Essential guide to electric vehicle charging

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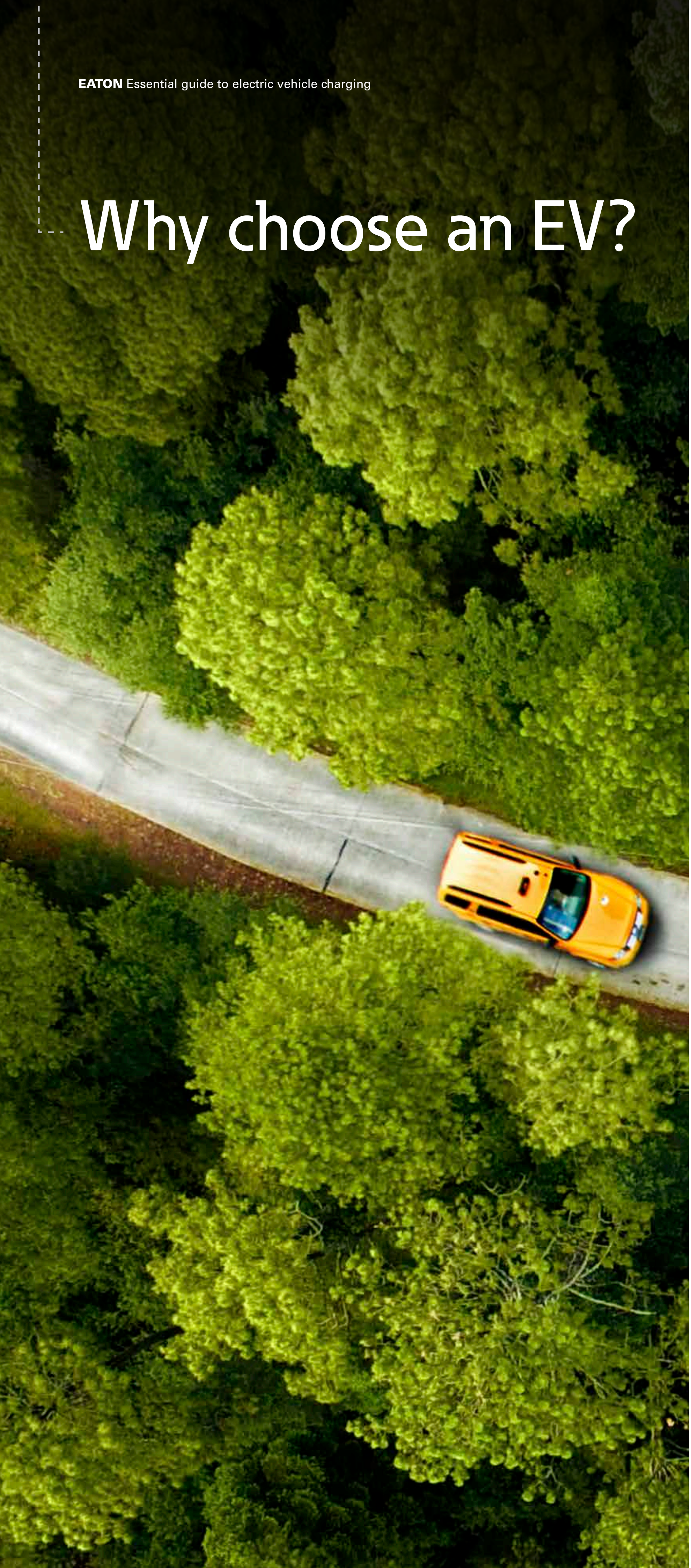
Introduction

In the evolving world of electric vehicles (EVs), and the charging infrastructure used to power them, there is a continuous flow of new developments. This Eaton guide is for those who are new to electric vehicles and want to find out more.

As well as explaining why EV ownership is growing so fast, we set out basic concepts that relate to the main types of EV currently available, focusing specifically on how to charge the vehicles most effectively and how they can become energy hubs by working in tandem with the buildings where they are charged.

Contents

Why choose an EV?



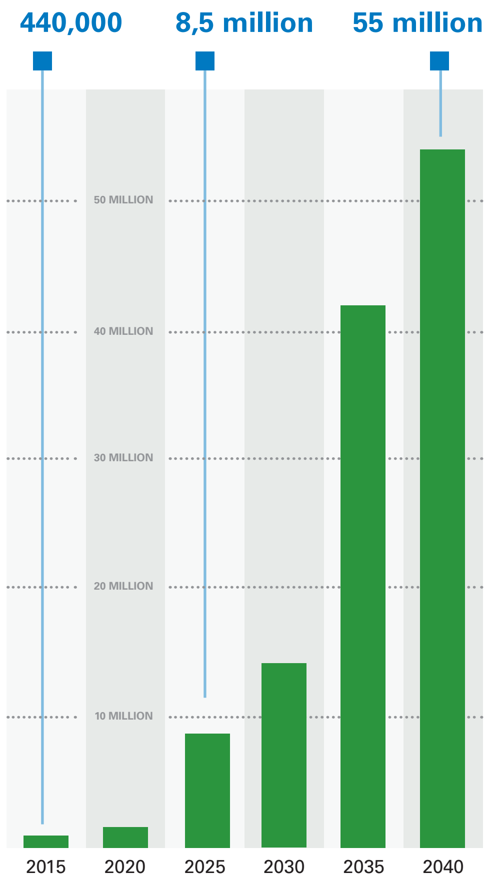
Why choose an EV?

In the global quest for a more sustainable future, the choices society makes about transportation amount to what many are calling a mobility revolution. EV ownership has become more prevalent in recent years and what started out as the choice of a relatively small number of early adopters, has quickly become a proposition that most of us are now considering, and perhaps sooner than we might have thought.

Huge leaps forward in the development and availability of EVs and the technologies that support them, coupled with societal impetus towards a more sustainable way of life, are helping to bring down the costs associated with EVs and their charging infrastructure. Increasing pressure from policymakers worldwide, manifest in various regulations designed to encourage the uptake of EVs and promote the installation of charging infrastructure, are propelling the trend. In combination, all of this is speeding up the phase out of internal combustion engine (ICE) vehicles.

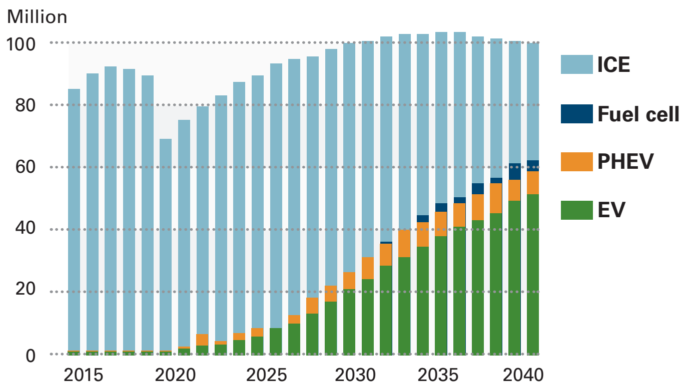
Confidence in EVs is rising and uptake has grown considerably in a very short space of time at a rate that is set to increase rapidly. By 2030, it is predicted that almost a third of cars sold worldwide will be electric. In 2020, the sale of EVs grew by more than 140 % in Europe despite the Covid-19 pandemic, so it is easy to see how such predictions could fast become a reality.

