GUIDE TO SMART CHARGING SOLUTIONS

COLOPHON & ACKNOWLEDGMENTS

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EDITORIAL

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Foreword

At ElaadNL, we research and test smart and sustainable charging of electric vehicles. We are a joint initiative of the Dutch grid operators. Through their mutual involvement in ElaadNL, the grid operators are preparing for a future with electric driving and sustainable charging. A huge challenge! While mobility and the power grid have had virtually nothing to do with each other in the past, they now are becoming inextricably linked due to the rise of electric driving.

The electric car poses not only a major challenge from a grid perspective (how do we provide millions of cars with electricity?), but also an important part of the solution: electric cars are basically big batteries on wheels! If we make smart charging the standard, we can make optimal use of the power grid and also accelerate the transition to local sustainable power from sun and wind. Add to this the potential of the car as a storage of electricity that we can use later, not only to get from point A to B, but also to power homes and businesses. And it is becoming very clear that electric vehicles (and the way we charge them) are key to the much-needed energy transition.

When ElaadNL celebrated its tenth anniversary in 2019, we published the Smart Charging Guide, in which we shared knowledge about smart charging. Now, five years later, it is time for a completely new edition: The Guide to Smart Charging Solutions. A lot has happened in those five years: the growth of electric passenger cars and charging infrastructure, the increasingly urgent problem of grid congestion, more knowledge about smart charging, important developments with respect to vehicle to grid, the start of the large-scale roll-out of grid-aware charging throughout the Netherlands, and the arrival of the first e-trucks and matching heavy-duty vehicles charging infrastructure. In this Guide, attention is paid to all these developments, with a focus on the Dutch situation. Due to good cooperation between governments, researchers, grid operators and companies, the Netherlands leads the way in a number of respects. We hope to inspire others, but we also like to learn from other countries. As the saying goes: together we go further!

Arnhem, January 2025
Onoph Caron, director ElaadNL

If we make smart charging the standard, we can make optimal use of the power grid.

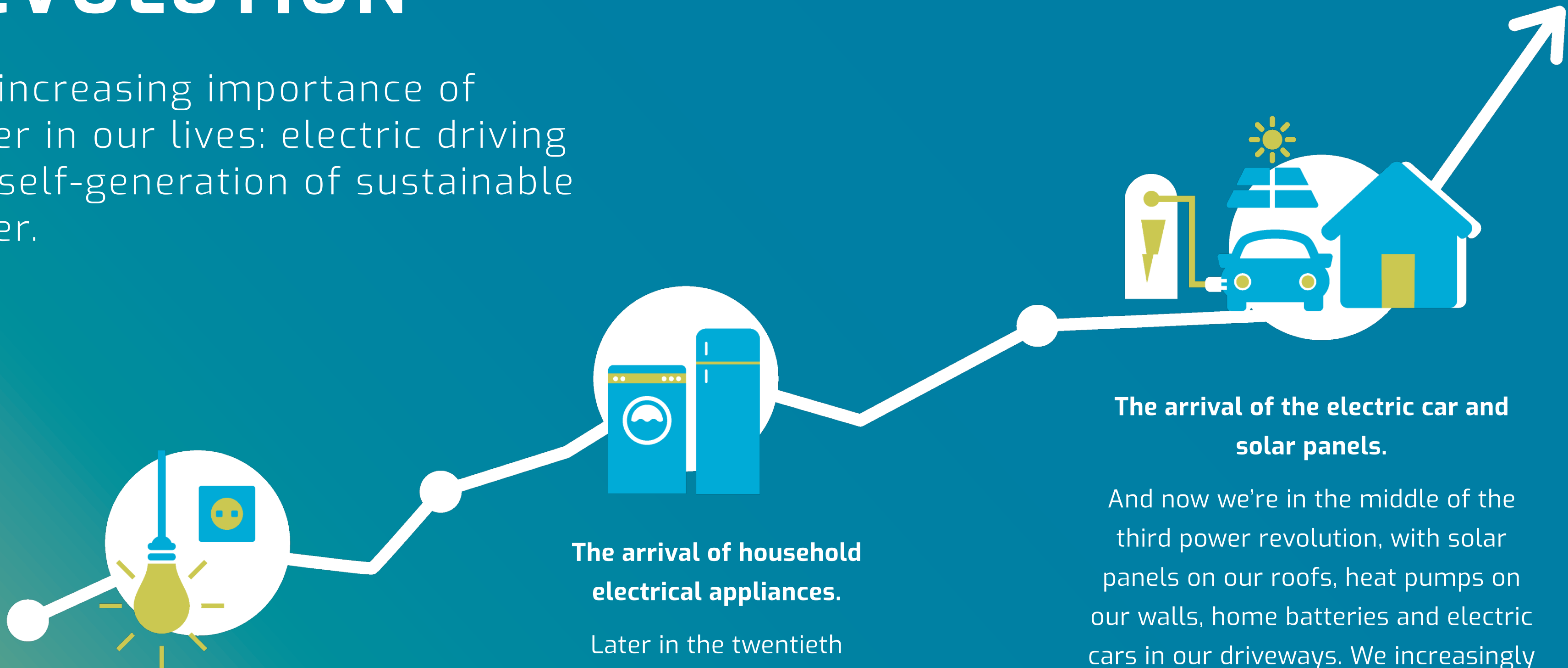
1

E-MOBILITY AND AN ENERGY SYSTEM IN TRANSITION


PTER

THE THIRD POWER REVOLUTION

The increasing importance of power in our lives: electric driving and self-generation of sustainable power.



The lightbulb replaces the gas lamp.

Electricity enters our homes for the first time in the late nineteenth and early twentieth century. Reliable, safe and clean light reduces our dependency on daylight for both work and life. And from the beginning of the twentieth century, the radio becomes more and more commonplace in households.

The arrival of household electrical appliances.

Later in the twentieth century, household electrical appliances come into our lives: such as, the fridge, freezer, washing machine, iron and vacuum cleaner. As a result, domestic work is no longer a day job.

The arrival of the electric car and solar panels.

And now we're in the middle of the third power revolution, with solar panels on our roofs, heat pumps on our walls, home batteries and electric cars in our driveways. We increasingly heat our homes with electricity, we plug in to power our mobility, and we're starting to generate and store electricity ourselves, for example in our electrically powered cars.

IN THIS FIRST CHAPTER, WE TAKE A LOOK AT THE HISTORY OF ELECTRICITY AND (ELECTRIC) MOBILITY. WE EXPLORE THE CHALLENGE OF THE TRANSITION FROM A FOSSIL-FUEL POWERED ENERGY TO ONE THAT IS SUSTAINABLE, AND THE ROLE OF ELECTRIC VEHICLES IN THAT PROCESS.

ELECTRICITY!

Since ancient times, people have known about electricity in the form of lightning. However, it wasn't until the 19th century that humanity began to understand and control electricity, making it a popular topic among well-known scientists. Consequently, various units of measurement were named after them, such as Ohm, Ampère, and Hertz.

The initial power grids were established after the first power plant was built in 1882 through an initiative of Thomas Edison, who sought to monetize the recently invented and improved light bulb. The progress in electrification was one of the major elements that fuelled the Industrial Revolution. Between the World Wars, household electrification began, through the development of various household appliances. Throughout the 21st century, electricity has been indispensable in our modern society. Many of our daily devices work thanks to electricity. Because of the impact of electrification on countless aspects of daily life, the National Academy of Engineering (NAE) ranked electrification as the greatest engineering achievement of the 20th century. Mobility is ranked second.

Transportation also became electric in the early 20th century, both in cities (with trams and metros) and beyond (with trains). Around 1900, there were also quite a few electric cars (relative to the period). However, by the end of the 19th century, improvements in the combustion engine led to a decline in the popularity of the electric motor. The fundamental issue with electric cars was the limited energy density of rechargeable batteries. It took more than a century for the electric car to gain popularity again.

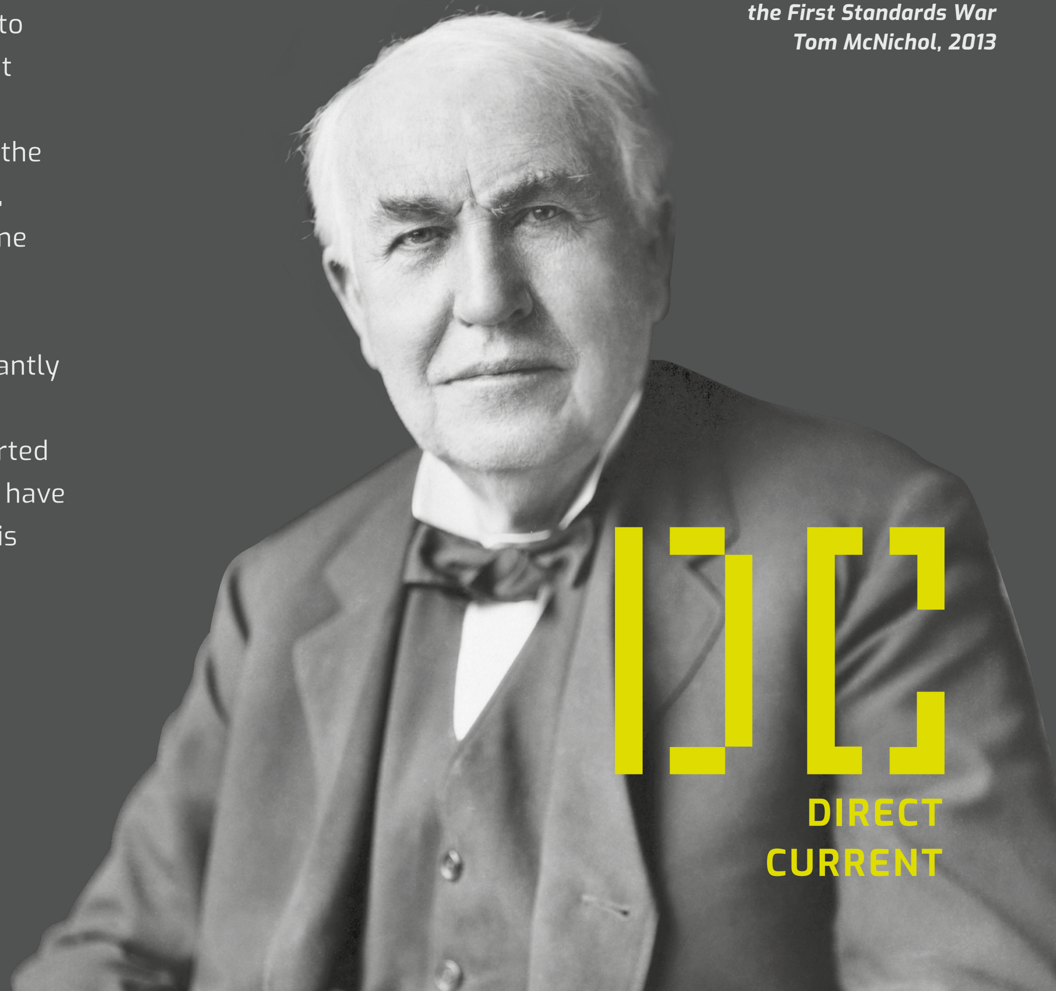
WAR OF THE CURRENTS: AC VS DC

Electric car batteries, and in fact all batteries, work on direct current, while electricity from the grid is alternating current. During normal charging, an inverter in the car converts alternating current (AC) to direct current (DC). With fast chargers, the inverter is in the charging station and the battery receives DC from the charging station. Note that the plugs and cables for fast charging are different from those used for normal charging.

Inventor Thomas Edison had to set up a completely new system for generating and transporting electricity in order to make his light bulbs burn. He did that with direct current. But soon after, a competitive system was introduced: the alternating current system. Later on, another inventor, Nikola Tesla, became embroiled in this and a fierce battle erupted over which system was to become the standard. This was brilliantly won by the AC camp, as this enabled electricity to be more easily transported over larger distances. That's why we have AC power from our wall socket to this day.

However, DC would always remain important in applications such as batteries. All modern electronics also work on DC. Nowadays there are even calls to make the entire grid DC.

Source
AC/DC: The Savage Tale of the First Standards War
Tom McNichol, 2013



The negative effects of using energy sources from fossil fuels for electricity, heat, and transport have become increasingly visible in recent decades, in terms of climate change and air pollution and other detriments. In the 2015 Paris Climate Agreement, countries agreed to halt the rise in the global average temperature, maximizing it to 1.5 - 2 degrees Celsius. Electrification plays a major role in reaching this goal, as it results in a more efficient use of energy and enables a shift to renewable sources. Heat, transport, and industry will be extensively electrified in the coming decades, which will result in a strong increase in the demand for electricity.

The energy demand previously supplied through heat (natural gas) and transport (petrol stations) infrastructure will be added to the load on electricity infrastructure. Electricity will primarily be generated from sustainable energy sources such as wind, solar, hydropower, and possibly nuclear energy. Electricity production is shifting from traditional plants to large-scale wind parks in the North Sea and decentralized generation through solar and wind on land. As a result, we will become increasingly dependent on the weather for electricity generation. To cope with periods of low generation, large-scale energy storage will be necessary, and adjusting the demand for electricity to meet the availability at a particular moment will be key. In essence, when there is a lot of electricity available on a sunny and windy day is the best time to use and store electricity to charge electric cars, for example. Additionally, the power grid will need to be significantly expanded.

THE ELECTRICITY SYSTEM IN TRANSITION

An energy system connects the demand and supply, transport, and storage of energy forms. This system is in transition.

A growing part of our energy demand is being electrified. The energy demand of small consumers is growing mainly through the increase in electric vehicles and heat pumps. Electrification leads to a significant increase in demand (energy)

ELECTRIC CARS: NOTHING NEW!

The first fuel-powered cars were built at the end of the nineteenth century; they were very difficult to drive and especially hard to start. To start the engine, the driver had to manually pump petrol to the carburettor float chamber, set the throttle and pre-ignition manually, and crank the engine.

At the time, city officials saw the electric car as a much cleaner alternative to horse-driven transport, rather than the petrol-powered car. As early as 1907 at an international congress in Berlin, a discussion was held on the negative effect of exhaust gases on public health, as it was recognised that these contained up to 3.7 percent carbon monoxide.

Thus, at the beginning of the twentieth century, electric cars were very popular: they were cleaner, easier to operate, and much more reliable than petrol cars. Electric taxis could be found driving clients in all the world's major cities, including New York, London, and Amsterdam. They sometimes had battery packs that could be changed within five minutes. Even then, when charging the battery packs, the London Electric Cab Company took the amount of electricity available on the electricity grid into account: smart charging avant la lettre.

Inventors like Edison and Marconi worked on new battery technologies as an alternative to existing lead-acid batteries, developing alkaline and iron-nickel versions. In 1900, Ferdinand Porsche designed a plug-in hybrid car powered by wheel hub motors. Electric cars were also found in motorsports. In 1896, the first car race to be held in the United States was won by an electric car in Rhode Island.

Source
Jan Wouters 'The electric car: is it's 1914 market share achievable in 2020?'

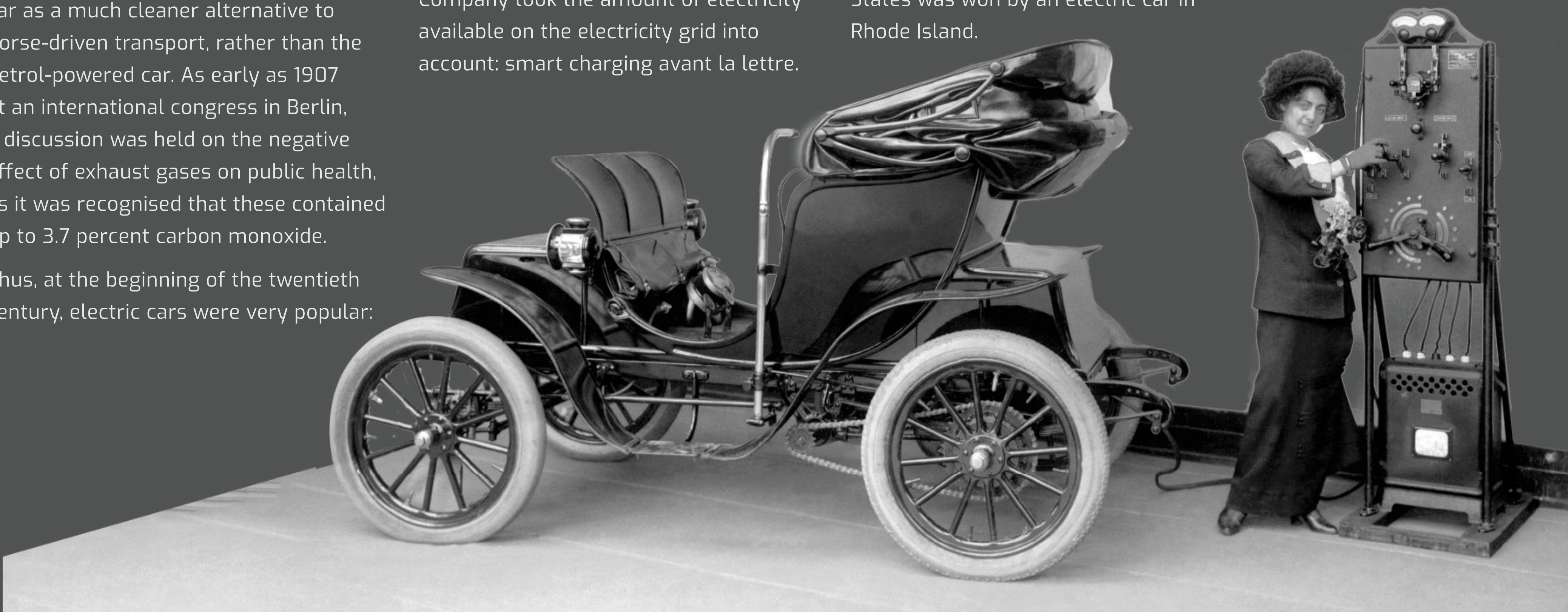


Photo
Columbia Mark 68 Victoria electric vehicle

Source: Corbis/Hall of Electrical History Foundation

and an increase in the simultaneous use of this demand, because electric cars can charge for hours, and heat pumps run for hours. This results in a higher peak load. At the same time, the demand from small consumers decreases due to decentralized production, mainly through solar panels (provided it is generated simultaneously with consumption).

On a larger scale, there is an increase in decentralized electricity production in the supply side of the energy market. This specifically concerns solar panels and wind turbines. The production of solar and wind energy is characterized by weather and seasonal dependence, independent of demand. As a result, the variability of production volume increases. These changes can cause moments where supply is bigger than the demand for electricity, because production is less controllable and cannot be quickly adjusted to use. In other words, the increasing volatility of electricity production complicates fulfilling the growing demand for electricity.

Our electricity grid must undergo significant changes and rapid expansion due to the energy transition. It is important that grid operators design these expansions efficiently and intelligently together. Electricity infrastructure occupies physical space, making integration into a densely populated country like the Netherlands challenging. By collaboratively designing the necessary grid expansions, we ensure good spatial integration with an optimal balance between social acceptance, costs, and the pace of expansion. The energy system of tomorrow is no longer a system developed by the energy sector and paid for by the customer, but rather a system that belongs to all of us.

STORAGE AND FLEXIBILITY: THE NEW PILLARS IN THE ENERGY SYSTEM

The energy transition changes the way we use the electricity grid. The growth in electricity demands that transport is faster than the speed at which grid operators can expand the grid. This means we will face capacity shortages and imbalance in the coming years. Managing electricity supply and demand is crucial to solving this. Flexibility refers to the ability of energy users to adjust their electricity demand or

A COMPLETELY SUSTAINABLE ENERGY SYSTEM IS POSSIBLE

Read more?
The future Dutch full carbon-free energy system, KIVI December 2017

In the near future, a fully sustainable energy system is possible. The essential conditions for this are far-reaching electrification of almost everything: transport of people and goods, heating of houses and offices and industrial processes, amongst others. All the electrical power needed for this has to come from sustainable sources, in particular sun and wind. But as these sources can't supply the same amount of electricity at any given time and for every season, our future energy system will have to rely heavily on adjusting demand to supply (demand response) and on energy storage. Batteries (in cars) can be used for short-term storage solutions, to cover a 24-hour period or even a week. However, to bridge the seasons, we will need to store energy in a different form, for example by producing and storing hydrogen.

Photo
Jacques Tillmans
Alliander

supply. Flexibility can ensure more efficient use of the electricity grid. Deploying decentralized flexibility will become an essential pillar of the energy system. Flexibility can contribute to the energy transition as a temporary solution or an alternative to grid reinforcement.

ELECTRIC VEHICLES: FLEXIBILITY ON WHEELS

Electric vehicles have the potential to make a huge contribution to flexibility. Electric cars are now very efficient, and most of them have large batteries; this means that the amount of energy required for daily trips is very manageable for most drivers. It is therefore not necessary to charge the car after every drive. An average electric car requires as much energy annually as an average household, and a full battery can store as much energy as is used by a household over a ten-day period. Additionally, electric vehicles (EVs) can charge with high peak power demands, which is much higher than other electrical devices in or around homes. If you add up all these factors, charging EVs can be the champion in providing flexibility in the demand for household power, and adding them up within the new sustainable energy system. The only thing needed in order to unlock this flexibility is to go from charging to smart charging!

Smart charging refers to the intelligent management of EV charging to optimize sustainable energy use, enhance grid stability, and minimize costs. It involves adjusting the timing and speed of EV-charging based on various factors such as electricity prices, avoiding peak demand on the grid, and the availability of renewable energy. Smart Charging can help to prevent grid overload, to integrate more renewable energy sources, and to provide cost savings for EV owners by charging during off-peak hours when electricity is cheaper.

Most cars are charged at home or at work. Home charging can occur on private property (behind the home connection) or in public spaces (on the street). For long distances, fast chargers can be used for a top-up during the drive. Especially with home charging or charging at work, the car is stationary for much longer than is needed to charge, which creates opportunities for smart charging.

Smart charging refers to the intelligent management of EV charging.

Photo
Kia

More and more electric drivers choose to charge their cars only when the battery is mostly empty, or to set a start time for charging that would benefit from rooftop solar panels and lower tariffs with their energy management system. This way, even without external incentives, electric car charging is already spread throughout the day. This is a basic form of smart charging that is already common and easy to implement. Scaling up smart charging, and automating the smart charging decisions made by the driver, will make it even easier and more comfortable for the driver. By automating the charging decisions, cars are not only being charged when it's financially attractive for the EV driver, but groups of chargers can also help to protect the local grid for being overloaded.

Additionally, as electric vehicles are basically batteries on wheels; therefore, the next step is using the batteries in cars for additional purposes—not just for driving, but also for providing power to your house, your office or the grid. This is called vehicle to grid (or to everything), otherwise known as bidirectional charging: this is an innovation that is still in its early days, but shows huge potential for enhancing the role of electric vehicles in providing flexibility to a new and sustainable energy system. Just imagine charging your car using solar panels when the sun is shining, and using the car batteries to supply your house with electricity for lighting, heating, and other electrical appliances, while still leaving more than enough power to drive to work the next day.

In the next chapters we will dive deeper into the concepts and solutions regarding smart charging and vehicle to grid, but first we will take a look at the current trends and opportunities in the world of electric vehicles.

Bidirectional charging. This is an innovation that is still in its early days, but shows huge potential.

2

THE GROWTH OF EVS: TRENDS AND PREDICTIONS


PTER

Photo
Stedin | Sicco van Grieken
Nieuw: thuisbatterij

IN THIS CHAPTER, WE EXPLORE THE CURRENT TRENDS IN ELECTRIC VEHICLES (OR EVs). SINCE THE REINTRODUCTION OF EVs ON OUR ROADS IN THE EARLY 2010S, THERE HAS BEEN A SIGNIFICANT SURGE IN THEIR ADOPTION. THIS TREND EXTENDS BEYOND PASSENGER CARS TO INCLUDE BUSES, TRUCKS, CONSTRUCTION EQUIPMENT, INLAND VESSELS AND EVEN SMALL AIRCRAFTS. IN THIS CHAPTER, WE FOCUS ON ELECTRIC CARS.

We will examine the expected growth trajectory of electric cars, its implications for the necessary charging infrastructure, and the impact on the electricity grid. To address these questions, we will refer to the ElaadNL Outlooks, which map trends and expectations for the Netherlands. These Outlooks are based on scenario studies developed through data analysis, research reports, and expert interviews. They are utilized by governments and grid operators as a basis for policy-making.

TRENDS IN ELECTRIFICATION OF PASSENGER CARS

Ten years ago, electric cars were a rarity on Dutch roads, but today they are an integral part of everyday life. In 2024 about half of new cars that are sold in the Netherlands have a plug (this number refers to both plug-in hybrids and full electric vehicles), and about 35% are fully battery electric (electric cars). All well-known car brands now offer multiple electric car models, and several new brands have entered the market, predominantly selling electric cars.

In 2024, over 122,000 new electric cars were added, a 28% increase compared to 2023. By December 2024, more than 550,000 electric cars were on the roads, representing nearly 6,1 % of the total Dutch vehicle fleet. The electric transport sector contributes €3.6 billion to the Dutch economy and employs over 30,000 people (RVO, 2023).

Ten years ago, electric cars were a rarity on Dutch roads, but today they are an integral part of everyday life.


FASTNED
R-348-PZ

Overview of key numbers on passenger cars in the Netherlands and EU-27.
** Estimated.*

Fleet (total number of vehicles)		Current state of electrification	
Netherlands	EU-27	Netherlands	EU-27*
8.7 M	257 M	6.1%	2.2%

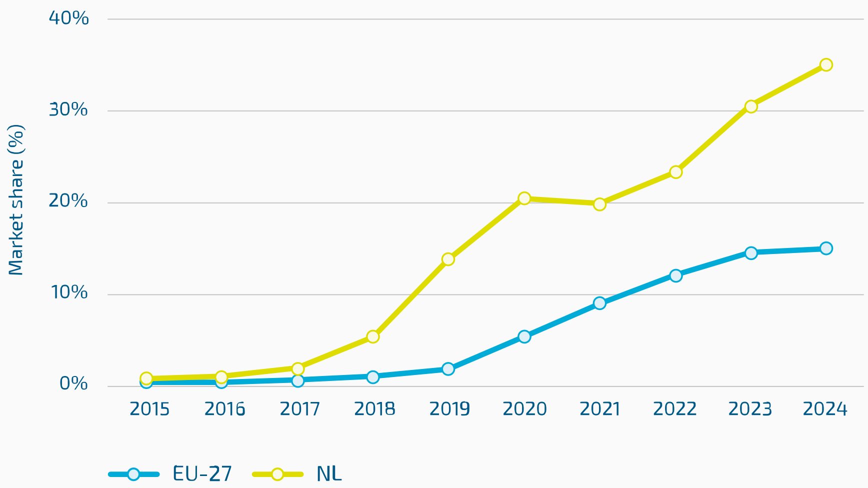
Source: EAFO (2025)

Despite many challenges, the charging infrastructure in the Netherlands is also growing significantly. The total number of charging points increased by almost 26% (+37,099) in 2024. By December 2025, there were nearly 178,000 (semi-) public charging points installed in the Netherlands, averaging three electric cars per (semi-)public charging point.

In 2024, 1,443 new fast-charging points were added, which represents a 34% increase from the previous year. There are more than five thousand fast-charging points, of which approximately 80% have a capacity of more than 100 kilowatt.

The chart below shows the annual market share of electric passenger vehicles in the Netherlands (35% in 2024) compared to the European average (15% in 2024).

Market share of electric vehicles in total registrations per year in EU-27 & the Netherlands



ELECTRIC DRIVING IS MORE EFFICIENT

An electric car uses energy much more efficiently than a gasoline or diesel car. The combustion engines of the latter have an efficiency of 25 to 35 percent; this means that roughly two thirds of the energy contained in the fuel is lost to heat through the cooling system and the exhaust; only one third is actually used to move the car.

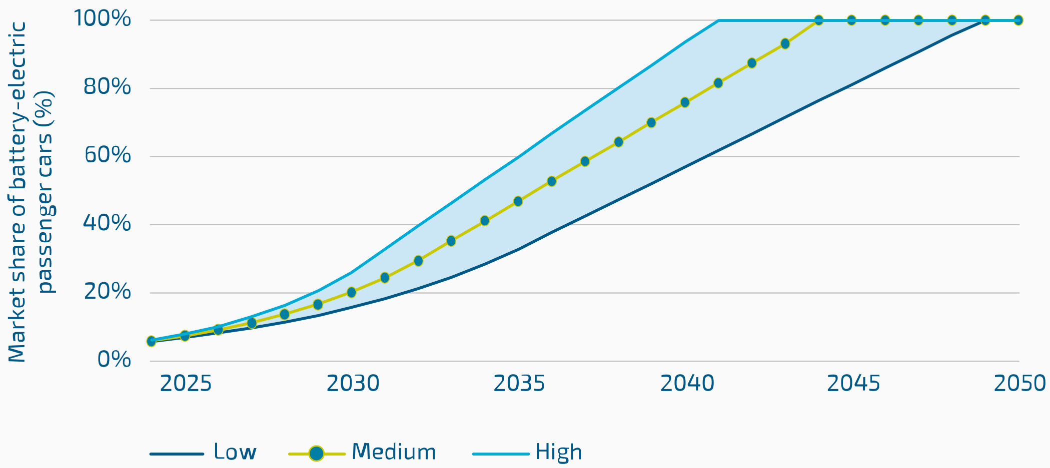
An electric motor can achieve an efficiency of 90 to 95 percent. The energy loss in an electric car is mainly due to the fact that the alternating current (AC) from the grid has to be converted into direct current (DC) that can be stored in the battery. The energy then needs to be reconverted from DC to AC, because the car's electric motor runs on AC.

ELECTRIFICATION SCENARIOS

In the ElaadNL Outlooks, the expected electrification of the vehicle fleet is quantified into three scenarios: low, medium, and high. Each scenario varies based on the predicted year when new sales and imports into the passenger car fleet will be 100% electric, and when the entire domestic fleet is electrified. The scenarios range from a fully electric inflow starting in 2027 (high) to 2035 (low). The entire fleet could be fully electric as early as 2041 (high) or as late as 2049 (low).

The phasing out of incentivisation measures, as well as uncertainty surrounding new policies in the Netherlands, appear to slow the current growth of the number of electric cars in the short-term. However, European regulations ensure that the Netherlands is clearly moving towards Zero Emission mobility, in which electric cars will dominate. Car manufacturers are set to introduce more 'affordable' models between 2024 and 2027. The decline in battery pack prices is expected to make electric cars cost-competitive with fuel models by 2030. While hydrogen was included in earlier scenarios, it is not expected to play a significant role for passenger cars going forward.

Adoption scenarios for battery-electric passenger cars in the Netherlands



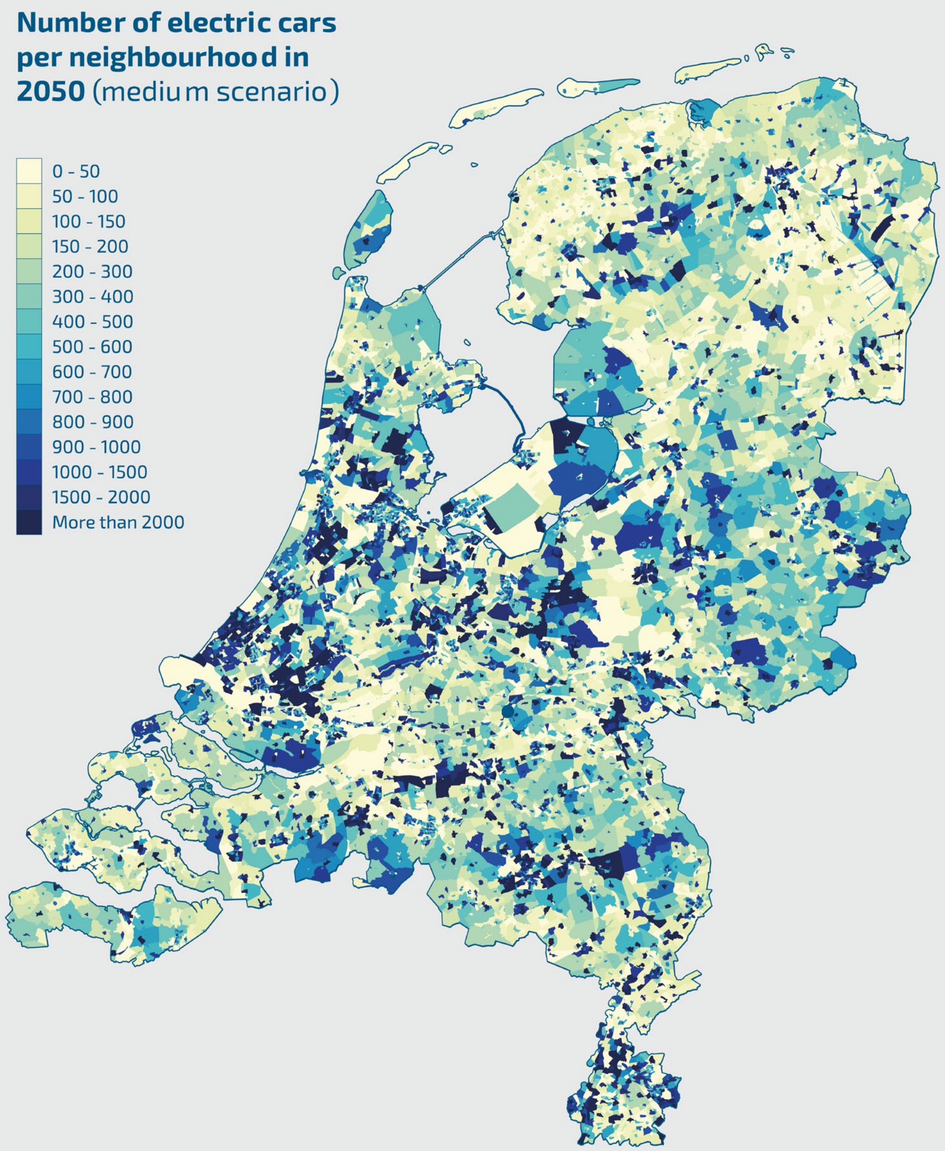

MICHELIN
PILOT SPORT 4

DIFFUSION OF ELECTRIC CARS PER NEIGHBOURHOOD IN 2050

The adoption of electric cars varies across different areas in the Netherlands. Using a diffusion model, we determined the locations of electric cars, which provides a good indication of where they will be charged for more than 14,000 neighbourhoods in the Netherlands. This diffusion model uses variables such as neighbourhood characteristics and the current distribution of new passenger cars across neighbourhoods.

This map shows the total demand for charging infrastructure per municipality in 2050. It illustrates the forecast for the distribution of charging points by type. Home-charging points will remain dominant nationwide in 2050, due to the (nearly) one-to-one ratio between the number of users and electric cars (at the home charging points)..

