INDUSTRIES & MARKETS

eMobility: in-depth market analysis

Market Insights report

statista

October 2023

Management summary (1/3)

The history of electric vehicles started in the early 1800s, but only took off when Tesla entered the market and reignited public interest in electric cars. In 2022, global electric vehicle sales surpassed 10.2 million units, an increase of 55% over 2021. Currently, Mainland China is leading the way with a market share of almost 58%. Car manufacturers are pushing to bring out new electric car models and have big plans for the future. The 2022 race for the highest market share was won by the Tesla Model Y with 8%, followed by BYD Song Plus (BEV + PHEV) and Tesla Model 3 with 5% each, Wuling Hong Guang MINI EV with 4%, and BYD Qin Plus (BEV + PHEV) with 3%.

There are five major drivers of the electric vehicle market: government policies, the Tesla effect, lower battery costs, 5G rollouts, and the launch of the Battery-as-a-Service model. Governments are trying to achieve their emission goals set out in various global agreements and have devised various incentive schemes to increase electric vehicle sales. While electric vehicles are a major step towards achieving environmental goals, Tesla managed to fuse this with high performance and aesthetics, thereby playing a pivotal role in changing the industry's overall appeal. The significant reduction in the prices of battery packs is also driving mass adoption of these vehicles. Further, 5G rollouts and new business models such as Battery-as-a-Service are expected to drive future growth.

Five main challenges hinder the adoption of electric vehicles: lack of infrastructure (such as charging stations), high upfront costs, lack of consumer knowledge and wrong perceptions, pressure from oil companies and the car manufacturer lobby, and potential long-term effects of the COVID-19 pandemic. Not only are charging stations still very few and far between, but they are also usually manufactured by different suppliers without a standardized charging and payment system. In addition, high upfront costs make electrical vehicles less attractive than traditional internal-combustion engine cars, mainly due to the high battery costs which often account for as much as 50% of the total vehicle cost.

Autonomous driving and electric cars go, without a doubt hand in hand. Thanks to easier integration and component control, it is easier to realize self-driving cars using electric vehicles rather than vehicles with internal combustion engines. While the U.S. has been pioneering this trend, Mainland China will be the market leader. Despite the challenges, lithium-ion batteries are still expected to dominate the battery market for electric vehicles.

Management summary (2/3)

This is mainly because the development of new battery technologies is both very expensive and complicated. Moreover, Mainland China's domination of the lithium-ion battery supply chain is expected to come to an end in the medium to long-term, as the U.S. and Europe are gaining more control over various elements of the supply chain. Interestingly, quantum computing is expected to significantly disrupt the electric vehicle industry, resulting in higher battery ranges, new product launches, and autonomous driving. Due to their low operating costs, electric vehicles are also part of the ride-sharing movement, with many car manufacturers launching electric car-sharing operations. Moreover, the demand for related electronics and software is expected to grow significantly over the next few years.

Lithium-ion batteries dominate the market mainly because they deliver the highest range at a lower cost when compared to any other battery. However, due to limitations such as long charging times, the size, its heavy weight, and limited battery capacity, companies such as Toyota, Volkswagen, Nissan, and Tesla are now investing in solid-state, lithium-sulfur, and zinc-air batteries for their future models. Further, universities, technology companies, and independent battery start-ups are collaborating to develop other types of batteries, such as aluminum-ion, smart membranes, and graphene-based supercapacitors to enable faster charging times and longer life cycles.

Rising pollution levels, potential operational cost savings, and heavy dependence on public transportation are the three major factors driving the gradual switch from hydrocarbon-based to electric public transport. The total number of electric buses in the world is expected to witness a 235% increase from 800,000 in 2022 to about 2.7 million in 2030, with Mainland China accounting for a share of more than 96%. Financial support from the government, a large urban population—and the resultant pollution, a lack of traditional transportation infrastructure, global trade, and increased public awareness are the five key reasons for Mainland China's dominance.

E-scooters have recently gained in popularity and are believed to be the solution to the last-mile transportation problem in many global markets. Even though the overarching reason behind the development of various alternative fuel technologies is restricting environmental damage mainly caused by polluting vehicles, the e-scooter industry is specifically driven by the rise of micro-mobility. The aim here is to transform urban transportation by using cheaper and faster alternatives to cars, especially in the U.S., Asia, and Latin America.

Management summary (3/3)

E-bikes are essentially conventional bikes equipped with a rechargeable battery and motor, helping them gain momentum faster and achieve speeds of up to 30 miles an hour. They look and function just like traditional bikes and give riders the option to pedal when they like.

They are classified according to functionality (mountain bikes, road bikes, hybrid bikes, folding bikes, and utility bikes) or according to design (pedal assist/pedelec, throttle, and speed pedelec). The growing popularity of e-scooters around the world has piqued interest in e-bikes. The first e-bike was manufactured in Japan in 1993, with Yamaha launching its pedal assist bicycle.

As electric drive vehicles are gradually gaining momentum around the world, the next phase of growth is expected to mainly be driven by vans and trucks. The need to switch to cleaner engines is far greater for these larger vehicles, given that they are more polluting than cars. Even though fewer than 5% of vehicles in Europe are commercial vehicles or heavy-duty trucks they contribute to almost 20% of greenhouse gas emissions. One of the main reasons why the light commercial vehicles (LCV) industry is witnessing electric disruption at such a fast pace is its high and predictable usage rate.

Tesla is the most recognized electric vehicle (EV) brand in the world. In 2022, combined sales of the Model 3 and Model Y totaled 1,247,146 units. Tesla's success is primarily attributed to its aesthetics and longer ranges compared to other EVs. BYD is one of the largest selling brands in Mainland China, but its focus on international markets is limited. The company's top-selling brand in 2022 was the Han with sales of over 274,015 units. Volkswagen sold a total of 572,100 EVs in 2022, up 26% from the 452,839 sold in 2021. The other European player, BMW, has 14 EV models in its portfolio and had over 2 million electric vehicles in circulation by the end of 2022.

In terms of charging infrastructure, Mainland China once again leads the pack with more than 1,760,000 publicly accessible charging points, followed by South Korea (approx. 201,000), the U.S. (approx. 128,000), and the Netherlands (approx. 124,300).

Mainland China is by far the market leader, not only in Asia but also worldwide. PEV sales amounted to over 4,400,000 units in 2022—nearly 175 percent more than the combined PEV sales in Europe. South Korea, Japan, and India are the other leading markets in Asia. As for e-LCVs, Mainland China and South Korea account for an 86% share in the Asian market, with combined sales of over 167,500 units in 2022.

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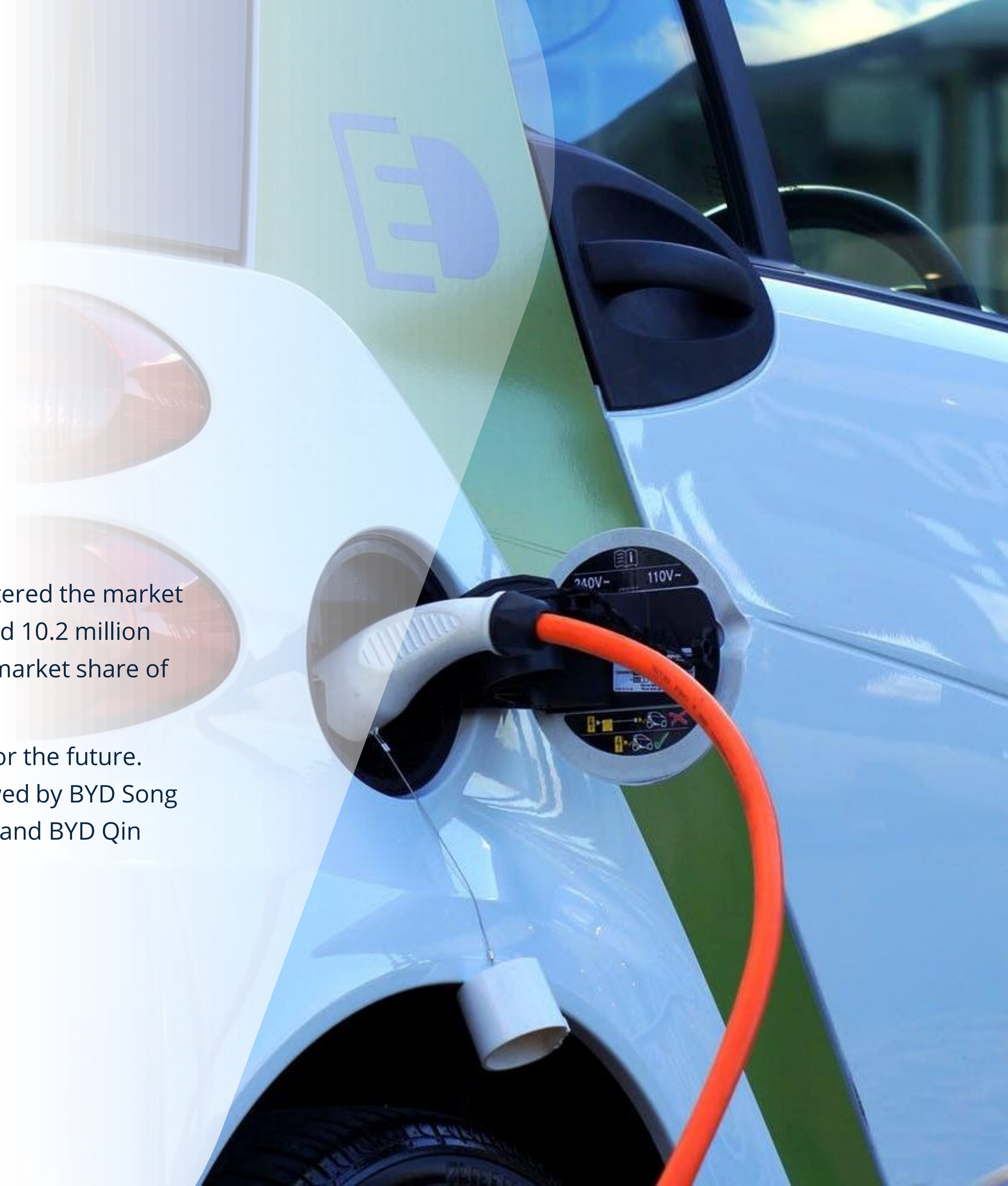
CHAPTER 1

