigated a charging strategy for electric vehicles on behalf of Netbeheer Nederland (Affiliate for Energy Grid Managers). The authors of the report presented an estimated demand profile in 2030 for an average Dutch household during a winter day (Movares, 2013). Three scenarios were investigated: no electric vehicles, 13 per cent penetration of electric vehicles and 33 per cent penetration of electric vehicles (see Figure 11 below). Compared with the situation in 2010, when peak demand was below 0.8 kW, the projected demand almost doubles in 2030 in the high penetration scenario. The results for low penetration of electric vehicles indicate a peak of slightly above 1 kW in the evening.

Figure 11: Average Dutch household demand profile



Source: Movares, 2013, page 41.

However, a 2018 study by EDSO gives a different picture of the average Dutch household (EDSO, 2018). The authors report that an average household in the Netherlands has a peak power demand of between 0.8 kW and 1.3 kW – the numbers which in 2013 were associated with the expected

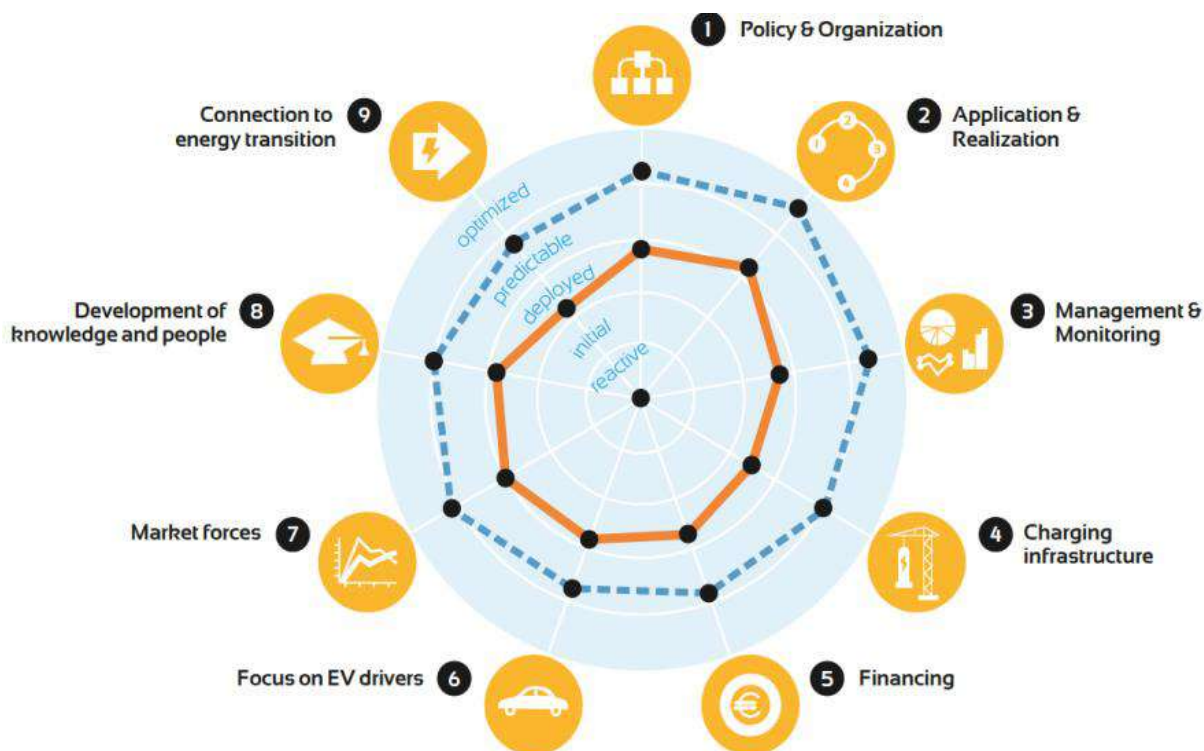


power demand in 2030. It hence seems that the growth in power demand has been faster than previously estimated. The report places the average power demand at 1.3 kW and estimates that if an average charging capacity of 5 kW is used, 1 million electric vehicles require 5 GW of charging power, as compared with the total Dutch power demand which is at the level of 8-9 GW. If the number of electric vehicles was to reach seven million, the additional power required for charging would be 35 GW (EDSO, 2018).

The role of the government in the rollout of charging infrastructure has been evolving over the last years. Initially, charging points were installed by network companies and only in big cities with the aim to create a “snowball effect” whereby other municipalities would start investing in infrastructure due to the increased number of electric vehicles on the road. Now, the aim is to create a functioning market model where a mix of private, semi-public, public and fast-charging points is available (MEA, 2017). As the model is still being developed, there is no fixed goal concerning the final number of charging points to be installed as of now. However, there is a clear objective to make the business model profitable and to encourage new entrants.

In 2018, the use of public charging stations has increased by 15 per cent as compared with the previous year (Table 8) and, according to Figure 12, some market segments are profitable even without support (NKL, 2018).

Figure 12: Maturity model - towards a professional Dutch market



Source: NKL, 2018

Figure 12 above describes the state of the market in 2018 (orange line) and the optimal state of the market around 2025-2030. Nine different categories are used to describe the level of development of charging infrastructure. In 2018, two categories were lagging behind: charging infrastructure and connection to energy transition. However, other categories have not yet reached an optimal state either. The NKL Benchmark report enumerates several action points for advancing the realisation of a mature market. Among other things, price transparency is mentioned.