(Semi-)public charging points, however, will be more heavily utilized . In the Randstad region, the proportion of public charging is relatively higher than home-charging points due to the spatial layout. Work-charging points are generally more evenly distributed across the country.

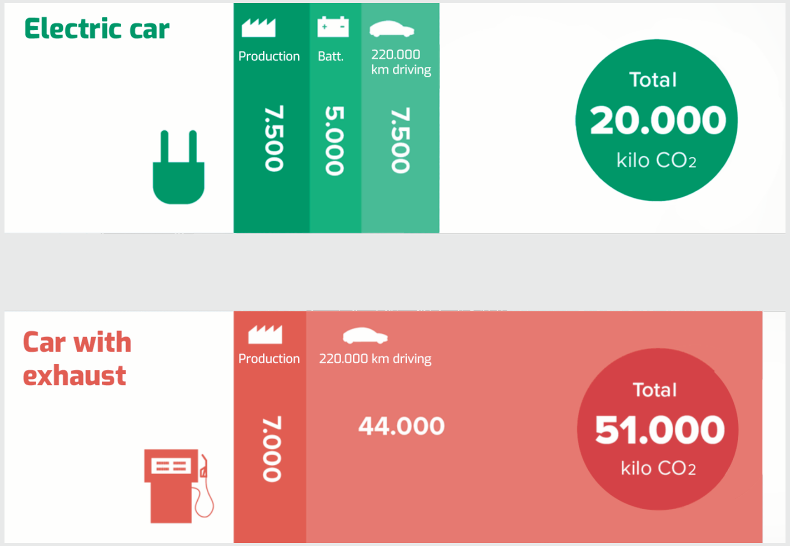


LIFE CYCLE ASSESSMENT

To make a fair comparison in energy consumption and CO_2 emissions between conventional and electric cars, we have to look at the entire chain: from the energy source to exhaust (even though an electric car doesn't have the latter!) We call this well-to-wheel. Moreover, we also need to account for the energy required to produce a car and, at the end of its life cycle, to recycle it. This leads to the following conclusion: even with mainly non-renewable electricity produced from coal and gas-fired power plants, on balance the electric car emits much less CO_2 than a gasoline or diesel car. Charging electric cars using energy from renewable sources maximises the environmental benefit.

60 percent less CO_2

In numbers? The researchers of Milieu Centraal calculated that the CO_2 emissions of an electric car (EV) over its entire lifetime are more than 60 percent lower than those of a petrol or diesel car. It takes more energy to produce an electric car; the manufacturing of the battery is especially energy-intensive. But this is more than recouped in the 18 to 20 year use-phase considering that an EV produces far fewer emissions than a conventional car. An electric mid-range car releases a total of about 20,000 kilos of CO_2, while a comparable fuel car releases about 51,000 kilos of CO_2. This assumes an average CO_2 emission from the electricity mix between 2024 and 2041: 140 grams CO_2/kwh. This is based on the Dutch electricity mix of green and non-renewable expected by Netherlands Environmental Assessment Agency over that period.



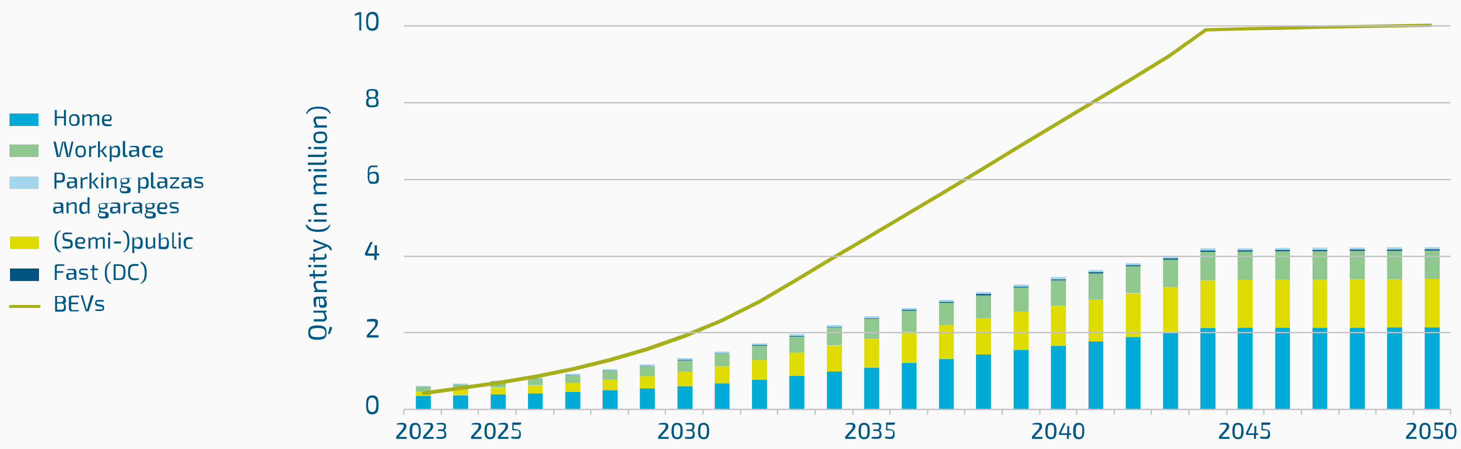
The CO_2 emissions were calculated for production (including the EV battery), maintenance, and estimated use of the car. The estimate is based on a new mid-size car driving 12,000 kilometers per year over 18 years. For the EV, the CO_2 emissions are based on a predicted energy mix for 2024-2041 (140 g CO_2/kWh). This emissions factor is based on PBL forecasts of the Dutch gray-green energy mix between 2024 and 2041.

FUTURE CHARGING DEMAND

Starting from approximately 2030, electric cars are expected to become cost-competitive across all car segments, enabling large-scale adoption without

the need for further direct incentivisation. However, the timely and adequate development of the necessary charging infrastructure by regional authorities remains crucial for the complete electrification of the vehicle fleet. In the mid-range scenario, over 10 million electric cars and approximately 4.3 million charging points are forecasted by 2050. This figure shows the forecasts for the number of electric cars and charging points in this scenario (up to 2050).

Forecast BEV & charging demand (medium scenario)




Overzicht
Timer
Profielen
Voorvrw/kl
Algemeen oplaadprofiel
Locatieafhankelijke oplaadprofielen
Nieuw profiel toevoegen
Accu opgeladen om:
2:27
Woensdag
42
%
149
km
0.00 km/min
Voorconditionerin

The increasing demand for charging cars will significantly impact the electricity grid and the physical space around us. By 2050, 26 Terawatt hours (TWh) will need to be transported through the grid to meet the electricity demand of passenger cars alone. This represents an increase of nearly 25% compared to the current electricity consumption in the Netherlands. Innovations such as smart charging can help manage the charging of electric cars efficiently to ensure that electricity demand is evenly distributed, which prevents extra high peaks on the grid. The spatial integration of vehicle electrification will also place additional demands on public space due to the growing number of charging points and the expansion of the grid, including medium-voltage spaces in residential areas.

In these different scenarios, we can see that a huge increase of the electric cars in the Netherlands is imminent, resulting in a 100% electric-passenger car fleet, as well as a related demand for charging infrastructure and power supply. In a later chapter, we will focus on other electric vehicles like vans, buses and e-trucks and their demand for high power charging. But first, in the next chapter, we will explore the challenges of charging a fully electric passenger car fleet and the crucial role of smart charging. How can we make it all work?

In all scenarios, we can see a huge increase of electric cars.

3 SMART CHARGING: BALANCING THE GRID WITH ELECTRIC CARS

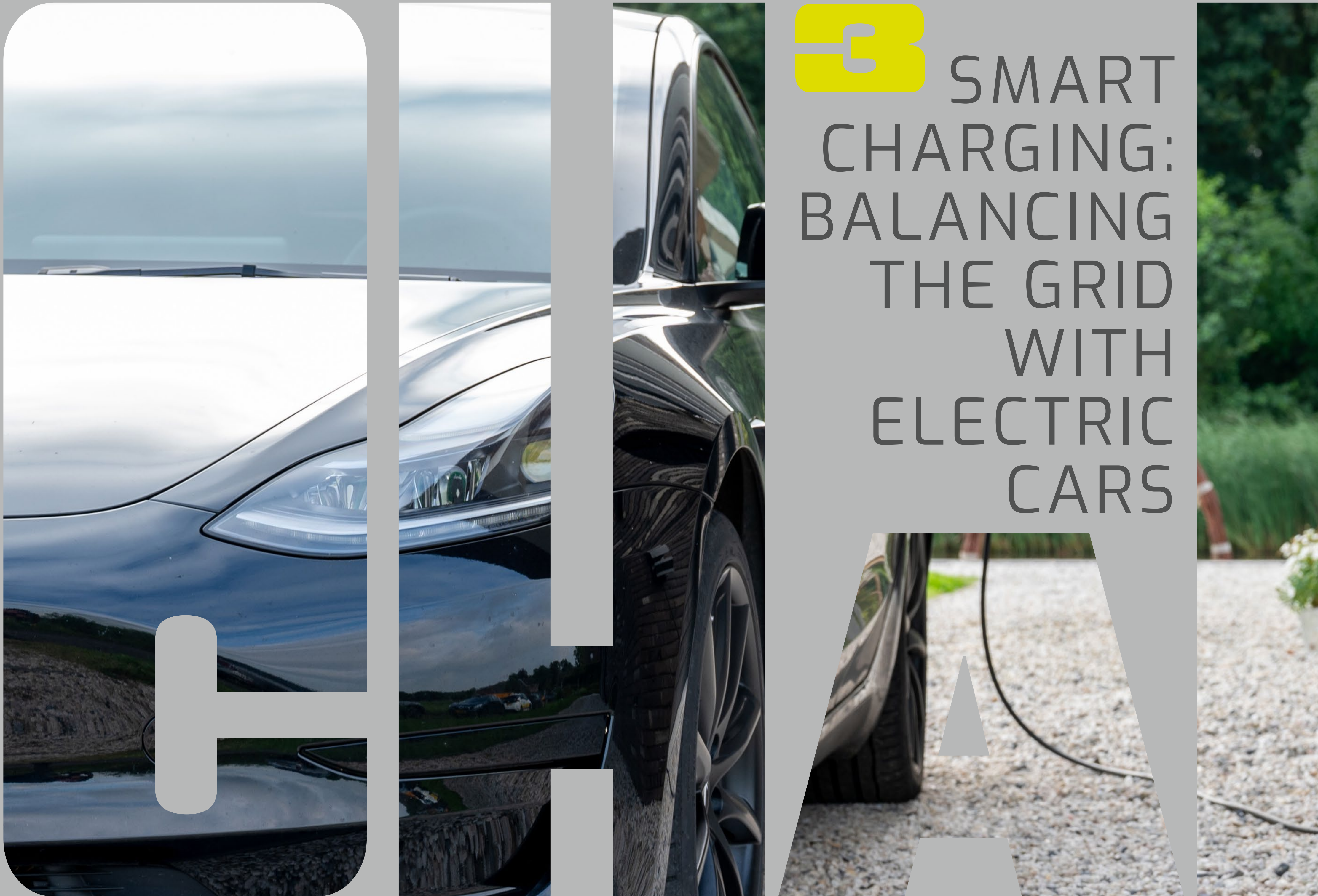


Photo
Celeste Mostert
Stedin

HOW DOES AN EV WORK?

Just like a fossil fuel-powered car, an electric car has an engine that drives the wheels. However, an electric car engine doesn't get its energy from the combustion of gasoline or diesel, but from the discharging of a battery.

The electric motor uses energy much more efficiently. It also has a larger torque* and speed range than a combustion engine. This means an electric car doesn't need a gearbox. This has many advantages: there is more space in the car, and it saves on weight and maintenance.

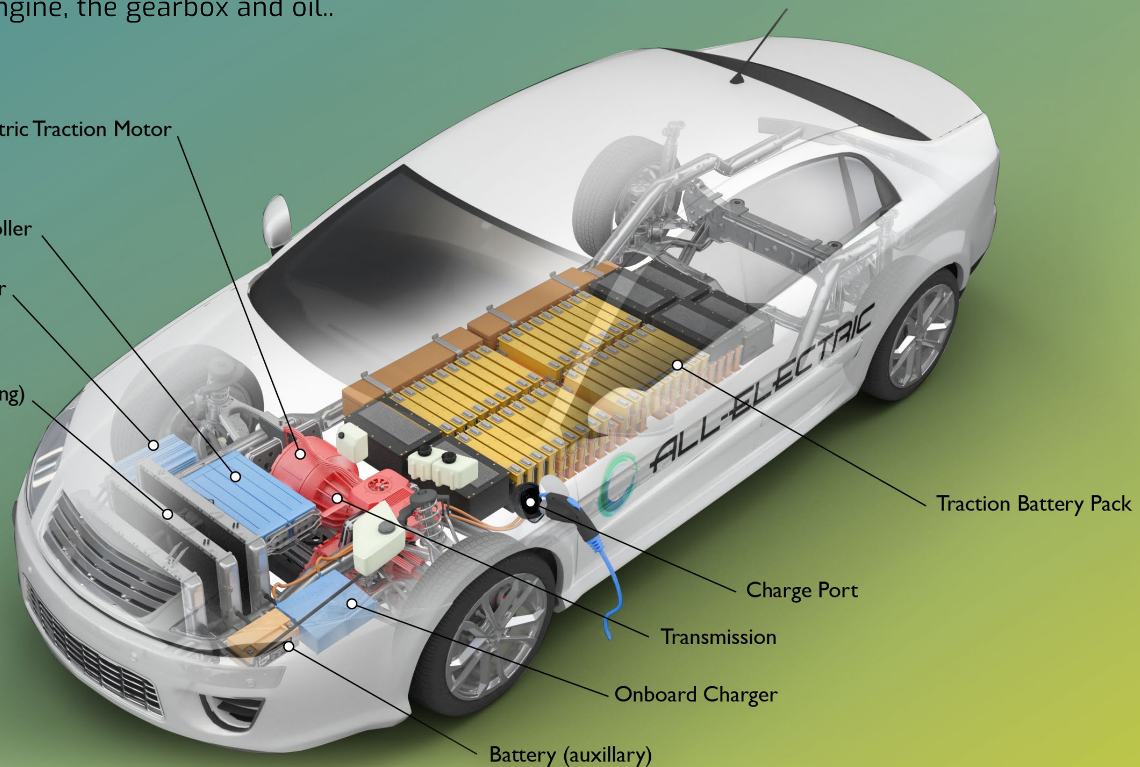
Moreover, an electric motor contains many fewer parts than an internal combustion engine, and no oil has to be measured or changed. An electric car therefore has lower maintenance costs.

Of course, space is needed for the batteries and they add extra weight. Electric cars are heavier than comparable non-electric models, despite the saved weight of the engine, the gearbox and oil..

A final important feature of the electric motor is that it acts as a dynamo: when a car slows down (for example, on a roundabout), the electric motor functions as a dynamo, recharging the battery.

Photo
EV

Source: US Department of Energy



** twisting force, or strength, of an engine*

IF MILLIONS OF CARS BECOME ELECTRIC, HOW CAN THEY ALL BE CHARGED IN A RELIABLE, SAFE AND SUSTAINABLE WAY? THAT IS A BIG CHALLENGE FOR THE POWER GRID AND THOSE WHO ARE TRYING TO ENSURE THAT THE POWER DEMANDS FOR THOSE CARS (AND ALSO ALL OTHER APPLIANCES) ARE MET. GRID OPERATORS, GOVERNMENTS, SCIENTISTS, COMPANIES AND CONSUMER GROUPS ARE ALL WORKING ON THIS CHALLENGE TOGETHER IN THE NETHERLANDS THROUGH THE DUTCH NATIONAL CHARGING INFRASTRUCTURE AGENDA.

The growth of electric mobility (and the much needed charging infrastructure) has a huge impact on the electricity grid, but it can also be part of the solution. The answer lies in smart charging. As a rule of thumb, a single electric passenger car can charge with peak power comparable to ten average households. By smartly controlling this demand (smart charging), the electricity demand can be adjusted to the available grid capacity, benefiting grid load and ensuring optimal use of the existing grid. Electric cars can also help to optimize the use of sustainable energy from solar and wind by primarily charging when there is a high supply of electricity from solar and wind. For the user or fleet manager, this can have another advantage: in addition to more sustainable charging, it generally also means charging at lower electricity prices, which ultimately means cheaper charging. In short: electric cars bring significant flexibility to electricity demand.

The growth of electric mobility has a huge impact on the electricity grid, but can also be part of the solution.

Photo
WeDriveSolar/Renault

In most cases, ElaadNL expects that the existing electricity grid can handle the growth of charging that is needed for passenger cars, their spread throughout the grid and their ability to charge at relatively low power—provided we widely implement smart charging both at public charging points and at home and businesses. Ultimately, grid reinforcements will be necessary due to all of the developments in the electricity market combined, but smart charging allows us to optimally use the existing grid in many more places and for a longer time, facilitating the growth of electric mobility and charging infrastructure.

If vehicle-to-grid (V2G) becomes common in a few years, there will also be a large flexible storage capacity available because a modern electric car easily stores enough electricity to power a household for a week. However, this technology is still in its infancy compared to smart charging.

GETTING IT DONE

Understanding the work and speeding it up

In 2023, an ElaadNL analysis showed that 35% of all high- to mid-voltage substations in the Netherlands (175 out of 500) will face congestion from either demand, supply, or both by 2030. This issue isn't only due to electric mobility. There are significant local variations, with the most impact expected in densely populated areas like the Randstad. For the low voltage grid, which includes 96,000 mid voltage stations, around 20% will be overloaded by 2030, and an additional 15% will need to be built. This is due to the increased use of heat pumps, solar panels, and EV charging. By 2035, the number of problem areas is expected to double compared to 2030.

Overall, it's clear that transitioning to cleaner energy requires smart solutions to unlock flexibility across the country. Smart charging can reduce the need for grid reinforcements by about 10-15% in 2030 and 15-20% by 2035. Custom charging profiles based on actual grid loads can improve this even more. However, smart charging isn't the only solution. Grid reinforcements will still be necessary, and it's crucial to identify where these reinforcements are needed and where smart charging can help.

Photo
Nationale Agenda Laadinfrastructuur

A FUTURE WITHOUT SMART CHARGING

The importance of smart charging becomes clear when you imagine a world without smart charging, where every time you plug in, the car starts charging at a maximum speed until the battery is 100% charged. Hypothetically, if all passenger cars in the Netherlands are electric and charge simultaneously at home, this requires three times more power than the current power plants and sustainable power sources can provide. Plugging in all cars simultaneously is therefore unrealistic, not only in terms of grid constraints but also in terms of power generation. With respect to grid constraints, ElaadNL calculates that in some residential areas of 250 households, as few as fifteen electric passenger cars without a smart charging option could result in an overload of the local electricity grid on a cold winter's day. This is not surprising, considering that fifteen electric passenger cars are equivalent to adding 150 extra houses to a neighbourhood.

Therefore, it is crucial where, when, and at what speed/power charging occurs. If the load on the electricity grid is not distributed optimally, local problems will arise even with lower numbers of electric cars. The electricity grid is not unique in this regard. Compare it to our road network. If we all want to go to the same place simultaneously, traffic jams occur. Similarly, if we all wanted to refuel our gasoline cars simultaneously tomorrow, that would not be possible either: there would be queues at the gas station. Good distribution of demand is needed in both the old and the new mobility system.

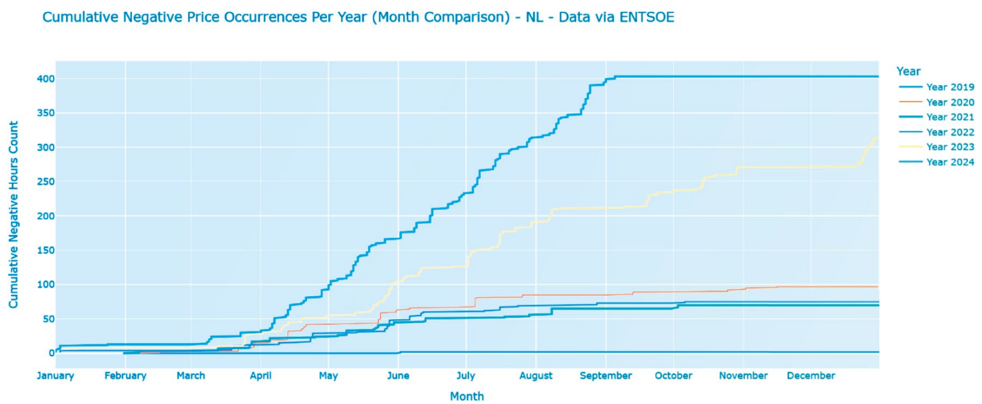
Now, queues in power demand are partly prevented on the electricity grid because there is a natural spread in user behaviour. Not everyone plugs in to charge every day, much like not everyone visits the gas station every day. However, simultaneity still occurs in the hours following the arrival of cars that do need to charge, since charging lasts much longer than refilling at a gas station. The spread in arrival times of those cars is not large enough to prevent excessive peak loads on the grid. Smart charging evens out the effects of simultaneity and, as such, prevents power demands from reaching levels that are too high. Cars are stationary much longer than they need to charge, and so there is plenty of opportunity to spread out charging.

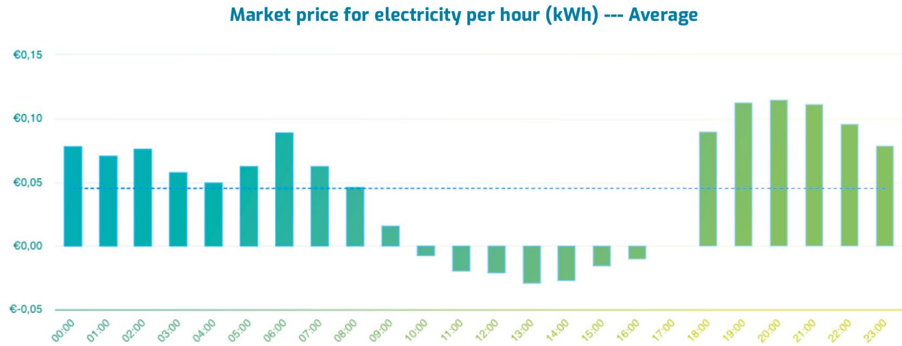
Smart charging evens out the effects of simultaneity.

GETTING PAID FOR CHARGING YOUR ELECTRIC CAR?

Because there isn't an on and off switch for the sun or wind, you need a much greater capacity of renewable energy generators to ensure enough power is generated compared with traditional power plants; the latter can always increase production to match the demand. As the share of wind and solar energy grows in the total production mix, there is a greater chance that at certain moments, energy production will be so large that it exceeds the energy demand. In European countries such as Germany and the Netherlands, sometimes so much electricity is produced from solar and wind sources while there is too little demand that electricity prices fall under zero. In these cases, you are paid to tap electricity (if you have a dynamic electricity contract). This can happen during sunny days with a lot of wind, and especially in weekends when industry needs are at a minimum. Any surpluses are often distributed abroad; however, as more and more European countries are generating their own sustainable electricity, this option will be more difficult.

This can lead to the temporary shutdown of solar panels or wind turbines. This is called curtailment and creates a waste of sustainable electricity. Fortunately, there are other solutions which allow us to adjust the demand for electricity to the supply (demand response): one such option includes charging electric vehicles at the low-demand moments by using smart charging.





Of course, the growth of electric mobility is not the only development leading to grid reinforcement; the massive installation of solar panels on roofs and the arrival of heat pumps also result in an additional burden on the electricity grid. ElaadNL, in collaboration with grid operators, is investigating where hotspots will emerge that require additional measures on top of smart charging in the coming years. This allows grid operators to proactively reinforce the grids in those areas.

THE TECHNICAL BACKGROUND

Of the 8.2 million electricity connections in the Netherlands, the majority are households with a connection of 1x25, 1x35, or 3x25 Amps. Although the technical capacity of these connections ranges from 5.8 to 17.3 kW, a household without a charging electric car has an average power demand of between 1 and 1.5 kW, with short-term peaks up to a maximum of 4 kW. When designing electricity grids, the expected simultaneous peak load of all connections is considered.

Most public charging points and households with a charging point have a 3x25 Amp connection to the existing low-voltage grid. Depending on the type of onboard converter in the vehicle and, in the case of public chargers, the occupancy of the sockets on the charger, an electric car takes 3.7 to 16 kW of power from a charging point (on average, this is a factor of ten times more power than a household). By 2030, we expect a larger portion of cars in a neighbourhood to be electric—if everyone then charges without smart charging, there will be a massive increase in simultaneous peak load on the low-voltage grid.

Photo
Stedin

Photo
Nationale Agenda
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SMART CHARGING FROM A GRID OPERATOR'S PERSPECTIVE

Grid operators aim to find an optimal social balance that justifies the reliability, affordability, and sustainability of the electricity supply. Various ways exist that can stimulate choices around charging behaviour, to be consistent with minimizing the total costs of the electricity system, meaning customer-friendly and affordable.

The Electricity Act prescribes grid operators to utilize demand control in addition to grid reinforcement. Unlocking flexibility through demand control allows peak loads to be managed, thus preventing overloads. This efficient use of the grid results in lower investment costs as grid reinforcements are avoided. Moreover, demand control can prevent interruptions.

Charging electric vehicles is a free market, so smart charging must involve a high degree of willingness. In practice, this means that consumers adjust their charging behaviour based on incentives, such as network tariffs or electricity prices. If there is occasional excessive electricity transport, the grid operator has a legal duty to act in the public interest. In that case, the incentive for smart charging can temporarily become mandatory.

SMART CHARGING FOR OPTIMIZATION OF THE USE OF THE POWER GRID

Smart charging involves controlling the timing and speed of charging through technology. One of its functions is grid usage optimization. To this end, 'grid-aware charging' is a specialization of smart charging that considers the local possibilities of the electricity grid. For example: you plug in when you get home, but the technology ensures that charging is adjusted based on grid capacity, so that not all vehicles that are on the same cable or transformer are charging at the same

Smart charging is controlling the timing and speed of charging through technology.

time when grid capacity is limited. Postponing charging in anticipation of local production is also part of grid-aware charging. By adjusting the speed and/or timing (i.e., delayed charging) of charging, the existing electricity grid can be optimally used.

Grid-aware charging ensures the smooth integration of electric cars into our electricity grid, enabling charging infrastructure to be rolled out unabated, while simultaneously avoiding local grid overload as much as possible. The basic idea of grid-aware charging is to give maximum space when possible and minimally restrict when necessary. Based on this principle, the technical capacity of a connection can always be fully utilized. Only when charging sessions take place in a grid section that is technically at its limit (e.g., if the neighbourhood transformer becomes overloaded) do Charge Point Operators (CPOs) temporarily get less capacity for charging cars, or charging is delayed to another time (delayed charging).

Research by ElaadNL (Smart Charging Plaza Pilot) shows that charging plazas operate with a capacity of 2 to 4 kW per charging point. Local congestion issues and congestion at higher grid levels during the concession period may require temporarily postponing charging regionally. Demonstration projects such as Flexpower in Amsterdam and FLEET (Flexible Energy Tariffs) in Utrecht show that e-drivers experience little inconvenience from temporarily reduced capacity.

E-drivers experience little inconvenience from temporarily reduced capacity.

DO WE ALL CHARGE ON THE SAME POWER GRID?

You can divide the power grid into three levels: high voltage, medium voltage and low voltage. The electricity is traditionally generated in large power plants and nowadays also with large wind farms. These are connected to the high-voltage grid. High voltage (on arrival at the edge of the city) is reduced to medium voltage through a distribution station. The transformer house in your neighbourhood converts the electricity to low voltage. And that low voltages electricity comes from your socket at home.

If you want to charge an electric car at home or at a charging station, the charging stations are supplied with power by the local low-voltage grid. The most common domestic (both private and publicly owned) charging station charges at 11 kilowatts (in the Netherlands).

When you are fast charging, for example along the highway, that power comes from the medium-voltage grid. This is converted on site via a transformer of the charging station operator. You charge there with 50 to 350 kilowatts power. However, e-trucks usually charge at a distribution centre or a logistics charging hub. The power for this comes from the medium-voltage grid: in this case, directly from a distribution station of the grid operator.

The same applies to the fast chargers that provide electric trucks with a lot of power in a short time on the road. Powers of up to 1,000 kilowatts are possible in this case (megawatt charging).

So, even though we all charge on the same power grid, where and how a vehicle charges makes a world of difference!

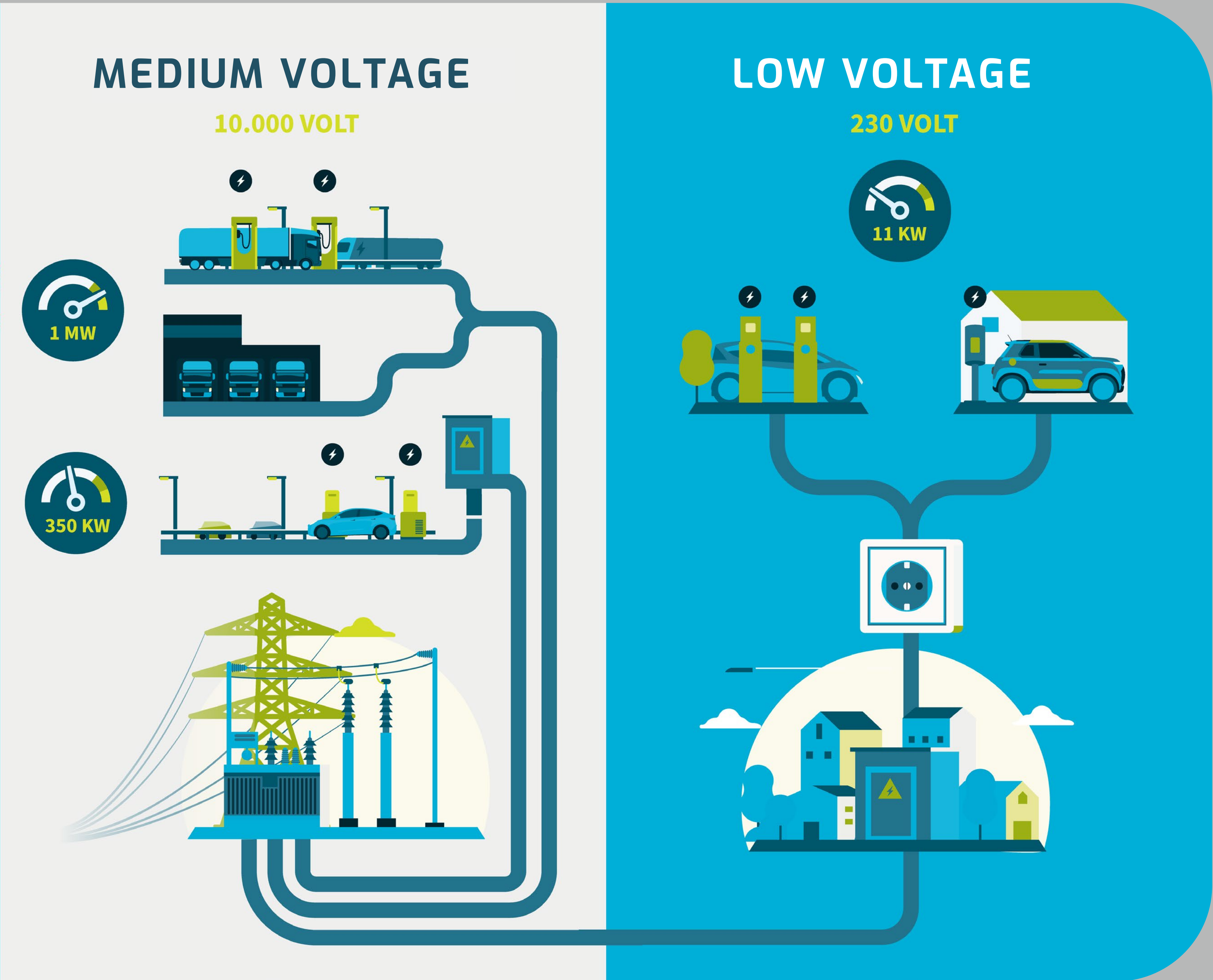
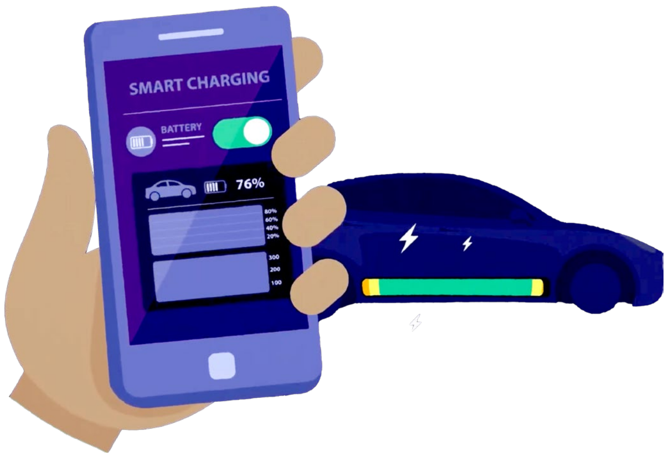

MEDIUM VOLTAGE
10.000 VOLT
1 MW
350 KW
LOW VOLTAGE
230 VOLT
11 KW

Photo
Liander

WAYS TO ENSURE GRID-AWARE CHARGING

To continue facilitating the mobility and energy transition, it is necessary to focus on the better use of the electricity grid and increased flexible capacity among users—in addition to grid reinforcement. The grid operator has the following instruments to stimulate grid-aware charging:



- ***Network tariffs*, *particularly the Small Consumption tariff structure.***
- ***Market solutions*, *through market-based congestion management.***
- ***Energy management*, *by energy suppliers.***
- ***Direct intervention*, *through mandatory congestion management.***

NETWORK TARIFFS

The first instrument is network tariffs. Dutch electricity connections are categorized based on the transport capacity of that connection. The connection and transport agreement is the basis for determining network tariffs. In tariff regulation, the cost causation principle is leads, which means that every connection pays a justifiable amount of the total grid costs for Dutch households; this translates to every household paying the same grid tariff, regardless of how much power demand they put on it.

The consumption profile of a small consumption grid connection that regularly charges an electric vehicle is significantly different from traditional household use. This leads to reconsideration of the causation principle. Grid operators are investigating how to better distinguish between fixed and flexible access to the electricity grid. In general terms, a new network tariff should encourage consumers to charge when grid capacity is available, in addition to their regular, non-flexible power usage, which can be guaranteed at all times. This results in the more efficient use of the electricity grid, and can prevent costly grid reinforcements for avoidable peak loads.