Global long-term EV share of new passenger vehicle sales



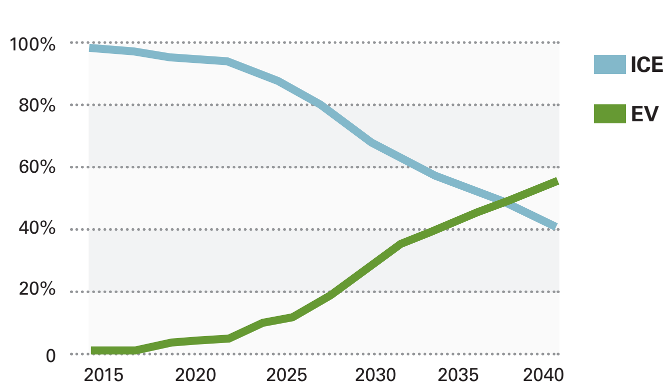
Source: BloombergNEF Long Term Electric Vehicle Outlook 2020

Global long-term passenger vehicle sales by drivetrain



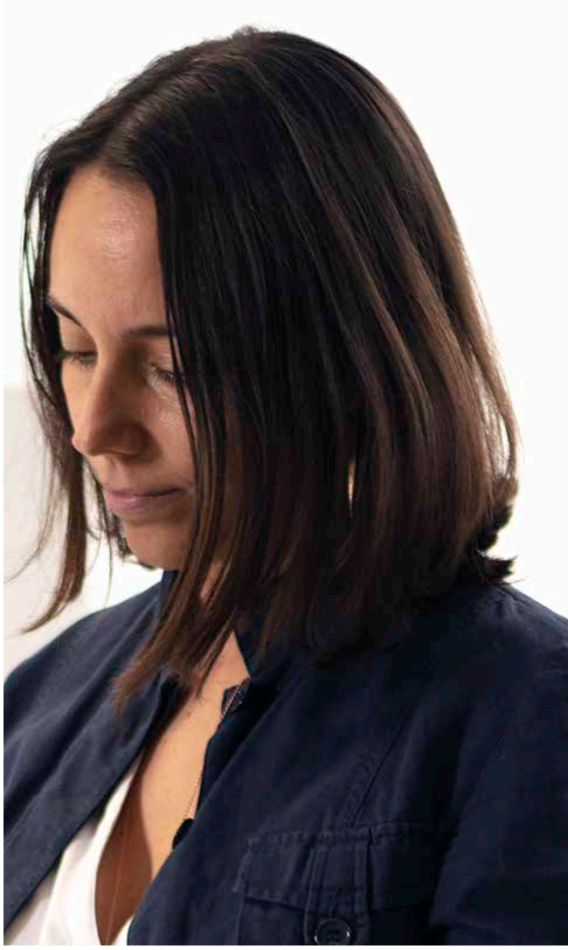
Source: BloombergNEF

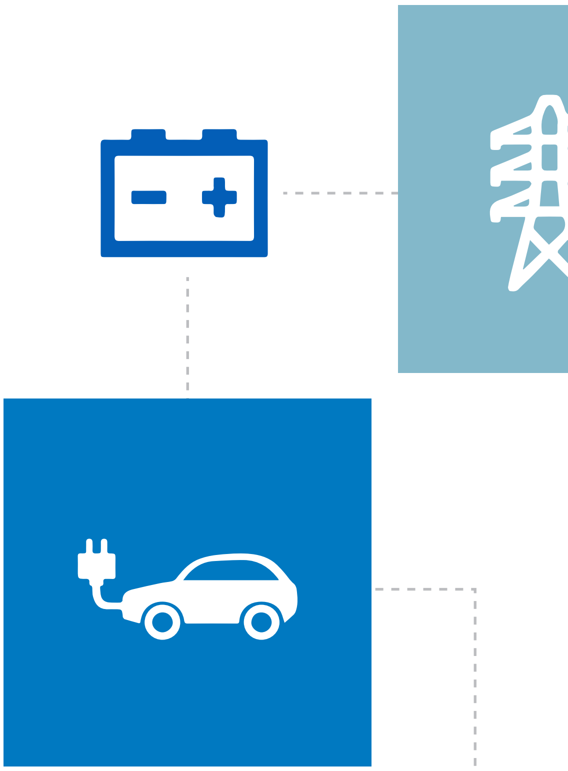
Share of annual sales

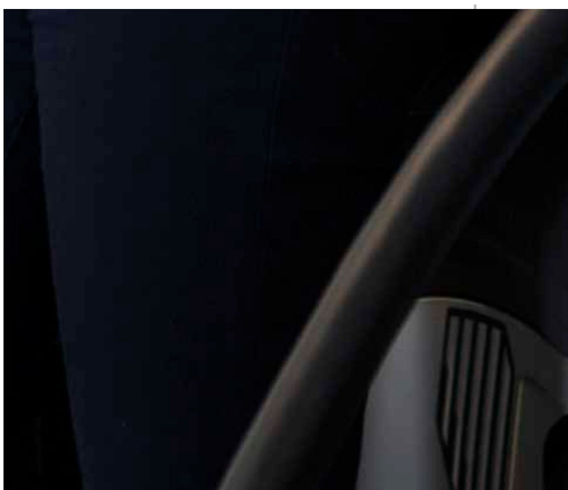


Source: BloombergNEF

EVs: the benefits







EVs: the benefits

EV Buyers and Owners	Environment and Society
Cost of EVs continues to fall relative to internal combustion engine (ICE) vehicles, making the total cost of ownership increasingly attractive	Emissions reduction – EVs emit zero carbon, so the more EVs on the road, the greater the carbon saving helping countries to meet decarbonisation targets.
Servicing and maintenance cost are lower for EVs than for ICE cars because there are fewer moving parts. Opportunity to fuel EV with self-generated renewable power, for example from solar panels.	Air quality improvement – EVs are clean – they emit none of the particulates in ICE exhaust fumes which can be seriously damaging to health.
Financial incentive schemes, including tax breaks in many countries, further reduce total cost of ownership; and as ICE phase-out dates come into force, EV buyers and owners will already be in compliance.	EVs reduce dependence on fossil fuels because they do not need the oil, gas or diesel that is required to both run and maintain ICE vehicles.
Increasingly wide choice of vehicles from a range of manufacturers that comply with the ultra-low emissions regulations that many cities are introducing.	Noise pollution is reduced because EVs are quiet, or even silent. Loud traffic noise will reduce as EVs replace ICE vehicles.

Cost efficient

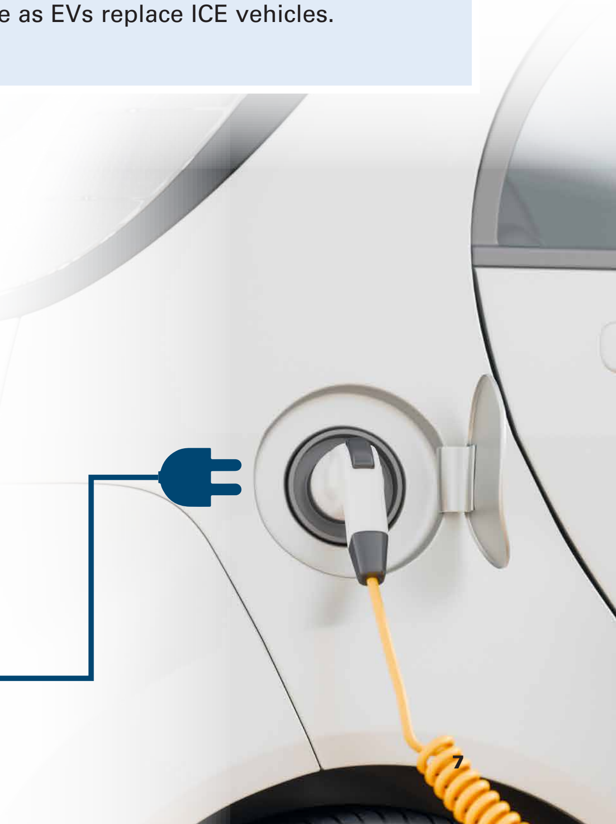
Lower total cost of ownership due to fewer parts, incentives in countries and it is possible to fuel vehicle with self-generated renewable energy.

Sustainable

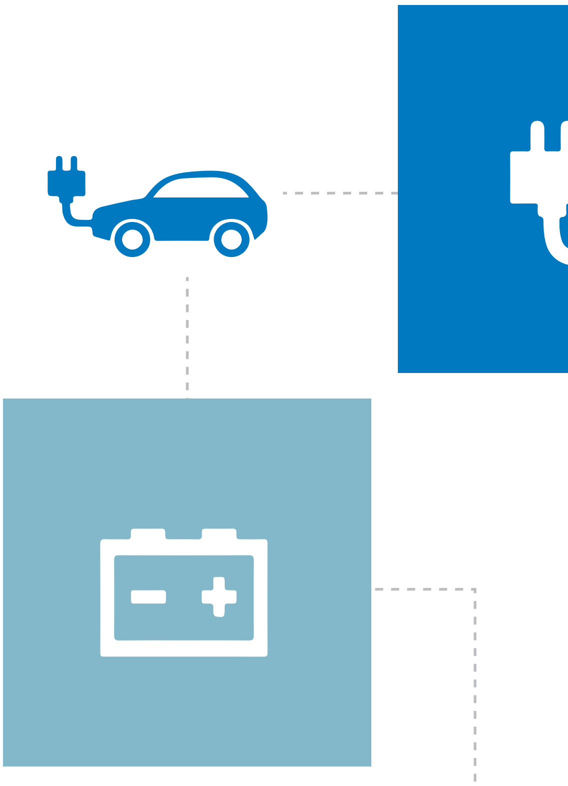
Improves quality of life where you live by improving air quality and reducing noise pollution.