According to the latest benchmark done by NKL (see Table 8 below) the average cost of a new charging station is decreasing and a continuous drop is forecasted into the 2025-2030 period. However, the total initial cost increased from €3,110 in 2017 to €3,270 in 2018. This is mainly due to increased costs of grid connection and installation of parking space. Operating costs (excluding energy) have decreased from €580 to €510, and a further 5 per cent decrease is forecasted. However, the reduction is much less steep compared with the initial 40 per cent cost drop since 2013, which may indicate that costs optimisation is slowly reached and, as the benchmark report suggests, further optimisation might involve innovative charging infrastructure solutions, e.g. charging hubs/plazas (NKL, 2018).

Table 8: Results of public charging station cost/revenue update

Category	Cost details	Benchmark 2013	Benchmark 2016	Benchmark 2017	Benchmark 2018	Forecast decrease 2025-2030
Initial costs (Total)	total	€ 4.655	€ 3.655	€ 3.110	€ 3.270	15% decrease (approx.)
Purchase price of charging station (3x25A, 2 sockets)	total	€ 2.000	€ 1.400	€ 1.330	€ 1.330	
Determining location	total	€ 700	€ 550	€ 320	€ 350	
Installation of parking space (location & signage)	total	€ 700	€ 450	€ 380	€ 450	
Grid operator connection costs	total	€ 655	€ 655	€ 690	€ 750	
Contractor's charges for station installation	total	€ 600	€ 600	€ 390	€ 390	

Category	Cost details	Benchmark 2013	Benchmark 2016	Benchmark 2017	Benchmark 2018	Forecast decrease 2025-2030
Periodic costs excl energy	annual	€ 835	€ 610	€ 580	€ 510	5% decrease (approx.)
Periodic charges for grid connection 3x25A	annual	€ 210	€ 210	€ 210	€ 190	
Communications	annual	€ 125	€ 75	€ 50	€ 70	
Insurance premium (damage)	annual	€ 25	€ 25	€ 25	€ 25	
Maintenance/Repairs	annual	€ 450	€ 275	€ 270	€ 190	
Service in the event of user problems	annual	€ 25	€ 25	€ 25	€ 35	

Category	Cost details	Benchmark 2013	Benchmark 2016	Benchmark 2017	Benchmark 2018	Forecast increase 2025-2030
Payment to supplier (purchase)	kWh	€ 0,06	€ 0,06	€ 0,06	€ 0,07	-
Energy tax	kWh	€ 0,10	€ 0,10	€ 0,05	€ 0,05	100% increase
Depreciation period	annual	5	7	9,2	9,2	-
Sales per kWh ex. VAT	kWh	€ 0,25	€ 0,28	€ 0,27	€ 0,25	-
Energy sales (kWh/day)	daily	5	8,5	8,6	9,9	+/- 50% increase

Source: NKL, 2018

In Amsterdam, the costs of curb side charging stations fell from around €12,000 per station in 2009 to now €2,000. However, charging infrastructure costs also include installation costs, land procurement, administration and maintenance (Hall and Lutsey, 2017).

Another important element of the market model in the Netherlands is charging standardisation and interoperability of the charging infrastructure. ELaadNL has been involved in the development of the Open Charge Point Protocol (OCPP) and Open Clearing House Protocol (OCHP) standards, which enable efficient communication between the various parties involved to ensure interoperability in operation and payment (Hall and Lutsey, 2017).

In order to facilitate the uptake of the charging infrastructure, NKL has compiled a list of Uniform Standards for Charging Stations that is updated yearly (NKL, 2018a). It contains a set of standards describing application and construction, environment and location, management and monitoring, functionality, design, engineering and safety, back offices and interfaces, smart charging and security. The enumerated standards are classified according to whether they are required (based on official standards, directives, laws or regulations) or desired. Among the payment standards, it is stated that a charging station must be accessible through valid charge passes (authentication apps) from various providers. The contractor is hence expected to sign contracts with mobility service providers (including foreign providers). According to the 2018 document, one of the desired functionalities of a charging station is its ability to accommodate charging for one-time users



through an alternative payment option without subscription, for example using a smartphone (NKL, 2018a). Payment covering both parking and charging (when applicable) is also encouraged. Among actions recommended to be included in a tender for charging infrastructure (but with potential incidental deviations) is the choice of power supplier. The document stipulates that “it must be possible for the electric vehicle drivers to make use of their own power supplier at the charging station (either through their card supplier/service provider or not), or in any case to have the choice between various providers at the charging station” (NKL, 2018a).

3.8. Conclusions

The Netherlands already has a well-developed network of charging points. The base for charging is provided by private charging points either at home or at work. Semi-public chargers with limited access are also an important category that is growing quickly. Public chargers are often deployed through a demand-driven approach, and this option of providing charging infrastructure where there is not enough private parking – and therefore a lack of private charging – is a solution used particularly in cities.

Smart charging is thought to be the answer for coping with too high instantaneous electricity demand and various research projects are investigating the potential of this technology. Charging hubs or plazas present another take on smart charging and are thought to become a profitable business opportunity where lower connection charges are met by a higher number of transactions, increasing the commercial potential of such charging solutions.

04

**CASE STUDY III:
LUXEMBOURG**



4. Case study III: Luxembourg

4.1. Introduction

The Grand Duchy of Luxembourg follows a different strategy for the provision of public charging infrastructure than Norway and the Netherlands. Instead of issuing public tenders with the aim to allow market forces to compete for the provision of the service, it is the DSOs who are in charge of developing the electric vehicle charging network in Luxembourg. The project is part of the government’s plan to prepare for the third industrial revolution where information and communication technologies (ICT), renewable energy, new models of transport and intelligent network meet (CREOS, 2017; TIR, 2016). The Grand Duchy follows a carefully scheduled plan for the deployment of its charging network. The plan for the core of the charging infrastructure – the public network Chargy – was drafted in 2016 through a ministerial regulation (Regulation, 2016).