Introduction

The history of electric vehicles started in the early 1800s, but only took off when Tesla entered the market and reignited public interest in electric cars. In 2022, global electric vehicle sales surpassed 10.2 million units, an increase of 55% over 2021. Currently, Mainland China is leading the way with a market share of almost 58%.

Car manufacturers are pushing to bring out new electric car models and have big plans for the future. The 2022 race for the highest market share was won by the Tesla Model Y with 8%, followed by BYD Song Plus (BEV + PHEV) and Tesla Model 3 with 5% each, Wuling Hong Guang MINI EV with 4%, and BYD Qin Plus (BEV + PHEV) with 3%.



Tesla reignited public interest in electric vehicles in 2008

Overview

Contrary to public opinion, EVs are not a new concept. They have been around since the nineteenth century, with the first car produced as early as 1828. However, the market never gained any significant traction and by 1912, high costs alongside limited research and development into advanced technologies resulted in a great reduction in public interest.

General Motors managed to revive interest in 1996, when it started leasing programs for the EV1, an electric car with a range of 70-100 miles. In 1999, the company also launched an upgraded version equipped with nickel-metal hydride batteries and an extended range of 140 miles. Even though 1,000 of these cars were manufactured, the project was later abandoned.

The current buzz surrounding the EV industry can be largely attributed to Tesla, which reignited public interest with the launch of its lithium-ion battery-powered Roadster in 2008. This proved to be pivotal, not only for Tesla but for other U.S. companies as well—all of whom received generous funding from the U.S. Department of Energy. Tesla used the money to develop the hugely popular Model S, therefore laying the foundation for increased adoption of EVs.

However, despite the excitement surrounding EVs, the market has experienced many false starts over the last decade. Given that EV adoption rates stood at around 14% of the overall car market in 2022, the global market is still very much at an 'innovator' phase of the product adoption curve. The primary reasons for this include concerns around range, price, charging infrastructure, and, at times—safety. Additionally, there is a general consumer inertia about switching from the internal-combustion engine (ICE), which has been the dominant automotive motor type for decades. Moreover, the sharp fall in oil prices around the world, which began in 2020 has significantly lowered the total cost of owning ICE vehicles, thereby driving their sales.

One other reason for the slow adoption of EVs is the big ecosystem they are dependent on. While there is a huge number of gas stations all over the world, the number of charging stations is still low. Additionally, charging stations from different providers use different charging methods, making it even harder for consumers to know in advance how much it would cost to charge their EV.

Even though the market for electric buses, trucks, and two-wheelers has also witnessed an upward trend, strong adoption is restricted to just a few countries and pockets of society.

Sources: Department of Energy; The Verge; McKinsey

Electric vehicles depend on a big ecosystem

Ecosystem

Electric vehicles ecosystem

- Battery manufacturers
- Charging stations
- Electricity providers

- Electric Vehicle manufacturer

Electric vehicles

FEVs[1] | PEVs[2] | HEVs[3] | PHEVs[4]

- Regulators
- Environmentalists

- End users

Notes: (1) Full EVs (2) Plug-in EVs (3) Hybrid EVs (4) Plug-in Hybrid EVs

Sources: Statista

Evolution of electric vehicles: Timeline (1/4)

Evolution (1/4)

- **1828** First car with an electric motor is introduced
- **1837** First American patent is filled for an electric machine/motor
- **1859** The first EV with a lead-acid battery is launched
- **1884** Thomas Parker builds the first practical production EV with rechargeable batteries
- **1911** First gasoline-electric hybrid car is launched
- **1976** The U.S. Congress passes the Electric and Hybrid Vehicle R&D, and Demonstration Act
- **1977** AMC and Gulton Industries launch a 3-passenger electric commuter city car
- **1996** General Motors introduces the EV1
- **1997** Toyota and Ford release the RAV4 EV & Ranger EV respectively
- **1998** Honda released the EV Plus
- **2001** Mahindra launches REVA, the first Indian EV
- **2003** Tesla motors is founded
- **2006** Tesla releases the Roadster, the first EV to use li-ion batteries
- **2008** The Think City EV is launched in Norway
- **2009** BYD releases the world's first plug-in hybrid compact sedan, the F3DM
  BMW starts initial trial of Mini Electric
  Tesla unveils the Model S electric sedan
  U.S. Department of Energy awards US$8 bn in loans to Ford, Tesla and NISSAN for development of EVs

Sources: Company information; Press releases

Evolution of electric vehicles: Timeline (2/4)

Evolution (2/4)

2010
NISSAN releases the Leaf
The Chevy Volt goes into mass production

2011
The Bolloré Bluecar is released in France

2012
Tesla unveils the Model X, an electric SUV/crossover
Tesla begins building a North American supercharger network

2013
Number of electric cars on roads crosses the 400,000 mark
BMW launches the i3

2014
Over 40 EV models are launched including the BMW i8
The NISSAN Leaf becomes the first electric car to see over 100,000 sales

2016
Tesla and Panasonic agree to invest US$6 billion to expand battery production

2016
Tesla announces plans to launch the Model 3 in 2017
Tesla announces that all its future vehicles would be fully autonomous

2017
Tesla temporarily halts production of Model 3; share price tanks amidst falling customer and investor confidence
Tesla delivers the first Model 3 in the U.S.
Mainland China announces definite plans to end production and sales of ICE cars

2018
Global electric vehicle sales cross the one million mark for 2017
Shenzhen electrifies its entire bus fleet of 16,359 vehicles
Jaguar launches its first all-electric vehicle, the I-Pace
Tesla lets go 9% of their 37,500 members of staff
BMW launched i8 Roadster in March 2018
Audi launches e-tron electric SUV in the U.S. in September
Global yearly electric vehicle sales near the two million mark

Sources: Company information; Press releases

Evolution of electric vehicles: Timeline (3/4)

Evolution (3/4)

2019
- Renault launches City K-ZE, the electric version of Kwid in Mainland China in September 2019
- Porsche launches its first electric car, the Taycan Turbo, in Canada, Mainland China and Germany in September

2020
- Tesla crossed 500,000 deliveries in 2020
- Apple announced plans to launch its first electric car in 2024 with new battery technology
- Mercedes announces that its next-generation eSprinter electric vans will be sold in the U.S. by 2023

2021
- Governments worldwide increase their influence on the eMobility industry in terms of both incentives and regulations
- Clean and renewable energy is increasingly integrated into the grid to further reduce the environmental impact of charging EVs
- EV maker Rivian Automotive is listed on the NASDAQ in the world's largest IPO in 2021

2021
- President Joe Biden sets a goal that 50% of all car sales be electric by 2030
- The U.S. government signs the US$1.2 trillion Bipartisan Infrastructure Law, which includes US$7.5 billion for EV charging stations
- UK based EV manufacturer Arrival is listed on the NASDAQ with a valuation of around US$13 billion, making it the largest-ever listing of a UK technology company
- China remains the top EV market in the world
- Price of spodumene, a source of lithium mainly mined in Australia, increases sharply
- Japan announces that only EVs will be on sale after 2030