THE ELECTRIC CAR AS PACEMAKER OF THE GRID

In Europe, the electricity grid operates at a frequency of 50 Hertz (Hz). This means that the voltage has a waveform that varies 50 times per second between maximum positive voltage and maximum negative voltage. This can be seen as the power grid's "heartbeat". This frequency is determined by the balance between electricity production and demand. If there is more energy demand than generation, the frequency decreases, and if there is more generation than demand, it increases.

It is important that this 50 Hz remains constant, as all of our devices are designed for this. The frequency of the grid thus determines the speed of a three-phase motor; if this deviates too much, it can start to run faster or slower than intended. Digital devices can also be disturbed by frequency changes. In early 2018, digital clocks were six minutes behind in the Netherlands and 25 other countries due to an imbalance between the energy grids of Serbia and Kosovo. If the grid becomes too unbalanced, this can lead to a failure of the entire electricity grid.

Tennet, the transmission system operator, manages this 'heartbeat' in the Netherlands, ensuring that it remains between 49.8 and 50.2 Hz. Tennet uses different energy markets for this, coupled with continuous checks. Balancing supply and demand was a relatively simple task in the fossil-fuel past: if the demand for energy increased, some more coal or natural gas would simply be incinerated in the power plants. However, because we now have more renewable energy in the form of wind and solar energy, the supply side has become more dependent on weather conditions and is therefore less directly manageable. On the other hand, the demand side has also become more flexible. Electric transport in particular offers an excellent opportunity to adjust electricity demand to the amount of available electricity. With smart charging, the charging speed can be varied and, with the latest charging techniques, you can even load back to the grid. When this is done with a large numbers of vehicles, the charging can be used to ensure that our grid's heartbeat remains steady at 50 Hz. The electric car thus can act as a pacemaker for the grid!

From the electricity grid's perspective, it is beneficial to charge cars outside of its traditional peak hours. This means to primarily charge around midday and at night to avoid the peaks in the morning and early evening. By charging at off-peak hours, we use our existing electricity system more efficiently, keeping grid costs low and more affordable. Through load control, we reduce peak moments (i.e., 'peak clipping') and promote use during valley moments (i.e., 'valley filling'). This is what smart charging is all about: controlled charging.

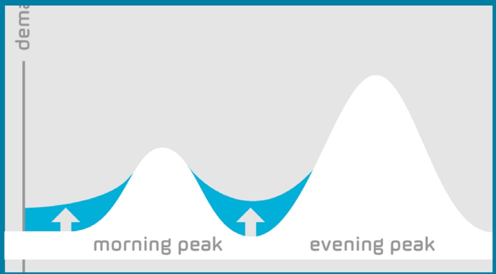
Under the Dutch national program 'Smart Charging for Everyone', research is being conducted into possible forms of new network tariffs, starting with public and semi-public charging. The charging strategy that is rolled out assumes that the full capacity per connection is available in normal situations. In the event of (impending) capacity scarcity, this capacity can be reduced.In the case of reduced capacity, charge point operators are allowed to pool the capacity of various charging points and distribute the available capacity among the charging points at their discretion. This 'pooling' is comparable to the approach used at charging plazas. A maximum total power consumption per connection per year could be considered. In this program, it is ultimately at the discretion of charge point operators (and not the grid operator) to create charging profiles that ensure the driver's car is charged on time while considering the grid limits. All grid operators are currently collaborating with charge point operators throughout the country, to gain experience with the operational aspects of grid-aware charging.

The user experiences from the first areas in which grid-aware charging is operated will result in input for new network tariffs. The figure illustrates a possible setup for new network tariffs.

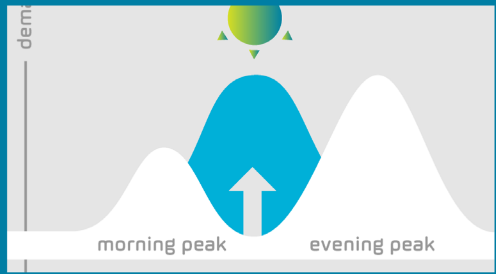
MARKET SOLUTIONS

The second tool to manage grid issues is market assistance. When electricity demand exceeds grid capacity in a specific area, a congestion management system is activated. This system is a temporary solution, where the grid operator asks market participants to adjust their electricity usage at certain times. Smart

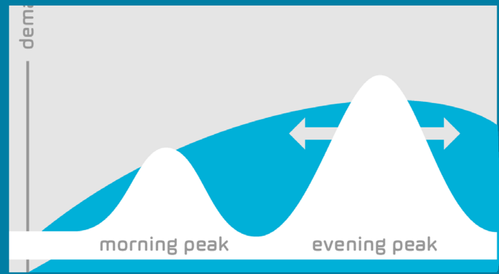
SMART CHARGING TECHNIQUES



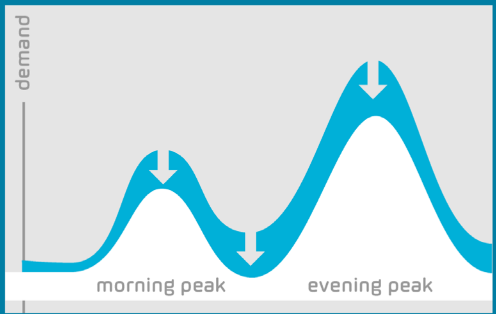
Valley filling



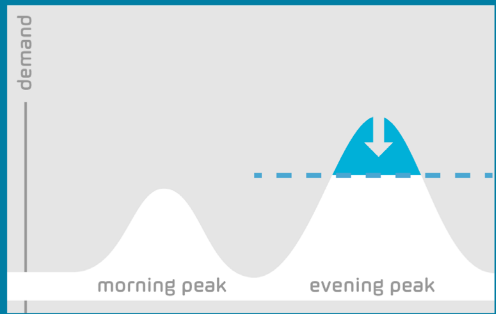
Stimulation (sun)



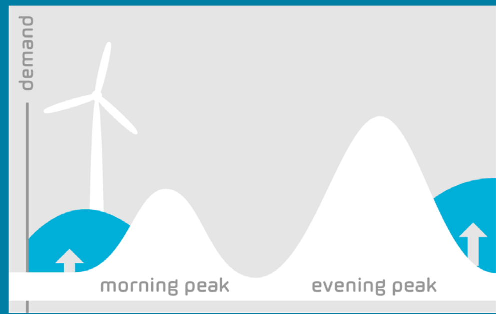
Stimulation (wind)



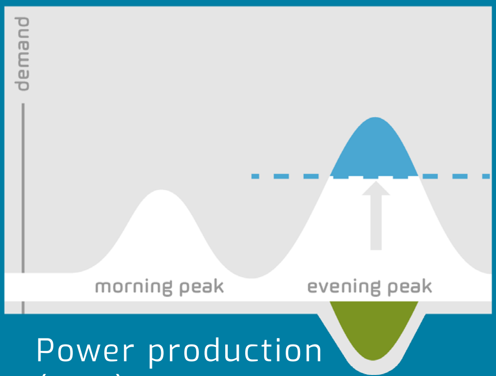
Load shifting



Energy conservation



Peak clipping



Power production (V2G)

- **Valley filling:** more or faster charging at periods of low energy demand.
- **Stimulation:** faster charging when more sustainable (or cheap) electricity is available.
- **Load shifting:** slower charging at times when peak loads are imminent; EVs then charge faster at other times.
- **Energy conservation:** at the time of charging, the speed is reduced to less than the technical maximum for the entire charging period.
- **Peak clipping /peak shaving:** less rapid charging at times when there is a risk of peak loads.
- **Power production:** resupply of energy from the EV.

charging of electric vehicles is one way for market participants to respond, and the grid operator compensates them for this adjustment.

Market assistance can be organized through contracts that guarantee flexibility when needed, such as with large charge point operators. Another option is a digital trading platform where the grid operator requests flexibility, and market participants submit bids. Although the result of this method is less predictable, it could attract more participants. Market participation platforms are still in early development because congestion management has only recently become a focus for regional grid operators.

A challenge that hinders the development is that local trading platforms often have low liquidity, meaning that there are few buyers and sellers with significant flexibility. Introducing a congestion management service provider can help, but achieving sufficient liquidity requires multiple parties with substantial local flexibility.

ENERGY MANAGEMENT BY ENERGY SUPPLIERS

Most charging points have smart controllers, which allows electric drivers to easily translate their mobility needs into a smart charging profile. Companies also benefit from this. Energy companies manage supply and demand in the electricity system, ensuring this is balanced for their customers. As more solar panels, wind farms, and heat pumps are added, a new local dynamic emerges in maintaining the energy balance. By providing electric drivers with energy management systems, companies enable smart programming of charging preferences in line with their interests. The electric driver, of course, retains the freedom to choose through which market party they receive energy (and possibly also feed it back).

With all the changes around electricity demand and supply, it is becoming increasingly challenging for energy suppliers to keep the energy program balanced. As more electricity is generated from solar and wind, the impact of weather on the energy balance also increases. Peaks and valleys will occur more often. Since the timing of charging can be very flexible, electric cars can play a significant role

in balancing supply and demand. Energy suppliers are considering how to balance their energy programs by using smart charging. The principle will be that the more flexible you are in charging your car, the more you can benefit from lower electricity prices.

DIRECT INTERVENTION

The fourth instrument is direct intervention. An example of this instrument developed by ElaadNL is called 'GridShield'. Even when both previous instruments (network tariffs and flexibility through market mechanisms) are implemented, a scenario where a critical grid situation arises must still be considered. The grid operator should then intervene directly to prevent the electricity supply from failing. Legislation already allows direct intervention with a legally determined fee. In practice, this would mean that charging electric vehicles is adjusted based on the current grid situation through a real-time signal from the grid operator. The signal for interventive smart charging is mandatory, regardless of the charging profiles that are established voluntarily. Since all charging points in the neighbourhood temporarily reduce the charging speed in this scenario, the electricity demand decreases, thus preventing overload. Technically, there are multiple possible options for implementation, which can be divided into central control (e.g., curtailment through the back office) and decentralized control (e.g., self-healing modules that are connected to the local grid transformer).

In a low-voltage energy system with a GridShield (or similar interventive measure), the safety margin for controlling charging sessions or other flexible devices can be much smaller. The GridShield records energy flows in real-time, and if they fall outside the grid's safety margins, charging is temporarily reduced in speed or paused. Control is automatically deactivated once the overload disappears (with a dead band to prevent systems from continuously switching back and forth without real improvement in grid load). For the grid operator, it does not matter how power is curtailed; what matters is that power is curtailed. Scenarios where the control signal is sent to an aggregator, smart meter (home) energy management system, or directly to a charging point are all conceivable.

Photo
Enexis

The regional grid operator can later determine whether a mandatory capacity profile has been followed based on reading smart meter values of homes and public charging points, as well as meter readings from the transformer room. More direct control may be desirable, for example, when a safety net is activated not only on the individual connection but also at the neighbourhood or business park level. Ideally, an independent platform should provide both parties with insight into the correct follow-up of capacity profiles. This can be managed by an aggregator or the metering company.

All ways to ensure grid-aware charging are still in development for large-scale rollout, but have been tested in pilots. We know it works! But how?

AUTONOMOUS CONTROL WITH VOLTAGE MEASUREMENTS

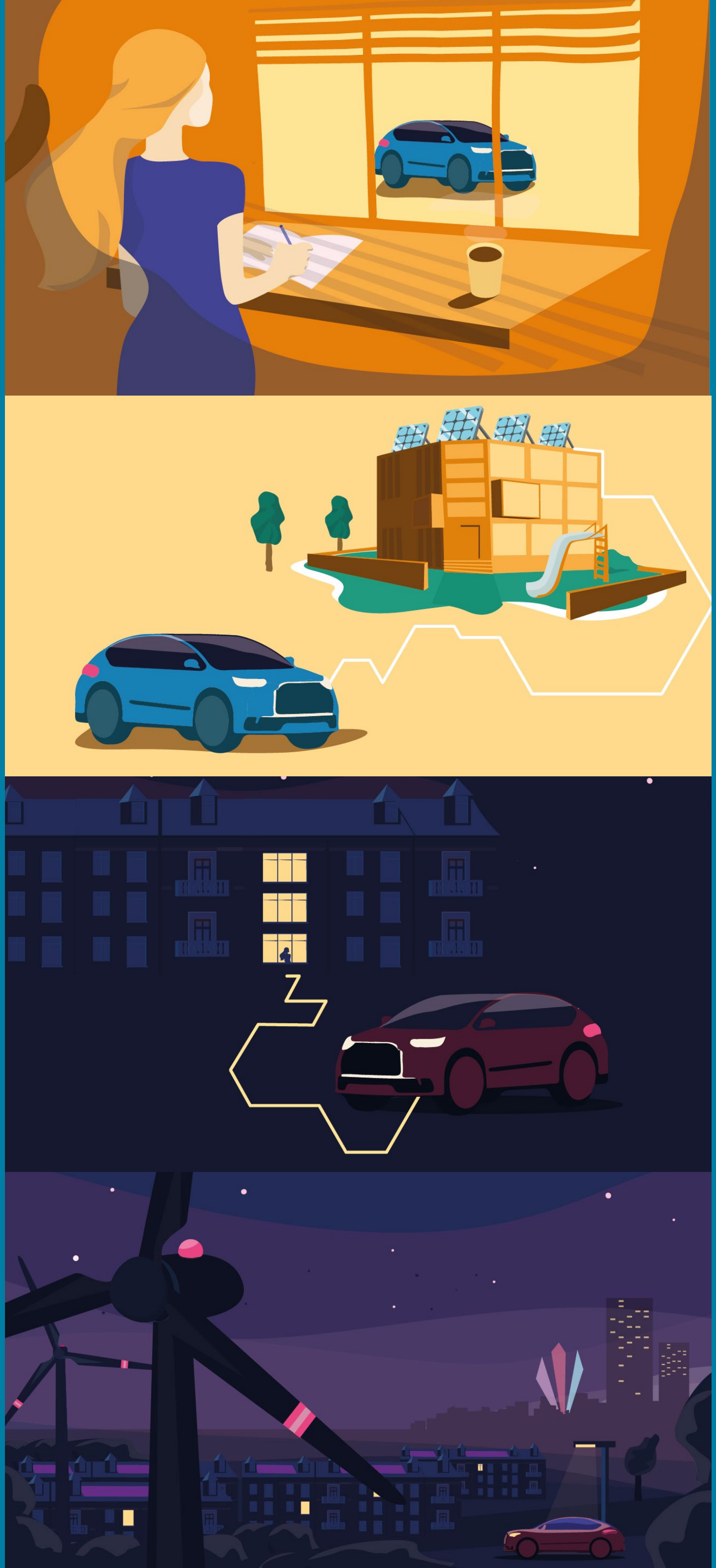
ElaadNL's latest proof of concept (PoC) explores an innovative approach: an autonomous control mechanism that adjusts the power delivered by EV charging stations based on real-time voltage measurements. This system is designed to automatically reduce the maximum allowable charging current when the voltage drops, helping to protect both the grid and connected devices. The voltage drops when power demand is higher than power supply. The reverse (too high of a voltage) occurs when there is more supply than demand, for example due to the generation from solar panels. These switch off automatically if the voltage is too high.

The PoC for EV charging uses a "droop" function within a voltage range of 180 to 220 volts (V), divided into two zones. In the first zone (200-220V), a mild adjustment reduces charging power by 20%, while the second zone (190-200V) calls for a sharper reduction of 40%, as

p.59

ONE DAY IN THE FUTURE ...

On a day in the near future, Eva gets up and gets ready for a busy day at work. She drives her electric car to work 30 kilometres away and plugs it in at the parking lot at the office. Thanks to smart techniques, the car knows that Eva has no external appointments and that there's more than enough energy in its batteries to get home. Her colleagues' cars are therefore given priority in charging. Anna's car only charges when the power demand is low and the solar panels on the roof provide enough power to charge all parked cars. When she drives home at the end of the day, the battery is almost full again. Once at home, she plugs her car in, as do most of her neighbours who have also just arrived home. Because she doesn't have to leave that evening and there's enough energy left, her car supplies her home with electricity until she goes to bed. The car starts charging again at night with electricity from a wind farm on the outskirts of the city. The following morning, fully charged with renewable energy, her car is ready for a new day!



it's closer to the critical threshold of 180V, at which charging stops entirely. This dynamic response helps prevent grid instability by automatically managing power demands without user intervention.

The controller communicates directly with the charging station, reading grid conditions and adjusting the charging current accordingly. This smart mechanism operates autonomously, reacting to rapid voltage changes with a built-in delay to stabilize readings.

By ensuring that EVs adapt their charging in response to real-time grid conditions, this autonomous system offers a promising solution to safeguard the grid against undervoltage, enhancing the resilience of our electric future.

TECHNOLOGY BEHIND GRID-AWARE CHARGING

Let's dive into the technology behind grid-aware charging. There are multiple 'technical routes' possible for controlling charging points. Essentially, there are two ways in which the control signal from the grid operator can end:

- ***The endpoint is a virtual central point (e.g., the back office of the charge point operator or back office home energy management system)***
- ***The endpoint is near the physical connection point (e.g., smart meter or local home energy management gateway, or directly in the charging point itself)***

In both routes (local- or internet-based), it is desirable to technically connect to an existing international standard rather than to develop something specific for the Netherlands. Functionally, choices can be made because the available standard protocols contain various options and/or message sets, but the recommendation is to choose a capacity profile. Registration of home charging points (as well as heat pumps and home batteries) is an important condition for control.

THE FOUR-LAYER MODEL

For smart charging to work well, it must, of course, be technically feasible. Both communication and IT must match and be secure. Moreover, rules and regulations have to be in place to make it possible from an organisational and legal point of view to ensure that stakeholders can work together.

With a control signal near 'the connection', the consumer is responsible for following the control signal. This mechanism (and possible sanctions) must be embedded in law.

LEGISLATION FOR GRID-AWARE CHARGING AND SMART CHARGING

Now let's take a look at the European, Dutch, and other countries' laws and regulations that enable smart and grid-aware charging. What is already in order well, and what can we learn from other countries?

Preventive tiers are the initial steps taken to avoid issues like grid congestion before they happen. For these tiers, the EU Directive 2023/1791 highlights that energy efficiency should be a top priority in future investments in Europe's energy infrastructure. This means making sure that energy is used wisely and efficiently to prevent subsequent problems. The European NIB guideline for network and information safety (2016/1148) is important for the later stages of preventing issues.

In Europe, the updated Renewable Energy Directive (RED) now requires smart charging at private charging points, the sharing of battery data (including from electric vehicles), and making sure electric vehicles can help manage grid congestion and offer flexibility services. Europe is working on a new law called the Alternative Fuels Infrastructure Regulation (AFIR) that will make smart charging a standard practice. In other countries, smart charging is often part of broader government-led programs aimed at preventing overloads on the low-voltage grid by proactively managing energy use.

The Dutch government and grid operators aim to legally anchor smart charging more firmly. The goal is to have smart charging legally secured by 2026 (preferably in broader European law, but at least in the Netherlands). In the interim period, practical solutions have been chosen. In (regional) concessions, collaborating with local governments can set requirements not only for the technology of

The Dutch government and grid operators aim to legally anchor smart charging.

THE HYDROGEN-POWERED ELECTRIC CAR

In addition to battery-electric vehicles (BEV), there is another type of electrically driven car: the hydrogen fuel cell car. You fill your car with hydrogen gas under high pressure, and this is used in the fuel cell to generate electricity to power the electric motor.

There are a number of potential benefits of hydrogen: the car can be refuelled quickly and you can drive further on one tank compared to the distance that can be driven in an average BEV.

A major disadvantage of hydrogen cars is the lower energy efficiency of the fuel cell car. Hydrogen is not an energy source, but rather is an energy carrier (and has to first be produced). At present, hydrogen is usually made from natural gas using an industrial process—which is, of course, not truly sustainable.

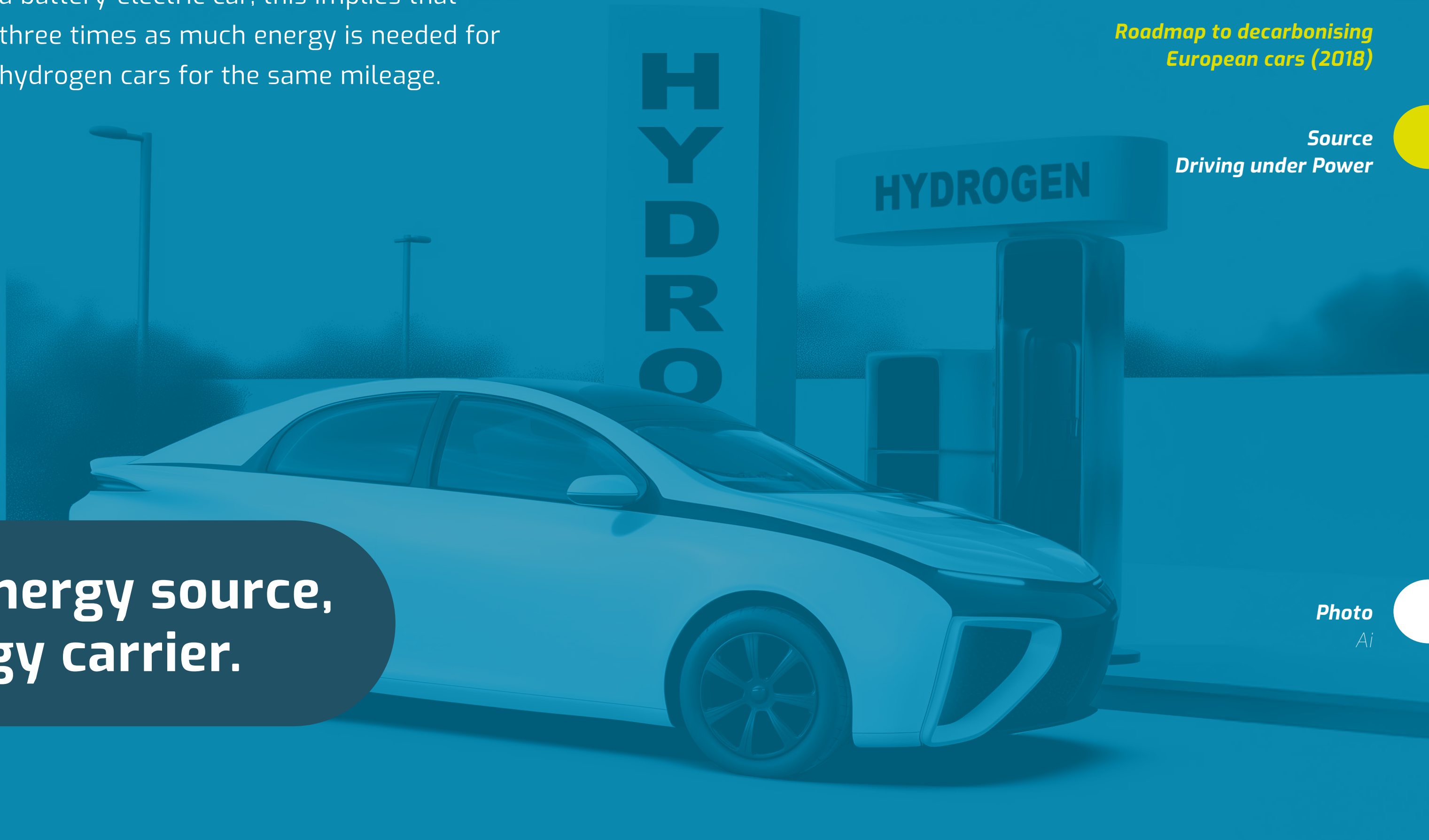
"Green hydrogen" can be produced by electrolysis, but 20 to 35 percent of the energy that is needed for this process is lost. Furthermore, when hydrogen is converted back into electricity by the fuel cell in the car 35 percent of the energy is also lost. Thus, the energy chain efficiency of a hydrogen car is a factor two to three times worse than that of a battery-electric car; this implies that three times as much energy is needed for hydrogen cars for the same mileage.

Hydrogen may still play a role in future mobility scenarios. However, for passenger cars we expect BEVs to remain dominant. Also for vans and even the majority of trucks, the battery electric driveline will be the best and most cost-effective solution.

Source
WTT (LBST, IEA, World bank), TTW, T&E calculations

Roadmap to decarbonising European cars (2018)

Source
Driving under Power



Hydrogen is not an energy source, but rather is an energy carrier.

Photo
Ai

public charging points (smart charging ready) but also for the applications of smart charging. The first is happening en masse, and the second must now be quickly implemented. For private locations, a subsidy scheme is being produced for charging points and smart charging services. Developments are faster abroad, particularly in England. The Netherlands leads in qualitative and quantitative pilots and trials for developing smart charging, but not yet in its legal anchoring.

Looking abroad, interesting developments are seen in securing smart charging such as the implementation of new network tariffs, mandatory registration of the charging point and connection to the smart meter, and regulations or policy rules regarding (mandatory) smart charging. A major difference between the Netherlands and other countries is that policy abroad is mainly focused on private charging points, while the focus in the Netherlands is on public charging points. From the mobility domain, an important observation is that by the end of 2023, public charging points represent “only” 15% of the total number of charging points in the Netherlands, while private charging points make up 78%. The number of private home charging points will also remain dominant in the long term (with substantial regional differences).

POLICY

For applying smart charging, the Smart Charging working group of the Dutch National Charging Infrastructure Agenda, together with the national government, is working on a scaling program called ‘Smart Charging for Everyone’, which will apply to both private and public charging. Besides technology (enabling smart charging control), charge point operators need to work with charging profiles, and grid operators must be able to give incentives to prevent local grid overload. The latter is referred to as Grid-Aware Charging in the program.

The desired end solution is to anchor grid-aware charging in the grid code and tariff code. In the current situation, there is practically no incentive for households and public charging points to not use the full capacity offered by their 3x25A grid connection. To stimulate and reward the use of flexibility in the low-voltage grid,

WIRELESS CHARGING!

Parking with wireless, plug-in-free charging, or even charging while you drive on a specially equipped road? There are plenty of exciting ideas for wireless charging. But how does wireless charging work?

It's based on two magnetic coils: one in the ground and one under the vehicle. Inverters ensure that a high frequency current flows through the primary coil into the ground; this connects to the secondary coil in the car (a gap of 15 centimetres between the coils is possible). The car's coil connects to an inverter, which then charges the battery. It's an efficient process: above 90% is achievable. However, this is still lower than plug-connected charging where returns of more than 95% are possible.

Car manufacturers are still fully committed to cable-charging. With the advent of larger batteries and therefore a greater range, there is less need to plug in after every ride, and for really long distances, fast or superfast charging should be possible. Currently, cable-charging is still the best option. In the future, we would expect self-driving cars to be able to self-charge; wireless charging would seem a good way to facilitate this.

At the moment, there are very few car manufacturers to officially offer a wireless charging system. However, this could change in the future.

Photo
BMW

grid operators must offer multiple customer propositions for small consumption grid connections for households and public charging points. The starting point is that a customer chooses the appropriate amount of flexibility, and the tariffs per customer proposition aligns with the underlying costs and actual use of the electricity grid.

NATIONAL PROGRAM *'SMART CHARGING FOR EVERYONE'*

The Smart Charging for Everyone program is working on a broadly supported approach where the new default option for charging certainty for drivers is that they can charge X kilowatt-hours in Y hours, with room for flexibility and control. At the start of this program, the value of 30kWh in six hours was chosen.

With this, drivers have charging certainty, and charge point operators have some 'flexibility' to develop competitive charging propositions. For example, charge point operators can respond to differences in purchase prices, participation in energy markets, and available sustainably generated electricity. The choices made, considering the charging certainty for the user, lead to a charging profile for a specific charging session. The driver benefits from this charging profile by charging the car at times when electricity is cheaper and/or more sustainable generation is available.

An essential part of the Smart Charging for Everyone program for the grid operator is Grid-Aware Charging. As said, Grid-Aware Charging ensures the smooth integration of electric cars into our electricity grid, allowing charging infrastructure to be rolled out unabated and power outages to be avoided. Only when charging points are in a grid section that is technically "full" (e.g., if the neighbourhood transformer becomes overloaded) do charge point operators temporarily get less capacity for charging cars. Local congestion issues and congestion at higher grid levels require temporarily postponing charging regionally.

SMARTER AND FASTER CONNECTING

Connecting public charging stations to the power grid requires streets to be opened and the employment of technicians. Given the enormous amount of charging stations required for a growing electric fleet, any innovation that leads to time-saving is a huge gain, especially when you consider that there are major shortages of technical personnel. In the meantime, we are also working hard to train more technicians to do this job.

FASTER

An example of such a time-saving innovation is the 'Compacte Aansluitmodule (CAM)' or compact connection module that the Dutch grid operators have developed with ElaadNL and the supplier Connectens. With the CAM, grid operators can connect charging stations (but also advertising columns and street lighting) in public spaces three times faster. The new compact connection module works faster due to a new connection technology. Many technical parts are already pre-assembled in the factory, so this no longer has to be done in the field. In addition, the final installation is very simple thanks to a handy connecting plug. The plug is also pre-mounted, making it possible to quickly connect the object to the electricity grid. This simplifies the work and accelerates the rollout of charging infrastructure, which directly contributes to making mobility in the Netherlands more sustainable.

SMARTER

Following the success of course materials co-developed by ElaadNL, November 2023 saw the first batch of students from a Dutch applied sciences school complete an in-depth ElaadNL training on charge points for electric vehicles. This two-month course is for students training to be electrical engineers and is also available part-time for those already in the field. The training covers installing chargers, commissioning them, and solving simple issues.

Charge point operators may pool the capacity of different charging points and redistribute it at their discretion (e.g., only to occupied charging points). It is entirely up to the CPO to determine how the charging profiles are adjusted, ensuring that the agreed-upon charging service is delivered to the driver while charging within the grid limits.

THE ADDED VALUE OF SMART CHARGING

The interests surrounding smart charging are significant. For governments, grid operators, and market parties, smart charging contributes to achieving various social and commercial objectives. However, the success of smart charging hinges on user acceptance. How can we ensure that smart charging is valuable for everyone? In this factsheet, we look at the importance of smart charging from four perspectives: the government, the grid operator, the market, and the user.

ENERGY TRANSITION

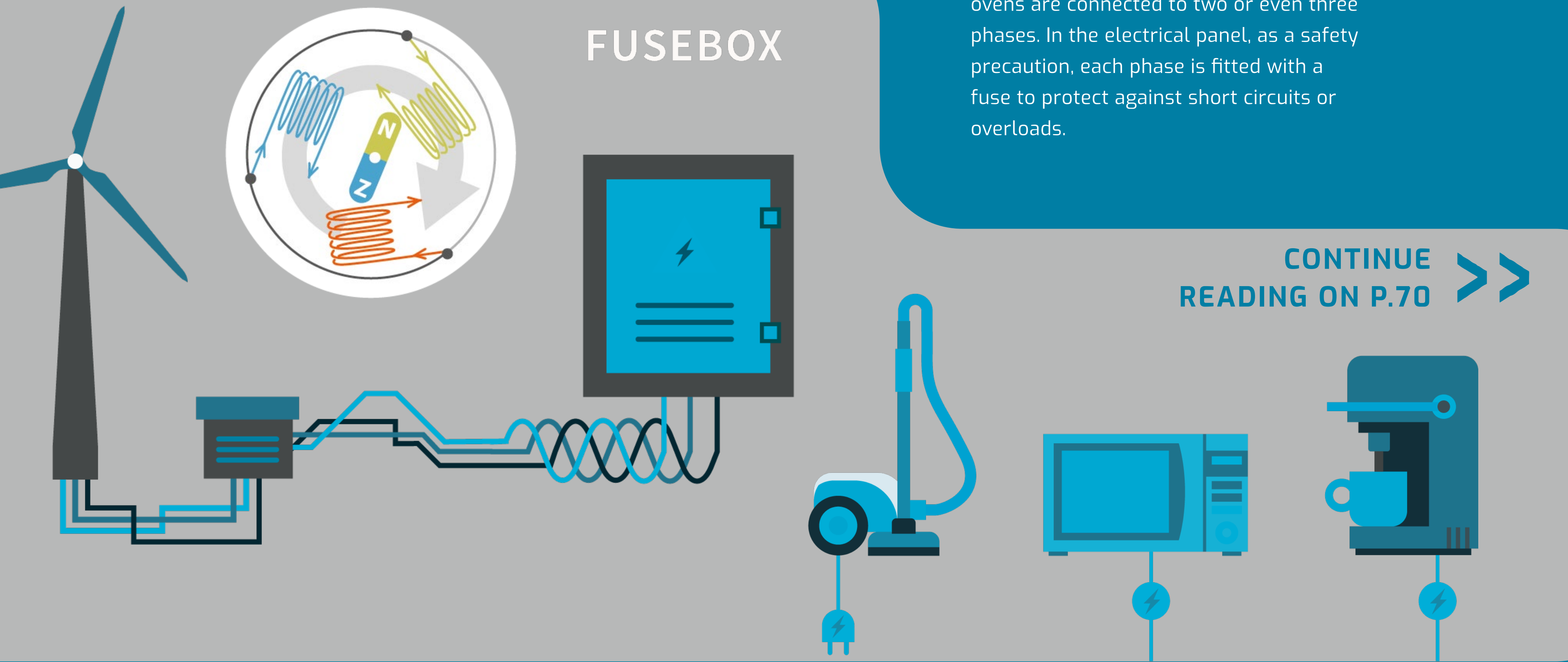
A successful energy transition starts with future-proof electricity grids. An electricity grid is operational for decades. Therefore, maintenance and expansion must be well considered in policy-making and political decision-making. Only then can a reliable and accessible energy supply that facilitates the sustainability of the energy supply continue to exist.

The large-scale adoption of the electric car is, however, a game-changer: the 'battery on wheels' becomes an integral part of the energy system. By using smart charging, the electric car balances electricity demand, stores surplus sustainable energy, and becomes the indispensable link between supply and demand. Moreover, smart charging increases the efficient use of the electricity grid as electric cars charge when the supply of sustainable local electricity is high and/or the prices for sustainable local electricity delivery are low. Thus, smart charging contributes to accelerating the energy transition as CO_2 reduction targets are achieved earlier.

THE DIFFERENCE BETWEEN 1-, 2- AND 3-PHASE CHARGING

In traditional electricity generation, a magnet rotates between three separate magnetic fields, with three distinct wave cycles (phases). Each phase is connected to a single power wire.

Most household appliances only require a one-phase connection. However, in some cases, appliances that use a lot of electricity such as electric hobs or ovens are connected to two or even three phases. In the electrical panel, as a safety precaution, each phase is fitted with a fuse to protect against short circuits or overloads.



CONTINUE READING ON P.70 >>

For decentralized governments, among others, smart charging plays an important role in preventing critical load on the local electricity grid, which would necessitate grid reinforcement. This is possible because smart charging stimulates charging electric cars when the electricity grid is not much used by other non-flexible devices. Smart charging ensures a predictable and even load on the local electricity grid. In implementing smart charging, undesirable side effects must be avoided, such as peak shifting, structural increases in capacity demand, and/or anti-competitive behaviour (gaming).