The transportation sector in Luxembourg is responsible for 61 per cent of energy consumption and 64 per cent of global warming emissions (TIR, 2016). In order to meet the target of reducing by at least 40 per cent greenhouse gas emissions by 2030, Luxembourg is therefore targeting e-mobility. It aims at deploying 40,000 electric cars by the end of 2020 (Gouvernement du Grand-Duché du Luxembourg, 2012) and reaching a 100 per cent electric fleet in 2050 (TIR, 2016).

4.2. Adoption of electric vehicles: current status

The uptake of electric vehicles, including both 100 per cent electric and plug-in hybrids, has been changing rapidly in Luxembourg since the early 2010s. The number of battery electric vehicles on the roads has increased from only 31 in 2011 to 1,567 in 2018, while the number of plug-in electric vehicles went from 30 in 2012 to 1,645 in 2018 (see Table 9 hereunder). However, when it comes to the adoption of electric vehicles, Luxembourg cannot yet be considered a mature economy.

Table 9: M1* fleet, electricity (Luxembourg)

	BATTERY ELECTRIC VEHICLE	PLUG-IN ELECTRIC VEHICLE	TOTAL
2011	31	0	31
2012	100	30	130
2013	263	60	323
2014	564	166	730
2015	635	279	914
2016	771	449	1,220
2017	1,091	1,075	2,166
2018	1,567	1,645	3,212

* vehicle max 9 seats including driver's

Source: EAFO

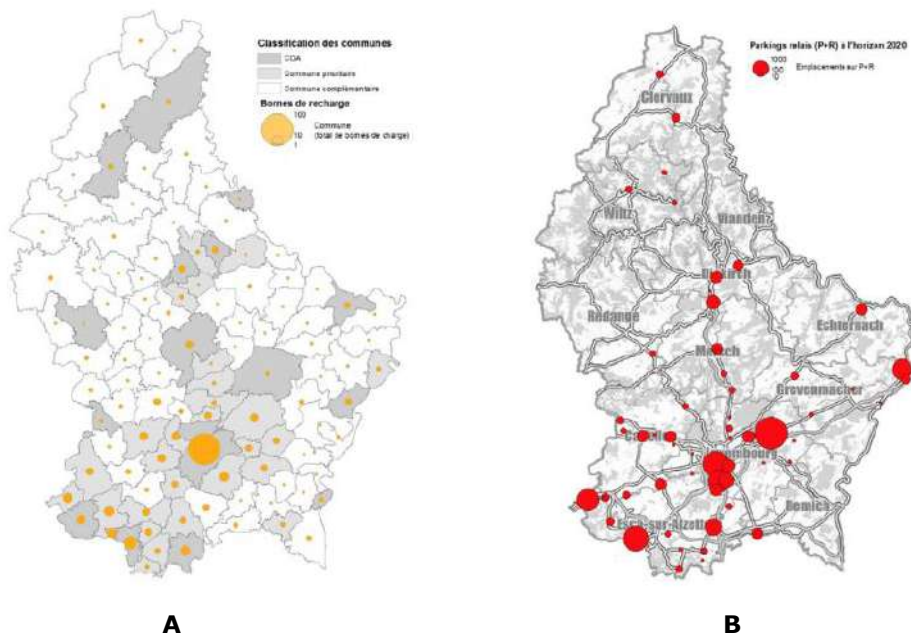


4.3. Infrastructure: the public network Chargy

In order to increase the penetration of electric cars, the government of Luxembourg has decided to invest in public infrastructure that would support owners of electric vehicles, but assuming that the primary charging place would be a private charging spot either at home or at work (Schwartz and Co, 2011). Two main regulations support the development of the public charging infrastructure: a regulation dating from 2015 setting the framework of the system (Regulation, 2015) and a regulation from 2016 which presents a detailed plan for the rollout of the network (Regulation, 2016).

The main public network – Chargy – has been set up and is developed, operated and maintained by the five distribution system operators: Creos, Electris, Sudstroom, Ville de Diekirch and Ville d’Ettelbruck. In 2016, subsequent to a tendering process, the operation of the infrastructure was awarded to Engie Cofely Luxembourg, while Powerdale became responsible for the delivery of charging stations and the operation of an internet service application, the “Common Operator Platform”.³⁵ Still, the distribution companies retained ownership of the network. The first public charging station within this network became operational in 2017. At the beginning of 2019, the Chargy network consisted of 243 electric vehicle chargers, each with two charging points.³⁶ The plan is however more ambitious: the 2015 regulation required that, by 2020, there be 400 two-points chargers in public parking spaces and another 400 in Park and Ride (P+R) facilities. It was decided early on that, in order to provide wide access to charging points across the Grand Duchy, there had to be at least one charging station in each municipality. A map with planned locations of Chargy infrastructure is presented in Figure 13 below. Panel A shows charging points on public parking places and panel B in Park and Ride facilities.

Figure 13: Map of planned locations for charging stations in Luxembourg: A = public parking places, B = P+R facilities



Source: Regulation 2016

³⁵ <https://www.powerdale.info/powerdale-have-been-awarded-the-contract-for-800-public-charging-stations-in-luxemburg-including-a-12-year-service-contract/>

³⁶ Personal communication with Chargy representative Carla Alves.