2022
- In February, India's government announces battery-swapping policies and interoperability standards for EVs in its annual budget
- Ford announces plans to increase investments in EVs to US$20 billion
- Jaguar announces the in-house development of its new EV platform

Sources: Company information; Press releases

Evolution of electric vehicles: Timeline (4/4)

Evolution (4/4)

2023

Tesla Model Y becomes the best-selling car worldwide in Q1, a first for an EV

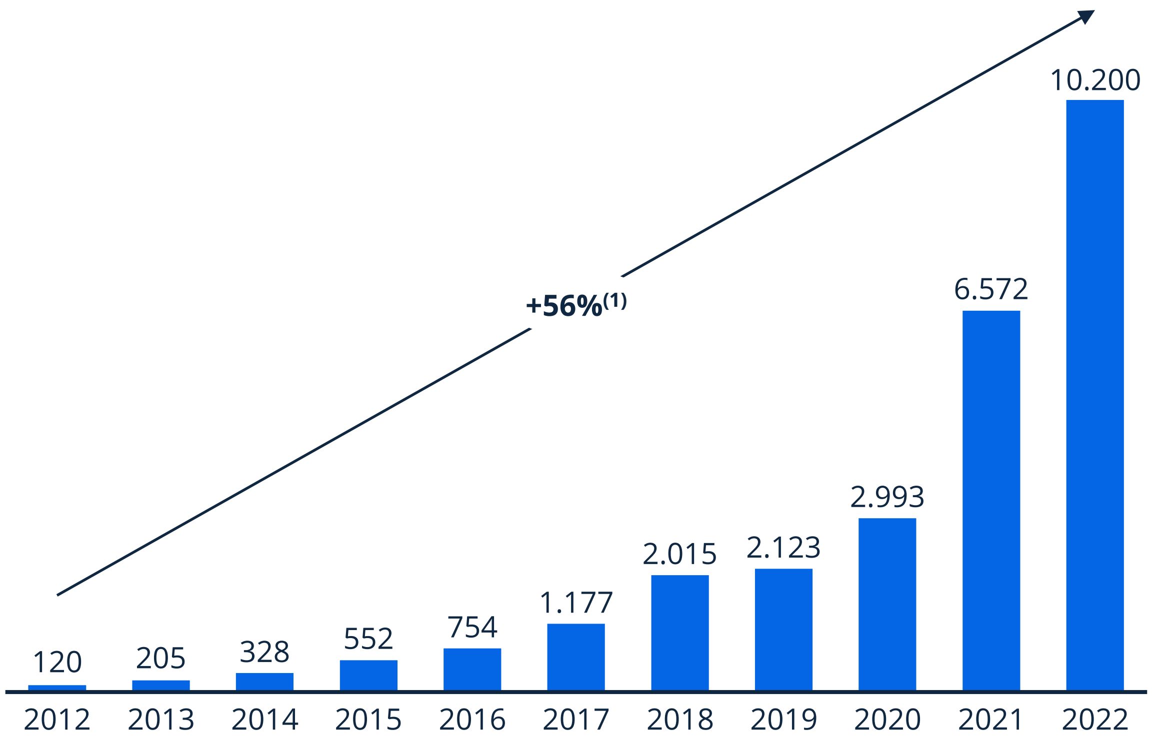
In August, the Indian government announced plans to introduce 10,000 electric buses in 100 cities across the country over the next 10 years for an estimated budget of US$6.9 billion

Sources: Company information; Press releases

Number of EVs sold reached the ten million mark in 2022

Electric vehicles: Sales (1/2)

Global plug-in electric vehicle sales in thousands



The global plug-in electric vehicle market has witnessed robust growth over the last few years with sales increasing from around 120 thousand in 2012 to 10.2 million in 2022, growing at a CAGR[1] of almost 56%. Notably, the sales figure increased by nearly 55.2% in 2022 over 2021. Stringent government regulations on carbon emissions, subsidies and other incentives, sharp reductions in battery prices, improvements in charging infrastructure, and the rise of the environmentally responsible consumer are some of the factors that drove this growth.

Mainland China is in the lead in terms of electrical vehicles with a sales share of over 58% in 2022, having sold over 5.9 million electric cars in 2022 alone. The U.S. and Germany lag far behind with a 10% sales share each and sold 990,000 and 830,000 electric cars, respectively, in 2022. The UK, France, and Norway are close together with a sales share of 9% and combined sales of around 876,000 cars in 2022.

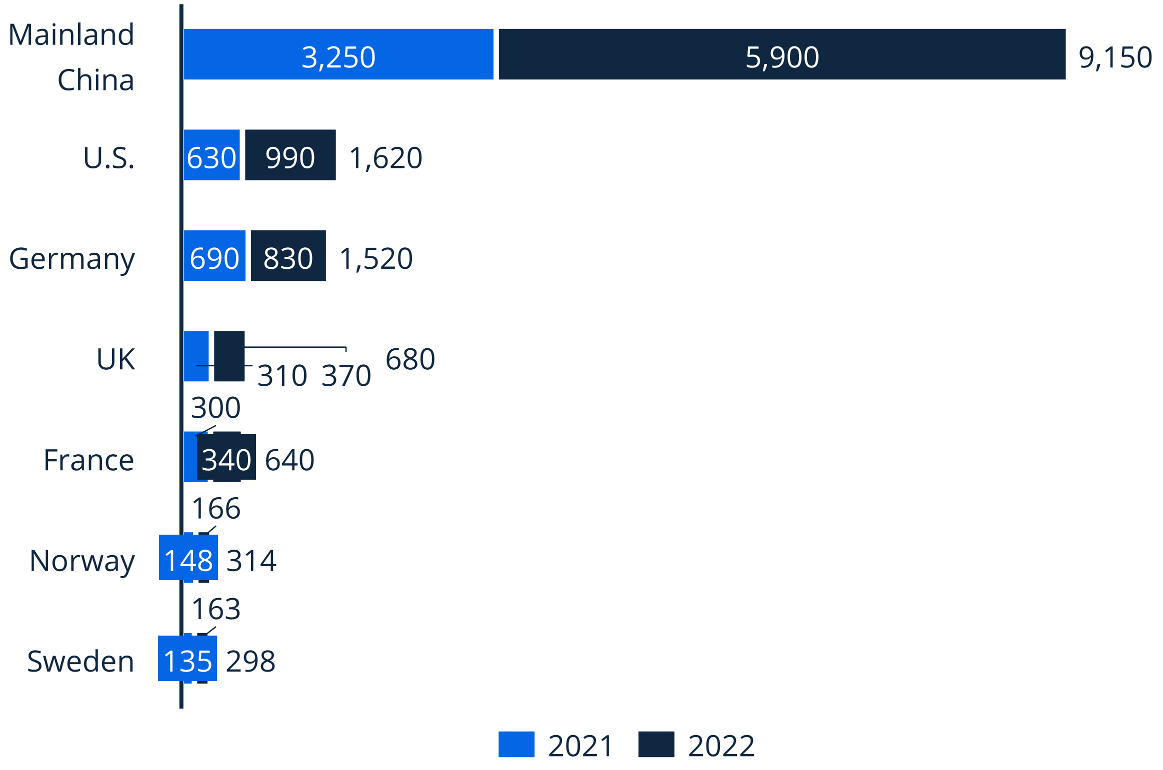
Notes: (1) CAGR: Compound Annual Growth Rate

Sources: International Energy Agency (IEA)

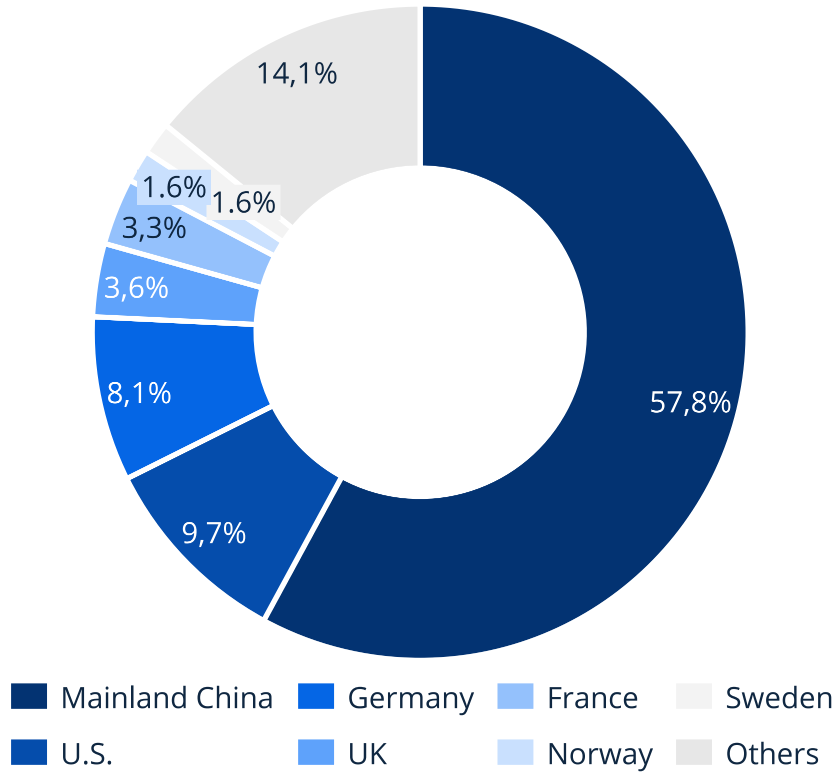
Mainland China is the leading country in terms of EV sales