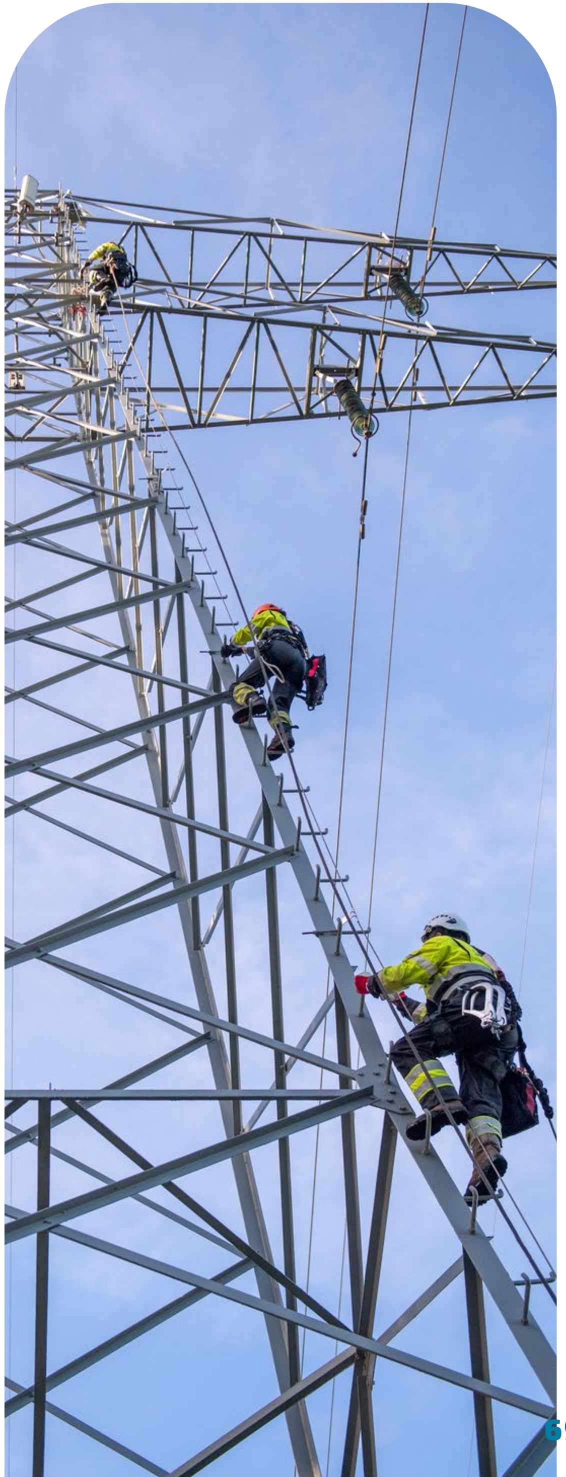
In summary, smart charging brings great promise. By optimally utilizing sustainable energy and electrical infrastructure, it ensures the seamless integration of electric transport into the energy system.

FEASIBILITY

The Dutch energy system is robust and highly reliable. However, it is undergoing a revolutionary development where the electricity grids – the backbone of the energy system – are being used entirely differently. The rapidly growing demand for transport capacity creates a queue of users in certain parts of the country. Therefore, it is important to also look at the overall system efficiency. In other words, smart charging must help us use public spaces, existing assets, labour, and financial resources more efficiently.

In the past century, the growth of the electricity demand directly led to expanding the electricity system and strengthening the electricity grids. Both the affordability and feasibility of this solution are under pressure due to the energy transition, not least because capacity issues are often very temporary. With smart charging, grid operators focus on smart services instead of stronger infrastructure. The result: the social costs of the energy system remain low.

Compared to grid reinforcement, smart charging can be implemented and operationalized in legislation and regulation (e.g., regulatory methods), information systems, and (public) charging points with relatively limited adjustments. In developing smart charging, it must be ensured that smart charging grows with



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ELECTRIC CARS

Many of the first generation EVs could only charge using one phase, with a maximum current limited to 16A, corresponding to a charging power of 3.7kW (16A x 230V x 1 phase). This also applies to most plug-in hybrid electric cars.

Car manufacturers have since developed a number of models that charge at a maximum current of 32A with a charging speed of 7.4kW (32A x 230V x 1 phase).

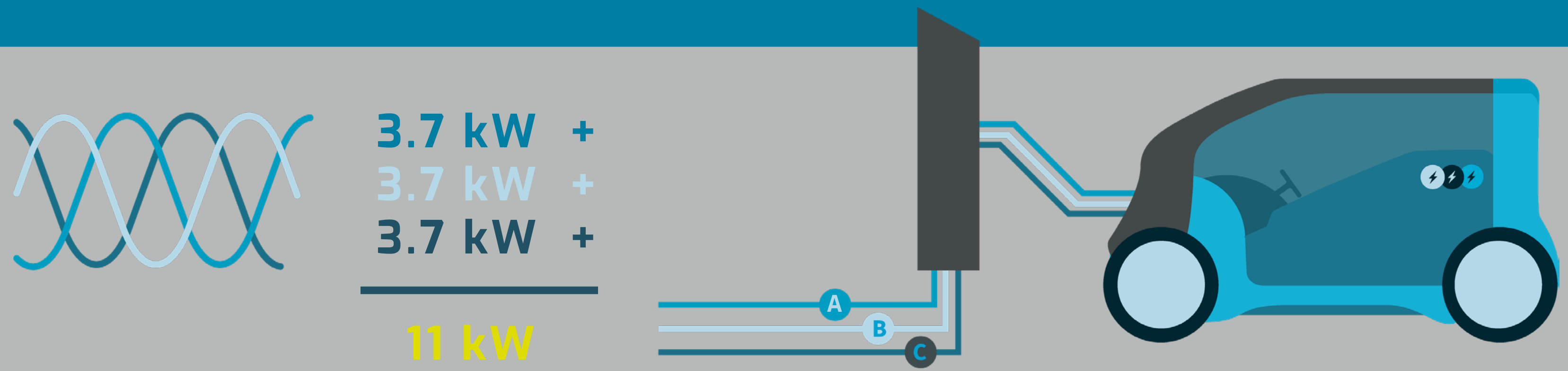
We expect the vast majority of new car models to be fitted with a three-phase charger with a current of (at least) 16A per phase and a charging speed of 11kW (16A x 230V x 3 phases).

CHARGING STATIONS

Street-side charging points almost always have three phases. As a charging station never 'knows' what kind of car will be connected, it always reserves the maximum current for all three phases. If an EV indicates that it can only charge on one phase, most of the current charging points reserve all three phases for this car. Moreover, at the request of the grid operator, the power wires are usually "twisted" across the two sockets, so that if two one-phase cars are being charged, two different power leads (phases) are used. This helps maintain an even distribution across the three phases.

At home, users can choose between one- and three-phase chargers. This depends on their EV model and the available grid connection. Home chargers are always connected to a separate group in the electrical panel. In the case of a three-phase home charger, the grid connection must also have three phases; in some cases the connection to the grid has to be reinforced from a one- to three-phase connection.

CHARGING THREE TIMES FASTER: 3-PHASE CHARGING



future developments, such as new generations of electric vehicles and charging points. The principle of smart charging can also be applied to flexible devices outside the EV domain, such as heat pumps, home batteries, or household appliances.

In addition to the grid operator, market parties will also develop solutions to enable smart charging. This requires significant investments by market parties, especially in ICT. The feasibility of this by market parties is high. Compared to physically expanding the power grid, the needed expertise is less scarce, the work requires fewer labour hours, has no impact on public space, and improves the use of existing assets.

With the scale advantages that will arise when the number of EVs and charging points continue to increase in the coming years, healthy business models for market parties are expected to emerge soon. We already see this reflected in the number of companies entering this market and preparing to offer smart charging services.

BUSINESSES OPPORTUNITIES

Electric transport has developed rapidly in the Netherlands, leading the country to become a global leader in electric driving and its infrastructure. However, we are still on the cusp of the large-scale adoption of electric transport. Therefore, the charging network must continue to grow, both in the number of charging points and in smart charging services. The current starting position offers plenty of opportunities for Dutch businesses, which can also be capitalized on internationally.

An important principle is that mobility remains affordable and that the costs of the transition are distributed fairly so that all Dutch people can switch to emission-free passenger cars. For this, an interoperable smart charging system is needed, ensuring data security, privacy, and cybersecurity.

For fair and competitive market development, a level playing field is required. The possibilities for developing new technologies and markets like smart charging

We are still on the cusp of the large-scale adoption of electric transport.

THE HUMAN FACTOR

As with any new technology, the human factor will play a crucial role in smart charging. Insights into the expected behaviour of people who will be smart charging their cars in the near future is important. Due to pilots and research, we know more and more about charging behaviour and also about users' preferences and preconditions, motivations and obstacles.

For example, research in which cars charge more slowly during peak hours shows that users find it important to have a "charge-me-now" button with which they can still charge immediately if necessary; however, this option is rarely used. This type of research provides important insights into how smart charging Hecould work best in practice.

The annual National Charging Survey (since 2020), has around four thousand respondents and is the largest national charging survey in the Netherlands, which reveals the opinions and experiences of electric drivers. The research is an initiative of ElaadNL, the Electric Drivers Association (VER) and the Netherlands Enterprise Agency (RVO), and is carried out by the University of Groningen.

This survey shows that interest in smart charging is increasing. However, there is still a big difference between awareness of smart charging and its use. The majority of EV drivers say they are familiar with it, but only half of the group says they use a variant of smart charging.

Looking ahead, electric drivers expect a lot from bi-directional charging or V2G (vehicle to grid). Forty-seven percent of participating EV drivers indicate that they would like this. For example, EV drivers would mainly like to use bi-directional charging to store the power from solar panels and use it later to power their own home to be more self-sufficient. EV drivers also see opportunities in using the EV to exchange power with the power grid to earn money and relieve the grid.

However, asking current electric car drivers questions and investigating their behaviour is not enough: today's users are not representative of future users. For example, the demographic of people who drive electric will broaden from a relatively small group of highly educated people, who are mostly men (in particular lease drivers), to a more representative group of the population.

are determined by existing frameworks such as legislation and policy. These frameworks must provide clarity on the rules for smart charging to offer sufficient investment certainty for market parties.

It is up to businesses to develop profitable solutions within the frameworks. Competition and innovation are the driving forces leading to new products and services. Companies compete for consumer favour by being cheaper, better, or more innovative than their competitors. This is how the market works, and as a result, consumers have more choices. This applies to both charging points and smart charging services. The smart charging offer thus meets the needs of electric drivers in terms of availability, price, and charging speed.

BETTER FOR USERS

For a driver, an electric car is primarily a device used to get from point A to B. What is often not considered is that a car is stationary 95% of the time. During that time, the car is stationary, and drivers can choose to charge smartly. The smart charging offer must, of course, be attractive to the driver. There are several considerations for smart charging, such as:

Battery Life *· Charging up to 80% instead of 100% of battery capacity positively impacts battery lifetime;*

Solar Power *· Allowing for charging when privately owned solar panels produce more electricity than the home uses, thus avoiding feed-back tariffs;*

Wind Power *· Charging when wind farms in the direct vicinity are running at full capacity and there is little other electricity demand, thus releasing stress on the grid;*

Financial *· Charging when electricity prices are low;*

Social *· Charging when there is plenty of capacity on the electricity grid, so the grid in your neighbourhood does not need to be reinforced. This reduces inconvenience.*

WHY OPEN STANDARDS ARE SO IMPORTANT?

Open standards in IT communication between different devices like charging station, car or back-office systems need to be transparent, user-friendly, and offer consumers freedom of choice.

Open standards lead to better solutions because many parties work together on an equal basis, leading to cheaper solutions. These better, cheaper and widely available solutions will accelerate the roll-out of charging infrastructure and ensure that smart charging is a success. Smart charging requires communication for transmitting control signals, so it is essential that a universal 'language' is used to enable control of each charging station through any back office system, regardless of brand. This universal language is called the Open Charge Point Protocol (OCPP). At the same time, every EV has to be able to talk to every station (IEC 61851 or ISO 15118) and possibly even to the solar panels on your roof, independent of brand: there must be no lock-ins tying users to a specific brand.

Finally, open protocols strengthen the export position of the Dutch EV: as an open standards leader, the Netherlands has access to other markets.

MORE BENEFITS

- An open infrastructure is good for the Dutch e-driver. Open protocols give the Dutch e-driver easy access to more charging points, both at home and abroad.
- Innovation and competition is encouraged. This translates into better services, lower prices and more new services such as smart charging, Plug & Charge, Car-sharing, etc.
- Open protocols help to accelerate the introduction of e-driving in the Netherlands.
- Parties that invest in charging infrastructures (companies, municipalities, provinces) have the freedom of provider-choice. They can choose the best price / quality ratio, add new providers to their existing infrastructure, and develop new services.
- There are a large number of e-driving stakeholders: the consumer, hardware makers, Electric Mobility Service Providers, energy companies, municipalities, car manufacturers. By developing a shared protocol, each stakeholder's interests are assured, and joint solutions can be introduced faster.
- Knowledge-sharing between a range of parties and countries leads to incremental gain: through open cooperation, new ideas and best practices spread faster. Electric transport is a global market where international cooperation is a "must".
- Open protocols for the charging infrastructure can be reused, enabling interaction with other devices such as heat pumps and solar panel inverters.

Whatever choices someone makes, the principle is that smart charging an electric car should be as easy as charging a mobile phone. This way, all Dutch people can switch to emission-free passenger cars. Smart charging should contribute to the adoption of electric transport and a positive perception of electric charging. This means that the service must positively impact from the user's perspective on:

Information Provision · *Users need clear and accessible information;*

Choice · *A wide-range of smart charging services and providers;*

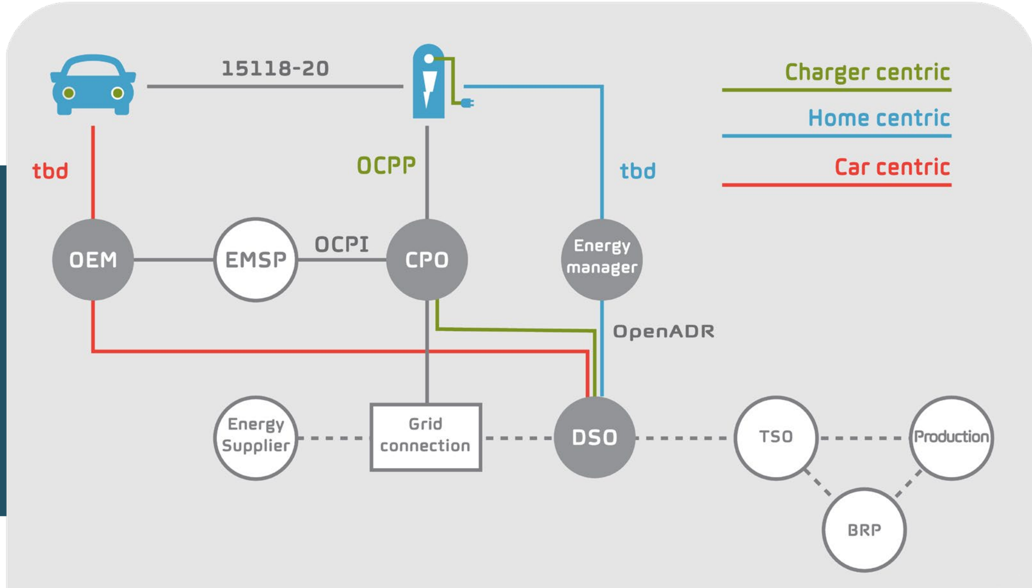
Convenience · *Charging should be easy and hassle-free;*

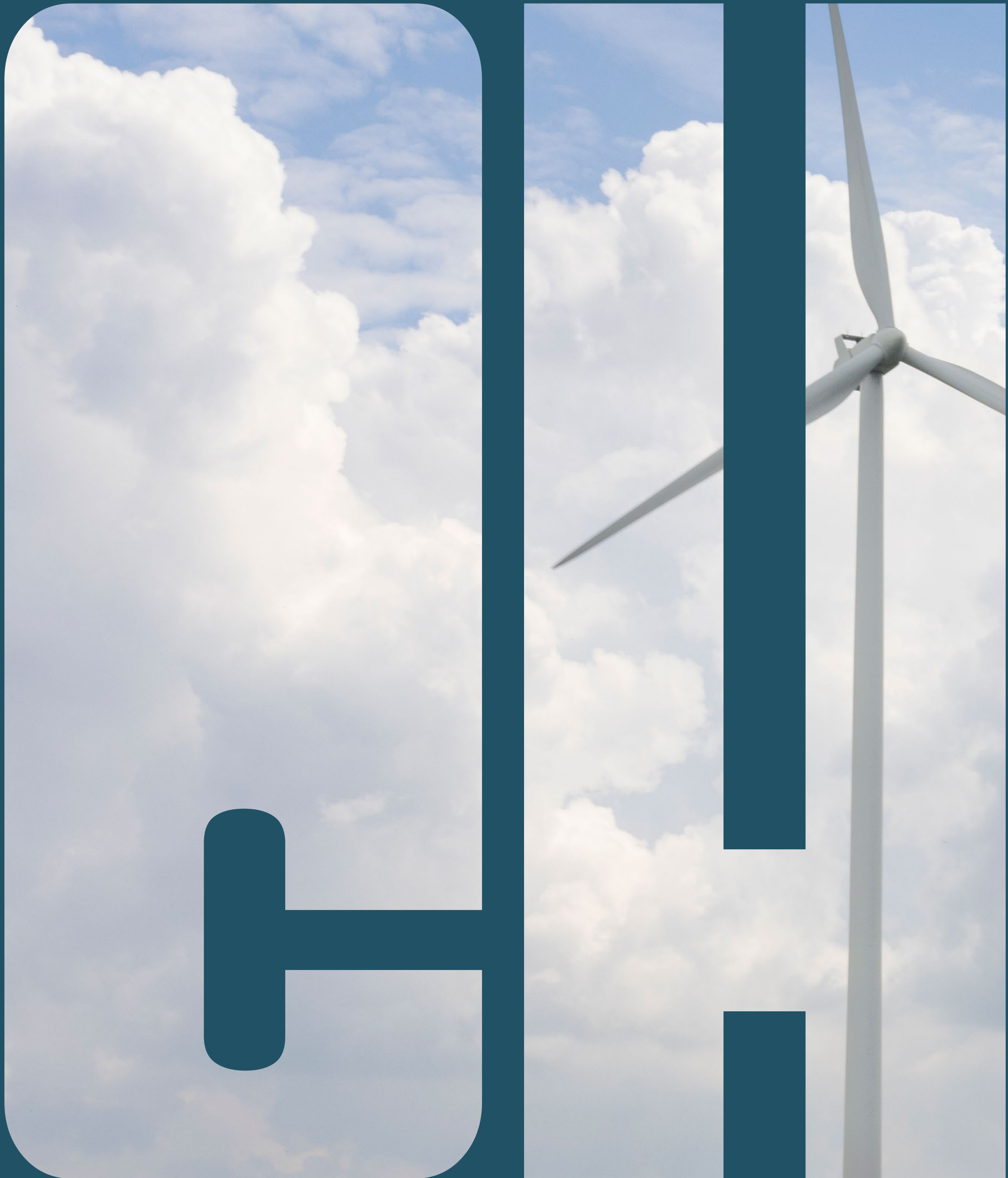
Reliable Service · *Users should trust the charging service to be consistent and dependable.*

In this chapter we looked into the crucial factor in making it possible to charge millions of electric cars on the power grid: smart charging, and more specifically grid-aware charging. What is it? How does it work and what technical and regulatory challenges have already been solved, and which still remain? Basically, we are well on the way to making smart and grid-aware charging the norm in the Netherlands. But we are not there yet. Next to that another challenge has become more and more clear the last few years: That is the electrification of transportation and logistics with its demand for heavy-duty charging. This is a rather different ball game!

OPEN STANDARDS

- **OEM** Original Equipment Manufacturer (read Car)
- **BRP** Balance Responsible Party
- **DSO** Distribution System Operator
- **CPO** Charge Point Operator
- **TSO** Transmission System Operator
- **EMSP** Electric Mobility Service Provider





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ELECTRIFYING TRANSPORT, LOGISTICS, AND OTHER HEAVY-DUTY ROAD EQUIPMENT


PTER

Photo
Nationale Agenda Laadinfrastructuur

SO NOW WE KNOW THAT WE CAN SMARTLY CHARGE CARS, BUT WHAT ABOUT THE OTHER VEHICLES ON OUR ROADS? HEAVY-DUTY TRUCKS, CONSTRUCTION EQUIPMENT AND PUBLIC TRANSPORT BUSES ARE ELECTRIFYING AND WILL NEED TO CHARGE AS WELL. IN THESE SECTORS, WE ALSO SEE A GROWING NUMBER OF ELECTRIC VEHICLES AND MACHINES, A GROWING NEED FOR A CHARGING INFRASTRUCTURE, AND A NEED TO CHARGE AT HIGH SPEEDS IN CONCENTRATED AREAS. THIS OFFERS OTHER (SOMETIMES LARGE) CHALLENGES FOR THE ELECTRICITY GRID. BUT BEFORE WE DIVE INTO THOSE, FIRST LET'S LOOK AT THE TRENDS AND EXPECTED GROWTH OF ELECTRIC VEHICLES FOR TRANSPORT AND LOGISTICS, SUCH AS WE DID FOR PASSENGER CARS.

TRUCKS AND VANS

The electrification of vans and trucks is rapidly advancing in the Netherlands, driven by national and European policies aimed at reducing emissions. The transition to electric vans and trucks will significantly impact the demand for electricity, particularly in logistics hubs and business parks where these vehicles are primarily stationed.

Sales of battery-electric trucks and vans are experiencing significant growth. As of December 2023, electric trucks held a 4.5% market share in new vehicle sales in the Netherlands and 2% in the EU-27 countries, despite their threefold higher purchase price compared to diesel trucks. Electric vans constituted 16.9% of new vehicle inflows in the Netherlands and nearly 7% in the EU-27 countries by the end of December.

KEY TRENDS

Several key trends are emerging in the field of electric transport that will influence the adoption and integration of electric transport vehicles in the Netherlands:

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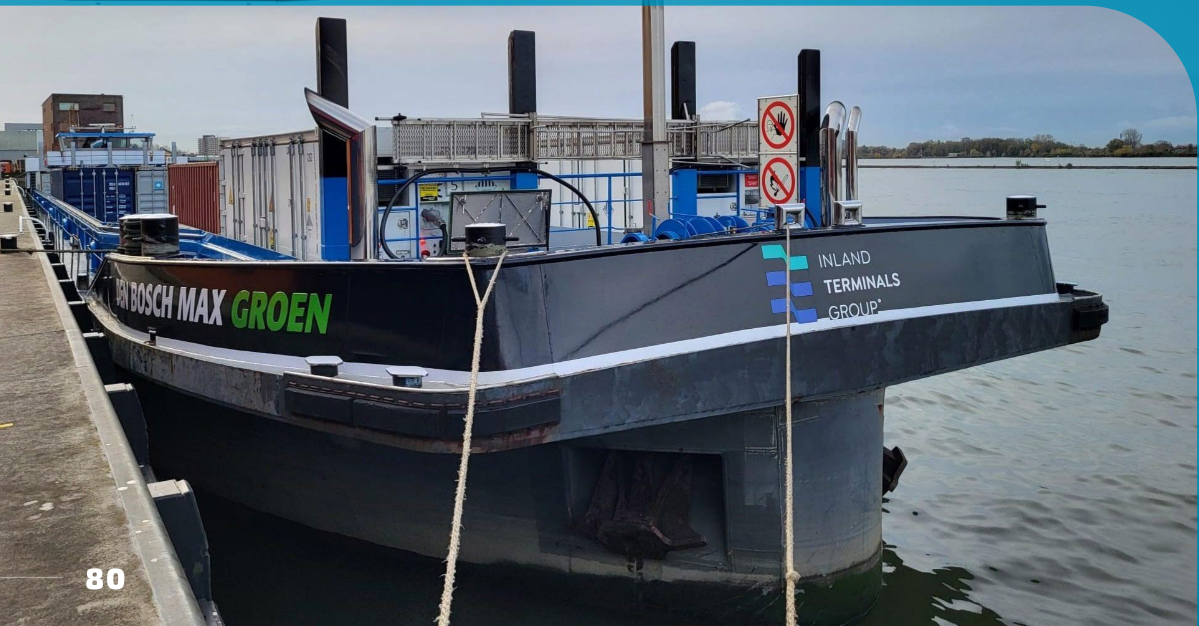
ELECTRIC INLAND SHIPPING: PROMISING BUT NOT YET ON TRACK

The electrification of container transport in inland shipping offers great opportunities, but has barely started and is expected to gain little momentum in the coming years.

We expect that the technological development of battery technology and charging technology will make electric boating more cost efficient. This could make it an interesting alternative for inland skippers. Current drives will increasingly be modular with an electric drive and a diesel generator. Interchangeable battery containers can make charging easy. When terminals are equipped with charging infrastructure, electric trucks can also be charged in the same place as to ships. We are currently working hard on the first container ships for inland shipping that sail fully electrically.

An inland vessel replaces its engine once every 15 to 20 years. The financing of electrification and early depreciation of current diesel engines can be a stumbling block, causing electrification to take a long time.

The government has an important role to play in the electrification of inland shipping. This can ensure that the costs of electricity improve compared to diesel (inland vessels use tax-free fuel). In addition, there is a strong demand for standardization of the way in which the ships will be charged. The Netherlands also has a special opportunity: with the small initiatives that are now in place, together with the large share that the Netherlands has in European inland shipping, our country can now set the standard for electric water transport.



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GROWTH IN ELECTRIC MODELS AND MARKET AVAILABILITY

The number of available electric models is steadily increasing, with both established and new manufacturers entering the market. At the UN COP26 in Glasgow in November 2021, 15 countries and major car manufacturers agreed that all new heavy-goods vehicles and buses will be zero-emission by 2040. As a result, manufacturers are heavily investing in developing and up-scaling the production of electric trucks.

ADVANCEMENTS IN CHARGING TECHNOLOGY

Innovations in charging technology, including the development of faster and more efficient charging systems, will facilitate quicker and more convenient charging for all types of electric vehicles. The introduction of the Megawatt Charging System (MCS) for heavy-duty trucks is a notable development in this area.

POLICY AND REGULATORY SUPPORT

National and European policies that are focused on reducing emissions are accelerating the transition to zero-emission vehicles. The establishment of Zero Emission (ZE) zones in major cities is the main driver. In 2025, major Dutch cities will implement Zero Emission zones and by 2030, diesel vehicles will no longer be allowed in cities.

If entrepreneurs buy a new tractor now, they will replace it after seven years on average; rigids have a longer lifespan, sometimes lasting up to 15 years. In 15 years' time, a diesel truck will definitely not be allowed into cities anymore. This has led some banks to perceive investment in diesel trucks as riskier than investing in electric trucks.

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ONE DAY I'LL FLY AWAY: ELECTRIC FLYING

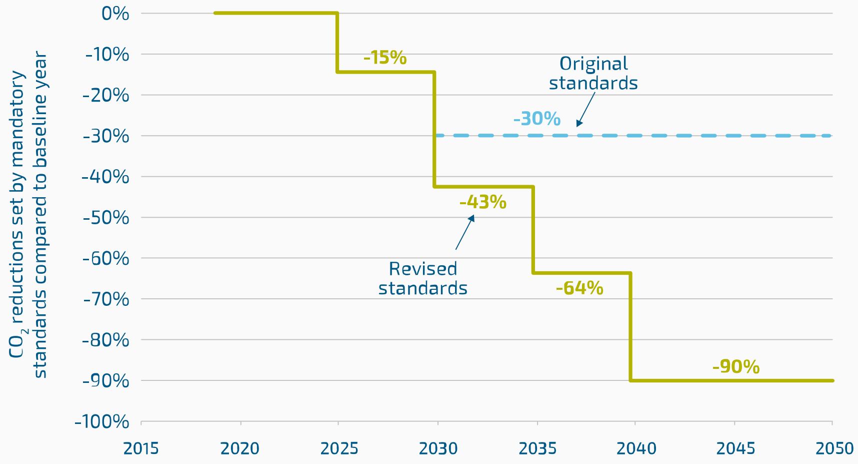
If you want to take to the air electrically in addition to driving on wheels, you will face additional challenges. The weight of the batteries becomes even more important. The energy density is much lower than that of fuel and the weight does not decrease during flight, which poses challenges for landing. Being able to charge quickly on a good charging network at airports is also crucial, as is standardization so that you can charge anywhere. But while battery-electric flying was considered virtually impossible not so long ago, we now see that the first electric aircrafts are already in use.

These are still the smaller ones (two-seaters), but it is a start. The first fully electric nine-seat and 19-seat aircrafts are expected to appear on the market around 2030. With current battery technology, it would even now be possible to fly from Amsterdam to London with a 19-seater electric plane. However, strict certification procedures in the aircraft industry are slowing the widespread introduction of electric aircraft. These procedures must guarantee safety, but make rapid innovations such as electrification difficult.

Electric flying is especially suitable for relatively short distances (under 750 kilometres). This concerns about 37% of all departing flights in the Netherlands. Electrifying these short-haul flights can lead to a total CO_2 saving of 1.78 Mton per year. This potential saving corresponds to 25% of the total emissions reduction target for the mobility sector in 2030, as established in the Dutch Climate Agreement.

Source and photo E-Flight

EU CO_2-emission reduction targets for trucks
(percentages relative to 2019 reporting period)



Source: https://theicct.org/publication/revised-co2-standards-hdvs-eu-may24/

ECONOMIC AND ENVIRONMENTAL INCENTIVES

The total cost of ownership (TCO) for electric vehicles is becoming increasingly competitive with traditional vehicles, especially in the light commercial and delivery sectors. The environmental benefits of reducing greenhouse gas emissions and improving air quality are compelling incentives for adoption.

INFRASTRUCTURE DEVELOPMENT

The expansion of the charging infrastructure, particularly at business parks and logistics hubs, is critical to supporting the growing number of electric vehicles. Coordinated efforts by regional governments and private stakeholders are essential to meet future demand.

INTEGRATION WITH RENEWABLE ENERGY SOURCES

There is a growing emphasis on integrating electric vehicle charging with renewable energy sources, such as solar and wind power. This integration can help manage grid demand and promote sustainable energy use.

SMART CHARGING AND GRID IMPACT

Smart charging technologies, which optimize charging times based on grid capacity and electricity prices, are becoming more prevalent. These technologies are crucial for managing the increased load on the grid and preventing peak demand issues.

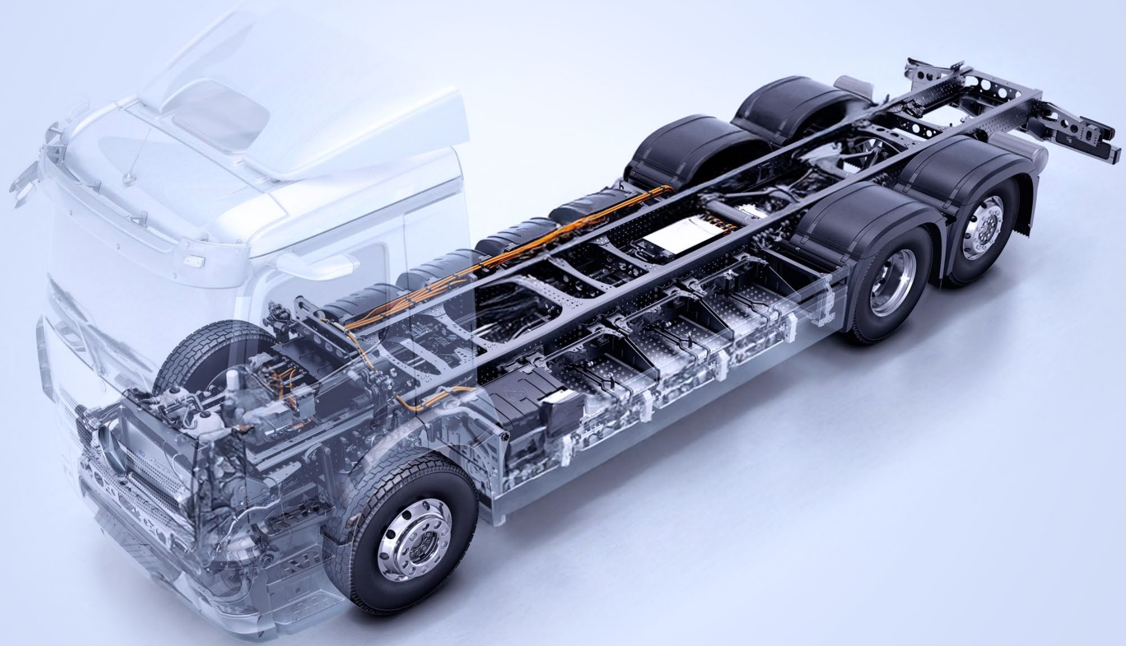
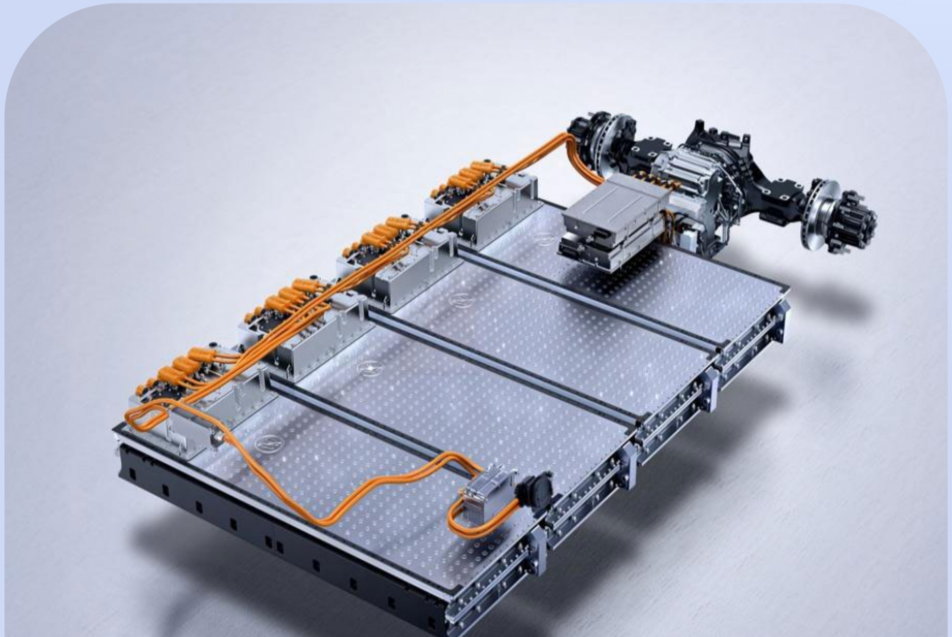
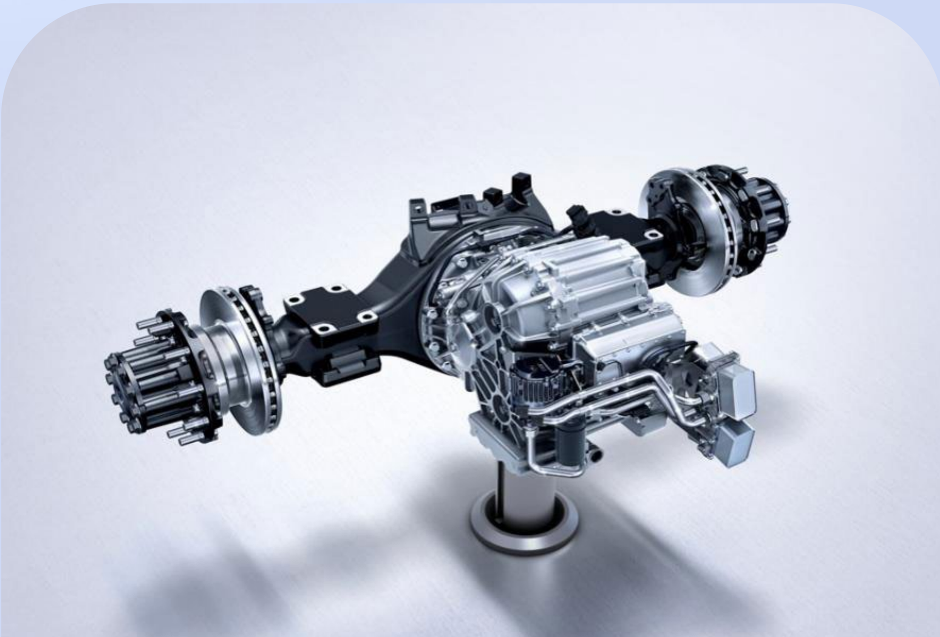


Photo
Daimler Truck AG





TECHNICAL DEVELOPMENT OF E-TRUCKS

Trucks are used in a wide range of applications and come in various shapes and sizes, from simple four-wheel delivery trucks to trucks that are custom-made for special transports, garbage trucks or built-in cranes.