62 Park and Ride car parks in Luxembourg should be equipped with charging stations by 2020. Those offer cheap or free parking and allow drivers to continue their journeys with public transport. The number of chargers to be installed at a given Park and Ride car park depends on the size of the park. All car parks with a minimum of 35 parking spots will be equipped with at least one charging terminal.³⁷ As for the charging stations, they are to be equipped with one of the three charging speeds, i.e. slow (below 3.7 kW), normal (between 3.7 and 22 kW) and fast (above 22kW). Due to their function, Park and Ride car parks prioritise slow charging: cars are left there during working hours, while owners use public transport to get to work.³⁸ Electric vehicles chargers in other public spaces can be equipped with normal³⁹ or fast charging, with the former solution being advised/privileged.⁴⁰

The charging network can be accessed with an “mKaart” – a card combining various prepaid mobility products and services. The electricity consumption related to vehicle charging is either billed via the regular home electricity supplier or via this prepaid card. There are currently 14 providers of recharging services for individuals on the Chargy network.⁴¹ The Chargy network also supports the MyChargy platform, which gives access to an interactive map showing accessibility of charging points, booking of charging slots, calculation of the route to charging stations and notification when the charging of the vehicle is completed. Users can also access their electricity consumption data via the platform.⁴²

In 2016, the Luxembourg Institute of Regulation has accepted a proposal put forward by distribution network operators concerning the flat-rate costs of acquiring and installing a public charging station (decision E16/50/ILR from 8th of November 2016).⁴³ The costs cover acquisition and installation of a normal speed charging station (terminal and connection cabinet without smart meter) evaluated at €10,045.22 (without VAT), as well as connection costs (trench and cable). Connection costs are composed of two parts. An initial connection of up to 110 meters joining the grid and the nearest point of the car park, decided by the grid operator, which amounts to €247/m (without VAT) for the cities of Luxembourg and Esch/Alzette and €212/m for the rest of the country⁴⁴ (ILR, 2016). The other part of the cost covers a connection of a maximal length of 30 meters to the charging station itself, which is decided by the municipality and amounts to €235/m for the cities of Luxembourg and Esch/Alzette and €200 for the rest of the country. If the cost of construction and connection of the charging station is higher than the fixed costs approved by the regulator, the distribution company either indicates a different place for the charging terminal or indicates the amount of additional cost to be borne by the municipality (ILR, 2016). The costs of construction of any additional charging station are to be borne exclusively by the municipality (ILR, 2016).

4.4. Expanding the public network: Chargy-OK

In locations where there is already existing charging infrastructure financed by a municipality, the charging stations can either be integrated in the Chargy network and be part of the 1,600 public

³⁷ <http://luxembourg.public.lu/en/actualites/2015/11/09-electromobilite/index.html>

³⁸ <http://luxembourg.public.lu/fr/actualites/2015/11/09-electromobilite/Presentation-infrastructure-publique-mobilite-electrique.pdf>

³⁹ <http://luxembourg.public.lu/fr/actualites/2015/11/09-electromobilite/Presentation-infrastructure-publique-mobilite-electrique.pdf>

⁴⁰ Slow and normal charging terminals are to be equipped with a “Type 2” plug following the norm EN62196-2 and “type F” socket following the norm CEE 7/4.

⁴¹ Blue Corner, BLUEenergy.lu, Edissertio, Eida S.A., Electris, Electromaps, Enovos Luxembourg S.A., Mobilygreen, NewMotion, PlugSurfing GmbH, Pluxx Holding S.A., Route220, Sudstrom, Wirelane GmbH.

⁴² <https://chargy.lu/fr/particuliers/>

⁴³ <https://assets.ilr.lu/energie/Documents/ILRLU-1685561960-448.pdf>

⁴⁴ <https://assets.ilr.lu/energie/Documents/ILRLU-1685561960-297.pdf>



charging points, or they can become an expansion to the public network outside the core Chargy network.⁴⁵ In the latter case, the charging stations are labelled Chargy-OK.

Chargy-OK is a certification that can be obtained for the charging stations compatible with the public Chargy network. Currently, five brands of chargers are certified⁴⁶ and the producers of other charging stations must apply for Chargy-OK certificates. If chargers are compatible with the network, they can be integrated. There are a number of technical conditions that a charging point must fulfil in order to be connected to the Chargy-OK network (Chargy, n.d.).

Four types of charging stations can be part of the Chargy-OK network:

- private charging stations accessible to the public;
- private charging stations which are available to the public but where access is restricted;
- private charging stations not publicly available but used with a Chargy card and;
- private charging stations not accessible to the public.

Additionally, all charging stations can either have a single access point or a double access point. The costs of integration and exploitation of these charging stations differ depending on the type of station.⁴⁷

4.5. Policies

In order to promote electromobility, the government of Luxembourg has taken a number of initiatives addressed both to individuals and firms pursuing electromobility.

Until the end of 2014, a €5,000 subsidy was granted for the purchase of an electric vehicle, with the precondition of signing a supply contract for green electricity. In 2017, a €5,000 tax deduction for the purchase of a new battery electric vehicle⁴⁸ for private use was introduced (Clever-fueren n.d.). Currently, a range of tax benefits exists for new, private use vehicles: a €5,000 deduction for a battery electric vehicle, a €2,500 deduction for a plug-in electric vehicle with CO₂ emissions lower than 50 g/km, and a €300 deduction for a bike or electric bike that can be applied every 5 years (Portail Transports, n.d).

In 2017, a benefit in kind⁴⁹ for employees⁵⁰ was introduced, replacing a flat rate of 1.5 per cent which disregarded CO₂ emissions.⁵¹ As shown in Table 10, and in accordance with this regulation, electric cars have a tax rate of 0.5 per cent of the price of a new vehicle, and gasoline cars are taxed at a lower rate (-0.2%) than diesel engine vehicles in the same CO₂ category.

There are two options for a reduction of the tax due by a company as a reward of its eco-responsibility: an overall tax bonus (of 8 or 2 per cent depending on the size of the investment) or an additional tax rebate – 13 per cent of the additional investment in eligible goods.⁵²

⁴⁵ <http://luxembourg.public.lu/fr/actualites/2015/11/09-electromobilite/Presentation-infrastructure-publique-mobilite-electrique.pdf>

⁴⁶ These are: ABB Terra, Innogy eStation smart, Mennekes Premium, Mennekes Smart and Powerdale Nextender.