Future ready

EVs accord with the direction of regulation and legislation and are designed and equipped for the future.



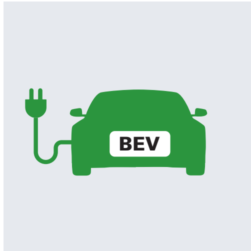
What are the different types of EVs and how do they work?



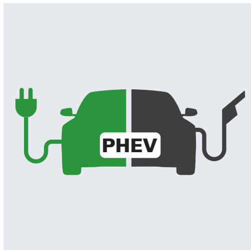
What are the different types of EVs and how do they work?

There are two basic types of EV that can be charged by external electric chargers:

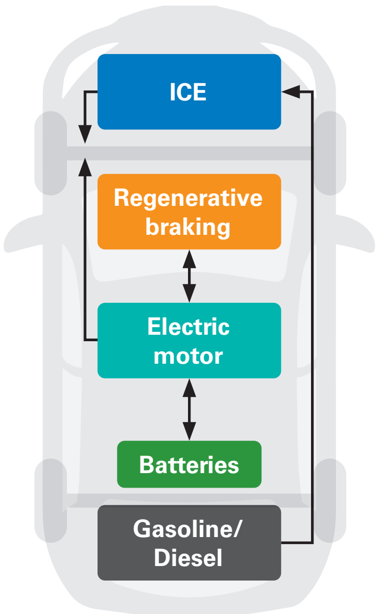
A **Battery Electric Vehicle (BEV)** is propelled by a battery-powered electric motor that relies exclusively on an external electrical source for charging and recharging.

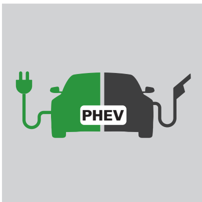


A **Plug-in Hybrid Electric Vehicle (PHEV)** has both an internal combustion engine and an electric motor which means it can switch between petrol or diesel power and its battery. As the batteries are usually smaller in PHEVs than BEVs, they tend to have a shorter electric-only range.

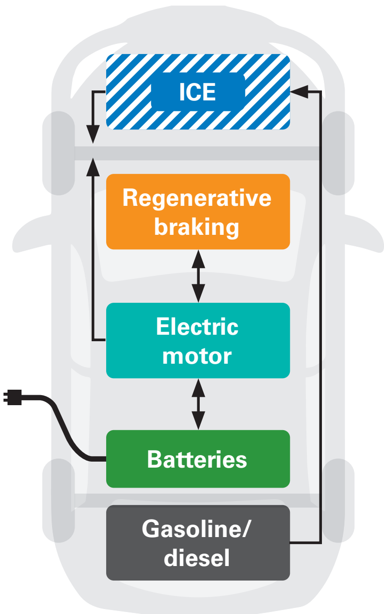


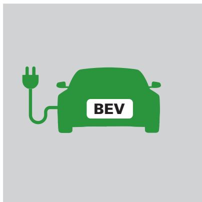
Hybrid (HEV)



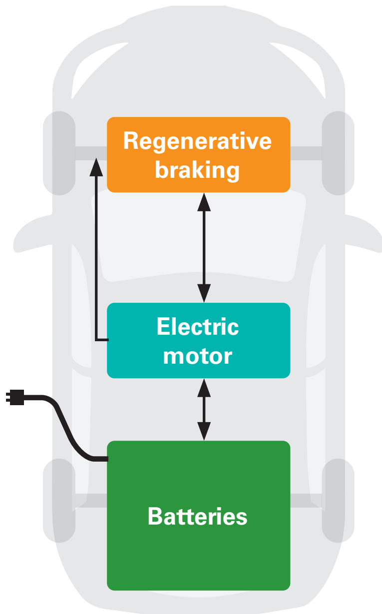


Plug-in Hybrid (PHEV)

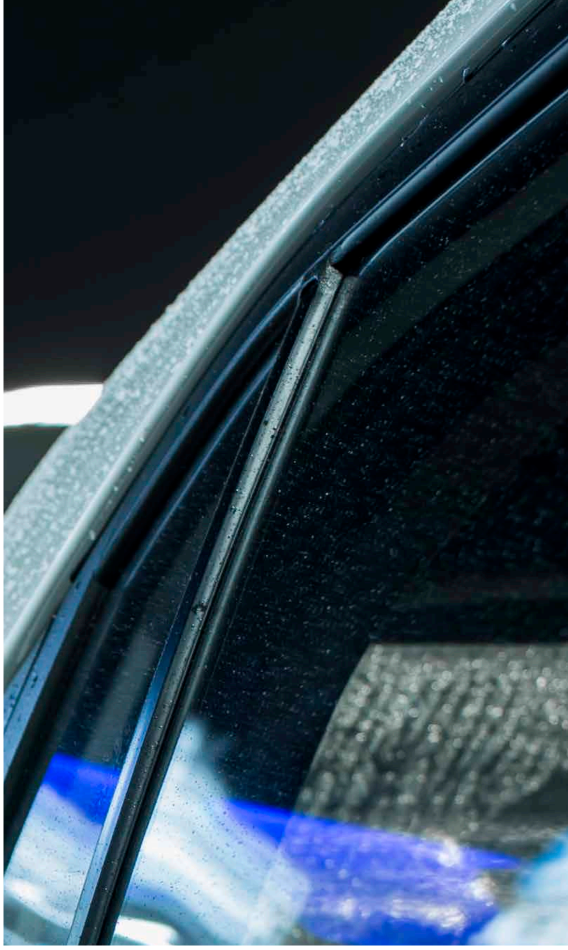




Battery Electric Vehicle (BEV)



The difference between kWh and kW



The difference between kWh and kW

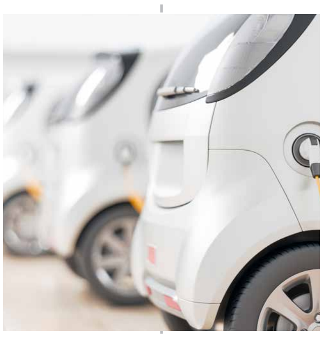
It is important to differentiate between the two most common abbreviations associated with EV charging: kilowatt-hours (kWh) and kilowatts (kW).

50 kW

Kilowatts (kW) measure power. The higher the number of kilowatts offered by a charging station, the faster it will charge the EV, provided that the EV's onboard charger (OBC) can support the rate of charge.

100 kWh

Kilowatt-hours (kWh) measure battery capacity. Every EV has a maximum kWh rating which represents the maximum amount of energy it can store in its battery. The larger the kWh, the greater the EV's driving range will be.



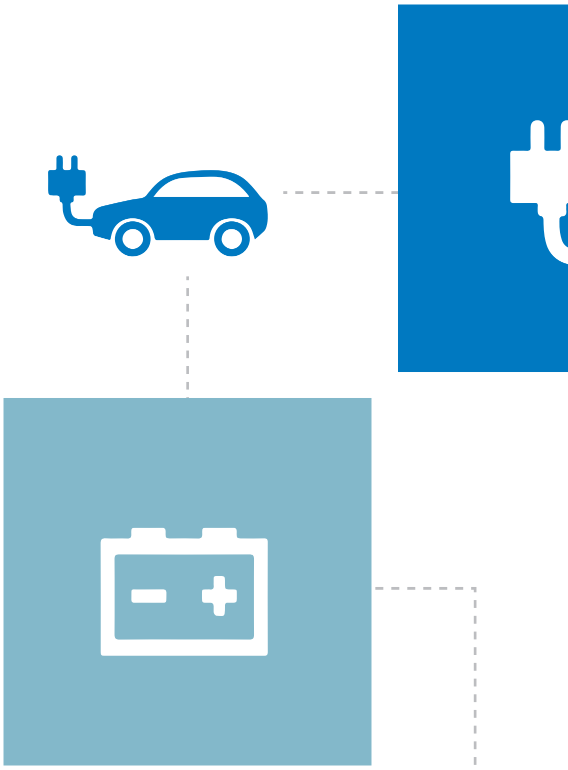
Calculating how long it will take to charge an EV to full capacity involves knowing both the capacity (in kWh) of the vehicle's battery pack and the power (in kW) offered by the charging station.