Electric vehicles: Sales (2/2)

PEV[1] and PHEV[2] sales in selected countries in thousands



Share of leading countries in PEV[1] and PHEV[2] sales in 2022



Notes: (1) Plug-in Evs (2) Plug-in Hybrid EVs

Sources: International Energy Agency (IEA)

Electric vehicles stock (PEV and PHEV) by country in thousands

Electric vehicles: Stock

Country	2015	2016	2017	2018	2019	2020	2021	2022
Canada	17.7	29.3	45.9	90.1	141.1	209.1	298.0	380.0
France	54.5	84.0	118.8	165.5	226.8	416.2	724.9	990.0
Germany	48.1	72.7	109.6	177.1	238.8	633.4	1,314.8	1,890.0
India	4.4	4.8	7.0	7.9	8.6	11.8	23.5	72.1
Italy	5.7	8.5	13.4	23.1	40.3	99.5	235.7	350.0
Japan	134.6	153.1	202.9	236.3	263.8	293.1	337.4	410.0
South Korea	6.0	11.0	25.7	61.1	97.3	137.3	227.9	357.0
Mainland China	292.7	628.7	1,207.7	2,288.8	3,349.1	4,508.7	7,842.8	14,100.0
Mexico	0.3	1.0	2.2	4.0	4.7	7.2	11.5	24.0
Netherlands	87.5	112.2	119.3	142.7	203.4	291.1	385.1	530.0

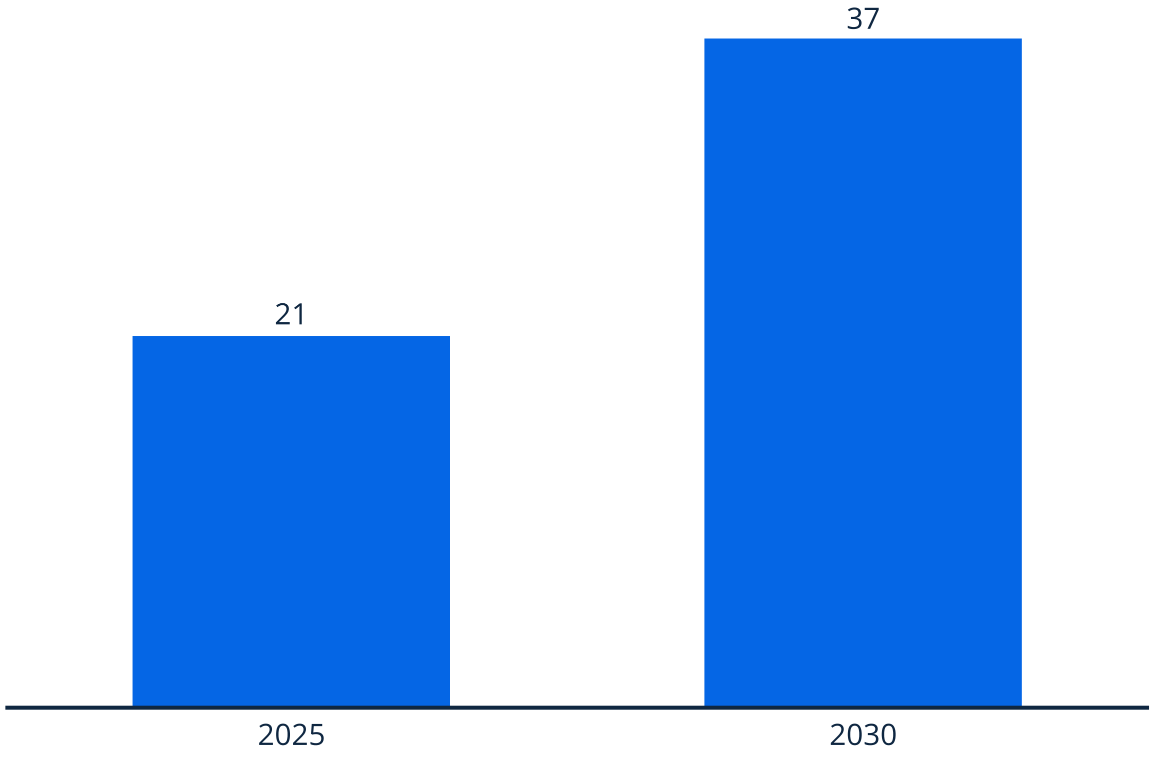
Country	2015	2016	2017	2018	2019	2020	2021	2022
Norway	69.2	114.1	176.3	249.0	328.6	484.7	636.6	790.0
Portugal	2.5	4.3	8.7	17.0	29.7	49.7	78.9	111.0
South Africa	0.3	0.7	0.9	1.0	1.2	1.5	1.7	2.2
Spain	5.7	9.3	16.7	28.4	45.8	87.9	155.6	226.0
Sweden	14.5	26.4	43.3	66.1	97.0	178.1	299.7	440.0
UK	48.5	86.4	133.7	184.0	258.6	433.7	745.9	950.0
U.S.	404.1	563.7	762.1	1,123.4	1,450.0	1,778.1	2,064.5	2,960.0
Others	55.1	89.5	148.9	234.3	365.8	623.3	1,114.3	1,317.7
Total	**1,251.3**	**1,999.6**	**3,142.9**	**5,099.8**	**7,150.6**	**10,244.4**	**16,498.8**	**25,900.0**

Sources: International Energy Agency (IEA)

Global EV sales to reach 37 million by 2030

Forecast

Global PEV[(1)] and PHEV[(2)] sales forecast in millions



PEV[(1)] and PHEV[(2)] stock share by country

Country	Stock in 2021 in thousands	Stock in 2022 in thousands	Share in the total 2022 vehicle stock
Canada	298.0	380.0	1.6%
France	724.9	990.0	2.7%
Germany	1,314.8	1,890.0	4.0%
South Korea	227.9	357.0	1.7%
Mainland China	7,842.8	14,100.0	4.9%
Netherlands	385.1	530.0	5.6%
Norway	636.6	790.0	27.0%
Portugal	78.9	111.0	2.0%
Sweden	299.7	440.0	8.8%
UK	745.9	950.0	2.8%

Notes: (1) Plug-in EVs (2) Plug-in Hybrid EVs

Sources: International Energy Agency (IEA)

Proposed launch of new electric vehicles

Production plans (1/3)

- **2015** — Sales 0.5 million EVs
- **2017** — Sales 1.2 million EVs
- **2018** — Sales 2.0 million EVs
- **2019** — Sales 2.1 million EVs
- **2020** — Tesla, Audi, Toyota and BMW launched new EV models
- **2022** — BMW, Cadillac, Fisker, Hyundai, Kia, Lucid, Lotus, Mazda, Mercedes, NIO, Nissan, Polestar, Subaru, Tesla, and others plan to launch new EV models.
- **2025** — Sales 21 million EVs
  Hyundai, Volkswagen and BMW to have >125 EV models
- **2030** — Sales over 37 million EVs

Existing key players	New entrants
TESLA, BYD, TOYOTA	
Ford, HYUNDAI, KIA MOTORS	DAIMLER, VOLVO
NISSAN, GM, Audi	Faraday Future

Sources: Company sources; Press releases; Electrek

Overview on electric vehicle production and sales plans

Production plans (2/3)