⁴⁷ There is no integration cost, except for the private charging stations that are not publicly accessible. In this case, the cost is €120 without VAT (VAT of 8% is applicable). The price of remote charging station management service and provision of data is as follows: cost of GPRS communication is 3.30€/month (without VAT), the cost of exploitation varies from €4 per month for a simple private but publicly accessible charging station to €20.10 per month for the double private charging station that is not accessible for public (Chargy, n.d.).

⁴⁸ Registered in 2017.

⁴⁹ <http://legilux.public.lu/eli/etat/leg/rqd/2016/12/23/n7/jo>

⁵⁰ https://blog.kpmg.lu/luxembourgs-new-emissions-based-company-car-tax/?utm_source=Mondaq&utm_medium=syndication&utm_campaign=View-Original

⁵¹ Steierreform 2017.

⁵² <https://transports.public.lu/fr/contexte/initiatives/mesures-fiscales/clever-fueren-steiere-spueren/vehicules-entreprise.html>



Table 10: Tax rate for battery electric vehicle, regular and diesel cars in Luxembourg

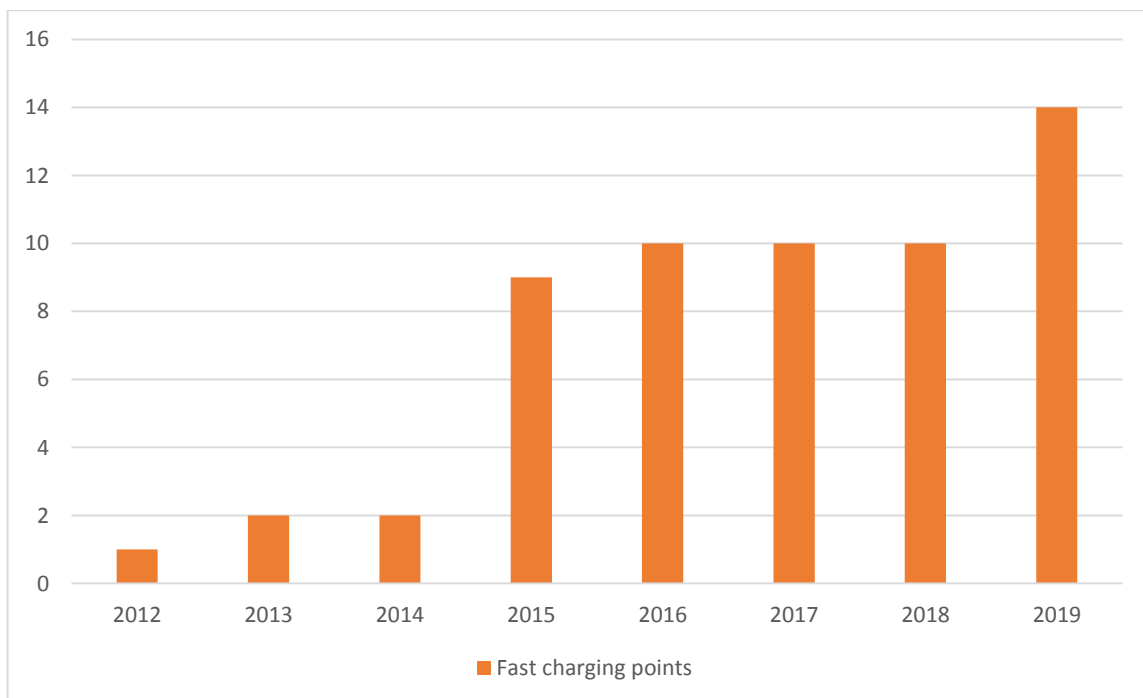
LEVEL OF CO ₂ EMISSIONS	Percentage of price of the vehicle purchased new (incl. VAT)		
	Gasoline (pure or hybrid) or compressed natural gas	Diesel (pure or hybrid)	100% battery electric or hydrogen
0 g/km			0.5
> 0-50 g/km	0.8	1.0	
> 50-110 g/km	1.0	1.2	
> 110-150 g/km	1.3	1.5	
> 150 g/km	1.7	1.8	

Source: KMPG, 2018⁵³ after Portail Transports. Véhicules de fonction (n.d)

4.6. Outside the Chargy network

Apart from the regular public charging stations, there is also a network of fast-charging stations in Luxembourg, although it operates on a much smaller scale. Between 2012 and the first half of 2019, 14 fast-charging stations were installed. These stations are not part of the public Chargy network.