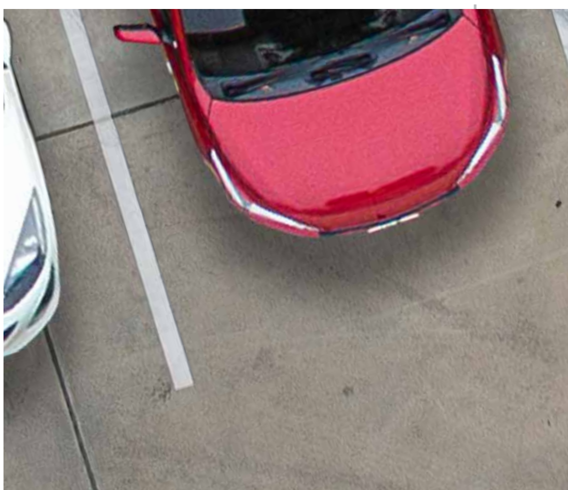
50 kW x **2 Hrs** = **100 kWh**

Units used in electric cars compared to the traditional (ICE) vehicles:

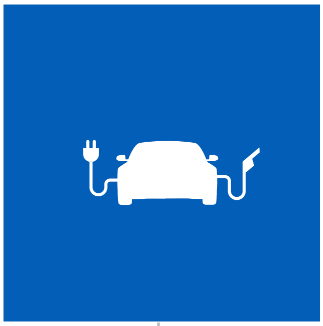
	ICE Vehicles	BEV Vehicles
Amount of fuel	Liter	kWh
Consumption	Liter/100 km	kWh/100 km
Speed of refuel	Liter/minute	kW
Engine performance	Horse power or kW	kW
Recharge performance	-	kW

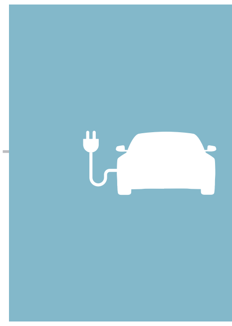
PHEV vs BEV





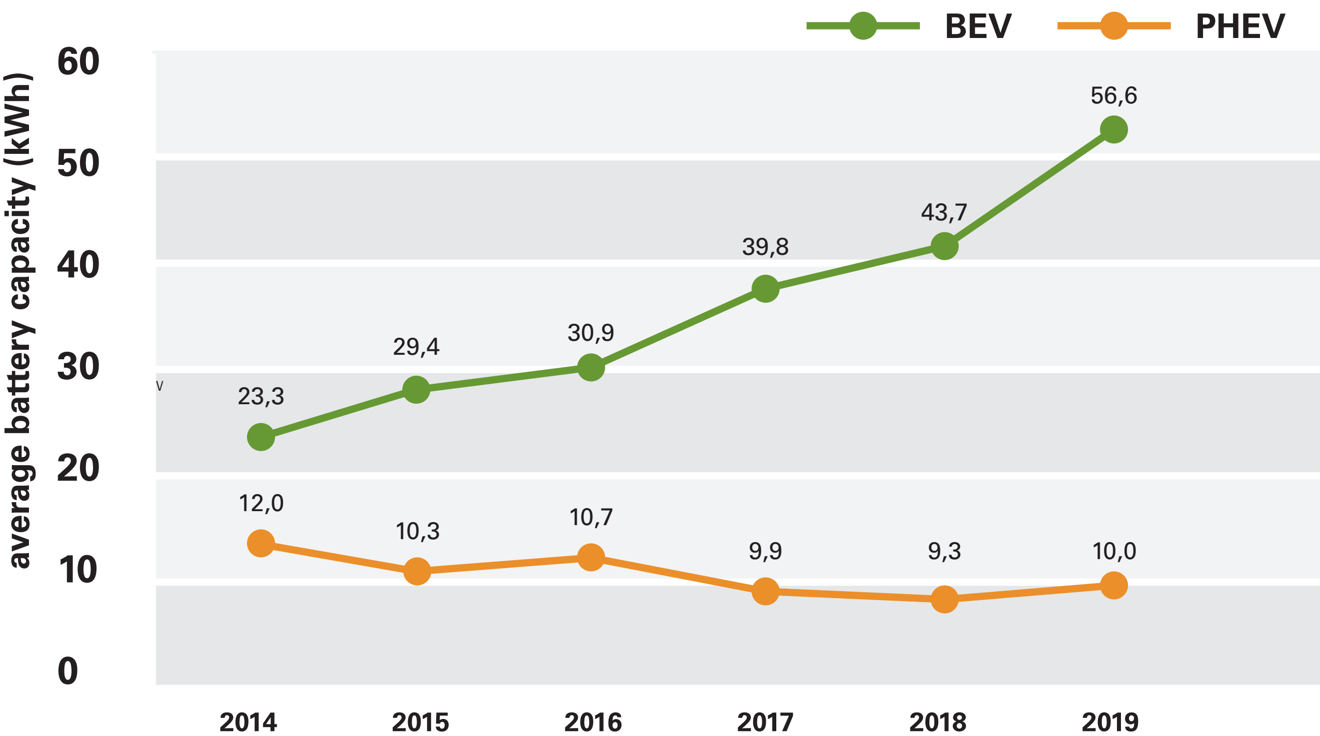
PHEV vs BEV





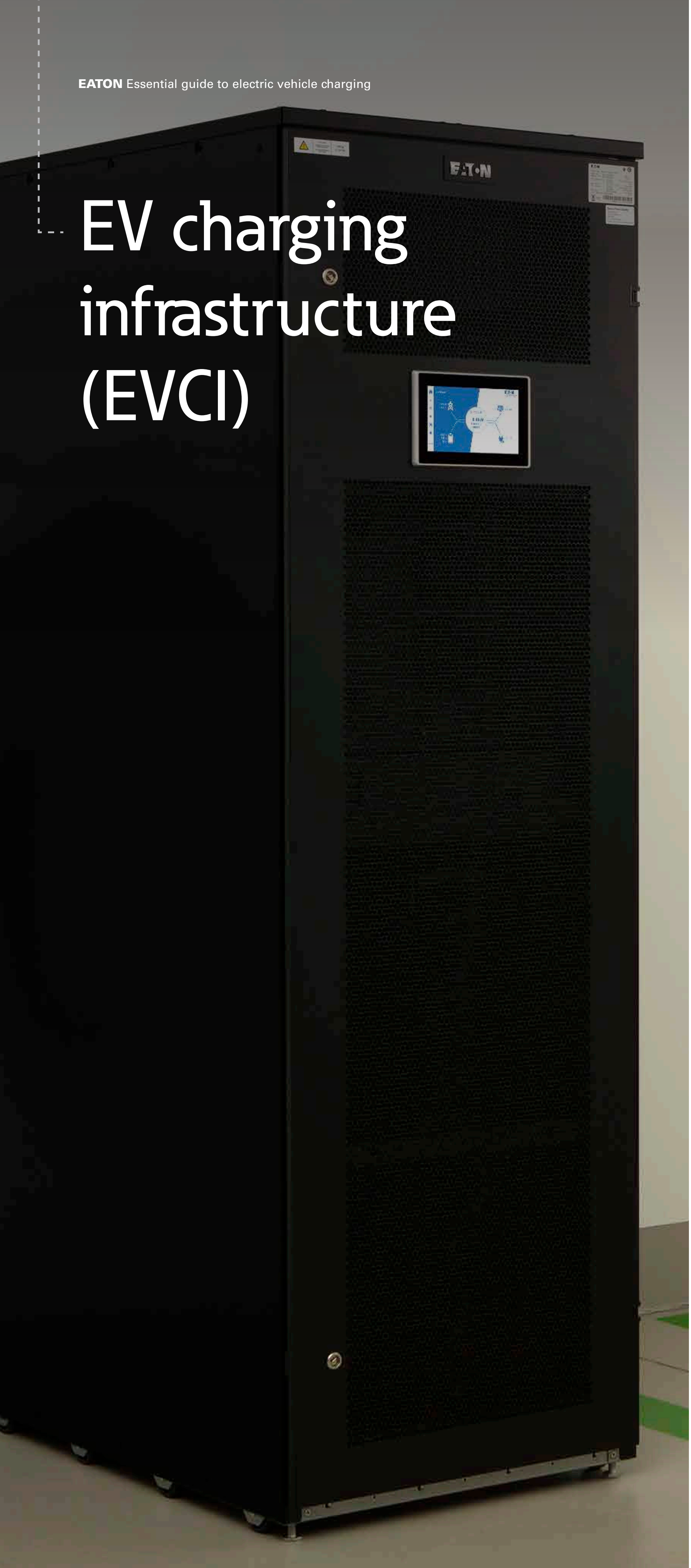
Sales of electric vehicles are increasing across the board. According to the European Automobile Manufacturers Association (ACEA), in the fourth quarter of 2020, almost one in 6 passenger cars sold in the EU was an electrically-chargeable vehicle (16.5%), compared to 4.4% during the same period in 2019. Much of this growth is thought to be due to the greater availability of bigger battery capacities. The average range for a BEV is now around 291 km/181 miles. PHEV battery capacities are smaller, most PHEVs can only be driven a relatively short distance (16-80km or 10-50 miles) before switching over to their internal combustion engine.