OEMs	Electric vehicle production plans	Targeted sales
Apple	Expects to launch an EV by 2024 as part of Project Titan. The battery's chemistry will be LFP	-
Audi	30 electrified and 20 fully electric vehicles by 2025	800,000 electric vehicles in 2025
BMW	6 BEVs by 2025	Approximately 10 million PEVs by 2031
Chinese OEMs	-	7 million electric car sales annually by 2025
Daimler	3 new EV exclusive platforms by 2025	100% of EV sales in some countries by 2030 50% of group sales will be EVs by 2025
Ford	2 million EVs by 2026	33% of overall sales to be electric by 2026 and will increase to 50% by 2030
Honda	30 new EV models by 2030	100% EV sales, including Hydrogen Fuel Cell vehicles, in North America by 2040 500,000 EV sales by 2030
Hyundai-Kia	15 new EV models by 2027	1.6 million electric vehicles by 2026

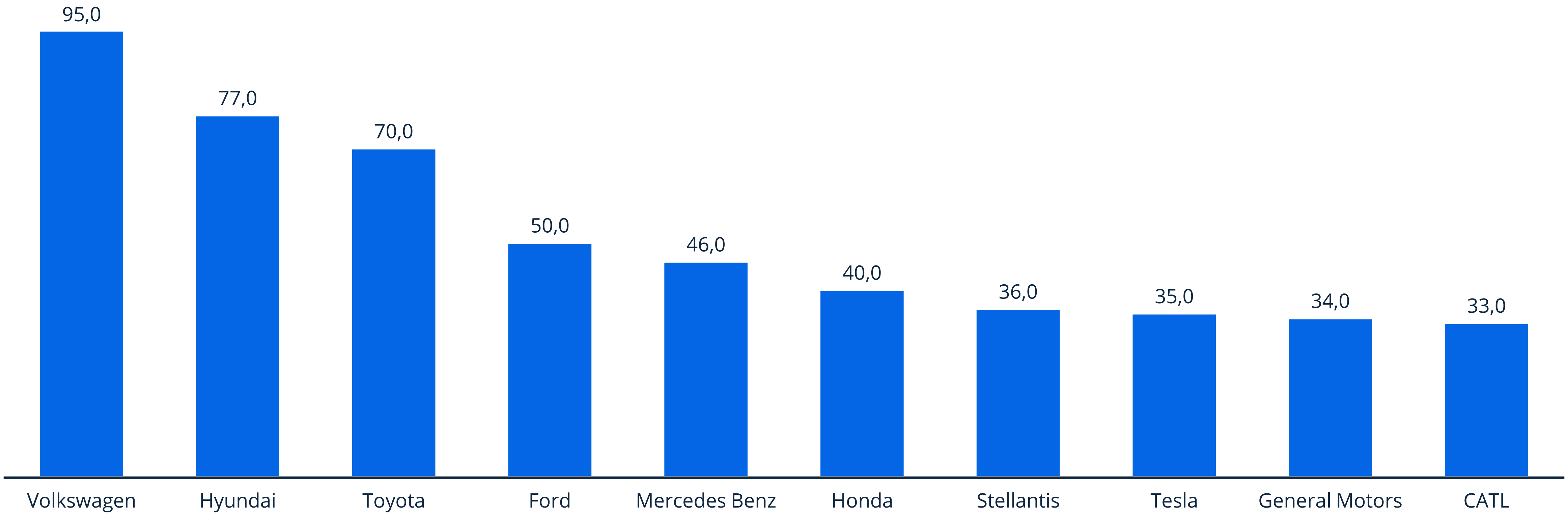
OEMs	Electric vehicle production plans	Targeted sales
Nissan	19 new electric vehicles by 2030	• 98% EVs in Europe, 35% in China by 2026 • 40% EVs in the U.S. by 2030
Renault Nissan Mitsubishi	35 EVs by 2030	-
Tesla	The Generation 2 Roadster in 2024, up to 10 new models by 2030	20 million electric car sales by 2030
Toyota	10 new EV models by 2026	• 1.5 million EV sales by 2026 • Transform Lexus into an EV-only brand by 2035 • Two next-gen EV batteries by 2027 • 55% EV share in Europe by 2030
Volkswagen	10 new EV models by 2026	• 80% EV sales in Europe and 55% in North America by 2030
Volvo	6 new BEVs by 2026	• Half of its sales to come from electric vehicles by 2025 • 1 million electric cars in total by 2025

Sources: Company sources; Press releases; EV Globe; Business Standard; Hindustan Times; Electrive; Benzinga; Inside Evs; Drive; Electre; CNBC; Reuters

EV manufacturers invest to increase production capacity

Production plans (3/3)

EV related investment by manufacturers in billion US$

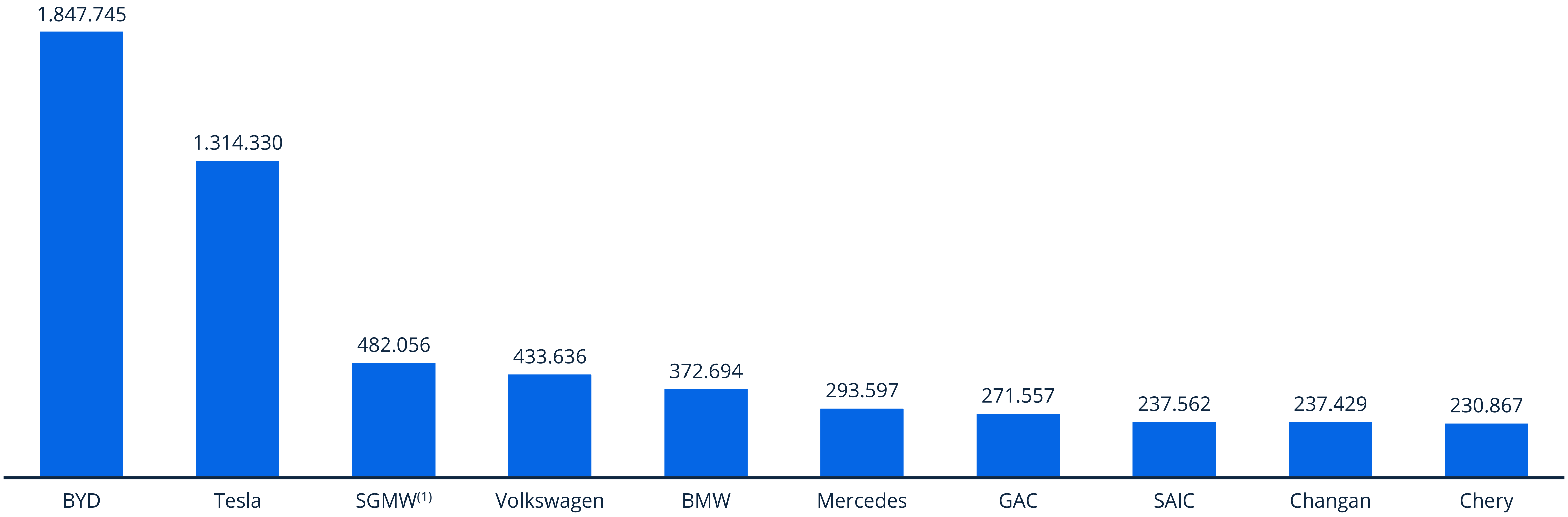


Sources: EV hub

BYD sold most EVs in 2022

Comparison of leading brands

Top 10 brands with most EV sales in 2022



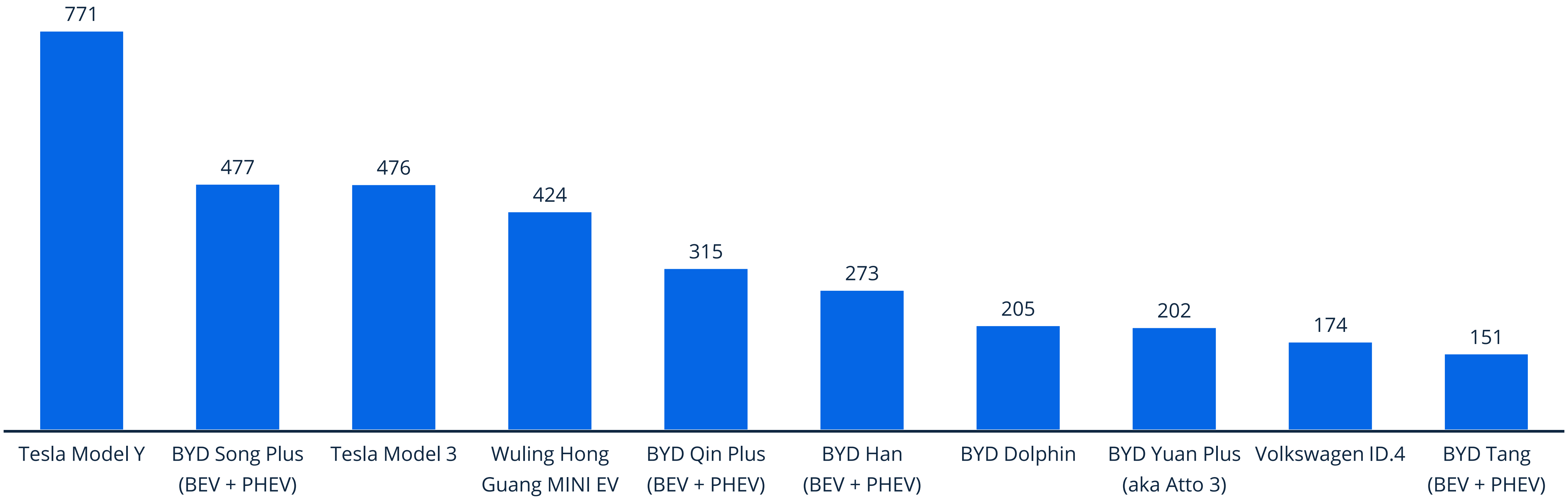
Notes: (1) SGMA (SAIC-GM-Wuling) Automobile is a joint venture between SAIC Motor, General Motors, and Liuzhou Wuling Motors Co Ltd