Not all types of trucks are available in electric models yet. Sometimes the battery weight is too high, the body design is too complex, or there aren't enough annual sales to justify development. At this moment in time, basic truck models are available from all manufacturers with an electric drive line,but they do not cover the entire truck range yet.

The development of electric trucks is advancing rapidly. Initially, manufacturers converted diesel trucks by replacing the engine with a battery pack and electric motors. Newer models are now designed with electric powertrains from the start, making them more efficient and cost-effective. Battery technology is improving, with prices decreasing and energy density increasing, which is reducing the cost and weight of batteries while extending the range.

So far, electric trucks have been relatively simple configurations due to space constraints for battery packs. As battery technology improves and market demand grows, more complex and varied electric trucks will be developed, with different axle configurations, larger batteries, new power take-offs, etc.

Future generations of electric trucks are expected to move away from traditional engine-prop shaft-axle configurations. Instead, the electric motor will be integrated into the driving axle, potentially with a 2- or 3-speed gearbox. This change will make the drivetrain lighter and more efficient, freeing up chassis space for batteries, which could even become part of the chassis structure, further reducing vehicle weight.

ELECTRIC TRANSPORT AND ELECTRIC CHARGING MUST BE SAFE

Electric charging points are appearing everywhere: in busy places urban areas, in parking garages, and on industrial estates. The safety of these facilities is important. Consider fire safety and collision safety.

Initial studies indicate that electric cars catch fire less frequently than fuel-powered cars. But, if a fire occurs, it must be extinguished differently because of the batteries. For example, immersion pools are used by the fire brigade. Immersion containers can be used effectively to limit the consequences of a battery fire. In addition, more and more new extinguishing techniques have come onto the market for situations in which immersion containers are not suitable.

By exchanging knowledge and properly monitoring and investigating incidents, better advice can be given for the prevention and management of future issues. This way, electric vehicles can be used and charged safely. In the Netherlands, all involved parties work together in the safety working group of the National Charging Infrastructure Agenda (NAL).

WEIGHT

Current electric trucks are significantly heavier than their diesel counterparts, which reduces payload and profit margins in road transport. Although technology improvements will address this issue, the European Commission is already taking steps. In 2019, an extra two tonnes of weight allowance was introduced for zero-emission trucks. By the second half of 2024, an additional two tonnes and a one-tonne axle increase are expected to be agreed upon.

LENGTH

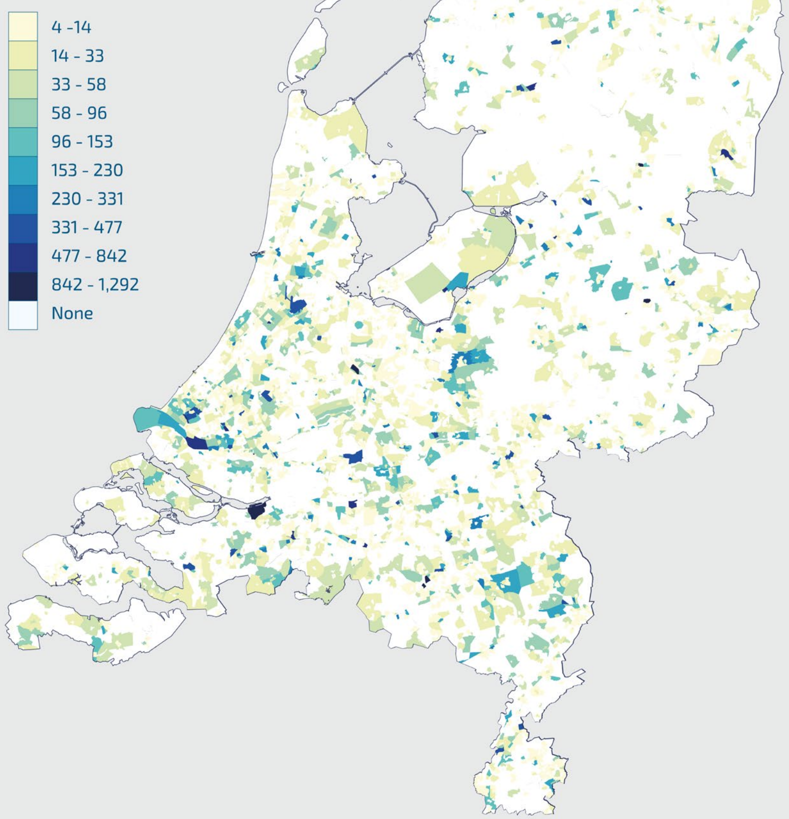
The standard length for trucks with trailers in Europe is 16.5 meters, and for rigids with trailers, it's 18.75 meters. Trailers have a standard length of 13.6 meters, limiting the space available for the tractor. This is why European trucks have flat fronts, unlike American trucks with "noses." Although the EU has allowed slight extensions for aerodynamic and safety purposes since 2020, the gains are relatively small due to the need to maintain the same turning radius.

COST

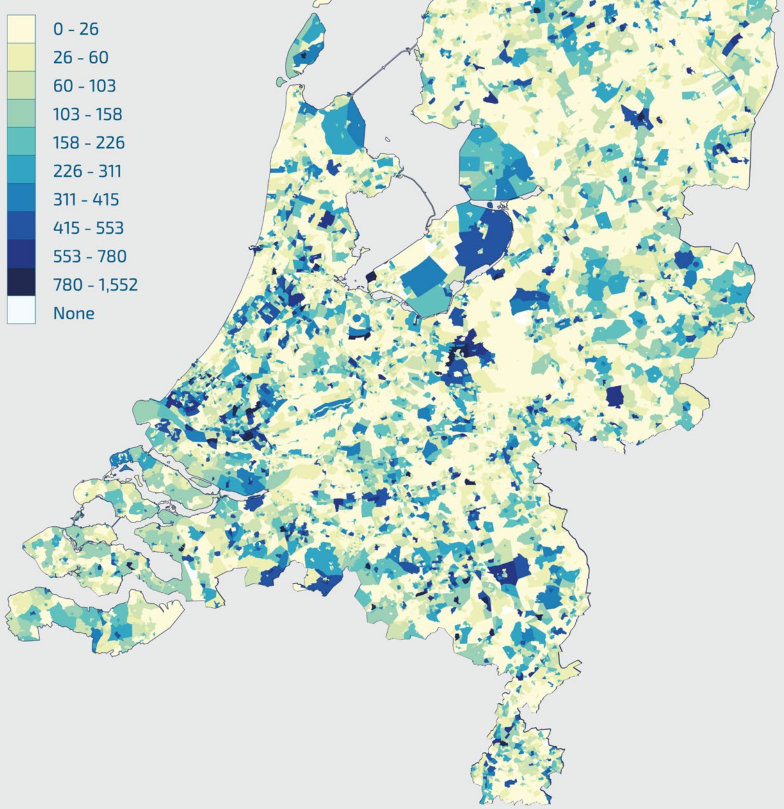
While there are some subsidies in the Netherlands, these are not enough to cover the higher investment of an electric truck. However, in the transport industry, mileage costs are more critical than investment costs. The Total Cost of Ownership (TCO) shows that, despite higher initial costs, electric trucks can save on operational costs. Maintenance is cheaper, and a new tax per kilometre which will be introduced in 2026 is much lower for electric trucks. Diesel will become more expensive due to the EU Emissions Trading System.

The Netherlands has a Renewable Energy Units system from the EU Renewable Energy Directive, where certificates are issued for every kWh of electricity used for charging a battery electric vehicle. These certificates have monetary value, as oil companies can use them to meet renewable fuel obligations.

Number of electric trucks per neighbourhood in 2050



Number of electric vans per neighbourhood in 2050



Overall, the electric truck already has some operational cost advantages. With decreasing battery costs and increased production, electric trucks will become cheaper to buy. Combined with lower operating costs, electric driving will be more economical than diesel on a TCO basis leading to rapid growth in electric truck sales.

ELECTRIFICATION SCENARIOS

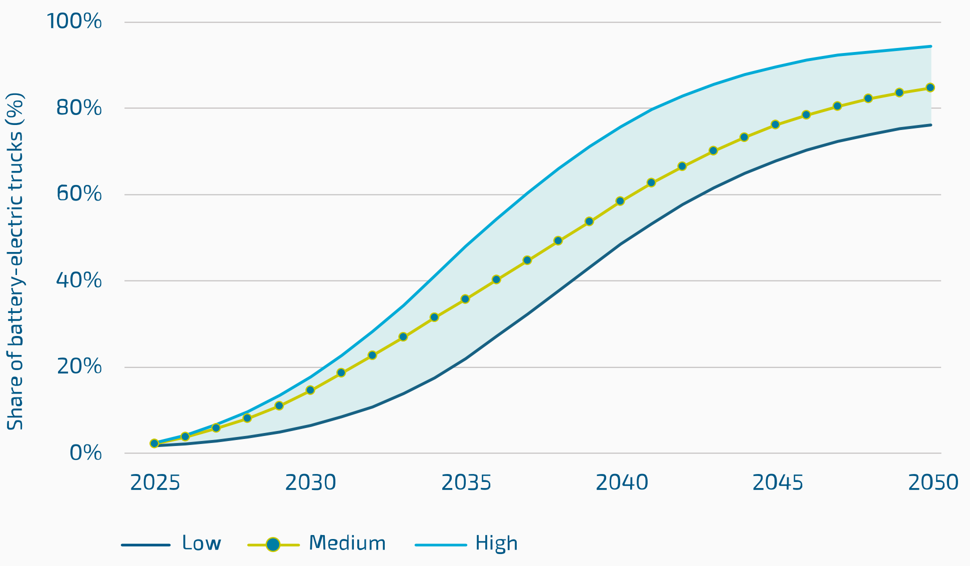
The adoption of electric trucks is expected to become cost-competitive across all vehicle segments around 2030, enabling large-scale adoption without the need for further direct incentives. However, the timely development of the necessary charging infrastructure by regional authorities remains crucial for the complete electrification of the vehicle fleet.

ADOPTION SCENARIOS FOR E-TRUCKS

The number of electric trucks is expected to increase more gradually compared to passenger vehicles. Projections in the ElaadNL Outlook indicate about 24,000 electric trucks by 2030 and more than 147,000 by 2050. The transition for trucks is influenced by factors such as the availability of suitable models and charging infrastructure.

In the medium adoption scenario, the share of battery electric trucks grows to 75% by 2041. This graph illustrates the adoption scenarios for battery electric trucks in the Netherlands, highlighting the expected growth trajectory over the coming decades.

Adoption scenarios for battery-electric trucks in the Netherlands



SHARING IS CARING: SHARED CARS ON THE RISE

Particularly in cities, shared cars are on the rise and are often electric. But what are the consequences if more and more people opt for shared cars instead of owning or leasing?

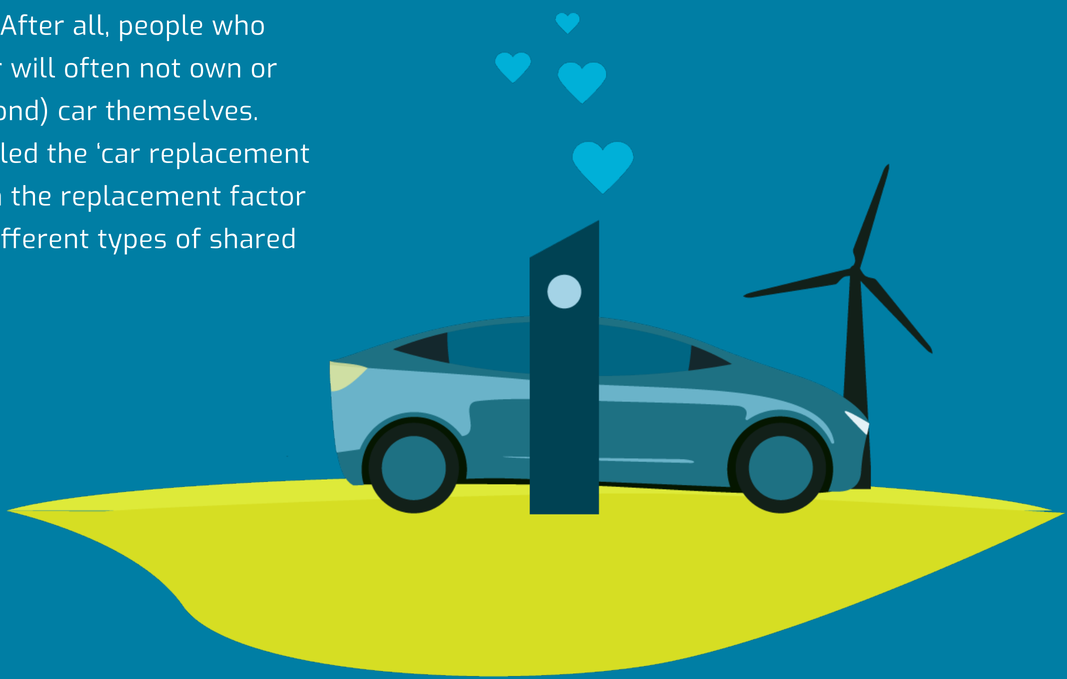
Car sharing allows people to rent locally available cars at any time and for any length of time. These cars can be owned by private individuals, but also by a commercial provider and are offered through a platform or a permanent association of private participants.

At the end of 2022, there were approximately 562 shared cars available per 100,000 inhabitants in the Netherlands, or approximately 100,000 shared cars in total (Source: CROW).

In 2021, approximately 10% of the shared cars were fully electric. Of the shared cars that are available 24 hours per day, an even larger proportion are fully electric: 36.5% at the end of 2022. Of the shared cars without a fixed location (the free-floating concept), all cars are fully electric. The percentage of electric shared cars is therefore well ahead of the percentage of regular electric passenger cars in the car park (4.2% in May 2023).

We expect an accelerated increase in shared cars in the Netherlands in the coming years, based on the strong growth of the previous five years. The fleet of shared cars will grow to 270,000 vehicles in 2030. The growth of shared cars will affect the total number of passenger cars. After all, people who use a shared car will often not own or purchase a (second) car themselves. This effect is called the 'car replacement factor'. Although the replacement factor differs for the different types of shared cars, researchers (from MuConsult) expect that the total fleet could shrink by as much as five percent.

Because their use is easily predictable, electric shared cars can also be used by the operator for smart charging and recharging. This way, the fleet can be supplied with sustainable power and with V2G it can even function as a buffer for power storage.

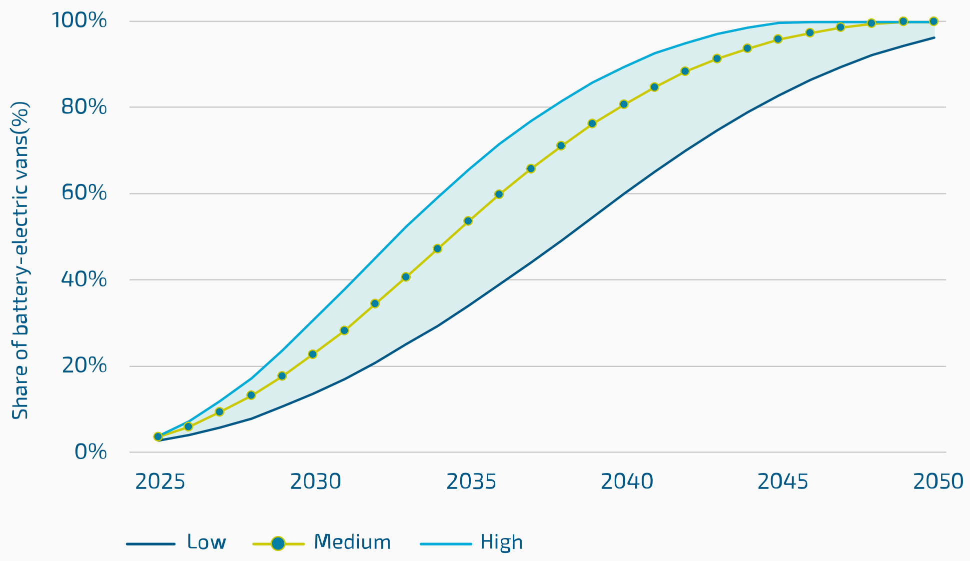


ADOPTION SCENARIOS FOR E-VANS

In the medium adoption scenario, the number of electric vans is projected to grow significantly, reaching approximately 257,000 by 2030 and more than 1.2 million by 2050. This growth is driven by the increasing cost-competitiveness of BEVs and supportive policies.

In the medium scenario, all vans in the Netherlands are expected to be battery-electric by 2049. This graph illustrates the adoption scenarios for battery electric vans in the Netherlands, showcasing the projected growth and transition timeline.

Adoption scenarios for battery-electric vans in the Netherlands



LOCAL DIFFUSION

Our diffusion model indicates that 88% of trucks and 61% of vans are clustered in neighbourhoods that include one or more business parks. These locations are the most logical for meeting the power demand of trucks and vans, as these vehicles remain stationary for extended periods. Consequently, the electrification of the vehicle fleet will result in a significant portion of the charging demand being concentrated in business parks in the coming years.

The images on page 88 show the expected diffusion of battery electric trucks and vans in the Netherlands by 2050. Trucks will have specific infrastructure needs that must be addressed, due to their size and charging requirements.

CHARGING WHILE DRIVING?

Trains and trolleys have been doing it for years. They are supplied with power while driving. Will we also charge electric vehicles while driving in the future?

Roads on which vehicles can charge electricity while driving are called Electric Road Systems (ERS). When a suitable vehicle runs on an ERS, the energy goes directly to the propulsion system or is used to charge the on-board batteries. Once the vehicle is on a normal road, it switches to other sources (mostly batteries or hydrogen).

ERS can be seen as an alternative to both depot charging and opportunity charging of battery electric trucks. With ERS, truck manufacturers could install smaller batteries in the vehicles, thus saving weight and cost, and for operators route planning would not have to take into account any additional stops for opportunity charging.

The integral cost (and allocation of cost) of ERS compared to conventional charging infrastructure should be considered. From the grid operator's point of view, it should be carefully considered whether ERS offers advantages over conventional charging infrastructure in terms of construction costs, feasibility, grid topology and power demand profile.

ERS can be achieved with an overhead line, a rail in the road, or by contactless infrastructure using induction. Their respective infrastructure is as follows:

1. Overhead line: a built-in mechanical arm is connected to the power supply. This is especially used for trucks and buses that are tall enough
2. Rail in the road: power is transmitted through rails that are installed in or on top of the road surface.
3. Induction: Coils placed in the road transfer energy to coils in the vehicle without cables. The power from the grid is converted into high- frequency alternating currents to create a magnetic field which is then captured by the coils under the vehicle to produce voltage.

The first pilots in Germany and Sweden used dynamic charging with an overhead line. This option seems to have the highest potential, but it is still very much in its infancy since truck manufacturers now focus on battery electric vehicles using conventional charging infrastructure.

HYDROGEN FOR TRUCKS?

What about hydrogen? Isn't hydrogen more suitable for long-distance driving? Hydrogen has many advantages, but it also has some disadvantages.

Hydrogen can be used in a fuel cell where the powertrain is otherwise electric, similar to a battery electric truck. This type is called a Fuel Cell Electric Vehicle (FCEV). Experts believe that the Total Cost of Ownership (TCO) for an FCEV truck will be much higher than that of a BEV truck, at least until 2035.

Some truck manufacturers also use hydrogen in a modified internal combustion engine (H2ICE). Due to high combustion temperatures, NOx emissions can be significant, but truck manufacturers can address this with an exhaust gas after-treatment to meet the upcoming Euro-7 emission standards. Although an H2ICE truck emits a small amount of CO_2 from burnt engine oil and some NOx, some authorities might still consider it 'zeroemission' and allow access to inner-city ZE zones. Others reject this due to the NOx emissions, which deteriorate local air quality. The TCO for an H2ICE truck will be higher than for a battery electric truck in the initial years.

There is also the debate about the physical form of hydrogen and the necessary refuelling infrastructure. Most manufacturers prefer compressed hydrogen, up to 350 or 700 bar. A few manufacturers consider liquefied hydrogen, which requires cooling to -253°C. Until truck manufacturers agree on the form, standardizing refuelling stations is impossible, and the infrastructure will remain very expensive.

Finally, there is the sustainability debate regarding hydrogen. Most hydrogen available today is produced from fossil gas through a process called 'steam methane reforming' (SMR), known as 'grey' hydrogen. A step better is 'blue' hydrogen, which is also produced through SMR but with CO_2 capture and storage. The best option is 'green' hydrogen, which is produced by electrolysis using green electricity.

While hydrogen is seen as an important energy carrier for the future, the production of green hydrogen is still small-scale and expensive. Moreover, there is

The production of green hydrogen is still small-scale and expensive.

WHAT IF CARS START DRIVING AND CHARGING THEMSELVES?

Experts expect that in the coming years, cars will quickly become smarter and more independent, and will eventually be able to participate in traffic autonomously. Cars are equipped with a large number of sensors for this purpose. Together with specially developed camera techniques and LiDAR, these sensors keep a close eye on the environment. The car itself analyses these data and anticipates them. Only when driving is fully automated and the vehicle can find its way completely independently, will it be called a fully self-driving or autonomous vehicle (Level 5).

How quickly this development will proceed depends on many factors: not only from the developments in technology in the car, but also from social acceptance and the development of appropriate legislation and regulations.

It is expected that the self-driving car will be battery-electrically powered in most cases. Where and how these cars are charged is subject to speculation. If cars can drive to charging stations themselves, this does not necessarily have to be at your home or at the destination. But it could also be a charging hub at a wind and solar park on the outskirts of cities, for example. And how do they plug in? With robot arms or will wireless charging (induction) get a push with the arrival of self-driving electric cars?

Photo https://waymo.com

the issue of low energy chain efficiency. Producing green hydrogen by electrolysis loses roughly 30-35% of the energy content; the fuel-cell process, being the reverse, has similar inefficiency. Thus, about 70% of the energy is lost, compared to much smaller losses (23%) in a battery-electric truck, according to knowledge centre Transport & Environment.

In short: battery-electric trucks remain the best solution, even for long-haul transport. Hydrogen has advantages for specific use cases and market segments, but is too expensive for large-scale rollout at this time.

ZERO EMISSION CONSTRUCTION EQUIPMENT

If we look at the trends, the expected numbers are clear for e-trucks and vans. But another important sector is electrifying: construction equipment. The construction sector in the Netherlands has a total of 160,000 non-road mobile machinery units in operation. About 30% of vans and 15% of trucks are used for construction logistics. The construction sector in the Netherlands is moving towards zero-emission operations, driven by the need for better air quality, reduced CO_2 emissions, and strict nitrogen emission regulations. The urgency for zero-emission construction equipment has increased, especially after the November 2022 legal ruling that removed the exemption for nitrogen emissions in construction activities near Natura 2000 areas (a European network of protected nature areas). Emission-free construction has now become crucial for many projects.

The 'Schoon & Emissieloos Bouwen' (SEB, Clean & Zero Emission Construction) covenant in the Netherlands supports the transition to clean and emission-free construction by 2030 and beyond. In collaboration with policymakers, clients, and contractors, a unified approach is being developed to achieve ambitious emission reduction targets. The Netherlands, along with Norway, is a frontrunner in this effort, with similar public-private initiatives starting in Norway in 2019 and aiming for largely zero-emission construction by 2030.

ELECTRIC MOTORCYCLES STILL IN THE EARLY STAGES OF GROWTH

In the Netherlands, only 0.2% of the total number of motorcycles are fully electric (about 1,500 motorcycles so far). However, sales of electric motorcycles have increased in recent years, from one percent in 2017 to 2.3% in 2022. More and more models are also coming onto the market. Factors that play a role in the still modest share of fully electric motorcycles include a wait-and-see attitude of the major manufacturers (although this is improving quickly) and government policy that does not stimulate electric motorcycles in the same way as electric passenger cars. The use is also different—currently, it is mostly used for recreational purposes and not business. Personal preference and the higher purchase costs therefore play a greater role than with passenger cars. We do not expect a real breakthrough in the share of fully electric motorcycles in the short term.

As long as electric motorcycles are mainly used recreationally, they will mainly be charged at home and on the road. We do expect that the electric motorcycle will be increasingly used as an alternative for (business) commuting. This also creates a charging demand on industrial estates, for example.

Electrification of two-wheelers also offers additional opportunities. Electric motorcycles can be used in many areas, for example, in inner-city logistics and services (in zero-emission zones). But off-road activities on two-wheelers such as nature management, law enforcement and supervision and defence activities are also eligible for full electrification.

There are about 150,000 mobile equipment units in the Netherlands, of which only 1% are fully electric. However, this number is steadily growing due to the SEB covenant. Despite being small markets, the Netherlands and Scandinavian countries lead in emission-free construction, but the limited demand means OEMs only offer a small range of all-electric machines from the factory.

TECHNOLOGY DEVELOPMENT

To enable emission-free work, converters are entering the market to retrofit machinery with internal combustion engine (ICE) power to all-electric. While OEMs are also working on introducing all-electric machines, their timeline is longer. According to ElaadNL, the development toward a market-wide supply of all-electric construction equipment will follow three key steps. The first step is conversion, where existing vehicles are converted to electric by converters or OEMs. These vehicles are built separately from the existing production line, which makes the integration of electric powertrain components less optimal and more expensive. The second step is the hybrid phase, where vehicles with both diesel and electric powertrains are developed, incorporating lessons learned from the conversion phase, leading to a gradual decrease in prices. The final step is the development of an all-electric platform, where vehicles are built with a 100% dedicated electric drive. This allows for optimized component placement and subsystem alignment, resulting in lower costs and increased production efficiency.

BATTERY TECHNOLOGY

Two main applications of battery technology are emerging:

Fixed Batteries · *Installed in the machinery, offering straightforward operation;*

Portable Batteries · *Swappable units that can be exchanged on-site, providing flexibility but requiring logistical management.*

There are about 150,000 mobile equipment units in the Netherlands, of which only 1% are fully electric.


ans
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GEVAAR
VERBODEN BINNEN HET DRAAIBEREIK VAN DE MACHINE TE KOMEN
ZIE JIJ MIJ
ZIE IK JOU
DEZE MACHINE WERKT EMISSIELOOS

TRENDS

Several key trends are shaping the transition to zero-emission construction. These trends highlight the momentum towards zero-emission construction, driven by technological, regulatory, economic, and infrastructural developments:

TECHNOLOGICAL ADVANCEMENTS

The market for electric construction equipment is expanding, with various manufacturers offering battery-electric models. Currently, about 5% of light construction equipment is electric, highlighting significant growth potential. However, the exact amount of battery-electric construction equipment is not precisely known.

POLICY AND REGULATORY DRIVERS

Strict regulations on nitrogen emissions and air quality are major drivers of electrification. The SEB (Schoon en Emissieloos Bouwen) covenant, signed by 45 parties, sets ambitious targets for NOx and CO_2 reductions and aims to minimize health impacts from construction emissions.

ECONOMIC FACTORS

The total cost of ownership (TCO) of electric machines is becoming more competitive with diesel alternatives. Financial incentives such as the SSEB (Subsidie Schoon en Emissieloos Bouwmaterieel) and other tax benefits are making the adoption of zero-emission equipment more attractive.

INFRASTRUCTURE DEVELOPMENT

The availability of charging infrastructure is critical. Solutions like on-site charging, depot charging, and mobile battery systems are being explored to meet the varying needs of construction sites.

MARKET GROWTH

The demand for electric construction equipment is projected to grow significantly. This growth is supported by advancements in battery technology, increasing market availability of electric models, and regulatory pressures.

WHAT ROLE CAN AI PLAY IN SMART CHARGING OF ELECTRIC CARS?

Smart charging has become an increasingly well-known concept. At the moment, smart charging is often achieved by sending static charging profiles (fixed times). But with the use of Artificial Intelligence (AI), dynamic charging profiles can be generated for charging plazas based on the departure time and state-of-charge of the electric car. This way, the available power can be optimally distributed, while maintaining ease of use. Charging plazas with V2G (vehicle to grid) poles and cars can also be used in the future as an energy buffer in a sustainable energy system.

In order to optimally distribute power, it is useful to know whether a car will be plugged in for a long or short time and needs many or few kilowatt hours. A self-learning algorithm can help with this. This form of AI learns to recognize patterns so that, for example, regular customers (who are known to be plugged in for a long time every working day or who usually need few kilowatt hours) can be given a different priority than cars that need a lot of power in a short time. In this way, AI can help to make optimal use of the available capacity without negative consequences for the user.

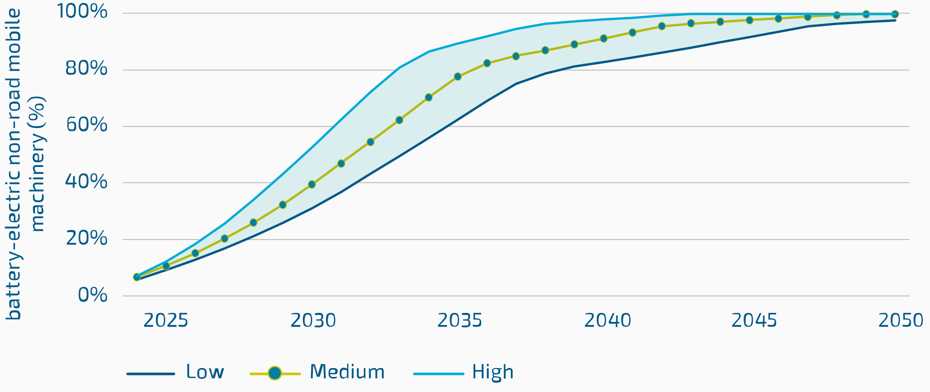
ELECTRIFICATION SCENARIOS

The electrification of the construction sector can be envisioned through three scenarios: low, medium, and high. Each with different assumptions about market development, regulatory impact, and technological progress.

This graph shows the adoption scenarios for battery-electric non-road mobile machinery in the construction sector in the Netherlands.

In a 100% electrification scenario, the total electricity demand of construction equipment is about five TWh per year. Approximately 45% of this electricity demand comes from non-road mobile machinery, while the remaining 55% is from vans and trucks.

Adoption scenarios for battery-electric non-road mobile machinery within the construction sector in the Netherlands



Forecast of electricity demand (TWh) of construction equipment (medium scenario)

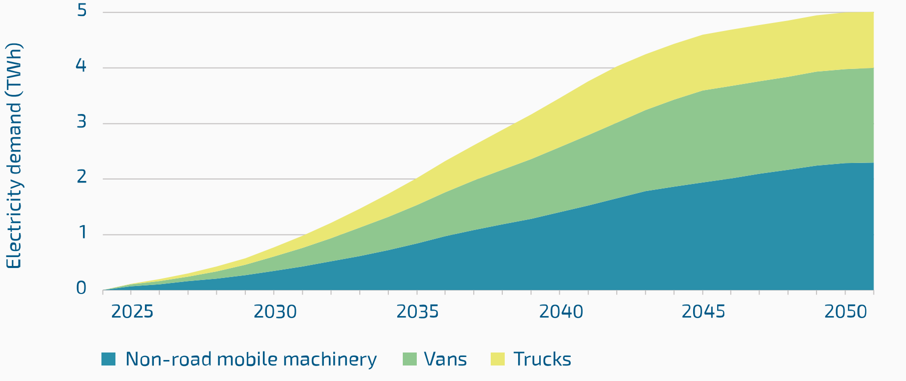


Photo
OV Bureau Groningen Drenthe

ELECTRIC BUSES

Public transport has been partially electric for a long time (trains, metro, trams and trolly buses), but this sector is expected to further electrify as public transport buses are becoming battery electric. In 2016, public transport authorities in the Netherlands committed to a Zero Emission Transport agreement: from January 1, 2025, all new buses must be zero-emission and by 2030, the entire fleet must be zero emission. ZE buses will also use locally generated renewable energy. This goal is much more ambitious than EU requirements, which mandate a 90% emission reduction for new urban buses by 2030 and zero-emission for new urban buses by 2035.

Up to 2020, electric buses were mainly used on city routes, sometimes with fast chargers at the endpoints. Now, more regional buses are becoming fully electric as well. The next step is to use electric buses for Bus Rapid Transit, which involves high-frequency and high-speed bus routes, especially where there are no railway lines available.

Over 27% of public transport buses in the Netherlands are electric, and this number is growing rapidly as the deadline approaches. As a result, new bus contracts will almost exclusively involve electric buses. A short-term challenge is that the delivery time for electric buses is now up to two years, as many European cities are also electrifying their public transport. Manufacturers are struggling to keep up with the demand.