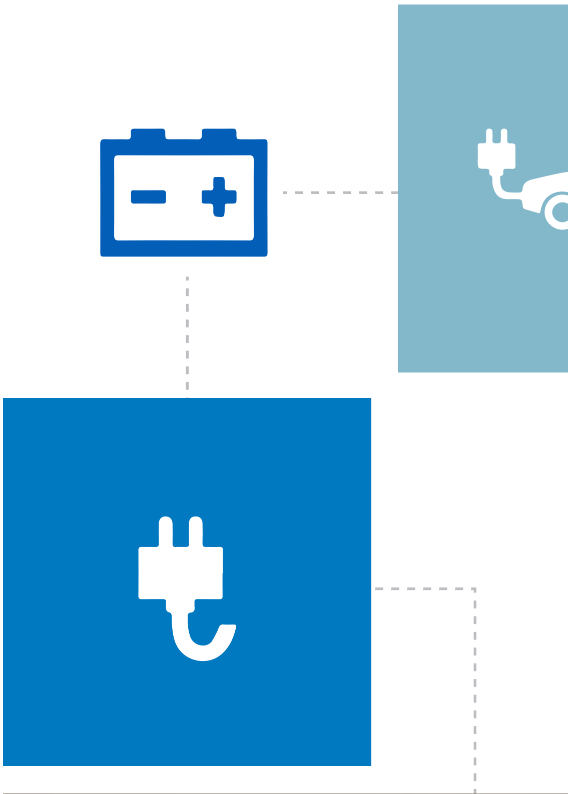
European EV sales in 2020 were dominated by BEVs which outsold their PHEV counterparts by more than 100,000 vehicles according to statistics from the ACEA. With more BEVs on the road every year, the EV charging infrastructure is now growing fast to keep up with demand.

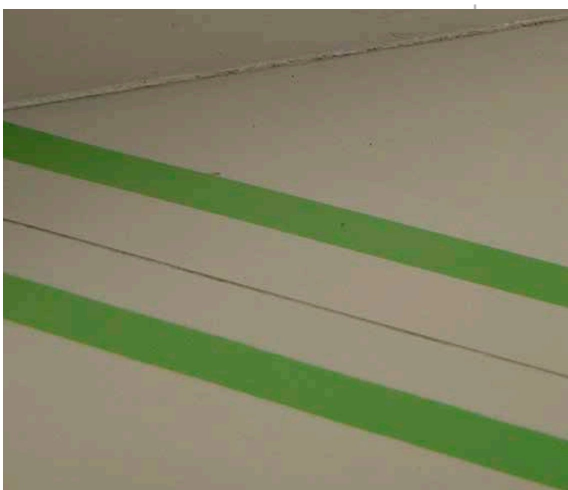


Source: Green Motion

EV charging infrastructure (EVCI)







EV charging infrastructure (EVCI)

Drivers need to charge their EVs at home and away, which means they need access to charging points in residential and public settings such as fuelling stations and workplaces. Charging can be either by AC (alternating current) or DC (direct current).

AC charging

This is the most affordable type of charging infrastructure to install because AC is available straight from the grid. It can be single-phase (run through a single converter) or three-phase (run through three convertors for greater power transfer). In commercial and industrial settings, the three-phase system is almost always used because it is a more efficient way of meeting higher power demands.

AC

The battery in an EV – just like the battery in a laptop or mobile phone – runs on DC. This means the current from an AC charger must be converted from AC to DC before it can be used to power the EV battery. To make this happen, the current is passed through the EV's onboard charger (OBC), which regulates the voltage and current. The speed of charge depends on the OBC's power output. This means that even if an EV is charged with a relatively powerful 22 kW AC charger, the power the battery receives – and therefore how quickly it reaches capacity – depends on the capabilities and limitations of the OBC.

DC charging

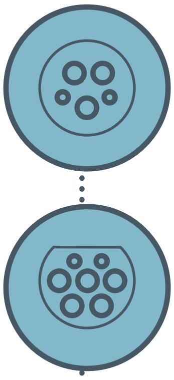
DC charging tends to be found at dedicated DC charging points away from home, which offer higher power and faster charging speeds. In DC charging, the energy is sent directly to the battery, bypassing the potentially limiting OBC. Early DC chargers started at around 50 kW but the power range from most has now increased from 20 kW to more than 150 kW in line with the wider availability of bigger EV battery capacities. DC charging offers higher power and faster charging speeds and this is why it tends to be found at commercial charging points. However, the increasing availability of units at 20 kW means that DC chargers are now becoming more prevalent in the residential space and in office buildings, too. Building owners who levy a fee for EV charging will be able to earn greater revenue from DC chargers because of the faster charging speeds they can deliver.

DC

EV plugs and sockets

EV plugs and sockets

There are different types of charging plugs for EVs depending on whether they are being connected to an AC or DC charging point. The vehicle's inlet port and charger type will determine which socket can be used.

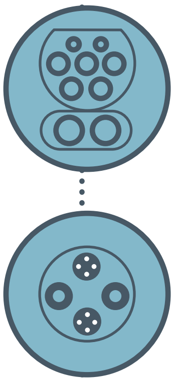


AC connectors

These are largely known as Type 1 and Type 2:

Type 1 is a single-phase plug that allows charging up to 7.4 kW, depending on the capability of the EV and the capacity of the grid. Type 1 connectors are most often found in EVs manufactured in America and Asia.

Type 2 supports single phase and three phase current, so it permits faster charging up to 22 kW. Type 2 connectors are most often found in EVs manufactured in Europe*.



DC connectors

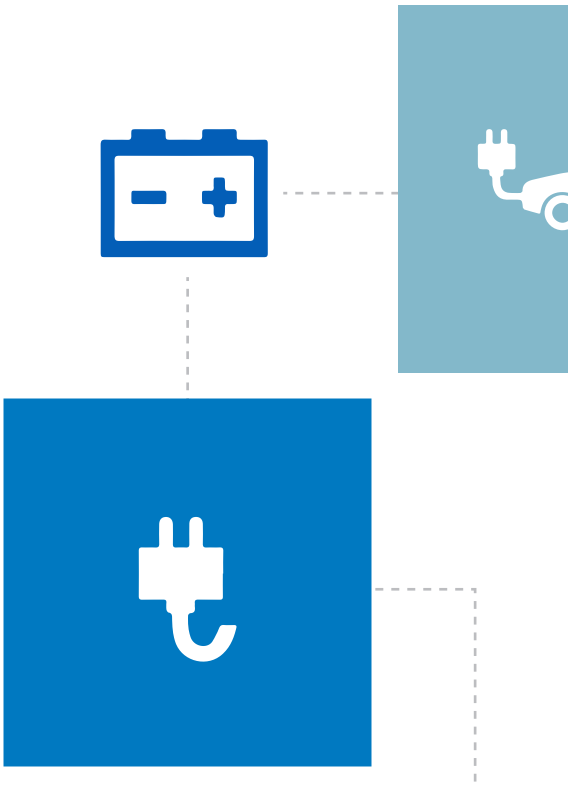
There are two main type of DC connectors, CCS and CHAdeMo:

CCS (Combined Charging System) combines a Type 2 connector with two additional power contacts to allow for DC 'quick charging' alongside standard three-phase AC.