Figure 14: Fast public charging points above 22 kW in Luxembourg



Source: EAFO

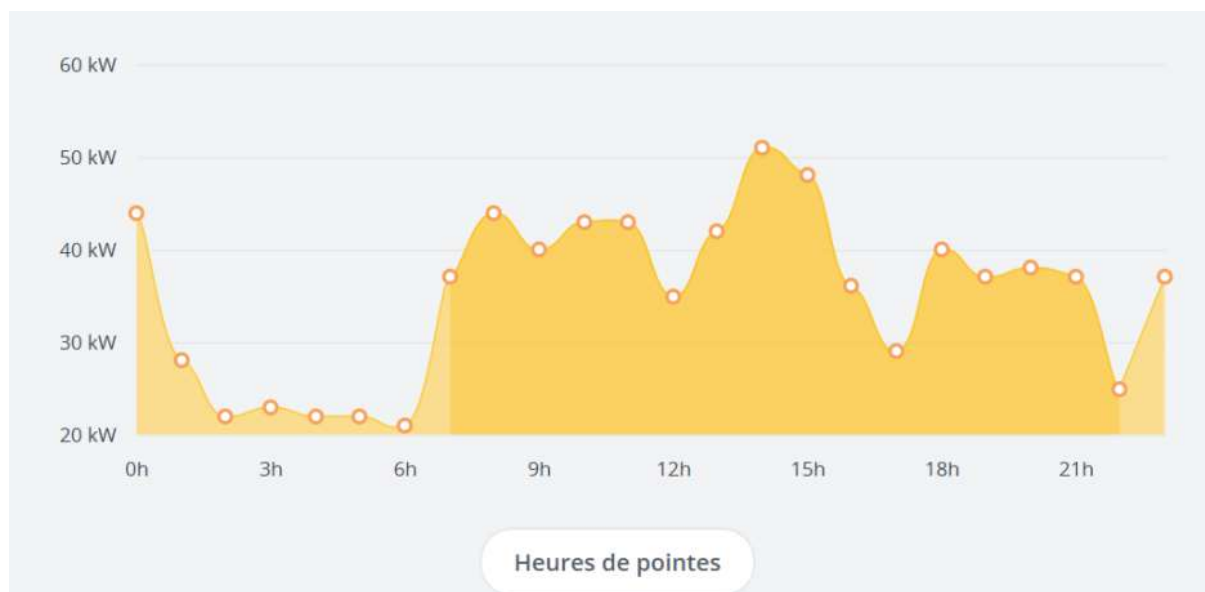
⁵³ https://blog.kpmg.lu/luxembourgs-new-emissions-based-company-car-tax/?utm_source=Mondaq&utm_medium=syndication&utm_campaign=View-Original



4.7. Impact on the grid

Data describing the average daily load profile in the Chargy network indicates that the peak reaching 50 kW is observed around 2:00 pm (see Figure 15 hereunder). Occupation of the public charging points is on average at the level of 33 per cent.

Figure 15: Daily load profile on average for 2018 in Luxembourg



Source: Powerdale

Since the penetration level of electric vehicles in Luxembourg is still relatively modest, there is not enough data to show the real effects e-mobility has on the grid. However, according to estimations reported by Creos (one of the distribution companies in the Grand Duchy), with a large uptake of electric vehicles, the peak power per car on the high voltage grid will be at about 1.33 kW (Creos, 2018). Calculations from 2017 indicate that in case of a "light acceptance", i.e. with 110,000 electric vehicles on the roads, and an homogenous distribution of charging points with a mix of charging capacities, there should be very few or no overloads on the low and medium voltage grids. However, the estimates suggest that the additional load, even in the case of "light acceptance", would use up the entire remaining power reserve of the existing high voltage network.

In Luxembourg, low, medium and high voltage grids will thus be impacted differently by e-mobility. As argued by Creos, "the highest relative additional load of the e-mobility will occur on the low voltage grids, because the simultaneity is much higher when a few electric vehicles are recharging during the same time at home or on a public charging station on the low voltage grid" (Creos, 2018). Medium voltage grids will encounter a smaller probability of simultaneous charging, so the problem of potential congestion will be less frequent than on the low voltage connections. The high voltage grid can expect to be less loaded. However, superchargers on highways – especially during busy travel periods – could generate peak loads that could not be shifted in time, nor flattened over some longer period. "This could become a major issue on the higher voltage levels as the simultaneous factor will be close to 1" (Creos, 2018).



4.8. Conclusions

The Grand Duchy of Luxembourg has organised the development of its charging infrastructure centrally. The main public charging network – Chargy – is owned by distribution companies and offers normal speeds of connection. Engie Cofely Luxembourg is responsible for the maintenance of the network, while Powerdale is in charge of the operation of the *My Chargy Platform* internet service application.

Due to its location, the Grand Duchy is cooperating a lot with the Netherlands (eViolin) and Belgium (Open Chargepoint) to facilitate the usage of electric vehicles in the region so that users of electric vehicles can charge their cars in any station belonging to the three networks (Chargy, 2017).

When it comes to the number of electric vehicles on the roads, the Grand Duchy of Luxembourg is a small, still developing system. However, its charging infrastructure concerns not only people living in the Grand Duchy, but also the 200,000 cross-border commuters who travel to Luxembourg every day to get to work. "For the majority of them, the car remains the preferred means of travel, whether for geographical, cultural or practical reasons" (Luxinnovation, 2019). For those who drive, charging at a Park and Ride car park might be an option. Among other solutions, the so-called TERMINAL project was launched at the beginning of 2019, with the aim of testing a shuttle service operated by electric minibuses for cross-border commuting.

05

CONCLUSIONS

LESSONS LEARNED & POLICY IMPLICATIONS



5. Conclusions: lessons learned & policy implications

5.1. Lessons learned

There are important lessons to be learned from the case studies presented in the previous sections of this report.

The first lesson is that, while developments on the supply side of the electric vehicles market have been crucial for the steep rise in the number of those vehicles in recent years, the phasing in of those is also very dependent on public policy.

All countries across Europe have access to the same electric vehicle models. The price of those has been dropping—largely as a result of a significant fall in battery costs. In terms of user experience, improved models can now compete with conventional internal combustion powered cars.

Still, not all European countries have experienced a rapid rise in electric vehicle numbers. In fact, Norway's leadership in that sphere is no doubt largely due to the generous subsidies and benefits enjoyed by buyers and owners of electric vehicles there.⁵⁴ This works both ways: both the rise and the subsequent drop observed in purchases of plug-in hybrids in the Netherlands came as a consequence of, first, the introduction and, later, the withdrawal of tax incentives for companies to lease such cars.