Sources: CleanTechnica

Tesla Model Y was the most sold electric car globally in 2022

Comparison of leading models (1/2)

Top 10 selling electric car models in 2022 in thousands



Sources: Inside EVs

statista

Lucid Air models have the largest range so far of approximately 500 miles

Comparison of leading models (2/2)

EV Models	Type	Charging Rate	Battery Range	Battery Used
Lucid Air Grand Touring	PEV	22 kW	516 miles	112 kWh lithium-ion
Mercedes-Benz EQS 450+	PEV	11 kW	452 miles	108.4 kWh lithium-ion
Fisker Ocean Extreme	PEV	11 kW	440 miles	106.5 kWh lithium-ion
Polestar 2	PEV	11 kW	406 miles	82 kWh lithium-ion
Tesla Model S	PEV	11.5 kW	405 miles	100 kWh lithium-ion
BMW i7 xDrive60	PEV	11 kW	387 miles	101.7 kWh lithium-ion
BMW iX xDrive50	PEV	11 kW	382 miles	105.2 kWh lithium-ion
Mercedes-Benz EQE 300	PEV	11 kW	380 miles	89 kWh lithium-ion
Polestar 3	PEV	11 kW	379 miles	111 kWh lithium-ion
Mercedes-Benz EQE 350	PEV	11 kW	376 miles	89 kWh lithium-ion

EV Models	Type	Charging Rate	Battery Range	Battery Used
BYD HAN EV	PEV	11 kW	374 miles	76.9 kWh lithium iron phosphate
Tesla Model X	PEV	11.5 kW	348 miles	100 kWh lithium-ion
Tesla Model 3	PEV	11.5 kW	333 miles	82 kWh lithium-ion
Tesla Model Y	PEV	11 kW	330 miles	81 kWh lithium-ion
BYD Tang	PEV	7.4 kW	328 miles	86.4 kWh lithium iron phosphate
BYD Atto 3	PEV	11 kW	261 miles	60.5 kWh lithium iron phosphate

Sources: Company sources; News articles

CHAPTER 2

Market drivers

There are five major drivers of the electric vehicle market: government policies, the Tesla effect, lower battery costs. Further, 5G rollouts and the battery-as-a-service model. Governments are trying to achieve their emission goals set in various global agreements and have devised various incentive schemes to further electric vehicle sales.

While electric vehicles are a major step in furthering environmental goals, Tesla achieved to change their image with increased focus on high performance and aesthetic appeal. Further, 5G rollouts and new business models such as Battery-as-a-Service are expected to drive future growth.

From 2010 to 2022, the price of battery packs dropped by more than 87%, making electric vehicles a lot more affordable than before.

Subsidies and emission targets are used to foster EV development

Government policies: Overview

Government efforts to control climate change is one of the main drivers of the global electrical vehicle market. A 2022 study conducted by sustainable energy company Ricardo PLC found that over the course of covering 200,000 miles within the U.S., a conventional internal combustion vehicle generates about 66 tons of greenhouse gas emissions, while a battery electric vehicle produces approximately 39 tons of such emissions over the same travel distance. Another study conducted by the University of Michigan in 2022 found that emissions from BEV sedans amount to 35 percent of the emissions generated by internal-combustion sedans, while BEV pickups generate just 34 percent of the emissions produced by their internal combustion counterparts.

There are several incentives governments use to get people to buy EVs:

- Tax exemptions or credits in various forms
- Grant
- Subsidies
- Non-financial incentives (e.g., road access privileges, dedicated parking spaces)

But these incentives work differently in every country and might only apply in certain cases, like the incentives in Japan which are only eligible for new vehicle owners. A table with information of incentives for Mainland China, France, Germany, Japan, Russia, and the U.S. can be found on the next page.

Global governments are not only offering incentives but are also laying down permissible emissions levels for large automobile manufacturers. This leaves them with no choice but to invest in zero-emission vehicles in order to offset the CO2 emissions by their ICE vehicle fleets.

While countries like the UK and France announced that they won‘t allow ICE sales by 2040, Mainland China runs ahead and set hard targets starting in 2019. These targets are based on a credit rating system for so-called new energy vehicles, that include battery-electric vehicles and plug-in hybrids. In 2019, car makers needed to have a new energy credit rating of 10% of their annual sales, with this quota having risen to 18% in 2022. All companies selling more than 30,000 cars annually have to comply, buy credits from other companies exceeding the quota, or they will be subject to penalties.

Sources: Department of Energy; The Verge; McKinsey; Green Car Congress; The New York Times; The International Council of Clean Transportation

"The need for to focus on clean mobility is more relevant and urgent than ever before. Alarming pollution levels and increasing fuel costs have necessitated adoption of electric vehicles (EVs). While the government is making efforts both in terms of policy push and infrastructure, efforts should be made by individuals as well as enterprises to embrace sustainable mobility."

Samarth Kholkar
CEO & Co-founder, Blive, 2022

Tesla's model 3 was pre-booked 325,000 times in only one week

Tesla effect (1/2)

For decades, EVs have been perceived as cars that are good for the environment but low on performance and aesthetics. This is primarily because large auto manufacturers simply have too much invested in the success of the ICE to invest any significant amount of money in making an advanced EV. For long, they also perceived the typical EV customer to be one who didn't care how the car looked or how well it ran, as long as it didn't pollute the environment. However, this perception is changing, according to Wharton management professor and automobile industry expert John Paul MacDuffie.

Tesla has played a pivotal role in bringing about this change in mass public perception of the electric car. All its cars, including the Roadster, Model 3, Model S and Model Y, have scored high on both performance and aesthetics, while sticking to their zero-emissions policy. The fact that Tesla has now started to eat into the market share of not only other plug-in EVs and plug-in hybrid electric vehicles but traditional ICEs as well, has prompted big auto manufacturers to develop their own line of advanced EVs. This is why, when one of its marketing blogs for the launch of Model 3 was titled: "The Week that Electric Vehicles Went Mainstream", it wasn't ignored as just a marketing gimmick.

The car managed to get over 325,000 pre-bookings, which translates into US$14 billion in future sales and is the single largest one week launch of any product ever. MacDuffie also noted that EV bookings have been strong despite low gas prices, indicating that gas prices are not the primary driver of demand for electric vehicles. "People buying a US$70,000 to US$110,000 car [which is what Tesla's premium models cost] aren't worried about what they pay out at the gas pump," he said, "if the demand exists even with gas prices being low, it is [because] of that repositioning away from just an environmental pitch."

According to EVForward, a 2021 study by Escalent, a human behavior and analytics firm, the top attributes that motivate people to buy a Tesla are range, performance and acceleration, styling, and production quality. Tesla's cars achieved the following milestones over a two-year span (2021-2022):

- In April 2021, the Model 3 became the best-selling premium sedan worldwide.
- In January 2022, the Model 3 ranked #2 for best-selling cars in the UK.
- In May 2023, Tesla reached the weekly production milestone of 5000 Model Y electric crossovers, which translates into 250,000 units annually.

Sources: TechRepublic; Tesla; Wharton; Escalent

Elon Musk is leading several technological advances

Tesla effect (2/2)

Tesla's founder, Elon Musk has contributed immensely to enhancing the brand's image and value which has soared over the last year or so. In fact, Tesla's market cap increased by over US$500 billion in 2020 alone and surpassed the US$1 trillion mark in October 2021, making the company more valuable than the ten major automobile manufacturers immediately in its wake. Tesla's market cap stood at around US$778 billion as of 10th August 2023. The fact that Musk is also involved in other roles such as space transportation (through his company SpaceX) and solar power (SolarCity) has further boosted Tesla's mass appeal.