CHAdeMO (also known as Japanese JEVS) is the trade name of a connector developed in Japan for fast high charging. Asian manufacturers are leading the way in offering EVs compatible with this plug which supports DC charging only.

**Tesla does allow for DC charging via Type 2 sockets up to 120 kW and forthcoming version 3 Tesla superchargers will deliver even faster charging up to 250 kW.*

How to charge an EV



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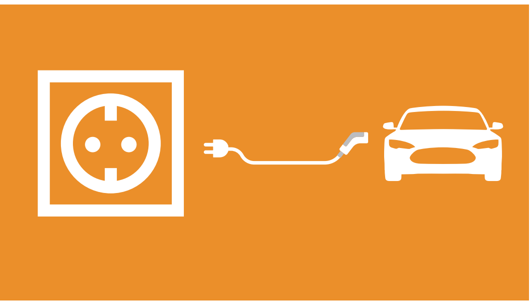
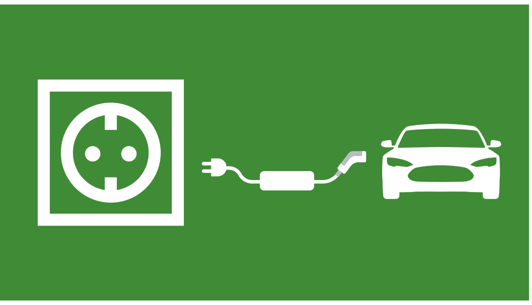


Mode 1

Household socket and extension cord (AC)

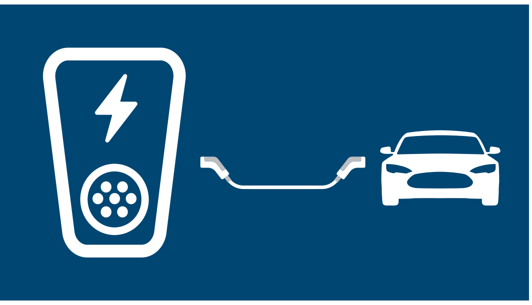
This involves connecting the EV to the grid via a standard domestic socket and cable without protection equipment. **Due to the high draw from the charger that takes place over several hours, there is increased likelihood of fire or electrical injury, so Mode 1 is not recommended.**



Mode 2

Household socket with cable-incorporated RCD (AC)

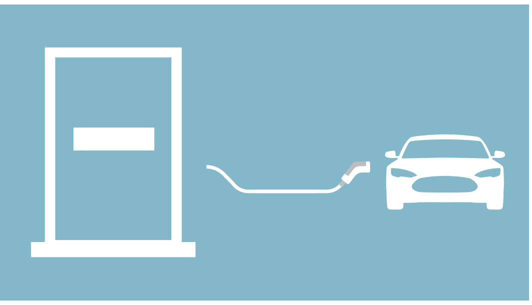
The EV is connected to the grid via a household socket, but charging is done using a cable with built-in protection (a residual current device or RCD) to protect against electrical shocks and fires.



Mode 3

Dedicated EV charging system (AC)

An EV is connected to the grid via a specific socket, plug and a dedicated circuit. Mode 3 can be used in residential, commercial and public charging and operated at varying powers depending on its application.



Mode 4

Dedicated EV charging system (DC)

The only mode for DC charging, which is done via a dedicated circuit and plug and usually at public charging points only. The conversion of AC to DC is carried out within the charging station, which allows for power of around 50 kW, or higher if the supply to site permits.

How to charge an EV

Home	Multi-home	Workplace	Destination	On the go
Mode 2 Mode 3	Mode 3	Mode 3 Mode 4	Mode 3 Mode 4	Mode 4
AC	AC	AC DC	AC DC	DC
10-12 h (overnights)	10-12 h (overnights)	~8 h employee ~2 h visitors	1-2 h visitors 8 h employees	15-20 min

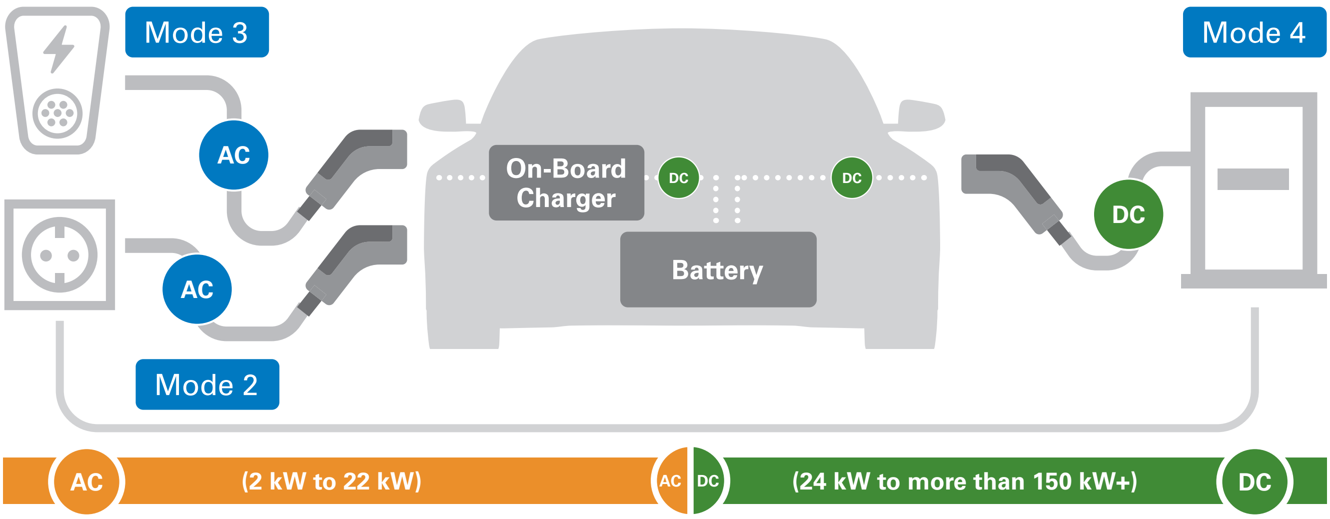
EV charging infrastructure (EVCI)

Supply type	AC/DC	Rated power*	Time to charge 10 kWh	Time to charge 30 kWh
Single phase 16 A	AC	3.7 kW	2 h 40 min	8 hours
Single phase 32 A or 3 phase, 16 per phase**	AC	7.4 kW	1 h 20 min	4 hours
3 phase, 16 A per phase**	AC	11 kW	55 min	2 hours 45 min
3 phase, 32 A per phase	AC	22 kW	27 min	1 hour 22 min
3 phase, DC	DC	50 kW	12 min	36 min
3 phase, DC	DC	120 kW	5 min	15 min

*Simplistically (ignoring Power Factor correction):

- For single phase 230 V connections, Power (kW) = **Amps (A) x 230 V*0.001**
- For 3 phase 400 V connections, Power (kW) = **1.732*Amps per phase (A) x 400 V*0.001**

**depending on countries



Expected Dwell Time	Regular Home Plug	Type 1 American	Type 2 Mennekes European	CCS	CHAdeMO Japanese
BMW i3 (2018)	19 h 30 m	-	4 h 15 m	36 min	-
Tesla Model 3 (2019)	20 h 30 m	-	4 h 30 m	39 min	-
Renault Zoe (2020)	26 h 45 m	-	3 hours	56 min	-

The above dwelling times are estimations regarding the time required to charge the different models from empty to full considering the limitations of the on-board charger. For DC charging, the time indicates to charge the battery from 10 % - 80 %, as charging tends to slow outside this range to protect the battery.
Source: https://ev-database.uk/car

Vehicle compatibility

Vehicle compatibility

PHEVs and BEVs have very different battery sizes so their charging requirements, and the methods of charging with which they are most compatible, are different.