MORE OUTLOOKS AND QUICKSCANS

In this chapter we looked at the trends in expected growth of electric trucks, vans, construction equipment and public transport buses. Off course there is more going on. If you are interested in the expected growth of electric motorcycles, inland shipping, and even electric aviation we recommend you to read all Outlooks and Quickscans on the ElaadNL website. For now, we focus on passenger cars and the above mentioned transportation sectors. They all have to charge on the power grid, but have a large impact that differs from that of electric cars. This will be the subject of the next chapter. How to charge them all?

https://elaad.nl/projecten/elaadnl-outlooks/

5

CHARGING TRANSPORT, LOGISTICS, AND OTHER HEAVY-DUTY ROAD EQUIPMENT

Photo
Celeste Mostert
Stedin

SHORE POWER: THE RISE OF SHORE-BASED POWER

Photo
Onshore Power Supply Network. Walstroomkast: Seijsener.

Shore power is a power connection for ships at a berth. Sea-faring vessels and inland vessels that are moored also use energy in the port. However, running diesel generators in the port is harmful to the environment; that is why work is being done on electrification. More and more ports are offering shore power so that ships in the port can use a connection to the electricity grid.

With the introduction of the Alternative Fuels Infrastructure Regulation (AFIR), European ports are obliged to supply ships such as container ships, cruise ships, passenger ships and combined passenger and cargo ships with shore power from 2030.

The Dutch seaports have calculated that 270 megawatts (MW) of shore power capacity will have to be installed. According to Rijkswaterstaat, approximately 70 shore power points have been installed for inland shipping by early 2023. By 2030, it is estimated that shore power points should be installed for 1,437 ships per day.

This task is in addition to the expected electrification of shipping, and the increasing need for charging for electric sailing.

USUALLY PASSENGER CARS CAN CHARGE WITH RATHER LOW POWER (EXCEPT FOR EXAMPLE, WHEN A FAST-CHARGING SESSION IS NEEDED ON A HOLIDAY); THE STORY CHANGES, HOWEVER, WHEN CHARGING E-TRUCKS, CONSTRUCTION EQUIPMENT AND PUBLIC TRANSPORT BUSES. THEY HAVE SUCH A HUGE DEMAND FOR ELECTRICITY THAT MANY TIMES THEY WILL NEED TO CHARGE AT HIGH POWER (AND MOST OF THE TIME WITH MANY VEHICLES TOGETHER), RESULTING IN MORE PEAK POWER DEMANDS AND ADDITIONALLY PUTTING DIFFERENT DEMANDS TO THE EXPANSION OF THE POWER GRID. SMART SOLUTIONS ARE NO LESS IMPORTANT IN THIS CASE, BUT THEIR CONTRIBUTION IS LIMITED. LET'S FIND OUT MORE ABOUT THE CHARGING OF THESE VEHICLES AND THE ASSOCIATED CHALLENGES AND SOLUTIONS.

CHARGING ELECTRIC TRUCKS

It is generally cheapest to charge electric trucks on private property, either at the carrier's or shipper's location. Since most trucks operate during the day, charging is primarily done at night. With a truck stationary for 10-12 hours and a battery capacity of 400-500 kWh, a charging power of 40-50 kW is needed at depot locations. Daytime opportunity recharging should be done quickly, and therefore with higher power, and ideally during natural breaks like loading/unloading or lunch breaks. Public fast-charging locations should allow drivers to reserve charging stations in advance to avoid unnecessary waiting.

CHARGING DEMAND E-TRUCKS AND VANS

By 2050, the increase in electric trucks and vans in business parks will result in an additional electricity demand of 10.7 billion kWh (or 10.7 TWh). Business parks will need to support charging for various types of vehicles, including passenger cars. Each vehicle type has different charging needs. The figure on the next page shows regular and smart charging profiles for a typical business park on an average workday, with 125 passenger cars, 110 vans, and 35 trucks. Smart charging has the potential to significantly reduce peak demand.

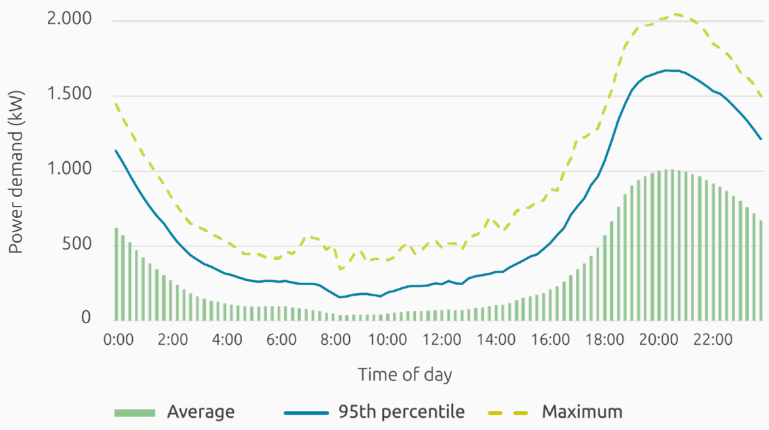
THE USE OF BATTERIES WITHOUT WHEELS

Stationary and mobile battery systems are increasingly used to store locally generated sustainable electricity, but also to charge electric vehicles in places where the desired power is not available due to grid congestion. This also includes construction sites for dyke reinforcements, for example, where zero-emission work must be carried out. Or, a group of fast chargers for electric trucks where the power from nearby wind turbines and a solar park is buffered so that high power can be charged without excessive peaks on the grid.

But how do you optimally control the charging and discharging of these batteries? Standardization of charging and discharging and smart charging is crucial to better integrate these systems into the electricity network. Little has yet been arranged for the rapidly growing use of these batteries. There is no standard plug, and the protocols that smartly control charging and discharging are not yet standardised. At this point, for batteries without wheels, we can learn a lot from the standardisation of batteries with wheels.

The rise in electric trucks and vans will greatly impact the grid, causing more local bottlenecks in the short term. Currently, many business parks face grid capacity shortages or have been warned by grid operators of (future) congestion problems. While the grid impact varies depending on electrification in other areas, electrifying trucks and vans in business parks is a substantial task. It requires not only quick implementation of planned grid investments but also new solutions to ensure efficient use of the electricity grid.

Charging profile of a fictious business park



LONG-HAUL ROAD TRANSPORTS

Many people think electric trucks are only suitable for short journeys, which essentially means city logistics. However, e-trucks can also be used for long-haul transport. This is due to European rules on maximum driving time and the requirement from the Alternative Fuels Infrastructure Regulation (AFIR) that require fast chargers for trucks every 60 kilometres along Europe's major freight corridors.

According to driving time regulations, a driver is allowed a maximum of 4.5 hours of driving before a mandatory 45-minute break. If the trip is scheduled so that the break occurs at a fast charger, the e-truck can recharge while the driver takes their break, losing no valuable driving time compared to a conventional diesel truck.

For example, an e-truck with a 600-kWh battery and an average energy consumption of 1.4 kWh per kilometre can drive 385 km if it leaves with a full battery and arrives at the fast charger with 10% State of Charge (SoC).

A NETWORK OF FAST CHARGING STATIONS FOR TRUCKS

In the 'LoLa' program, ElaadNL collaborates with the Dutch Ministry of Infrastructure and Water Management to develop a network of fast charging stations for trucks in the Netherlands. The LoLa initiative is somewhat similar to the German HoLa project. There are many specific requirements for these stations compared to those for passenger cars. Firstly, there must be enough space for trucks to manoeuvre safely next to the charger, preferably in a drive-through set-up. The canopy must be high enough to accommodate the vehicles, and the pavement must be strong enough to handle the weight of a truck. Initially, CCS chargers of at least 350 kW will be required, but in a few years, there will be a need to scale up to MCS chargers of 1,000 kW. This means that a site with six to eight chargers will need about 4,000 square meters of land and a grid connection of at least 5 MVA, which is a significant challenge given the scarcity of both space and grid connections. Additionally, security must be closely monitored, possibly with camera surveillance, and facilities for drivers must be provided.

Fortunately, despite these challenges, many market players are ready to develop and operate such truck charging stations. With the LoLa programme, ElaadNL supports these market parties, along with grid operators and governmental bodies, to create a nationwide network of fast charging stations for battery electric trucks, facilitating the transition to sustainable transport.

In 4.5 hours, the driver can cover a maximum of 4.5 x 80 km/h = 360 km. A 600-kWh battery is therefore sufficient for a full stint.

To recharge from 10% to 90% SoC (i.e., 480 kWh) in 40 minutes, an average charging power of 720 kW is needed. This requires a Megawatt Charging System (MCS) charger, which can be installed alongside the usual CCS chargers. Theoretically, the MCS standard goes up to 3.75 MW (3,750 kW), but such high power is not necessary in Europe. With current battery technology, charging is faster at low SoC, and the charging power decreases as the SoC increases. Thus, an MCS charger should deliver a peak capacity of 1 MW (1,000 kW). In the future, new battery technology will flatten the fast-charge curve, requiring less peak power from the charger.

There are essential conditions to meet: the trip planning must ensure that the driver's break occurs at a fast-charging location. Logistics companies should be able to reserve MCS chargers in advance to ensure availability when the driver arrives.

Moreover, it's important to have a solid basic network of fast chargers for trucks spread across the Netherlands and Europe. AFIR's requirements focus on international TEN-T freight corridors, but truck chargers should also be available at other locations to create a nationwide network. Only by combining these efforts can a truly comprehensive fast-charging network be achieved for both national and international transport.

It's important to have a solid basic network of fast chargers for trucks.

CHARGING AT BUSINESS PARKS

As mentioned earlier, e-trucks will primarily charge their batteries at business parks, either on the carrier's premises or at the shipper's premises. Many bus depots are also located in business parks. Consequently, ElaadNL expects an additional power demand of around 3 GW during the day and 8 GW at night at the 3,700 business parks in the Netherlands by 2050.

‘SOCKET-ON-LAND’ FOR CHARGING INFRASTRUCTURE AT SERVICE AREAS ALONG THE HIGHWAY

Offshore wind farms are connected to the electricity grid via an ‘offshore socket’. To this end, the grid operator (in this case Tennet) installs the grid before the wind turbines are built. Rijkswaterstaat wants to apply the same type of approach to enable the growth of fast charging infrastructure at highway service points at the lowest possible social costs.

The grid operator only needs to create one single heavy-duty and future-proof connection, so that the repeated digging of the ground and the laying of extra cables, as well as premature depreciation of cables and connections, are prevented. It also creates the possibility that local producers of sustainable energy can quickly and easily connect to this ‘socket-on-land’.

This innovation saves social costs and makes smooth growth of charging facilities at rest areas possible.

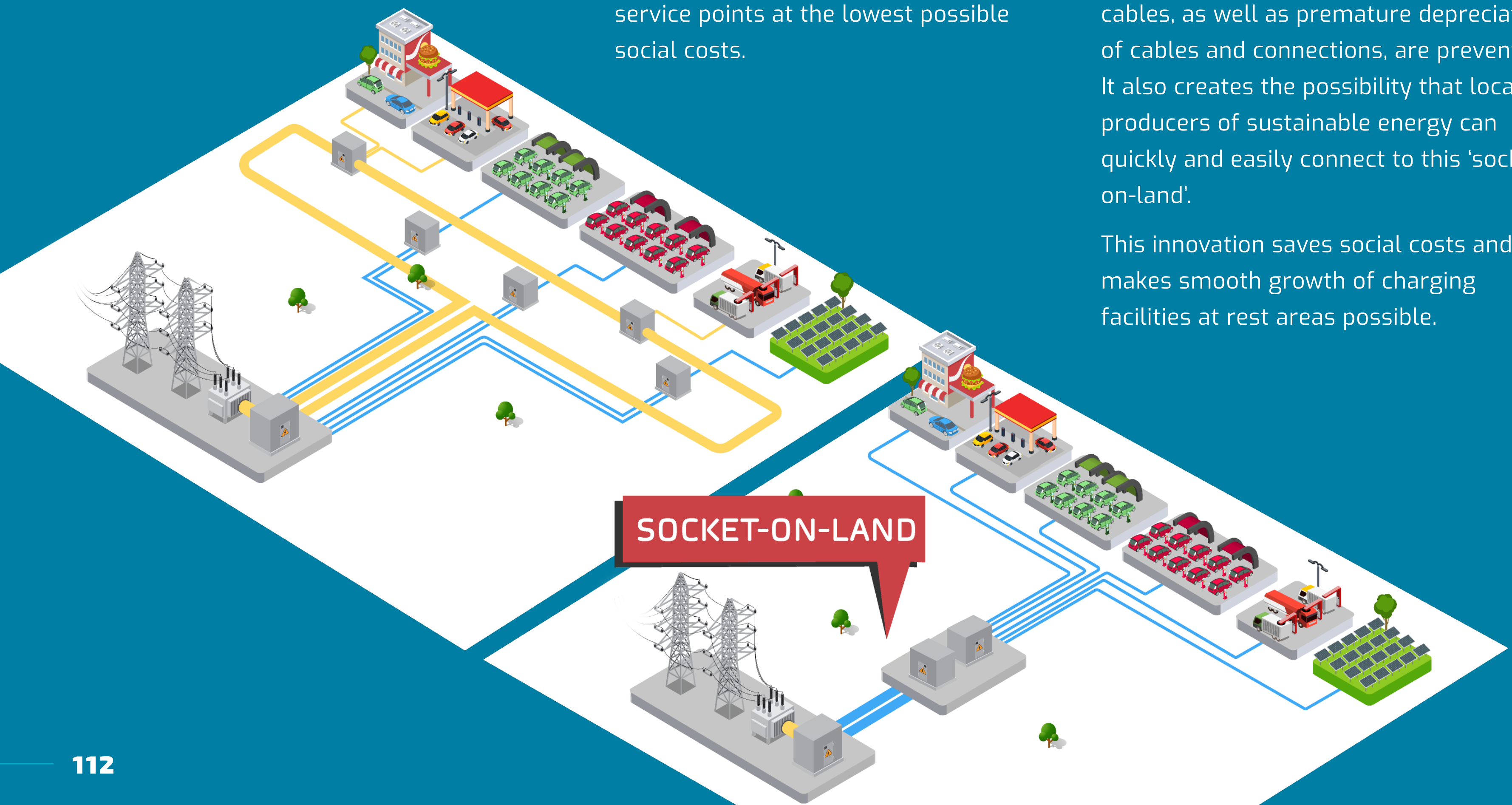


Photo
Situation with and without socket-on-land.

Currently, there is grid congestion in many parts of the Netherlands, particularly during the day. This is not only due to the increased power demand from electric mobility but also because companies are electrifying their business processes and heating systems.

This situation means that the electricity grid needs to be extended or reinforced in many places. This can take time because the underlying grid at higher voltage levels does not always have sufficient capacity. If an entrepreneur requests a large grid connection for an e-truck charging facility or a large bus depot, it can sometimes take years before the grid operator can fulfil this request. As a result, many companies are looking at 'mitigating measures' to bridge the period until the necessary grid connection is available.

One possible solution is the combination of solar panels and a buffer battery. This is a good solution in many cases, but it has its limits. In winter, when solar power is scarce, vehicles will still need to be charged. Therefore, the grid connection needs to have sufficient capacity to charge the buffer battery on such days. Furthermore, not every roof structure is suitable for today's solar panels. However, more and more lightweight solar panels are entering the market, offering potential solutions.

SOLAR PANELS REQUIRED TO CHARGE ONE TRUCK

To charge one truck with solar panels, you need approximately 584 square meters of roof area. This is based on a tractor driving 77,000 kilometres a year and consuming 1.5 kWh per kilometre, resulting in an annual energy consumption of 115,500 kWh. With modern solar panels producing 396 kWh annually per panel, and each panel covering about two square meters, you would need 292 panels. This total area requirement is about 15 times the footprint of a tractor with a trailer.

Photo
Jacques Tillmans
Alliander


RESEARCHING AND TESTING SMART AND SUSTAINABLE CHARGING
ZERO EMISSIE
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deBruyn Transport
Ballast Nedam
ElaadNL
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BETTER USE OF THE ELECTRICITY GRID: SMART CHARGING FOR E-TRUCKS

The current electricity grid can be better utilized by taking advantage of residual capacity during off-peak hours. To facilitate this, grid operators will introduce new contract forms. For example, a time block contract allows an entrepreneur to access grid capacity only during the night, which aligns well with logistics companies' needs to charge vehicles overnight. Another option is 'cable pooling,' where two companies with complementary energy profiles share a single grid connection. Furthermore, companies that share a cable and/or transformer can form an energy hub together. By setting up an entity, they can enter into a 'group transport agreement' with the grid operator, setting a maximum power for the group. The companies then manage energy among themselves, adjusting power consumption as needed.

As a temporary measure until a larger grid connection is available, a local generator can provide additional power. This generator doesn't necessarily need to run on diesel; options like green gas, hydrotreated vegetable oil, and future hydrogen technologies are viable alternatives.

CHARGING AT THE NEIGHBOURS

The measures above require quite a bit of paperwork, both between companies and between the contract holder and the grid company. Companies can also just share charging infrastructure efficiently, when grid capacity restrictions are not allowing extra load to be added to existing connections. For instance, if company A has charging stations that are not always in use, their neighbour, company B, with a different driving pattern, can use them during those available hours. This requires clear agreements on the charging tariff, liability in case of damage, and practical aspects such as access to facilities like toilets and parking.

LIVING LAB HEAVY DUTY CHARGING PLAZAS

The **Living Lab Heavy Duty Charging Plazas** project is a testing ground for heavy-duty charging infrastructure across six locations in the Netherlands. It aims to gather and share knowledge and experience to benefit Dutch market players and accelerate the development and rollout of charging plazas. This initiative is crucial, as the country expects a significant increase in electric trucks by 2030 (from around 400 in early 2023 to 10% of the truck fleet).. To support this transition, a nationwide network of public and private charging plazas is needed.

Commissioned by the Ministry of Infrastructure and Water Management, Rijkswaterstaat is conducting practical research into effective public charging infrastructure for heavy-duty vehicles, in collaboration with market partners and the National Agenda for Charging Infrastructure (NAL). The project also aligns with European regulations (AFIR), which requires sufficient publicly accessible charging infrastructure along major routes and urban nodes.

The Living Lab gathers and shares data and knowledge, helping market parties to more quicky scale up. It enables the effective design of government tools such as regulations and subsidies. It focuses on five research themes: energy, logistics, technology, spatial planning, and business cases. These themes guide the research, which involves six charging plazas ranging from truck parking areas to public locations, with available budgets to encourage further innovation.

PUBLIC CHARGING HUB

Another option is for the municipality to establish a public charging hub at the business park. This is ideal for small companies that cannot afford the investment in charging infrastructure and grid connection. Prerequisites include a reservation system to ensure availability, (camera) security for vehicles and cargo, policies for guest users, and possibly a fast charger for opportunity charging during the day, using the same grid connection.

Energy hubs

One potential solution for grid congestion is the implementation of energy hubs. An energy hub is a local collaboration between energy users and producers, where energy production, transportation, storage, conversion, and use are coordinated. This broad definition means that energy hubs can range from small mobility hubs to large business parks.

Currently, the development of energy hubs is in the experimental phase. Although they have the potential to optimize grid capacity and play a crucial role in the energy transition, setting up a functioning energy hub takes time. The initial challenge is the lack of a clear responsible party, making it difficult to initiate energy hubs. First, a feasibility study is needed, considering factors such as available grid capacity from both the DSO and TSO, the business case, and the willingness of stakeholders to collaborate. If the feasibility is positive, the next phases of design, realization, and operation can proceed.

These phases present challenges, including establishing new collaborations between parties that have not previously worked together, introducing new variables in sharing energy and grid capacity, and applying flexible capacity. Additionally, organizational capacity, legal agreements, information sharing, and technical adjustments (such as adding new production and/or storage assets) are

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Photo
Nationale Agenda Laadinfrastructuur

required to make the energy hub function properly. An agreement between the energy hub and the DSO is necessary, which is currently limited.

For future development, several points need attention. These include potentially extending existing regulations to allow new agreements between energy hubs and DSOs, creating a national program to stimulate the development of energy hubs, and developing new tools and methods to share lessons learned between existing and new energy hubs. Overall, energy hubs offer a promising solution to address grid congestion and enable the local use of locally produced energy, but their successful setup is complex and influenced by many factors.

CHARGING HUB

A large charging hub was constructed in Geldermalsen to support trucks, mobile batteries, and construction equipment. This initiative is part of a dyke reinforcement project aimed at achieving sustainability. The contractors opted to use electric equipment extensively, including 14 electric excavators, eight trucks, four shovels, five tractors, an electric phase paver, and two electric cranes.

For a better understanding, to reinforce 19 kilometres of river dike, 1.2 million m^3 of clay needs to be moved and 18,000 tonnes of sheet piling needs to be installed. This massive operation is being carried out almost exclusively with electric equipment.

The site is located next to a large wind and solar farm. The charging hub consists of 36 CCS chargers and 6 AC chargers for large batteries. A total of 5 MW of power is needed, supplied by 10 MW from the adjacent solar field, 10 MW from the local wind turbines, a 2.8 MW grid connection (usable only at night), and a buffer battery.

Through smart planning, all vehicles and construction equipment are charged as cost-effectively as possible, with additional space available for guest users, such as passing e-trucks needing a fast charge.

CHARGING FOR CONSTRUCTION

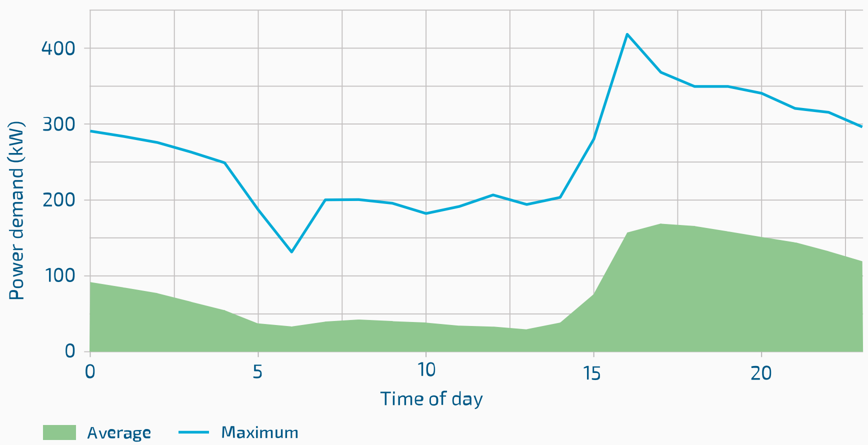
The construction sector uses various vehicles for site tasks or transporting goods and workers. The majority are vans for tradesmen, while trucks are used for specific tasks like concrete pumps, mobile cranes, and cherry pickers, or transporting goods like tippers, hook loaders, and cement mixers. Some trucks not only use power for driving but also for auxiliary functions, which are powered by a Power Take-Off (PTO) in diesel vehicles or an extra electric motor in electric vehicles. This extra motor draws from the battery, increasing the energy consumption of the truck.

Construction vans and vehicles typically drive to the site in the morning and return home after work. Transport trucks operate throughout the day, starting from their depot, a construction depot, or a supplier. Charging options vary: vans may charge at their depot or at the driver's home, while large trucks primarily charge at their home depot but may need to opportunistically charge at the construction site or en route. Transport trucks usually charge overnight at their depot, sometimes combined with fast charging during mandatory breaks or loading/unloading.

CHARGING PROFILE CONSTRUCTION

The figure below shows the actual power demand, aggregated for an average weekday, for a road construction project. This data provides insights into the typical energy consumption patterns and helps in planning the necessary infrastructure to support the electrification of construction equipment.

Power demand for road (highway) construction



BATTERY SWAPPING: THE COMEBACK KID

Swap or charge, that's the question. The idea of swapping batteries is as old as that of electric cars and makes a comeback from time to time, though not with great success in the recent past. Will we see a breakthrough now?

The concept of an exchangeable battery service was proposed as early as 1896. It was first offered by the Hartford Electric Light Company between 1910 and 1924, to serve electric trucks. The vehicle owner purchased the vehicle, without a battery, and then the power was purchased in the form of an exchangeable battery. Both vehicles and batteries were designed to facilitate a fast exchange. The owner paid a variable per-mile charge and a monthly service fee to cover truck maintenance and storage. These vehicles covered more than six million miles.

Since that time, there have been various small-scale attempts to revitalize the concept, such as the 50 electric buses at the 2008 Summer Olympics, as well as the Israeli company Better Place that tried to make the battery-switching model mainstream in 2011. The Renault Fluence Z.E. was the first modern car enabled to adopt the approach.

And now, the present moment:. Chinese car manufacturer NIO is developing electric cars with interchangeable batteries. Batteries can be changed at four swapping stations in the Netherlands. In 2022, NIO opened the first swapping station in Tilburg. A swapping station is about the size of two parking spaces and can replace up to 312 batteries per day, according to NIO. Each station can charge thirteen batteries simultaneously, and at a swapping station, the car's battery is replaced fully automatically for a full or newer one.

It is currently unclear whether this will become mainstream any time soon, though battery swapping is common in certain niches, for example, in electric forklift applications. Furthermore, it is used for electrification in construction where there is not always sufficient power available at the workplace. Because battery swapping makes charging possible at other times and places, it can also potentially reduce the strain on the power grid.

Photo
NIO Nederland

CHARGING STRATEGIES FOR CONSTRUCTION

Construction projects generally fall into two categories: fixed location projects and line projects. Fixed location projects, also known as point projects, include residential and non-residential construction such as tunnels, bridges, and buildings, all of which have a permanent power demand. For these types of projects, it is crucial to establish a sufficient grid connection before construction begins to facilitate on-site charging.

Line projects, on the other hand, involve infrastructure development like road construction, where the work progresses along a route. Charging strategies for line projects vary. Some options include on-site charging with temporary grid connections, which are potentially supported by mobile battery containers for energy buffering. Another approach involves using charging hubs near the construction site or at third-party locations that already have substantial grid connections. Contractors might also utilize their own charging locations near the construction site, known as depot charging.

Currently, some initiatives are exploring the feasibility of smart charging for construction projects. The primary focus remains on securing adequate grid connections before active smart charging can be considered.

PRACTICAL USE

In the Netherlands, several pioneering projects are already implementing zero-emission construction wherever possible, even though it is not yet mandatory. Some major infrastructural projects are currently being carried out emission-free, partially under the SEB covenant. These include embankment reinforcements, the construction and widening of roads (with fully emission-free asphalt sets in operation), and most of the preparatory groundwork for these projects. Energy supply-related projects and rail network maintenance are being performed with a focus on zero-emission practices. These projects showcase the practical application of zero-emission construction strategies, using the aforementioned scenarios and charging processes.

SOLAR CARS: NO NEED TO PLUG IN?

Will all future electric cars be equipped with solar panels so that they charge themselves? The Fisker Karma (a 2011 electric car with range extender) was fitted with a sunroof producing modest amounts of power. A few years ago, two solar-powered electric car models were on a development path to becoming commercially available: the Lightyear One and the Sono Sion. Both projects have sadly been terminated. But perhaps in one way or another they or other initiatives will make a comeback?

NO NEED TO PLUG IN?

That car manufacturers are trying to make electric cars as efficient as possible and integrate solar panels is an amazing development. But, don't overestimate the potential of a solar-sunroof: even on a sunny day it will only charge your battery between 10 and 30%, depending on battery size and the solar panels' production. In most cases (unless you live in Australia), it will still be necessary to charge your car's batteries from the grid, or your own solar panels, or from wind turbines at sea.

If solar cars were to become successful, it would certainly have a great impact on charging and the electricity grid—there would be less demand from car-charging, especially in summer.

Photo
Aptera.us

DECISION AID FOR CHARGING SOLUTIONS

To support construction companies and clients in the transition, ElaadNL developed the 'Ladder van Laden' ('charging escalator') for electric construction' in consultation with the grid operators. From the perspective of power grid management and social interests, the most desirable situation is that charging can be done on existing charging infrastructure and on existing power connections around the construction site. Flexible solutions such as interchangeable battery packs or large battery containers that are charged elsewhere are also suitable. This is followed by bringing forward an already necessary grid connection, as is possible in a new-build district. Because the capacity of grid operators to install new connections is limited, this option is less desirable. Least desirable is requesting a temporary grid connection that is only useful for the construction phase. Sometimes there is no other option, but if there are other solutions, they are preferable. In all cases, timely mapping of the expected power demand is crucial. So-called grid-aware charging is also important in construction. Charging is mainly done during off-peak hours of electricity use, for example at night. In many cases this is fine in construction because the tools are still stationary.

Preferred situation

0	**Draft expected electricity demand and charging profile**	Create a detailed power demand (charging) profile per construction project, including a 24-hour (charging) forecast and total power profile. Also consider smart and grid-conscious charging (e.g., only at night).
1A	**Use existing grid connection**	Utilize the existing connection on-site, from nearby third parties, and/or the site of the client.
1B	**Use existing charging infrastructure**	Utilize the existing nearby AC or DC charging infrastructure, possibly at third parties (for example, a construction charging hub or an existing charging plaza).
2	**Use flexible alternatives such as battery storage and alternative energy contracts**	Deploy battery containers or mobile battery packs, use flexible energy contracts, and/or employ (zero-emission/hydrogen) generators.
3	**Turn temporary grid connection into permanent solution**	Advance the planned grid connection (e.g., for housing construction) or ensure a permanent setup (charging plaza) after the construction is completed.
4	**Realize temporary grid connection**	Only establish a temporary (heavy-duty) grid connection as a last resort if the previous steps are insufficient.

Most undesirable situation

Photo
Nationale Agenda Laadinfrastructuur

CHARGING ELECTRIC BUSES

Interoperability of charging infrastructure is not guaranteed with buses: some buses charge with a cable, while others use a pantograph. A pantograph can either rise from the roof of the bus (panto-up system) or descend from the charging station to the bus roof (panto-down system). At bus hubs, where buses from multiple operators come together, different charging systems are sometimes used side-by-side.

The bus sector quickly realized that smart charging can save a lot of costs. They now use advanced software to manage charging, taking into account current energy prices. Drivers receive real-time information on the battery's state of charge (SoC) and, if necessary, feedback on their driving style.

Despite adopting smart charging, the public transport sector is now facing grid congestion problems for new charging locations and parking facilities. For grid operators, it is crucial that public transport authorities take ownership of more bus depots and strategic charging locations to avoid needing new grid connections with every operator change at the end of a concession period.

CREATIVELY REINFORCE THE GRID

E-trucks, construction equipment and public transport buses all pose their own charging challenges, as we have seen in this chapter. And as always there are smart solutions. But also the need to reinforce the power grid for this transition is necessary.

Grid congestion at business parks is a major challenge for the electrification of the logistics sector in the coming years. Many entrepreneurs will receive the necessary grid connection later than desired. As a result, they are seeking creative solutions. In some cases, charging electric vehicles can be made possible by installing solar panels and a buffer battery, while other companies may collaborate with a local

Grid congestion at business parks is a major challenge for electrification.

GUARDIANS OF THE GRID

By smartly managing the charging of electric cars and adding a 'safety net', more electric cars can be charged at a location without any problems. That is the idea behind SmoothEMS with Gridshield project. This multi-year project is testing smart-charging in the parking lot of the a.s.r head office building, using their solar roof, batteries and charging stations (a.s.r. is an insurance company in Utrecht). But also at the provincial government building in Zwolle and on the campus of the University of Twente.

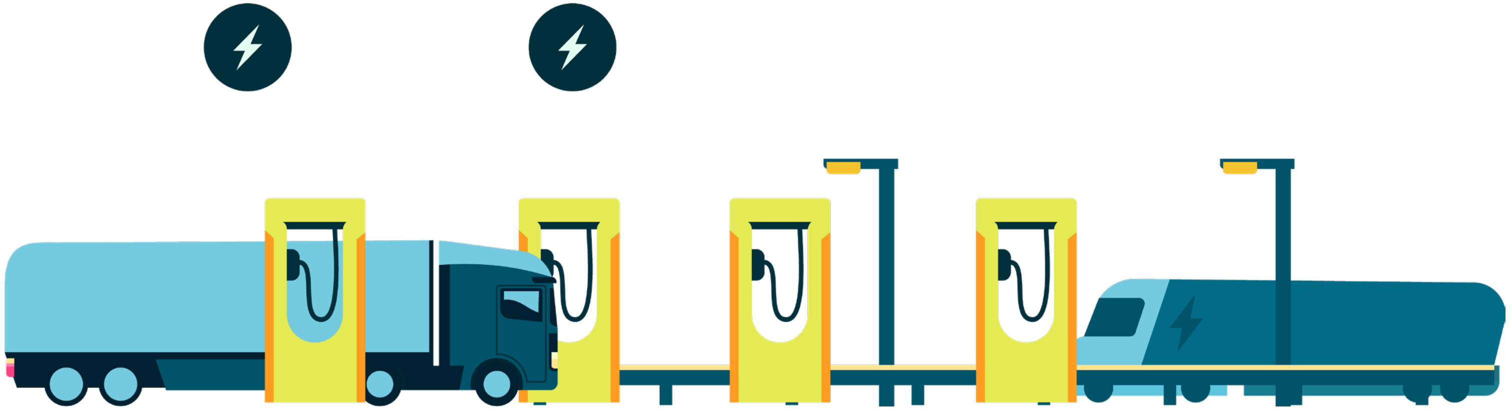
Basically, the Energy Management System (EMS) controls charging and all other flows (consumption and generation) at that location, as well as the building and the grid. Complex forecasts of consumption and generation are used for this. In a regular EMS, it is necessary to maintain a safety margin to accommodate any deviations from the forecast. In the SmoothEMS with GridShield environment, the safety margin can be much smaller. The GridShield registers the energy flows in real time—and if they fall outside of the safety margins of the grid, a signal is given locally and autonomously, which temporarily reduces the charging speed. If needed, this can also result in a temporary pause. As soon as the system returns to normal values, charging will resume. The user notices little or nothing of this process, because the intervention will only be needed in exceptional situations, only lasts for as long as necessary and automatically ramps up when it's possible. The project shows that a well-functioning GridShield can prevent power outages and enable maximum use of charging stations.

Parties from the entire chain are working together in the project, through the participation of the University of Twente, Kropman installation technology, Amperapark, Mennekes eMobility, a.s.r. insurance and ElaadNL. The project receives a subsidy from the MOOI scheme of the Ministry of Economic Affairs and Climate Policy.

wind farm. Companies are also likely to adopt advanced energy management systems, especially if they can flexibly control other equipment alongside smart charging of electric vehicles, such as a cold storage facility.

Network operators are introducing new contract forms to ensure that available network capacity is better utilized. Most companies demand a lot of energy from the grid during the day, whereas logistics companies typically want to charge their vehicles at night. Companies with complementary energy profiles are increasingly cooperating by forming energy hubs or entering into group contracts with the grid operator.