Another Elon Musk company creating a buzz is, the Boring Company, which works on a futuristic technology to fundamentally change the public transportation system. One idea is the hyperloop, where capsules are transported at speeds of more than 1,000 kilometers per hour through vacuum pipes. In June 2018, they were awarded a contract to build a new highspeed connection from central Chicago to the O'Hare airport. Even though the project was eventually shelved, the company is now building something similar in Las Vegas. Tesla has also announced that it will be using lithium iron phosphate (LFP) batteries in its standard Model 3 and Model Y models. Not only are these batteries less expensive than the lithium-ion batteries, they also do not depend on scarce raw materials such as cobalt and nickel.

Sources: Tesla; TechRepublic; CNN; TechCrunch

"The biggest challenge VW and other leading automakers face is that they lack the expertise required to compete in the age of the software car. Tesla and its flamboyant, and sometimes erratic, innovator Elon Musk have turned the more than a century old industry upside down in a mere 16 years."

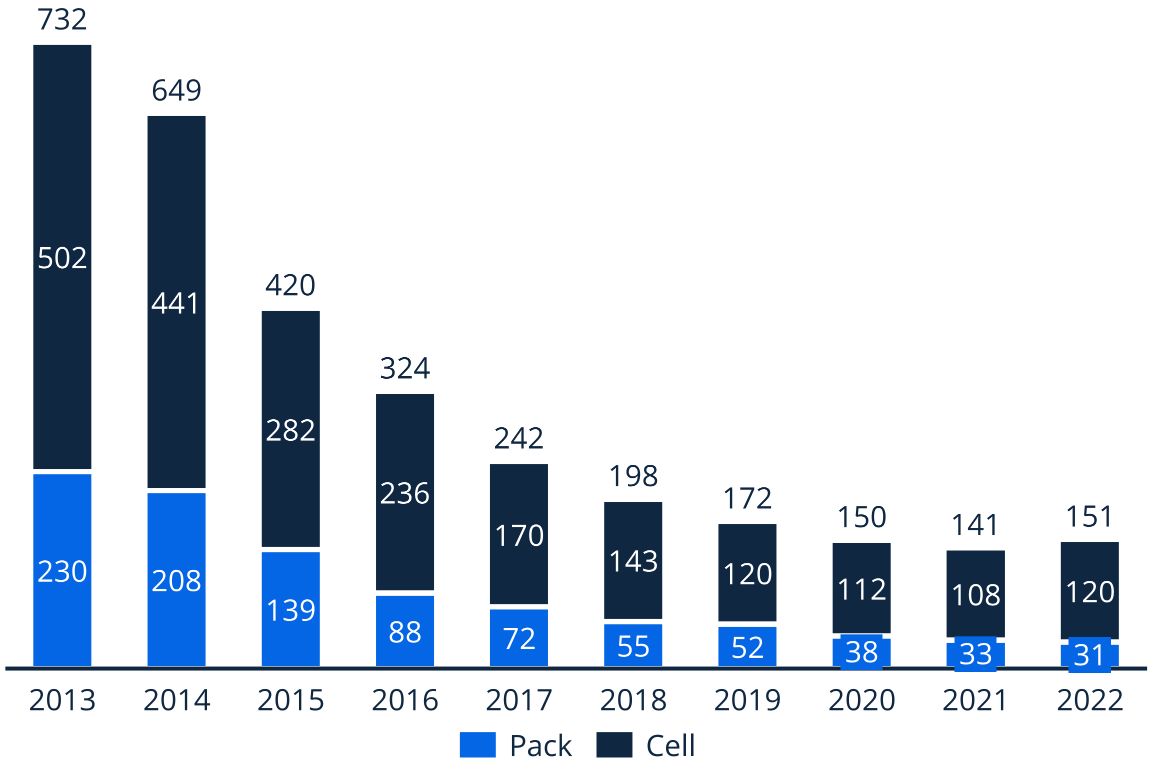
Lou Shipley, Lecturer

Harvard Business School, 2020

Lower battery costs make electric vehicles more affordable

Lower battery costs

Volume-weighted average pack and cell price in US$/kWh



Profitable production of EVs is of paramount importance if they are to achieve widespread adoption in the years to come. High costs of li-ion battery cells have been one of the main hindrances to large scale adoption, as they typically lead to higher purchase prices for electric cars than for comparable ICE models. However, over the last few years, prices of battery packs used in EVs have fallen strongly. According to a 2022 study conducted by Bloomberg New Energy Finance, battery prices have dropped 87% from a global average of US$1,200 per kWh in 2010 to US$151 per kWh in 2022.

Advancements in cell chemistry and manufacturing as well as aggressive pricing by large battery manufacturers looking to defend their market share are the main reasons for this sharp drop. This development resulted in EVs becoming cost competitive with ICEs in Europe. Consumers have responded positively to lower battery prices, and this is reflected in the robust increase in global EV stock over the last few years, which reached 25.9 million units in 2022, 60% more than in 2021. Even though this growth might seem strong, it dwarfs in comparison to the 65% in 2018, 77% in 2015, and 82% in 2014. In fact, over the last decade, the year-on-year growth only fell below 50% in 2019 and 2020 due to the impact of COVID-19.

Sources: BNEF; International Energy Agency (IEA); CleanTechnica; McKinsey; EV-Volumes

5G rollout to disrupt many aspects of the electric vehicle industry…

5G impact (1/2)

The global 5G rollout is expected to profoundly disrupt many sectors and nowhere is this more evident than in the EV industry. The four main areas where 5G is expected to have maximum impact are: manufacturing, V2X, autonomous vehicles, and new product development.

Manufacturing

In June 2020, automobile company Ford announced plans to deploy 5G technology at its EV manufacturing plant in Essex. The project which received £2 million in funding from the UK government, mainly aims to improve the connectivity of welding machines used to produce batteries and electric motors. The welding process generates over half a million pieces of data each minute for just a single product, and, thus, requires better connectivity for real-time control, data analysis, and remote expert support. In fact, according to Chris White, Ford's 5GEM project lead, the present 4G technology is one of the main barriers in reconfiguring and deploying next-generation manufacturing systems in the company. The company's factory in Dearborn, Michigan is also outfitted with a private 5G cellular network and multi-access edge computing (MEC) from AT&T.

Another example of an EV producer integrating 5G into its manufacturing facilities is General Motors. The company's assembly plant, called Factory ZERO at the Detroit-Hamtramck Assembly Center, has installed Verizon's dedicated 5G fixed mobile network technology to improve the functioning of its robotics, sensors, and automated guided vehicles (AGVs).

V2X

One of the main roles of 5G technology in the EV ecosystem is facilitating vehicle-to-everything (V2X) communication. V2X allows vehicles to not only communicate with each other through highspeed internet connectivity but also with other parts of the traffic system around them. By sharing data with other vehicles and infrastructures, V2X creates a large and complex web of information that enhances driver awareness and collision avoidance and reduces traffic jams. Other uses could include advanced high-definition (HD) mapping, remote operations, video streaming, and augmented reality (AR) applications. It could allow automobile manufacturers to offer advanced and immersive services, thereby creating more lucrative revenue streams. In 2016, eight organizations including Audi, Daimler, BMW, Ericsson, Huawei, Intel, Nokia, and Qualcomm created the 5G Automotive Association (5GAA) to support the development of various V2X technologies.

Sources: IHS Markit; Capgemini; Telekom; General Motors

…including new product development and deployment of autonomous vehicles

5G impact (2/2)

Autonomous vehicles

Achieving level 5 autonomy has been the holy grail of the electric vehicle and indeed the broader automobile industry, with both legacy and new auto manufacturers having tried and failed on numerous occasions. Since autonomous cars rely on machine-learning algorithms that incrementally perform better as more data is added and analyzed, one of the main challenges has been the limitations posed by the currently prevalent 4G technology. 5G, with expected download speeds of over 500 Mbps as compared to the current 100 Mpbs, is expected to enable manufacturers to not only bridge this gap but to also facilitate the creation of a fully interconnected and intelligent road transportation system.

5G technology is also expected to enhance fleet-charging services for these autonomous EVs. A good example is EVPassport, a provider of EV charging hardware and software platforms, which uses Verizon's 5G network and mobile edge compute (MEC) capabilities to reduce latency in charging sessions by over 50%. The technology has also enabled the company to seamlessly shift power in real-time to vehicles in greater need, such as those with lower charges.