PHEVs have a smaller battery size, usually between 6-15 kWh, and an OBC generally limited to either 3.4 kW or 7.4 kW. Given the size of the battery they carry, Mode 2 is most suitable for domestic charging, though the faster charging offered by Mode 3 may be preferable for batteries at the upper end of the PHEV scale, particularly for on the go charging.

BEVs have larger batteries sizes, usually from 30 kWh up to as much as 95 kWh for high-performance vehicles, with OBCs ranging from 7 kW to 22 kW. BEVs can use Mode 1, 2 and 3 when convenient, but almost all are compatible with the dedicated systems and extra power offered by Mode 4.

Let's take an example

A Tesla Model 3 owner charging his car on a 22 kW AC charging station will only get 11 kW, limited by the onboard charger of the car. It will take 5-7 hours to charge the battery. While using a 50 kW DC charging station, the DC charging capacity being 145 kW, there won't be limitation and it will take 40-60 minutes to charge the battery.

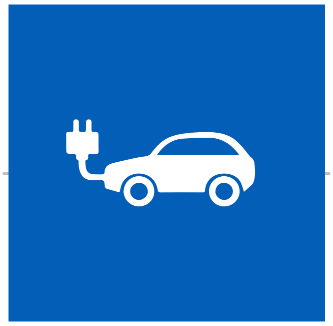
Top 15 PHEVs and EVs

(in terms of year to date unit sales) in 2020 in Europe

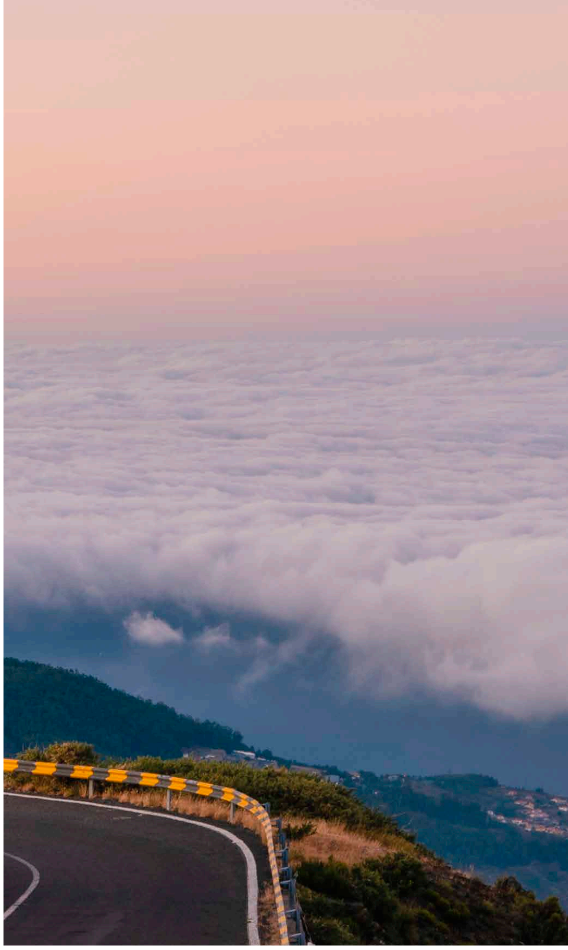
Legend: 

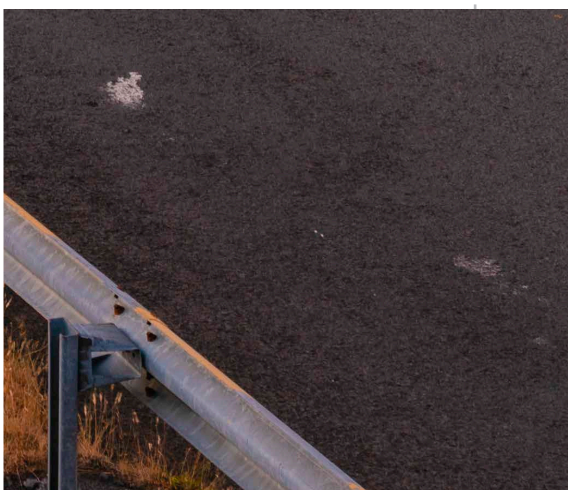
Brand	Model	Battery Capacity kWh	AC Charging Capacity kW	DC Charging Capacity kW
Renault	Zoe	44.1	22	50
Tesla	Model 3	75	11	145
VW	ID.3	48	7.2	50
Hyundai	Kona EV	67.1	7.2	77
Audi	e-Tron	95	22	150
VW	e-Golf	35.8	7.2	44
Nissan	LEAF	40	3.6	46
Peugeot	208 EV	46	11	100
KIA	Niro EV	67.1	7.2	77
Mercedes	A250e	15.6	3.7	NA
Volvo	XC40 PHEV	10.7	3.7	NA
Mitsubishi	Outlander PHEV	13.8	3.7	22
VW	Passat GTE	13	3.7	NA
BMW	330e	7.6	3.6	NA
Volvo	XC60 PHEV	10	3.7	NA

Source: CleanTechnica.com



Where and when to charge an EV





Where and when to charge an EV

ICE vehicle refuelling is based on the mindset of filling up when empty, but EV charging is very different. The focus must shift to **'opportunity charging'** where charging is secondary to other activities, such as shopping or going to work. The outcome is regular top up charging to ensure that the EV's charge never falls too low. A dense network of chargers is steadily being developed to enable this change in behaviour patterns. Locations for EV charging include:

Residential settings

AC charging at home often takes place overnight and tends to be slow. This may be the only location that an EV battery is ever fully recharged.

Workplace settings

Most likely powered by AC, workplace charging points are becoming more common. Charging usually takes place over the span of the working day, but the EV may not be fully charged in that time. Vehicles used for business, such as delivery vans, may be charged overnight.

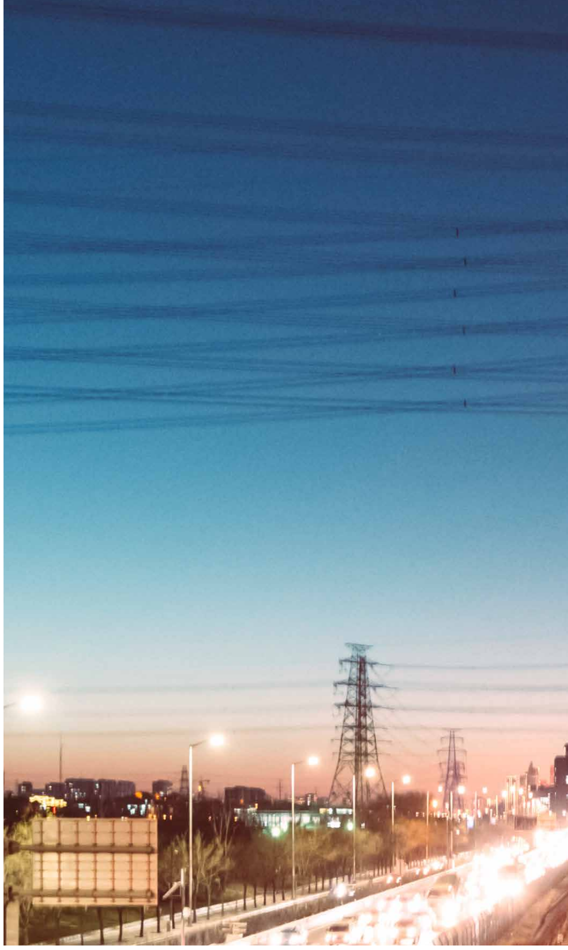
Commercial settings

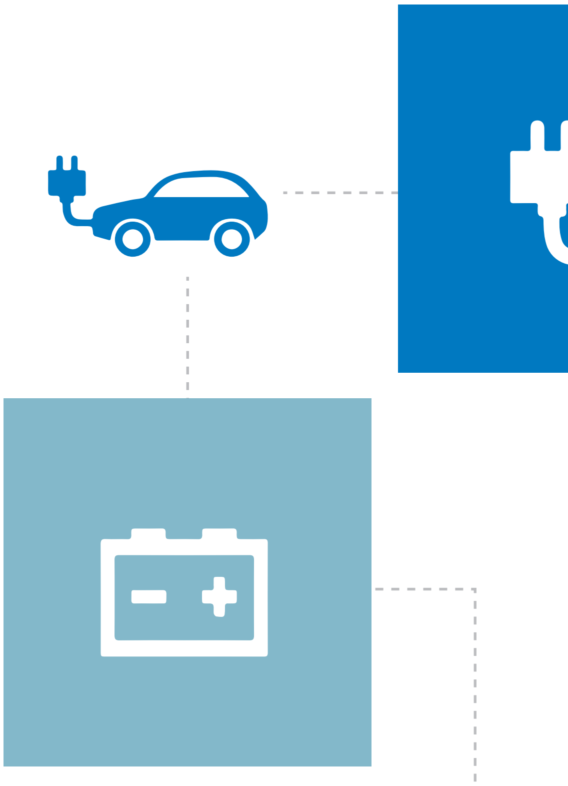
In locations that tend to be visited for shorter periods of time, such as supermarkets, leisure centres and car parks, AC charging is steadily being supplemented by DC charging points which can charge EVs faster, if the battery allows.