In all cases, smart charging, effective energy management, and collaboration are key to enabling electric vehicle operations during times of grid congestion. In the next chapter we take a look at large-scale rollouts of charging infrastructure and how to accelerate the process.



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SMOOTH ACCELERATION OF A LARGE-SCALE ROLLOUT OF CHARGING INFRASTRUCTURE

Photo
Nationale Agenda Laadinfrastructuur

AFTER LOOKING INTO THE EXPECTED GROWTH OF ELECTRIC TRANSPORT (E-TRUCKS, VANS, CONSTRUCTION EQUIPMENT AND PUBLIC TRANSPORT BUSES) AND HOW TO CHARGE THOSE VEHICLES, WE NOW GET BACK TO THE CHALLENGE OF CHARGING MILLIONS OF ELECTRIC CARS.

As we already know by now, smart and grid-aware charging is crucial to fitting all these charging cars on the electricity grid.

This chapter highlights a variety of subjects that all have a crucial role in managing energy loads and optimizing electricity use and in the smooth acceleration of large scale rollout of charging infrastructure. We start with the difference between AC (regular) and DC (fast or heavy) charging; we will then zoom in on stand-alone smart chargers, and we discuss bi-directional charging, which is a promising technology that allows EVs to serve as energy storage units, enhancing grid resilience and offering greater flexibility to consumers.

We also focus on the integration of smart charging within home energy management systems (HEMS). As more EV owners charge their vehicles at home, the importance of sophisticated energy management grows, requiring seamless interoperability between household devices to ensure efficient energy distribution.

The chapter further addresses the unique challenges of charging heavy-duty vehicles, particularly in industrial and business parks, where energy demands are significant. Concluding, we emphasize the critical need for cybersecurity to protect charging networks from potential threats that could disrupt both mobility and grid operations.

PREPARING EUROPE FOR SCALING UP SMART CHARGING

SCALE is a three-year European project (2022-2025) that aims to advance smart-charging infrastructure and facilitate the mass deployment of electric vehicles. The project aims to reduce uncertainties around the roll-out of smart charging, interoperable and V2X (Vehicle-to-Everything) solutions, whether these are technical, organizational, economic, social or policy-related, and help shape a new energy eco-system wherein the flexibility of EV batteries is harnessed.

A consortium of 29 partners composed of leading European cities, universities and knowledge partners, charging infrastructure companies, EV industry pioneers and more steer the project.

SCALE HAS FIVE AIMS:

1. To develop an open system architecture by 2023 for smart charging and V2X, which ensures interoperability, connectivity, openness of the system, and fair market conditions.
2. To deploy a user-centric approach, systematically collecting knowledge, removing existing acceptance barriers and developing solutions in line with 800 users directly involved in SCALE pilots.
3. To reduce the need for grid reinforcement by a minimum of 50%, better leveraging the existing grid, thereby limiting time-to-market in quality and quantity to ensure a timely transformation.
4. To prepare a mass-market and eco-system for smart charging & V2X paving the road for EU Fit-for 55 ambitions, ensuring all newly procured chargers are V2X-enabled from 2025 onwards.
5. To create the necessary momentum across Europe and maximize use, securing impact beyond the project lifetime through SCALE's V2X Alliance, including 50 committed members, and mobilize a total of at least 150 organizations through the networks of the SCALE partners.

The SCALE project is co-funded by the new Horizon Europe Program under grant agreement No 101056874.

AC AND DC

First and foremost, it's good to note that there are two kinds of charging: the normal or standard charging (AC-charging), and fast charging (DC charging). An EV battery is like a normal battery in which electricity flows in one direction, with two poles.

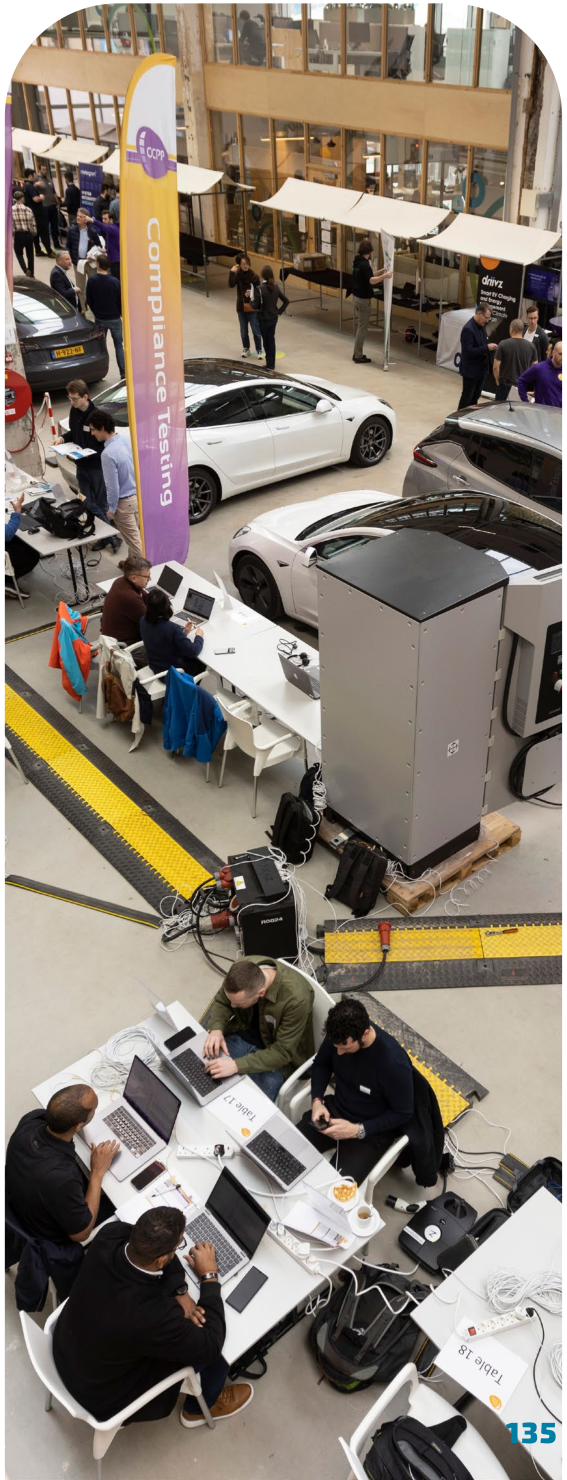
AC-charging is charging with Alternating Current (AC) which is the kind of power we use in our local grid and is used for the outlets in homes. The charging stations at your home or in the streets are AC-chargers; the on-board charger in the car converts the AC into DC for the battery. DC-charging is charging with Direct Current (DC) and is used for higher-power charging. Fast chargers are found near highways and other locations, for example, at larger stores and fast food chains or on industrial estates.

REGULAR CHARGING

Easily accessible charging is crucial for increasing the adoption of electric vehicles. To make this happen, we need widespread, publicly available charging infrastructure. Most charging currently happens at home, either on a private connection or at a public charger near the driver's home, or at the workplace.

The use of AC-charging infrastructure, both in public spaces and at private locations, will continue to grow over the coming decades. This is the most practical way for most people to charge their cars since they have plenty of time to do so (95% of the day is available). As a result, there is an increasing demand on existing grid connections in residential areas and workplaces. There is also a growing need for more powerful grid connections at the consumer level.

In the Netherlands, all connections between single-phase with 25A and three-phase with 25A are grouped into one category, known as the consumer tariff. There has been a steady increase in upgrades within this group to a higher connection type, likely due to the rise in electric vehicle use. These upgrades allow households to upgrade their technical capabilities without an increase in the grid tariff. However,



UTRECHT TRIAL: SMART CHARGING BASED ON FLEXIBLE GRID RATES

In the collaborative project FLEET*, Stedin (the grid operator), companies and knowledge institutions (including ElaadNL) started smart charging electric cars at 380 public charging stations in Utrecht in 2021. In this trial, smart charging was based on flexible network rates from the network operator. By varying grid rates, the grid operator could provide an additional financial incentive to charge point operators on top of the variable electricity prices to charge outside of peak times. At times of high grid load, the grid rate was higher, and it became less attractive to charge to full power.

This experimental price incentive resulted in a 15% reduction in peak loads for electric cars, thus relieving the burden on the local power grid. In most cases, users did not notice this because the car was plugged in for longer than necessary and there was enough space to charge it outside of the peak. As soon as it was calmer on the local network (and the network rate was therefore favourable), the electric cars were charged again at the maximum charging speed.

During the FLEET experiment, customers at the charging station could choose to be excluded from smart charging. Users had indicated in advance that they needed this overrule option, but in practice it was rarely used. Research among users also showed that most customers are happy that they can contribute positively to reducing congestion on the electricity grid in this way.

** In FLEET, grid operator Stedin, ElaadNL, charging station company We Drive Solar, Smart Solar Charging BV, the Municipality of Utrecht, Utrecht Sustainability Institute and Enervalis worked together under the leadership of the Copernicus Institute for Sustainable Development of Utrecht University. FLEET was supported by the Top Sector Energy Subsidy from the Ministry of Economic Affairs and Climate.*

this ability for individual households to increase their demand on the grid results in a higher overall load in their neighbourhoods. Since the transition to higher grid connections seems to be directly linked to the growth of electric mobility, smart charging becomes even more important than was first expected. In 2023, 77% of EV owners who charged at home did so using a three-phase connection, and 34% of them had their connection upgraded (National Charging Survey 2023). Of course, there must be technicians to install those charging points at home and to take care of them where the connection to the grid is upgraded.

FAST CHARGING

High-power charging stations have made impressive progress in recent years. Modern technologies now allow these stations to deliver ultra-fast charging speeds, cutting down charging times and making it much more convenient for users charging on a trip.

In 2023, about 9% of all consumer vehicle charging took place at fast chargers (source: Nationaal Laadonderzoek). This percentage has remained constant over the past four years. There are around 4,800 fast charging points in the Netherlands. A variety of suppliers have entered the market, each with their own unique approach. Car manufacturers, standalone fast charging companies, and traditional gas stations are all getting involved. Unexpected players like large companies, shopping malls, and roadside restaurants are now offering fast chargers. The available charging power is increasing alongside car capabilities, reaching up to 400 kW.

Given the high power required, it's crucial to plan the locations for fast chargers carefully. ElaadNL developed a model that determines the best spots for fast chargers by considering factors like proximity to highways, existing fast-charging locations, and grid capacity.

AMSTERDAM TRIAL: CHARGING MORE ELECTRIC CARS ON A BUSY ELECTRICITY GRID

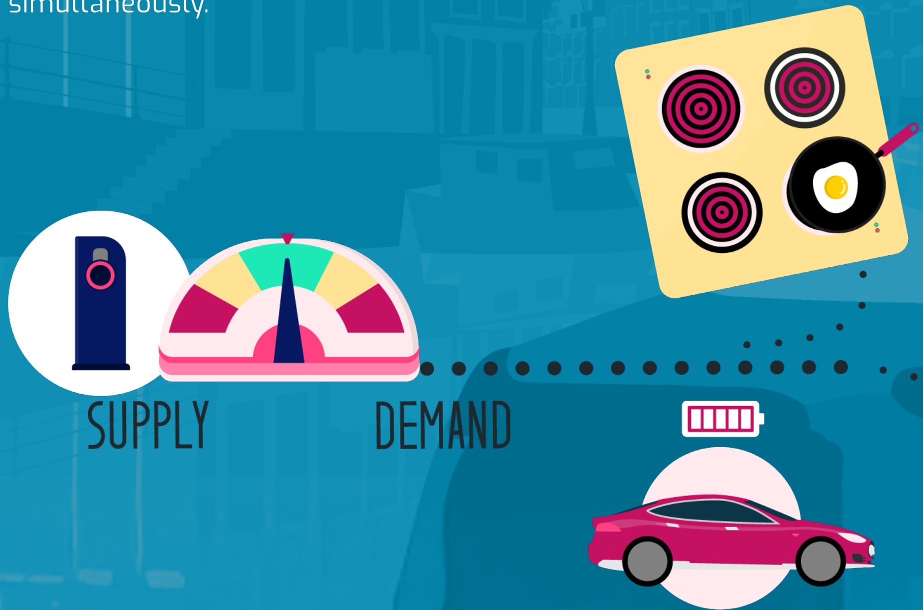
From December 2021 to October 2022, an experiment with flexible charging speed for electric cars (also known as 'Flexpower') was conducted at 126 charging points spread across ten Amsterdam neighbourhoods. Users could plug in their electric car as they normally would, but the speed of charging depended on both the number of charging cars in the area and the current available capacity of the electricity network.

Flexpower ensures that cars in a neighbourhood share the available power through a smart distribution of energy between the chargers present. If any cars in the area have finished charging and are left on the charger, the power from the unused charging points is then distributed amongst the other cars. Cars also receive extra power if there is more energy available on the electricity grid (for example, through local energy generation).

THREE TO FOUR TIMES MORE CHARGING POINTS

An important principle of the test was that the owners of the electric cars are not inconvenienced by the flexible charging speed. In practice, the speed of a charging session only decreases when necessary: when there is little space on the electricity grid and/or when many cars are charging at the same time. Because electric cars are usually plugged in for much longer than they are charged, in practice users usually did not notice anything from the test and their car was fully charged within the parking time. The researchers only saw a small effect for cars that parked for a short period, which concerned only 13% of the charging sessions. These cars received 4.8% less energy compared to a charging session without smart charging. No complaints have been received about this.

This method of smart charging creates more than three times more room for new charging points without increasing the peak load on the electricity network. This is because grid operators no longer have to reserve the maximum power for each charging point. Without Flexpower, this was necessary in situations where many vehicles would be charging simultaneously.



HEAVY-DUTY VEHICLES

As mentioned in previous chapters, passenger cars are not alone in their search for electric alternatives; buses, trucks, and construction machinery are also becoming electric. Most charging for these heavy-duty vehicles (up to 85% of the time for trucks and vans) will take place at corporate locations, leading to high charging activity at business parks. These areas are also changing in terms of heating and local electricity production. The Netherlands has about 3,700 business parks that will need grid upgrades to support this energy transition.

A challenge for these business areas is that many companies don't yet know their future energy needs. Close cooperation between logistics partners, office buildings, and grid operators is essential to prepare for future demands, whether that means smart controls, grid extensions, or both.

In the Charging Energy Hubs program, 27 companies and knowledge institutes are working together to create local smart energy systems using open standards, stationary batteries, and DC-grids. These efforts aim to find the best ways to use the grid efficiently in the logistics sector. ElaadNL is a key knowledge partner in this project, helping develop system architecture, standards, protocols, market roles, and general operations.

CHARGEPOINT INSTALLER TRAINING

The energy transition hinges on the availability of qualified personnel. Like all sectors, the shortage in the labour market poses a significant challenge for the charging infrastructure industry. To accelerate the rollout, there must be a strong focus on education pathways and the rapid deployment of new specialists.

Following the success of course materials ElaadNL helped develop, November 2023 saw the first batch of students from a Dutch applied sciences school complete an in-depth ElaadNL training on charge points for electric vehicles. This two-month course is for students training to be electrical engineers and is also available part-time for those already in the field. The training covers installing chargers, commissioning them, and solving simple issues.

Photo
Liander


COMPACTE
AANSLUIT
MODULE
fischer

COMPACT GRID CONNECTION MODULE

Due to ongoing economic growth, sustainability efforts, and digitalization, the demand for electricity keeps increasing. Grid operators in the Netherlands are working to expand the electricity grids to meet this demand, but there is a severe shortage of technicians. As a result, grid operators are seeking innovative solutions to make their work better, smarter, faster, and more safely. The development of the Compact Grid Connection Module (CGCM) is a prime example, saving significant time.

Enexis, Stedin, and Liander, representing all regional grid operators, developed the CGCM with supplier Connectens. The first charging station using the CGCM was connected at ElaadNL's premises in Arnhem. These new connection modules are more compact and ensure that installations can be connected more safely and three times faster, saving technicians' time and helping achieve energy transition goals. All grid operators in the Netherlands will start using these modules for unmanned installations such as charging stations, advertising pillars, and street lighting, further improving efficiency.

SAFETY AND SECURITY OF POWER SUPPLY | CERTIFICATIONS

All electric equipment in public spaces must be safe. Grid operators have high standards for all equipment connected to the public electricity grid. Requirements for EV charging equipment are in addition to those for items like lampposts, and ElaadNL performs tests to ensure new public chargers meet these standards. There is a standard procedure for these tests. Having a single list of requirements is an important step in standardizing the development of charging stations. If a new charger uses the same connection as a previous model, recertification isn't necessary, which speeds up development.

ElaadNL facilitates charge point certification, both administratively and operationally. All chargers that pass the testing procedure receive a certificate and are added to the list of approved charging stations. Many of these chargers, including charging lampposts, have been added to the ElaadNL charging plaza over the years, allowing interoperability testing and serving as a showroom for available charging stations in the Netherlands.

TESTLAB FOR CHARGING OF ELECTRIC VEHICLES OPENED BY DUTCH KING

Vivianne Heijnen, State Secretary for Infrastructure and Water Management: ‘ElaadNL is the first in the world to test the interaction between trucks, charging stations and the power grid on this scale. A nice prelude to a new era of electric transport!’

On June 8, 2022, His Majesty the King Willem Alexander opened the new Elaad Testlab in Arnhem, the Netherlands. The King plugged in an electric truck and officially started the first charging session in the new lab. After a guided tour in which different types of tests were explained, there was an information market with different types of charging infrastructure and electric vehicles, including an electric airplane, electric motors, a passenger car that can also supply power back (V2G), electric buses, the solar car, an electric excavator and a state-of-the-art electric asphalt spreader.

TESTING A NEW ERA OF ELECTRIC TRANSPORT

More and more vehicles are becoming electric: not only passenger cars, but also motorcycles, delivery vans, large buses, trucks and even heavy construction equipment, inland vessels and small aircrafts. It is important to conduct research to ensure that all of these electric vehicles can be charged without issues. Charging station manufacturers, charging station operators, suppliers of energy services, network operators, educational institutions and car manufacturers can use the test facilities of the Testlab in Arnhem. Equipment for measurements is available to measure the power quality and available infrastructure to charge power in a short time and with high power. The entire communication chain of vehicles, charging stations, registration systems and interaction with, for example, solar panels and local energy systems can also be examined in the test lab. In addition, the cyber security of this communication is a specific area of attention.

Photo
Patrick van Gemert

Other matters that are tested in the lab are interoperability (e.g., can every vehicle charge without any problem with every charging station?), the connection of charging stations to the electricity grid (e.g., legal task of grid operators) and smart charging. Additionally, the experiments test whether the electric vehicle follows the steering signals correctly.

The Elaad Testlab is possible thanks to funding from: Ministry of Infrastructure and Water Management, The Province of Gelderland, The joint Dutch grid operators.

CYBER SECURITY

In addition to physical safety, cybersecurity for charging infrastructure is very important. All charging stations together form a smart network to optimally use renewable energy and grid capacity. To make this possible, all the different elements must 'communicate' with each other and their connected IT systems and back offices of charge point operators. It is important that these systems—the charging infrastructure and the network—are properly secured.

Various types of cyberattacks can affect the charging infrastructure (such as ransomware attacks), in which criminals take control of the charging systems, and Distributed Denial of Service (DDoS) attacks, which overload the servers of charging station operators.

In the near future, with the increase in electric cars and charging stations, a cyberattack that targets a large number of charging points simultaneously could have serious consequences; for example, electric cars would be unable to charge, thus affecting mobility. Suddenly switching off the large combined power of all those charging cars, creates an imbalance in the electricity grid that may even result in a national or European power outage. An estimate of the potential negative economic impact of such an incident could be as much as approximately 4 billion euros per day for the Netherlands (Berenschot, 2021).

To prevent this, the cybersecurity of charging electric vehicles must be properly arranged, mitigating cyberattacks on charging points and back offices. Cybersecurity also involves protecting personal data, and securing transaction data.

Fortunately, grid operators, companies and governments are all aware of this. ElaadNL and ENCS (European Network for Cyber Security) have created guidelines for public charging stations. For example, physical and digital access to charging points must be limited and protected. This also means that every charging point has to meet several requirements, such as maintaining a future-proof design which ensures enough memory and processor capacity for future updates.

SMART EV SOLUTIONS IN OTHER EUROPEAN COUNTRIES

Across Europe, countries are rolling out creative solutions to make electric vehicle charging smarter, more efficient, and grid-friendly. By blending technology, incentives, and regulation, these nations are paving the way for a future in which EVs can thrive without straining the power grid.

In Germany, load control, including smart charging, has been mandatory since 2024, when controllable devices (EVSE, heatpump, storage units) were installed. The German grid companies have the opportunity to apply load control to the residential level when grid bottlenecks arise (on low voltage levels). The grid companies make use of the smart meter infrastructure to communicate a power limit profile to the connection point. The regulation and preconditions for the execution of this measure are recorded in Article 14a of the EnergieWirtschaftGesetz (EnWG).

Italy takes a creative approach which allows EV owners to boost their charging power at night, completely free of extra costs. The country is developing new technologies, including a Charging Infrastructure Controller, which will enable external power adjustments—making charging as flexible as it is smart.

Spain takes a tariff-based approach, encouraging drivers to charge during low-demand times. Smart meters automatically monitor power use, and penalties discourage exceeding contracted limits. It's a clever way to keep the grid happy while giving drivers a clear incentive to charge during off-peak hours. Spain is combining this approach with a so-called ICP (Power Control Switch installed into the smart meter). The ICP will trip and the power supply will be interrupted when the contracted power is exceeded.

France uses time-of-use tariffs that signal when electricity is cheapest, prompting EV chargers to shift to off-peak times. Current experiments are extending smart connections to broader areas, turning what used to be a tool for water heaters into a key part of EV charging strategies.

In Lithuania, a unique solution for apartment buildings allows for a mix of guaranteed and flexible charging power, using real-time capacity data to optimize usage. This set-up minimizes costs for consumers and businesses by avoiding expensive grid upgrades.

Belgium has updated its grid tariffs to cut down on peak usage. In 2023, a capacity-based tariff was introduced which makes usage at high-demand times more expensive, nudging drivers to charge smarter. Though not yet EV-specific, these changes are effective and setting the stage for a more balanced grid.

Austria and the Czech Republic are managing EV charging with controlled tariffs and specialized equipment, like ripple control receivers. These measures support grid stability and offer financial perks for those willing to charge during less busy times.

Together, these diverse approaches show how Europe is embracing smart charging, turning a technical challenge into an opportunity for innovation, sustainability, and smarter energy use on the road ahead.

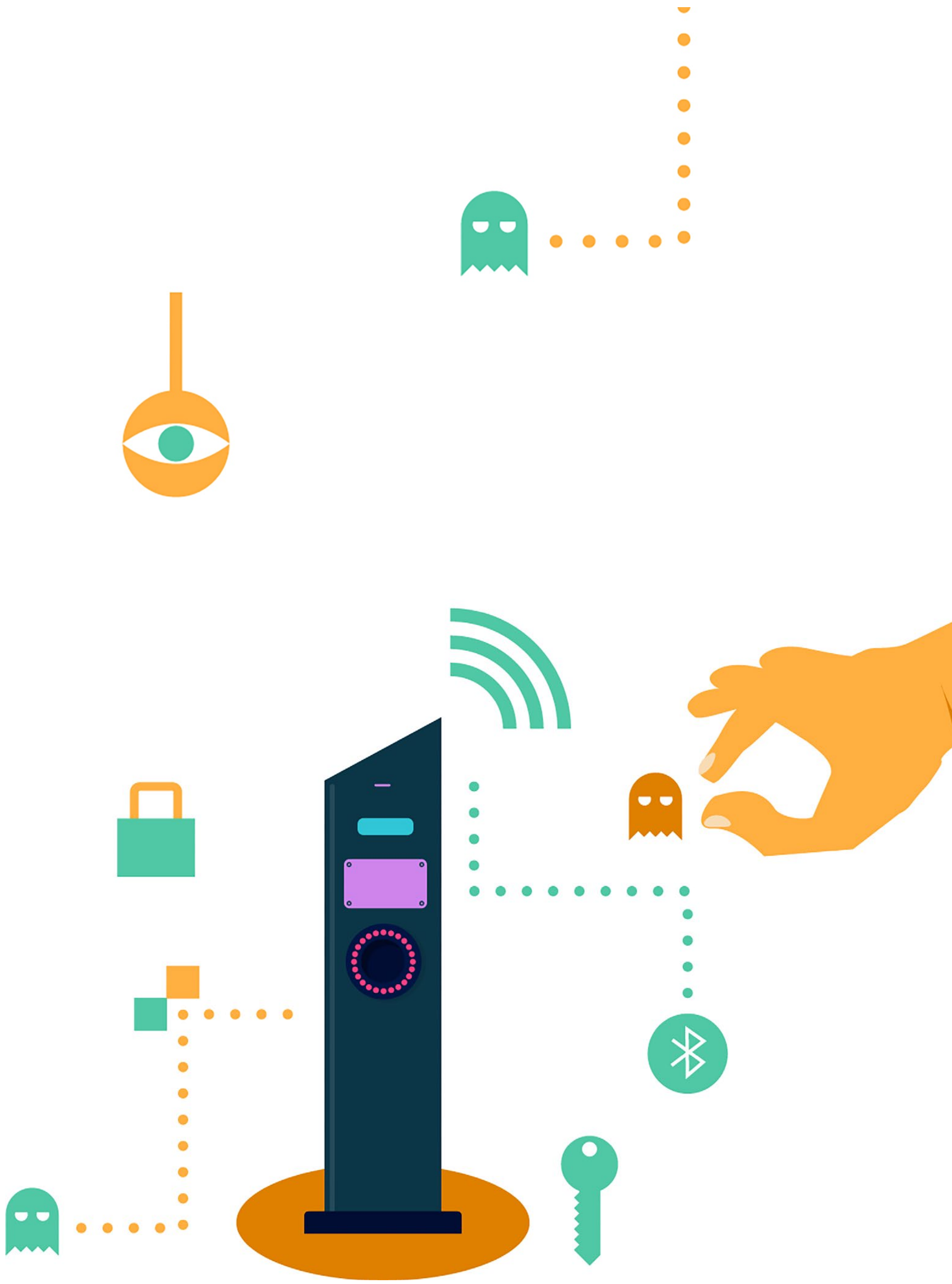
Source: E.DSO Technology and Knowledge Sharing Committee; Smart charging solutions survey 2024

This also includes implementing strong cryptographic algorithms and protocols, ensuring secure communication channels and enhancing the system's ability to withstand attacks (i.e., hardening and resilience).

Besides requirements for the charger, there are also requirements for secure operation in the transaction chain, like access control and user authentication at the authentication terminal.

As early as 2017, the first provinces and municipalities started to include cybersecurity requirements in their tenders for charging infrastructure. This meant that charge point operators and charge point manufacturers had to ensure that their products complied with these requirements. The cybersecurity of public charging stations is therefore improving, but that of private charging points is lagging behind. Private charging points are usually purchased from installation companies or web shops, making retail aspects like price and design more important than cybersecurity. The requirements published by ENCS and ElaadNL were initially unknown in this market segment. Considering that many private customers don't regularly update their appliances, don't change passwords properly, and lack firewalls, private chargers are a significant risk.

In 2023, the Dutch government announced that charge point operators that over 300 megawatts of charging capacity will be classified as 'Other Designated Vital Providers'. These operators have a reporting obligation and must therefore report hacks and cyber incidents on their charging infrastructure to the NCSC (National Cyber Security Center).




79%

This is an important step in anticipation of the translation of the European NIS2 (Network and Information Security)-directive into national legislation and regulations. The NIS2-directive focuses on improving the digital security of European Member States. This directive is being transposed into national law. Charging point operators who have now been designated as vital providers will also fall under the stricter rules of this new law. This means that charge point operators and others operating charge stations are obliged to have proper cybersecurity in place and report any incidents to designated authorities.

HOME ENERGY MANAGEMENT SYSTEMS

In relation to smart charging electric cars at home (on private charging stations), a Home Energy Management System (HEMS) will play a crucial role. A HEMS is a digital system that monitors and manages energy flows in and around your home. With a HEMS, you can monitor and optimize the different demands and supplies of energy in your home from charging your car to heating your home (heat pumps), and generating power with your rooftop solar panels.

This system knows the limits of your main connection to the grid and the needs of your appliances. The system might prioritize the heat pump and charge your car later, or it might charge the car when electricity is cheaper or your rooftop solar panels are providing excess power. If your car's battery is low and you need to leave soon, the system can ensure the car charges quickly while the heat pump uses less power temporarily.

In the past, devices at home used a relatively small amount of power individually, and their use was spread throughout the day, ensuring continuity in supply. This is changing. An electric car might charge for many hours, constantly drawing power, while on cold days, your heat pump might also run for hours. Local solar panels will all produce electricity simultaneously, creating new challenges for managing home electricity use. This results in a need for optimising and balancing energy flows in and around the house.

THE ROLL OUT OF FAST CHARGING SOLUTIONS

Even though most vehicles will be idle for the majority of the day, there are times in which fast-charging is necessary. In the growing world of EV, this does not only apply to cars that are in a hurry, but also to trucks that are on a schedule. There are various initiatives to roll out fast charging. Two examples are Fastned and Milence.

FASTNED

Founded in 2012, Fastned has developed a network of charging stations across the Netherlands and several other European countries, including Germany, the UK, Belgium, and Switzerland. Fastned's stations are strategically located along highways, in urban areas, and near retail locations, providing convenient access for EV drivers. The electricity supplied at these stations is sourced entirely from renewable energy, such as wind and solar power, aligning with the company's commitment to sustainability. Fastned's charging stations are designed to be scalable and modular, allowing them to expand as the adoption of electric vehicles grows. The stations typically offer charging speeds ranging from 50 kW to 350 kW, with the 350 kW chargers capable of adding up to 300 kilometres of range in just 15 minutes, depending on the vehicle. As of 2024, Fastned operates over 300 charging stations across Europe and plans to continue expanding its network.

MILENCE INITIATIVE

One of the companies active in the truck fast-charging market is Milence. This initiative, backed by major truck manufacturers such as Mercedes-Benz, Fuso, Renault, Volvo, MAN, and Scania, aims to roll out fast charging points for trucks and coaches of all brands along major corridors in 15 European countries in the coming years. One of the first operational charging stations is in Venlo, where four 400 kW CCS chargers have been installed to start. More chargers, including Megawatt Charging System (MCS) chargers, will be added to this site later. By 2027, Milence aims to have at least 1,700 high-performance charging points across Europe. Milence also provides on-site security and facilities for drivers. Not only do they offer fast charging, but also overnight and weekend charging options.

Photo
Top image: Milence
Bottom image: Fastned

As adoption of HEMS grows, it clearly also has an impact on the load on the power grid. Ideally, this will result in households optimally coordinating their generation and consumption, thus placing less burden on the power grid during peak hours. To maintain grid stability at the neighbourhood level, some form of communication between all HEMS will be needed, to ensure that the energy supplies and demands of all the houses in the neighbourhood are kept in balance.

INTEROPERABILITY

Controlling devices to use electricity at "the right times" is a challenge. Devices need to be connected and controllable, and their control method (through an interface and protocol) needs to be understood. The HEMS and devices like heat pumps and charging stations must communicate using the same language, and the system should be simple to use and easy for beginners to set up.

The challenge for home energy management is that many devices use different ICT communication languages, requiring a HEMS to understand multiple protocols, which often have variations. Standardization is necessary so that households are not restricted to one manufacturer and can switch devices without issues. A crucial factor in this is interoperability, ensuring that different devices work together seamlessly. In a smart home, this means that heating systems, electric car chargers, and solar panels can all communicate and coordinate their activities. Without interoperability, integrating new devices into existing systems can be difficult and inefficient. Interoperability also supports innovation by allowing manufacturers to develop new devices that easily integrate into any system, offering consumers more choices and better products. In the context of the smart grid, interoperability helps maintain stability and efficiency, ensuring effective energy distribution and preventing overloads. Overall, interoperability makes homes smarter, energy-use more efficient, and life easier. A good example of interoperability is WiFi or Bluetooth. It doesn't matter what brand or device: they all work together.

Controlling devices to use electricity at "the right times" is a challenge


Vehicle • Trip info
15:29
Current
History
20 km/h
Avg. speed after start
52 km
Trip range
01:00
Trip duration
Clear data
kWh/100km
40
30
20
10
15
10
5
Now
AUTO
AUTO
ECO
AUTO
OFF
VOL –
VOL +
21.0
21.0
FRONT
REAR
TEMP
TEMP
A/C
SYNC
AUTO
POWER

Currently, devices are controlled using various protocols like Modbus, EEBus, KNX, and RESTful APIs. Often, they also communicate with the manufacturer's systems through the cloud. Interoperability faces challenges due to diverse protocols and proprietary systems, which can prevent devices from working together. Integration complexity requires technical expertise, and the lack of standardization across regions and industries complicates matters.

To address these challenges, industry-wide standardization efforts are needed. Organizations like ISO, IEC, and IEEE are creating common standards. Developing middleware solutions can help translate between protocols, facilitating device communication. Encouraging the use of open protocols that are not tied to a single manufacturer can promote interoperability. Regulatory support can help by requiring new devices to adhere to these standards. Increased collaboration between manufacturers, utility companies, and technology providers can drive the development of standardized systems.

How easy it is to integrate—from the perspective of the device you want to control or from the control side (the HEMS)—will determine how quickly it is adopted.

Industry-wide standardization efforts are needed.

WHAT DO POWER QUALITY FLUCTUATIONS MEAN FOR YOUR LIGHTS AND HEAT PUMP?

To get a broader picture of what the future will bring for households and their use of energy, the Elaad Testlab explored for Netbeheer Nederland how common day-to-day appliances respond to undervoltage. As more solar panels, electric vehicles, and heat pumps connect to the grid, fluctuations in voltage are becoming more common. What does this mean for your toaster, television or porch light? This research aimed to uncover what really happens when the voltage drops: how different devices react, recover, or fail in such conditions.

The research revealed some intriguing findings. Lighting, for instance, is particularly sensitive to voltage dips. At approximately 200 volts, lights start to flicker, and as the voltage continues to drop, the brightness dims noticeably. By the time the voltage hits 180 volts, many lights simply go out. The good news? Most lights come back on automatically once the voltage returns to normal.

Heat pumps, on the other hand, show some resilience. They keep working even when the voltage falls to 180 volts, although minor issues like error messages can pop up around 190 volts. However, it's important to note that only a limited range of heat pumps were tested, so these results should be taken with caution.

Electric vehicles and their charging stations also have their quirks. Some EVs and chargers stop working when the voltage drops to 200 volts, but quickly resume once it's back at 230 volts. As the voltage dips further, between 200 and 180 volts, the number of failures increases slightly. In most cases, devices recover automatically, but sometimes a bit of manual help from the user is needed to get things going again.