Experience in Norway and the Netherlands also illustrates that the relative growth in battery electric vehicles and plug-in electric vehicles depends on the “policy mix”. This has been tilted towards favouring battery electric vehicles in both countries in recent years, resulting in faster growth of battery electric vehicles than plug-in electric vehicles, which is of course the aim of public policies in these countries.⁵⁵

Apart from tax incentives, which typically benefit all electric-vehicle owners in a given country, many cities have taken a lead in encouraging the penetration of electric vehicles through preferential policies in areas such as traffic, parking and charging. Clearly, this benefits people living in and near cities. In particular, suburbanites who use their car to commute to work and drive relatively short distances, stand to benefit from such policies. It is therefore not surprising that electric vehicle ownership is especially concentrated in these areas. This may also be explained to some extent by the fact that, so far, most electric vehicles have had very limited driving ranges and hence are mostly suited for local transport.

While access to public charging stations is clearly important for harnessing the full potential of electric vehicles, **the three cases studied in this report indicate that most people prefer charging at home or at work rather than using public charging stations.**⁵⁶ In both the Netherlands and Norway, we find a clear pattern in charging behaviour, with peaks in the morning (charging at work) and in the afternoon and evening (charging at home). If left uncontrolled, this could result in an exacerbated peak in electricity demand in the afternoon and evening hours, as people tend to plug in their cars as they return from work or after-work activities.

In the Netherlands, only one car in fifty is electric. Hence, increased peak load does not yet seem to be a problem for the electricity infrastructure. Neither is it in Norway, which has five times the

⁵⁴ Differences in operating costs could also play a role. E.g. in Norway and the Netherlands household electricity prices in 2016-2018 were in the range 0.16-0.19 €/kWh compared to the EU average of 0.20-0.21 €/kWh over the same time period (Eurostat, 2019).

⁵⁵ This report pays only limited attention to other aspects, such as distributive concerns and road congestion, which could be relevant for policy makers.

⁵⁶ This is also evidenced elsewhere; see e.g. Ofgem (2018). Apart from convenience, this preference may in part be due to the difference in costs between public and private charging. Due to the plethora of pricing schemes for public charging, it is however difficult to make direct comparisons of costs. See e.g. La Monaca and Ryan (2018) for an overview of public charging costs and different business models for public charging.



stock share of the Netherlands. This is largely due to the strong electricity infrastructure in Norway, which is built for electric space heating. However, if the policy aim of a fully electrified car fleet was to be realised – this would imply fifty times as many electric cars in the Netherlands and ten times in Norway – and in the absence of countervailing measures, localised problems are likely to occur in many countries, especially where the infrastructure is not as strong as in Norway.⁵⁷

Such negative outcomes are, however, not a foregone conclusion. Since it is the peak demand during specific times of the day and at certain points, rather than the energy demand as such that can be problematic, it is critical to change the behaviour leading to those problems. **'Smart' technologies create the technical opportunity to shift and distribute charging over time, so as to reduce peak loads created by electric vehicles.**

Electric vehicles not only pose challenges for the power system, but also create opportunities. **A large fleet of plugged-in electric vehicles forms a huge storage facility in the aggregate.** The average non-commercial car is parked 96 per cent of the time (National Grid, 2018). Thus, if infrastructure is there to connect most stationary cars to the grid, and if smart charging technology is in place, there is a technical potential to harness this storage. If this technology is successfully brought to the market, electricity sourced from electric vehicles could provide flexibility and balancing services when needed. This would be of crucial importance for the power system, especially in a system with a high share of variable renewable energy (wind and solar). **But as the cases show, technology alone is not sufficient; a change in charging behaviour is also needed if this potential is to be harnessed.** So far, it has not really been utilised in any of the three countries studied (nor, as far as we are aware, anywhere else).

As evidenced by the experience in the Netherlands – and in the city of Amsterdam in particular – it is possible to utilise relatively simple measures to affect charging behaviour. The “Flexpower” network of “intelligent” public charging stations was launched recently, with the aim of reducing load from electric vehicle charging during evening peak hours, and instead shifting it to hours when load, net of solar generation, is low.⁵⁸

Luxembourg has taken a somewhat different approach to creating a charging infrastructure for electric vehicles. There, responsibility for ensuring the necessary infrastructure has been vested with electricity network companies, who have produced a comprehensive national scheme, based on public tenders, to ensure timely roll out. Given the relatively low numbers of both electric vehicles and charging points in the country to date, it is not yet clear how well this approach is working, especially compared to the alternative pursued in the Netherlands and Norway.

Both the Netherlands and Norway have adopted more decentralised approaches to charging infrastructure. However, in both countries, such infrastructure has developed in line with the fleet of electric vehicles and charging facilities do not seem to provide an obstacle to further growth of the fleet. The Norwegian experience is perhaps of particular interest, given the unusually high penetration of electric vehicles there. The fact that distribution networks are guaranteed financing of necessary upgrades from users has clearly played a part in facilitating the connection of charging points. The Netherlands has developed more of a bottom-up approach to account for the fact that a large proportion of people live in multi-home dwellings without access to a garage or a private parking space. Citizens can request that a charging point be set up near their home. Their request is then evaluated from a demand, cost and grid perspective. This seems a sensible approach, likely to lead to reasonable cost efficiency, and allowing for the reduction of congestion and capacity problems in the network, although this will depend on the implementation.

⁵⁷ There is anecdotal evidence from Stockholm that the inner-city electricity infrastructure is having problems coping with the recent very rapid growth in plug-in electric car sales – sales almost tripled over January-May this year, following on increased tax incentives for electric vehicles (Automotive News Europe, 2019).

⁵⁸ In Italy a “time-of-use” power limitation, higher by night than the contractual limit applicable in the remaining hours, is being considered. See ARERA (2019) part IV.