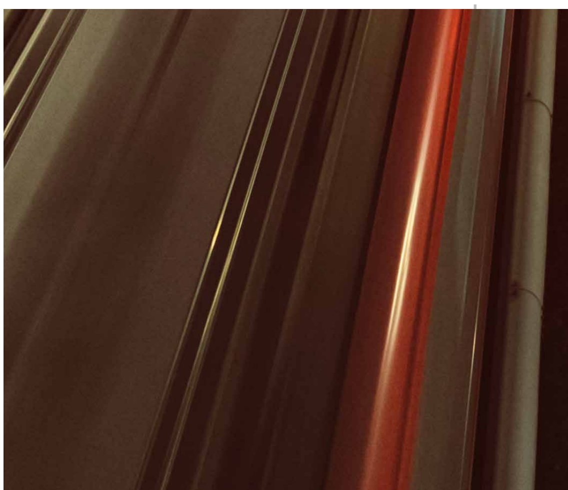
On the go settings

Speed of charge is essential at locations that are visited purely to get enough charge to continue a journey, such as at motorway service stations. DC charging is usually used in these locations to recharge EV batteries with a large quantity of power in as little as 20 minutes.

EVs in the energy transition

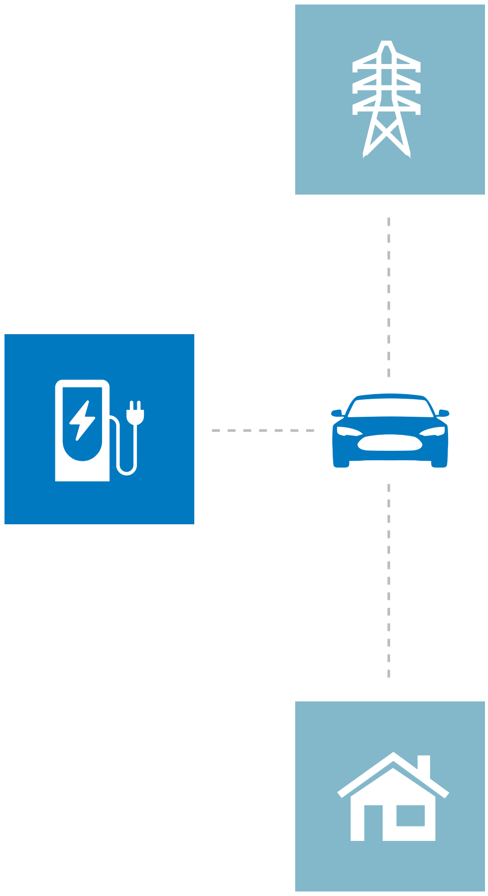






EVs in the energy transition

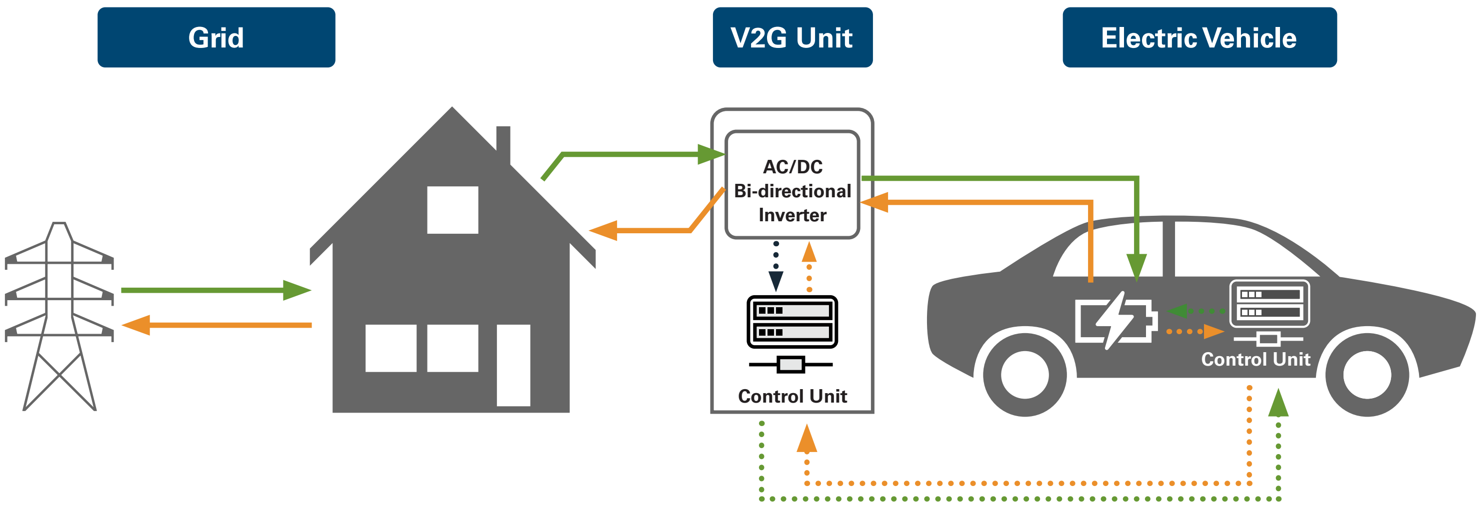
Growing numbers of EVs and the infrastructure to support them is only the start of the mobility revolution. In the future, EVs will play a key role in supporting the transition to an energy system predominated by variable renewable generation. Bi-directional EV chargers will allow EV batteries to help stabilise the grid by acting either as a power store or power supply, depending on energy availability and requirements.



By allowing energy to flow from the EV to the building (and therefore to the grid) and not only from the building to the EV, bi-directional chargers introduce a tremendous level of flexibility in the use of EV-based technologies that are known as **V2X (vehicle to anywhere), V2G (vehicle to grid) and V2H (vehicle to home)**. These technologies mean that an EV can be used for much more than transport.

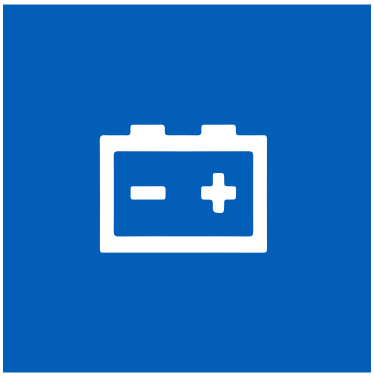
Examples include:

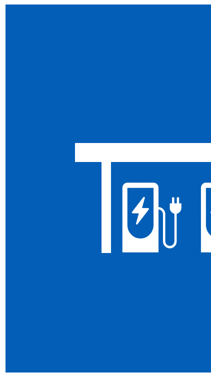
- Acting as an emergency power source in case of power outage
- Helping to stabilise the grid by offering power storage and supply capabilities
- Earning an income by selling unused power to the grid
- Saving money by storing low-tariff energy for use during peak rate hours
- Storing excess self-generated renewable energy for use when required (which helps to both stabilise the grid and save money)

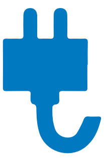


Glossary

AC	Alternating current
BEV	Battery electric vehicle
CCS	Combined charging system
DC	Direct current
EV	Electric vehicle
EVCI	Electric vehicle charging infrastructure
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
kW	Kilowatt
kWh	Kilowatt-hour
OBC	On-board charger
PHEV	Plug-in hybrid electric vehicle
RCD	Residual current device







EVERYTHING
AS A GRID

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