Overall, the impact of undervoltage varies depending on the type of device, but it's particularly noticeable in lighting and some EV chargers. While most devices handle minor drops well, more significant drops can lead to moderate to severe issues. Understanding these effects is crucial as we continue to build a future with more renewables and electric mobility, ensuring that our everyday devices can keep up with the changing demands of the grid.

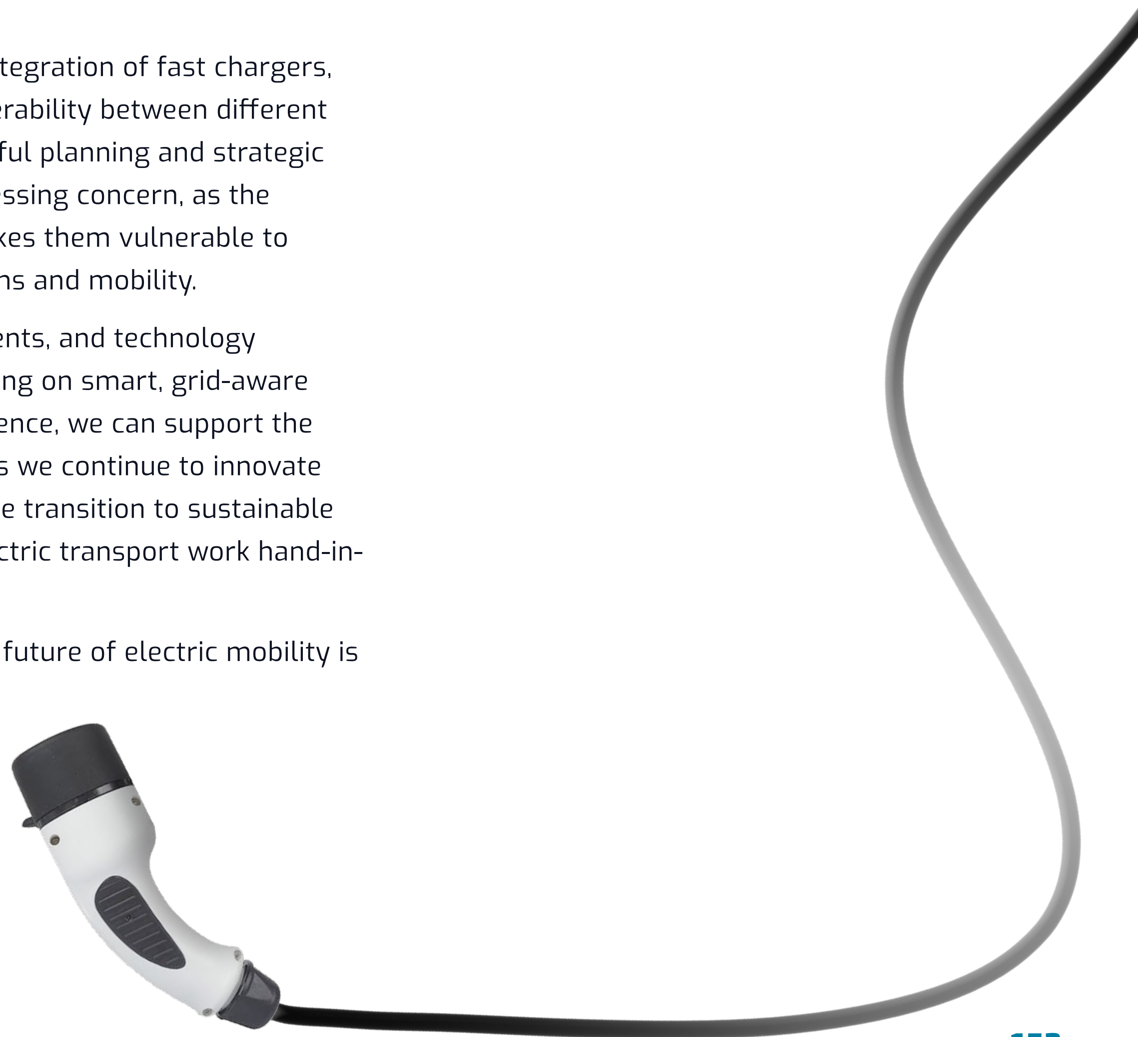
CONCLUSION

In conclusion, the rapid development of smart charging infrastructure is essential for the successful adoption of electric vehicles and the broader energy transition. This chapter has highlighted the crucial role of smart charging technologies—from AC and DC charging solutions, to bi-directional charging and advanced home energy management systems—in optimizing energy use and maintaining grid stability. These innovations are key to managing the increasing demand for electricity as more vehicles plug into the grid, offering a pathway to a more flexible and resilient energy landscape.

Yet, this transition is not without its challenges. The integration of fast chargers, managing peak loads, and ensuring seamless interoperability between different charging systems are complex tasks that require careful planning and strategic investment. Furthermore, cybersecurity remains a pressing concern, as the interconnected nature of smart charging systems makes them vulnerable to potential attacks that could disrupt both grid operations and mobility.

Collaboration among industry stakeholders, governments, and technology providers is vital to overcome these hurdles. By focusing on smart, grid-aware charging solutions and enhancing infrastructure resilience, we can support the efficient rollout of electric vehicles on a large scale. As we continue to innovate and adapt, smart charging will play a pivotal role in the transition to sustainable mobility, shaping a future where clean energy and electric transport work hand-in-hand to power our world.

How to proceed on this journey, and how to shape the future of electric mobility is the subject of our next and final chapter.

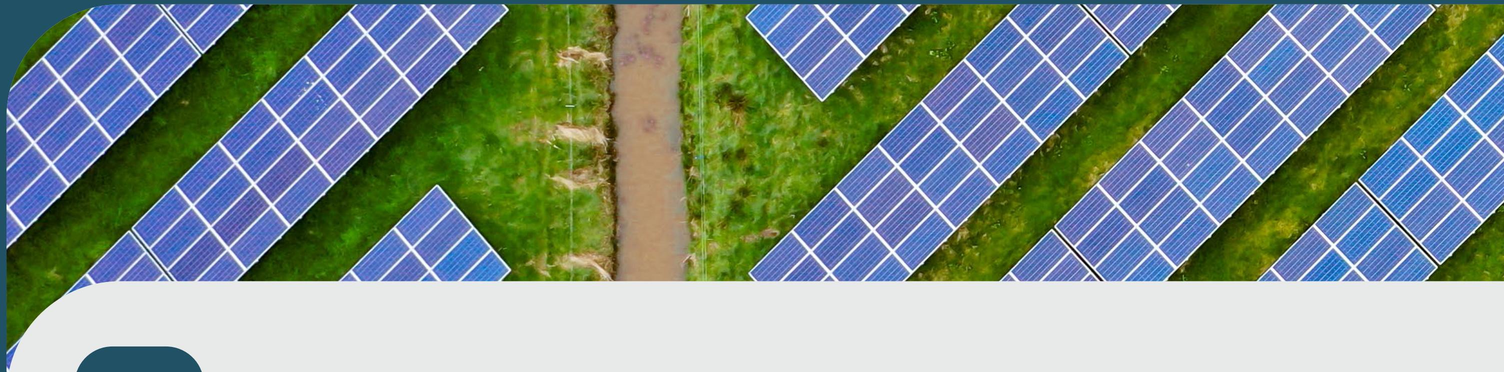


TO DO


LIST

WE ARE AT THE BEGINNING OF AN ACCELERATED SCALING UP OF ELECTRIC VEHICLES AND THE ROLLOUT OF SMART CHARGING POINTS. THE MARKET IS TRANSITIONING FROM A “PILOT” PHASE TO A COMMERCIAL ROLLOUT AIMED AT THE “EARLY MAJORITY.”

The first mature generations of electric vehicle technology are available and will continue to expand over the coming years, for example, with V2G technology. In the coming years, increasingly sophisticated algorithms will be developed for the optimal management of electric vehicle charging from multiple perspectives: driver's charging needs, commercial revenue models, and flexibility for the electricity system. It is important to ensure choice, interoperability, and simplicity in smart charging for drivers. Greater integration of electric mobility with renewable energy and the security of electricity supply is expected. Finally, a balance must be found between societal costs and benefits of smart charging on the one hand and a healthy business model for the charging industry on the other. Below is a to-do list for a successful large-scale rollout of electric mobility.



1

SMART CHARGING TOOLS FOR USERS

INFORMATION ON ELECTRIC CHARGING

The breakthrough of electric mobility among the general public means that careful attention must be paid to questions, opinions, and experiences of new users. It is important to explain electric charging clearly and at the right time to users. The past few years have shown that electric vehicle drivers generally have a positive attitude towards smart charging when they perceive that it helps better utilize renewable energy, take advantage of lower prices, and/or maintain a stable power grid. Various practical studies have shown that people who have actually used smart charging tend to express positive opinions about it afterward.

INSIGHT INTO CHARGING PRICES

Currently, it is often unclear to electric vehicle drivers what the underlying costs are for charging. Drivers pay a fee to the energy supplier (for home charging) or to the charging service provider, but this is often only visible afterward. Greater transparency in the costs of electric charging allows drivers to better assess the financial benefits of electric driving.

Photo
Jacques Tillmans
Alliander

DEFAULT SETTINGS FOR SMART CHARGING

When implementing smart charging, simplicity must be considered. Most drivers prefer to set standard smart charging preferences just once. Examples include delaying charging at private charging points until off-peak rates apply, charging based on dynamic energy prices, charging when self-generated renewable electricity is available, and adjusting charging power according to household consumption to avoid overloading the connection. Drivers also find it important to have a "charge me now" option for faster charging at public charging points in exceptional situations. These default settings need to be integrated into practical tools for drivers, such as mobile apps and home energy management systems.

LET USERS DECIDE WHO HAS ACCESS TO SMART CHARGING DATA

To optimize smart charging, insight is needed into the flexibility within a charging session. This requires data such as the state of charge (battery capacity and the extent to which it is charged), the expected departure time, the time required to fully charge the battery, the type of electric vehicle, the charging speeds accepted by the vehicle (thresholds for minimum and maximum charging power), and the driver's preferences (e.g., minimum range required). Currently, it is not sufficiently legally defined who has access to which data and when? The unavailability or selective availability of data poses a risk to electricity system management, can hinder free market operations, and may lead to unequal competition. It is therefore necessary to determine who has access to which data for smart charging, under what conditions, and at what cost, while ensuring user privacy. This should be anchored in European and national laws and regulations. For the statutory tasks of the grid operator, it is necessary to have free and consistent insight into the scale and concentration of the charging points population on both private and public properties. Grid operators need free access to metering data and charging data. These data allow for forecasting and optimal deployment of smart charging.

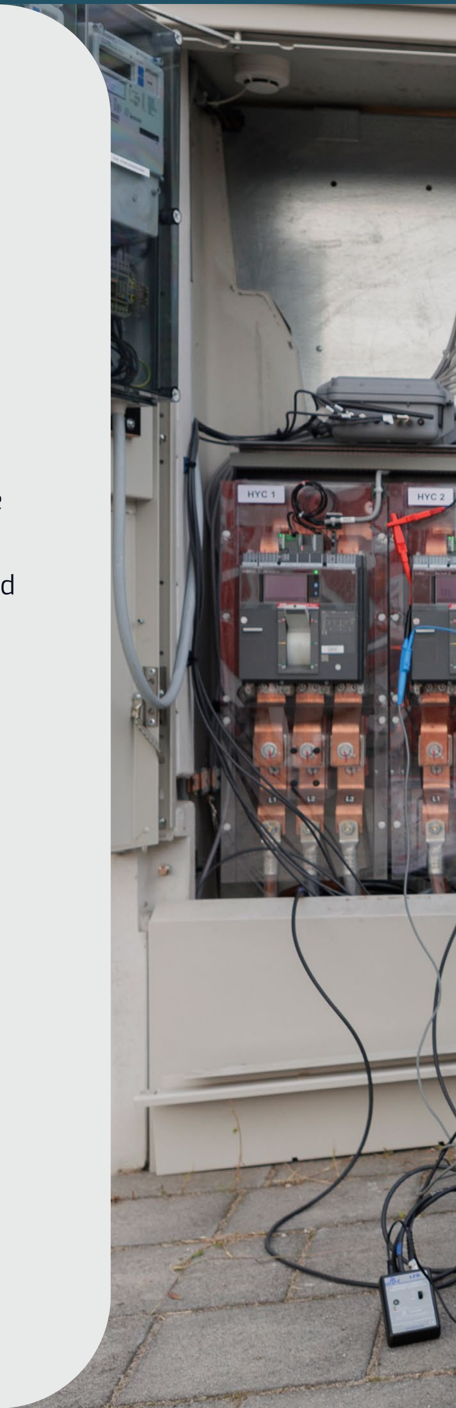
2

SMART CHARGING TECHNOLOGY

Adding specific requirements for charging electric vehicles to existing electricity regulations for power quality is important: due to the conversion from AC to DC, electric vehicles can both degrade and improve power quality in the electricity grid. If electric vehicles draw large amounts of power locally, the voltage quality of the local grid can decrease. This can reduce the grid's capacity and potentially damage electronic devices connected to the grid. ElaadNL research has found that charging electric vehicles can cause supraharmonic disturbances, which are disturbances in the frequency range of 2 kHz to 150 kHz. Current standards do not include requirements for this frequency range. Moreover, single-phase charging can cause phases to become unbalanced, possibly leading to electricity supply issues or overloading. Charging on three phases logically avoids this imbalance and is therefore preferable where possible. Power quality requirements for electric vehicles and charging points could be added to the Electromagnetic Compatibility Directive 2004/108/EC (EMC).

NETWORK CODES

The purpose of network codes is to ensure a harmonized and stable electricity network in Europe. They establish technical and operational standards for the connection and operation of various actors within the electricity grid, such as power generators, transmission systems, and distribution systems. These codes ensure that the networks operate safely, reliably, and efficiently, and contribute to the integration of renewable energy sources, cross-border electricity trade, and overall stability of the European electricity grid. Current network codes do not yet consider electric vehicles. In late December of 2023, ACER recommended amendments to the European Commission for the Net Code Requirements for Generators (NC RfG) and Net Code Demand Connection (NC DC). The European Commission is currently considering these recommendations to expand the scope of the network codes to include new electricity storage, electric vehicles, and associated supply equipment.



3

MANDATORY SUPPORT FOR SMART CHARGING BY VEHICLES AND CHARGING POINTS

Currently, there are no mandatory technical requirements for smart charging in vehicles or charging points. However, various standards and protocols have been developed by the market, which are supported by the majority of the industry. These include IEC 61851, ISO 15118-20, OCPP, OCPI and Open ADR. ElaadNL strongly advocates for the use of open standards. This enables global deployment and prevents "technology lock-ins," allowing the system to continuously evolve. The obligation for technical smart charging standards/protocols in vehicles can be mandated through UNECE type approvals and/or EU Whole Vehicle Type Approval (WVTA) under Regulation (EU) 2018/858. The obligation for technical smart charging standards and protocols can be included through, for example, an implementing act or delegated act under European regulations such as the Alternative Fuels Infrastructure Regulation (AFIR), Energy Performance of Buildings Directive (EPBD), Renewable Energy Directive (RED), or Energy Efficiency Directive (EFD).

4

CYBERSECURITY: PROTECTING THE E-DRIVER AND THE GRID

With the electrification of mobility, two vital infrastructures—mobility and energy—are becoming intertwined. As most charging points are “connected,” the charging infrastructure and, by extension, the electricity grid are becoming increasingly vulnerable to hacks. If charging points are hacked, hackers could cause power outages, grid overloads, or gain access to the personal data of electric vehicle drivers. Therefore, charging infrastructure should be considered critical infrastructure. In collaboration with ElaadNL, the European Network for Cyber Security (ENCS) has developed the Charging Systems Security Requirements. The EV Charging Systems Security Requirements can be viewed via www.elaad.nl.

However, these requirements have no legal anchor and are being applied by market parties on a voluntary basis or because the purchasing party requires them to do so. We need formal laws such as the Network and Information Systems directive and the Cyber Resilience Act to refer to international industry standards regarding the cyber security of charging infrastructure.

5

PROTECT THE GRID FROM OVERLOADS

INSIGHTS INTO LOCAL GRID LOADS

Based on future scenarios, grid operators identify potential bottlenecks in transport capacity to develop long-term transport planning for each area. The energy transition has made the development of future scenarios much more complex. Therefore, we must work towards a planned rollout of smart charging infrastructure, ensuring that the market and grid operators have a high degree of certainty. A nationwide network of charging points is best achieved when local governments collaborate with market parties and grid operators to create a phased rollout plan. This enables faster and more effective investments in people, technology, materials, and sufficient grid capacity. Applying smart charging allows more charging points to be realized on the existing electricity grid than would be possible without smart charging. However, grid reinforcement will still be necessary in some areas, even with the use of smart charging.

Choosing to deploy flexibility means more accurate insight is needed into the actual grid load to identify expected shortages in the grid and determine the correct amount of short-term flexibility. The grid can be used more efficiently by charging electric vehicles at off-peak times. The more frequently that information is shared, the more flexibility that can be deployed—but this also increases the system's complexity and costs.

6

INSIGHT INTO LOCAL FLEXIBILITY

In addition to grid load, it is important to have insight into the available flexible capacity in an area. From a mobility perspective, this includes insight into electric vehicles, charging points, and charging behaviour. Consider the number of vehicles per location, time periods, response speed, flexible storage capacity, and minimum and maximum (dis)charge speed: to ensure the effectiveness of smart charging, it is important to measure and understand what actually happens during charging. It is not yet clear which measurements can be used for this. To make smart charging economically attractive for all parties involved, it is important that it is beneficial for drivers during daytime hours when they are at work and during periods when they are at home for long periods. For market parties, smart charging is attractive when charging takes place during periods of surplus renewable energy and low electricity prices. It is important to investigate how the general system benefits of smart charging can be translated into benefits for individual parties. Moreover, it must be possible to verify to what extent the promised flexibility has actually been delivered. The agreements made in advance about the deployment of flexibility must be compared with the actual measured load profiles. Further research is needed to determine which measurements can be used for this and how this information should be shared. Then, the method for allocating the costs of flexibility needs to be developed.

Photo
KIA

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PYRAMID OF PROTECTION MECHANISMS

PROTECTION 1: NETWORK TARIFFS TO CHARGE AT LOW PEAK TIMES AS TIME/ LOCATION DIFFERENTIATION

Price incentives through market mechanisms encourage consumers to change their own behaviour, reducing the need for the system operator to intervene through grid expansion and reinforcement, which comes at a higher cost.

DSOs would ideally create incentives (either through differentiated tariffs or market-based mechanisms) to avoid/prevent congestions. However, currently small-scale users in the Netherlands (with capacities up to 3x25A) pay the same annual flat fee for network connection. There is no time-differentiated price component included in their tariffs.

In the 2019 EU electricity regulation, provisions were made for differentiated network tariffs, allowing for differentiation based on users' consumption profiles. These provisions provide the opportunity to introduce grid transport tariffs that incentivize users to participate in smart charging. As of now, these directives have not been implemented into the national tariff regulations in the Netherlands. Nevertheless, they offer the potential for the introduction of grid transport tariffs that encourage users to engage in smart charging.

Also congestion costs in the low voltage grid of DSOs should be reflected in the grid tariff structure to incentivize controlled charging with the goal of avoiding congestions. This requires time or location-based differentiation within the tariff structure.

Varying degrees of time-based DSO tariffs are in place in France, Belgium, Norway and Sweden. There is evidence that Time of Use (ToU) based tariffs reduced peaks in household demand during the five most congested hours in Sweden.

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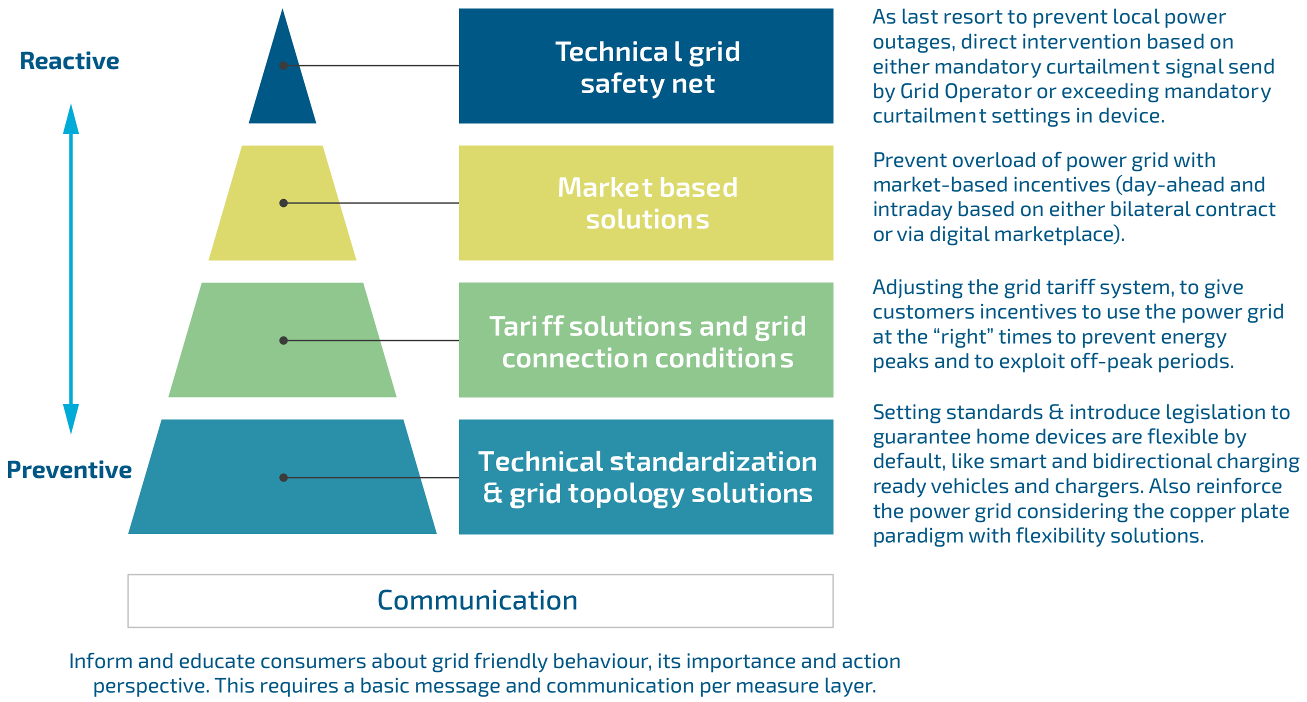
The Dutch regulator ACM is advised to assess the impact of introducing alternative forms of distribution tariffs (with either capacity- or volume-based differentiation in time and/or location) on congestions in the LV grid. Based on the outcome of this analysis, a proposal should be developed for policymakers to amend existing tariff codes.

PROTECTION 2: CREATE A LOW VOLTAGE CONGESTION MARKET MECHANISM THROUGH WHICH DSOS CAN COMPENSATE THE FLEXIBILITY OF EVS



Currently, there is no compensation mechanism in place for small end-user flexibility if it makes itself available to the DSOs for resolving congestions in the Low Voltage (LV) grid. For CPOs managing a large volume of chargers, a direct one-on-one contract is a possibility. Complementary to one-on-one contract a market mechanism would be required.

There is such a mechanism for large end-user flexibility through the GOPACS platform which aims to connect congestion requirements (demand bids by DSOs) with available flexibility (supply bids by generators and/or large loads). Due to insufficient scale of flexibility from EVs, DSOs have not yet invested in building out the GOPACS platform further to include flex from EVs.

To reduce transaction costs and encourage wide participation from end-users, DSOs would ideally introduce a platform that performs market clearing based on automatic matching of supply (congestion requirements in a certain location) and demand (flexibility from EVs in that location) bids.

DSOs are advised to setup bilateral agreements with CPOs (where transaction costs are low) to develop and design the LV congestion module within GOPACS2. Some key learnings that need to be taken into account are low minimum bid size, pay-as-bid and/or capacity-based pricing, etc.

PROTECTION 3: DSOS TO DEVELOP SYSTEM TO CURTAIL CHARGE POINTS AS LAST RESORT

In emergency scenarios, DSOs should have the possibility to curtail loads by sending signals to the relevant connection points in order to avoid black-outs/ brown-outs, i.e., to maintain the structural and functional integrity (reliability) of the grid.

Clear regulation and compensation mechanisms for users can enable direct load control by DSOs.

Dutch DSOs are advised to develop a joint proposal directed at policymakers that highlight the costs and benefits of introducing different forms of Direct Load Control (DLC) mechanisms (e.g. Consent-based vs Default sign up based). This proposal should make concrete recommendations on the design and explicit changes required in network codes to allow a DLC mechanism under specific conditions. The proposed approach can be either consent-based or default opt-in based, but it must align with Article 13 of the EU's Electricity Market Regulation (2019/943); 2), which is the existing MV/HV congestion platform run by Dutch DSOs.

Create a comprehensive communication standard b/w the DSO & CPO/Aggregator to enable smart charging for protecting the grid for overloads through the three means mentioned above, DSOs are required to cooperate with individuals or entities establishing or operating a charge point . The manner of communication between these parties is not yet specified with a set standard.

The communication standard for DSO-CPO communication defines data formats and security protocols, including for payments. A DSO-CPO communication standard is necessary to enable smart charging and congestion management through an API (the software sending SC commands).

EU Working Groups that are developing standards for smart charging (including representatives from regulatory bodies like ACER) are advised to engage with the charging infrastructure players and research institutions to jointly establish a robust DSO-CPO communication standard that can be rolled out across Europe. Since this is a pan-European issue, it is advised that the solution be driven at an EU level.

LIST OF ABBREVIATIONS

A Ampère

AC Alternating Current

ADR Automated Demand Response

CPM Charge Point Manufacturer

CPO Charge Point Operator

CS Charging Station = **EVSE** Electrical Vehicle Supply Equipment

DC Direct Current

DSO Distribution System Operator, regional grid manager

EMSP E-Mobility Service Provider

EV Electric Vehicle

GW Gigawatt

GWh Gigawatt hour

HEMS Home Energy Management System

HV High Voltage

Hz Hertz

kW Kilowatt

kWh Kilowatt hour

LV Low Voltage

MSP Mobility Service Provider

MV Mid Voltage

OCHP Open Clearing House Protocol

OCPI Open Charge Point Interface

OCPP Open Charge Point Protocol

OEM Original Equipment Manufacturer (car manufacturer)

OSCP Open Smart Charging Protocol

TSO Transmission System Operator: national grid manager (Tennet in the Netherlands)

TWh Terawatt hour

V2G Vehicle to Grid

V2H Vehicle to Home

V2X Vehicle to Anything

FINAL WORD

It's now five years later, and a lot of progress has been made. But we're not there yet. We still have a long way to go. Let's work together to make smart charging and also vehicle to grid the norm—so that we can charge millions of electric cars effortlessly and sustainably. And, let's keep working on solutions for all kinds of charging—not only passenger cars, but also vans, e-trucks, public transport buses, construction equipment and much more. The electrification of mobility is unstoppable and desperately needed. Let's help to make it happen!

We call on everyone involved in the evolving charging ecosystem to contribute to this, in particular national and European governments.

ElaadNL enjoys working together with all the stakeholders involved in charging, and will continue to contribute to research and further innovation. In this way, we strive to make electric vehicles a successful part of our future's fully sustainable energy system!

ABOUT ELAADNL

The knowledge and innovation center ElaadNL researches and tests smart and sustainable charging of electric vehicles. ElaadNL is an initiative of the joint Dutch Grid Operators. Due to their mutual involvement in ElaadNL, the network operators are preparing for a future in which electric driving and sustainable charging thrive.

Together with manufacturers from all over the world, ElaadNL tests the latest techniques for charging electric cars, trucks and buses in the Elaad Test Lab in Arnhem.

We are investigating the expected growth of various forms of electric transport, the associated charging infrastructure and how to integrate this smartly into the power grid.

The projects described in this publication are conducted by a large group of enthusiastic partners—not all have been listed for increased readability of this report. We would like to express our thanks and appreciation for everyone's commitment!

ELAADNL IS AN INITIATIVE OF:

INTRODUCTION TO THE ELAAD TESTLAB, WHERE EV CHARGING TECHNOLOGIES MEET!

ELAAD TESTLAB

TOGETHER WITH MANUFACTURERS FROM ALL OVER THE WORLD, WE TEST E-MOBILITY PRODUCTS TO IDENTIFY NECESSARY IMPROVEMENTS ON THE PRODUCTS AND THE STANDARDS THEY ARE BASED ON.

CHECK YOUR TECH!

The new and improved Elaad Testlab was officially opened by Dutch King Willem Alexander on June 8th 2022. At our location in Arnhem EV charging technologies meet and are put to the test. You are welcome to check your tech in our open charge lab. Testing is free of charge.

OUR AVAILABLE TESTS

INTEROPERABILITY TEST

Testing interoperability between vehicles and charging infrastructure during regular, smart, and bidirectional charging.

SMART CHARGING TEST

Testing the ability of the charging station and electric vehicle to execute smart- and bidirectional charging control signals in different scenarios.

POWER QUALITY TEST

Investigating the impact of charging on the electricity grid and on other devices, and testing the immunity of chargers and EVs to grid disturbances.

CYBER SECURITY TEST

Testing the cyber security of connected charging infrastructure.

GRID OPERATOR TEST

Official approval test for connecting public charging stations to the Dutch power grid.

ARBITRATION TESTING

Independent third-party research into issues that arise in the EV charging ecosystem. Tests are available for AC/DC, normal, fast, and heavy-duty charging.

GRID CODE TESTING

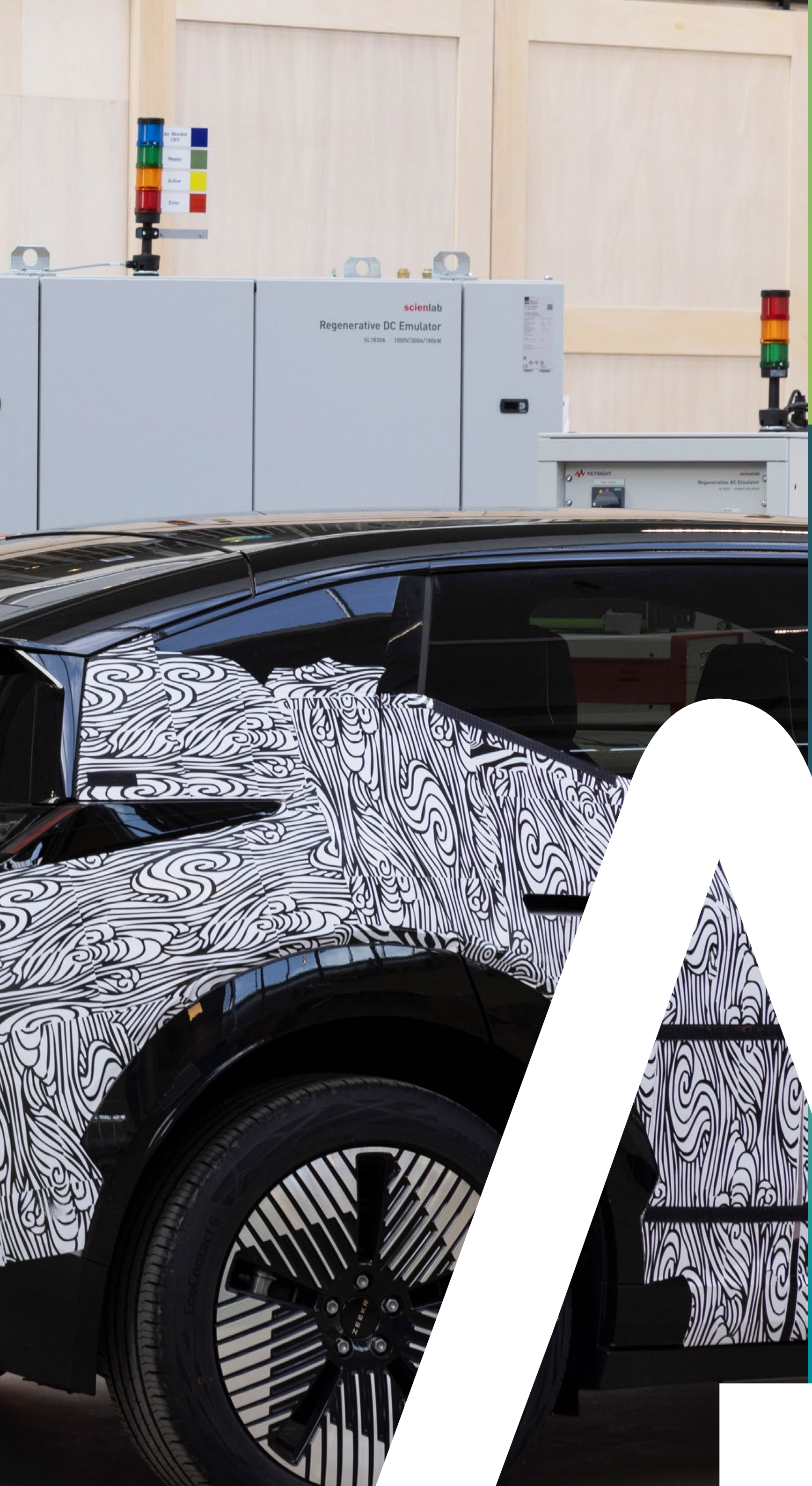
Pre-certification tests of chargers and vehicles to relevant grid codes, currently the Requirements for Generators (RfG) for bidirectional devices, in the future the RfG 2.0 and Demand Connection Code 2.0

THE ELAAD TESTLAB

- A 900 m^2 indoor test location and an outdoor charging plaza
- All types of public AC chargers and Home chargers
- DC Chargers including test options for heavy-duty charging
- Suitable for all kinds of electric vehicles including construction equipment, buses and trucks
- 360 kW of grid emulation power for Power Quality tests
- A charging station and electric vehicle communication emulator, including ISO 15118-20
- 360 kW of bidirectional DC power emulating DC charging
- Highly accurate measurement equipment for detailed measurements

TESTS ARE AVAILABLE FOR AC/DC, NORMAL, FAST, HEAVY DUTY AND BIDIRECTIONAL CHARGING


TESTING
KEYSIGHT
Regenerative DC Emulator
KEYSIGHT
HJA 21C



CONTACT US

- For more detailed information about the tests
- To provide input to the test process
- To add your ISO 15118-2(0) AC or DC charging station to the interoperability test base
- To have your EV or DC charging station fully tested on interoperability, smart charging, and power quality
- To schedule a test and/or the delivery of the device

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THE NEW ELAAD TESTLAB IS POSSIBLE THANKS TO FUNDING FROM:

- Ministry of Infrastructure and Water Management
- The Province of Gelderland
- The joint Dutch grid operators

GUIDE TO

SMART CHARGING

SOLUTIONS