5.2. Policy implications

The rise of electric vehicles and the electrification of transport can go smoothly, supporting, rather than hindering the conversion to a greener energy system and reaching goals on the limitation of climate change. This, however, depends on whether we seize the opportunities created by new technologies – some already on the market or close to market deployment, others under development, and yet others still unknown – or not. For this to happen, it is crucial that the right incentives and market structures be in place. Otherwise people and firms will be very unlikely to change their current behaviour. **It is doubtful that the incentives are correct at present.**

For example, in most systems, there is no time-of-use differentiation of electricity prices and tariffs. Hence, there is no price incentive for shifting home-charging from peak-demand hours (late afternoon and early evening) to the low-demand hours (night). One of the challenges for distribution system operators is to ensure that charging mostly takes place during off-peak hours. **Time-of-use pricing is a possible option for shifting general demand for charging at or near homes from peak to off-peak hours.** Utilities around the world have been experimenting with – and in some cases have successfully introduced – time-of-use tariffs (e.g. Kolokathis et al., 2018; Hildermeier et al., 2019). In a system with high wind- and solar-powered generation, and where the appropriate metering technology is in place, prices could depend inversely on demand, net of variable renewables generation.

This may not suffice to solve the localised problems in distribution networks described above. For this, a much more granular approach to pricing would be needed, reflecting not only overall supply and demand in the market at a given time and, perhaps, at a given node, but also the situation in a given neighbourhood or even a given street. Moreover, time-of-use pricing would have less of an impact on demand for charging at public charging points than at homes or at work. **A change in regulation, e.g. on when and where charging can take place, rather than a change in the tariff and pricing structure, could be more appropriate in such cases.** In fact, the Flexpower network in Amsterdam provides an example of a promising “command and control” technology where demand from electric vehicles charging is shifted to times of the day with low net demand, not by changing prices but by rationing supply through the charging point.

Placement of charging points in places where the network impact is relatively low and loads are spread over the day is also very important. While this can pose challenges when people charge at or near their homes, this is an obvious consideration for dedicated charging stations. Super-rapid charging technology, i.e. high-capacity chargers that can, in a few minutes, enable an electric vehicle to run for long distances, is under advanced development and even in an initial phase of implementation in some countries (e.g. the Netherlands). If successful, this could shift a substantial part of the load from residential neighbourhoods to charging sites. Such technologies would have to be placed in areas with strong infrastructure that could feed electricity to the sites without overloading the network. But again, the right incentives need to be in place. One incentive which may work against this shift is the fact that, in most areas, it is more expensive to charge at high-speed chargers than at home.

To set the right incentives for placement of charging points, the Norwegian regulation provides a possible model for other countries: there, owners of all charging points – both at charging stations and at home – must pay the full network connection cost imposed on the system. The cost of necessary upgrades and strengthening of the grid is therefore covered by users. Moreover, this option allows for the locations of charging stations to be chosen efficiently. However, from a transport policy perspective, one of the drawbacks of this policy is that it may raise the costs of charging – especially home charging where location is not really a choice of the user – and, hence, may slow down the adoption of electric cars. This has not been the case in Norway so far, due to the limited need for infrastructure upgrades in residential areas and to the



efficient location choice for charging stations. Where upgrades have been required, the associated costs are limited (typically multi-home dwellings). **The Netherlands' approach to allocating charging points in neighbourhoods could also be a useful model elsewhere, especially in areas where private parking space is scarce.**

As noted above, electric vehicles – or rather, their batteries – could potentially provide important storage and flexibility in a de-carbonised energy system based in large part on renewable energy sources.⁵⁹ **While time-of-use tariffs and pricing or command-and-control regulation would be the appropriate tools to shift charging demand to off-peak hours, they will not be sufficient to exploit the full potential of electric vehicles as storage.** For that potential to be realised, the vehicles need to be plugged into the grid while they are parked, the vehicle-to-grid technology has to be developed and in place, and market agents – aggregators – need to be operating and to have entered into contracts with electric vehicle owners for the use of their (mobile) batteries. One challenge in this regard is simply having enough charging (or de-charging) points for parked vehicles. Electric vehicles also need to be allowed to stay connected without penalties – i.e. even while not charging. Given the scarcity of public charging points at present, it is not surprising that such penalties exist, as is the case in Oslo.

5.3. Conclusions

Europe is in the very early stages of what is predicted to become a full-scale shift to electric vehicles. This goes hand-in-hand with a transition to variable renewable energy sources and it provides the opportunity to de-carbonise transport and the energy system simultaneously, utilising synergies between the two systems. But there is great uncertainty about how fast and along precisely what pathway this will happen. For example, during the time – less than two years – that has passed since the preparation stage of this report, the worldwide number of electric vehicles has more than doubled and projections for future growth have been revised substantially upwards. Predictions on the rise in peak electricity demand due to the growth in electric vehicles numbers have in some cases been revised drastically downwards due to a growing optimism about smart charging and the implementation of vehicle-to-grid technologies and markets. The goal of new regulations and of changes to pricing and market structures must be to avoid overloading and inefficiencies in the power system related to the rise of electric vehicles, this dynamism and uncertainty notwithstanding.

It is possible to identify different options to organise the electric vehicle “ecosystem” in which multiple actors (i.e. charging point operators, DSOs, platforms, mobility service providers and EV users) operate and interact. Irrespective of the regulatory arrangement, a more centralised model (e.g. Luxembourg) highlights the possibility of defining pre-existing roles for most of the actors. While this model could better apply to local and regional realities, more decentralised models (e.g. The Netherlands) may also proliferate and coexist across Europe.

Alongside the time dimension, spatial aspects also need to be taken into consideration. There needs to be foresight but also flexibility, so that regulation can be adapted to developments in the market and in technology, and to regional and local specificities. Importantly, any changes should encourage rather than hinder the uptake of new and efficient technologies and the development of markets where they are employed.

⁵⁹ In a longer-term perspective, used batteries may also become an important stationary storage facility (Element Energy, 2019).



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