New product development

Electric vehicle manufacturers, especially those in China have already announced the launch of various 5G capable cars. Even though most of them have been postponed due to the COVID-19 pandemic, they have started hitting the market in early 2023. One such example is BYD's Han EV, which is equipped with Huawei's 5G HiCar system. Other imminent launches include Guangzhou Automobile Corporation's Aion V, BAIC's ARCFOX α-T, SAIC Group's Roewe Marvel R, and Human Horizon's HiPhi1. Other global launches include BMW's iX and releases from Audi, Volvo, and Mercedes-Benz.

The launch of new 5G chipsets is expected to play a pivotal role in these cars by driving a new wave of advanced functionalities. These chipsets are based on industry standards from the Third Generation Partnership Project (3GPP), which released its 17th version in 2023. Even though Qualcomm released the industry's first 5G modem-RF system based on this release in June 2021, its applications are currently restricted to sectors such as airports, stadiums, and offices. However, several announcements regarding the launch of automotive 5G chipsets have been made in 2023.

Sources: IHS Markit; Capgemini; Telekom; Automotive World

Battery-as-a-Service model to accelerate large scale EV adoption

Battery-as-a-service

With the battery of an electric vehicle accounting for around 35-40% of its end value and being one of the main barriers to large scale adoption, manufacturers have started offering Battery-as-a-Service (BaaS) in order to drive sales. In this business model, manufacturers offer consumers the option of purchasing the electric vehicle without the battery, in order to lower its acquisition cost.

The battery can instead be rented from a service provider or swapped with another battery when its charge is exhausted. This novel model has been shown to reduce the price of the vehicle by as much as 40%, thereby making it comparable to conventional internal-combustion vehicles (ICEs). Additionally, it also offers more convenience, as consumers can now refuel in just a fraction of the time it takes to recharge a battery, while eliminating any maintenance cost. The two popular renting models are:

- Paying a monthly rental to car companies, irrespective of the distance travelled.
- Paying a rental based on the expected number of kilometers covered annually.

Battery-swapping on the other hand simply involves replacing a discharged or partially charged battery with a fully charged one at an authorized swapping station.

This model is particularly gaining traction in Asia, with motorcycle makers in Japan already developing vehicles with shared swapping mechanisms. Additionally, as mentioned below, Chinese electric vehicle manufacturer NIO has been offering battery-swapping technology since 2014. However, this trend is yet to catch on in the U.S., which is still in the process of building out its charging infrastructure.

Below is a list of automobile manufacturers offering Battery-as-a-Service (BaaS):

- In August 2020, Chinese auto maker NIO launched its BaaS service with subscriptions for a 70-kWh battery pack, starting as low as US$140. Under this model, the vehicles are offered at a discount of over US$10,000. The company has already built a network of 1,400 battery swapping stations across China since the year 2000, which allows car owners to swap a battery in just three minutes.
- Japanese automotive company Honda has partnered with Yamaha and Piaggio to manufacture swappable batteries for light electric vehicles.
- Ample, a U.S. based startup that provides energy delivery solutions for electric vehicles, has partnered with Uber, to offer battery-swapping services to Uber drivers in California.

Sources: McKinsey; NIO; Science The Wire; Reuters

Arrival of new entrants will give consumers more choice

New entrants

Even though Tesla has been largely responsible for the mainstream adoption of electric vehicles worldwide, the arrival of new entrants and models is expected to drive future growth. A few notable examples are mentioned below.

Mercedes-Benz: Even though Mercedes has not been as aggressive with its electric vehicle strategy as some of the other major automobile manufacturers, it recently released details of its Vision EQXX concept prototype, with a range of over 1,200 km on a single charge, thus surpassing the industry average of around 190 miles.

U.S. OEMs: American legacy manufacturers have invested considerable sums of money to launch new EV models and ramp up the production of existing ones. These models include General Motors' US$27 billion for an electric Hummer supertruck and an electric version of its top-selling Silverado pickup, among others; Chrysler's crossover model called Airflow; and Ford's F-150 Lightning.

Vinfast and Togg: Vietnamese automobile manufacturer Vinfast has recently entered the U.S. market with the launch of two all-electric SUV models, a midsize VF e35 and a larger VF e36. The former is expected to have a range of 310 miles and the latter 422 miles. Togg, a Turkish company, started the serial production of the country's first electric car, an SUV with a range of over 310 miles, in Q4 of 2022.

Sources: strategy&; Business Insider

CHAPTER 3

Challenges

Five main challenges hinder the adoption of electric vehicles: lack of infrastructure (such as charging stations), high upfront costs, lack of consumer knowledge and wrong perceptions, pressure from oil companies and the car manufacturer lobby, and potential long-term effects of the COVID-19 pandemic. Not only are charging stations still very few and far between, but they are also usually manufactured by different suppliers without a standardized charging and payment system. In addition, high upfront costs make electrical vehicles less attractive than traditional internal-combustion engine cars, mainly due to the high battery costs which often account for as much as 50% of the total vehicle cost.

Private investment is needed to develop charging infrastructure...

Lack of infrastructure (1/2)

Even though there is growing consensus on electric vehicles as being the future of mobility, the lack of adequate charging infrastructure and the resultant 'range anxiety' among potential buyers continues to hamper industry growth. In fact, according to a June 2023 survey by the Pew Research Center, as many as 53% of respondents in the U.S. are not confident that the government will build the required charging infrastructure to support large numbers of EVs on the road. Compounding the problem are the misgivings about EV charging points and other, related infrastructure among private and public investors, who are waiting for the market to gain more traction before making any significant investments.

Even though most electric vehicle charging happens at home or at work, an adequate public charging infrastructure is imperative to increase consumer confidence. A 2021 study by Boston Consulting Group (BCG) found that 20-50% of charging will take place on the road and at destination chargers, depending on the region. Moreover, another 2021 survey by Shell Recharge Solutions (formerly NewMotion) found that 33% of EV drivers in Europe were not able to install a charging point at home. Therefore, the limited availability of public charging infrastructure, including a lack of adequate business and financing models, is one of the biggest obstacles to the widespread adoption of electric cars. As more and more electric cars enter the market driven by government subsidies, improved performance, and a general willingness among consumers to go green, the need to build out a robust charging network assumes primary importance.

Even though many electric vehicle manufacturers such as Tesla, BMW, Ford, and Volkswagen are ramping up their efforts to develop a comprehensive charging infrastructure, it is the lack of large-scale investment from private companies looking to establish standalone charging businesses, that is impeding the market. While government investments in charging infrastructure were critical to foster early electric vehicle adoption, private investments are likely to play a pivotal role in catalyzing subsequent market growth. As a result, governments will now have to rely on public-private partnerships or other methods that would encourage private companies to take on a bigger share of public charging infrastructure financing.

Moreover, strong competition among private companies is anticipated in profitable urban areas but not rural areas and highways. As a result, the risk runs high that large areas will be overlooked and not have charging stations.

Sources: World Business Council for Sustainable Development; BCG

...but private companies face several obstacles

Lack of infrastructure (2/2)

Private companies seeking to develop the charging infrastructure face several obstacles:

Lack of sustainable business models

Even though the current buzz around electric vehicles has brought the related charging infrastructure into the limelight, thin margins and a capital-intensive business is making private investors wary. This is especially true of platform-agnostic service providers who are currently shying away from making any long-term commitments in light of related bankruptcies (ECOtality and Better Place) and a general lack of viable business models. In fact, Toby Clothier, a finance specialist at Mirabaud Securities, expects these businesses to generate marginal returns, even in the long-term. Therefore, despite the advancements made by companies like ChargePoint and Greenlot, high installation costs and other market uncertainties are discouraging the proliferation of other such players. According to Clothier, the electric vehicle charging space will eventually be dominated by major oil companies such as Royal Dutch Shell, BP, and Exxon. In fact, in January 2021, Shell acquired Ubitricity, one of Europe's largest on-street electric car charging companies. In 2018, BP acquired UK's ChargeMaster.

Interoperability

Customers who subscribe with one service provider run the risk of not being able to charge at other locations or paying premium costs for doing so. This is primarily because each manufacturer has different standards for connectivity for charging. For example, Tesla's superchargers are incompatible with other EVs.

As a result, drivers must enroll in each network separately and have multiple charging cards in order to charge at a networked public station. Even though companies like Blink and ChargePoint now have a comprehensive network of interoperable charging stations, there are other emerging networks with no current plans for interoperability.

Sources: KPMG

"A mass deployment of electric vehicle (EV) chargers will require creative third-party financing and innovation from utilities. New EV infrastructure should be linked to business model innovation that actually makes sure private sector dollars can make a lot of money. Then public money, rather than being the sole source of funding, becomes just a catalyst that proves the business model to support robust private and utility investment."

Jigar Shah, Director

The Loan Programs Office at the U.S. Department of Energy, 2022

High costs–mainly driven by batteries–prevent mass adoption

High costs

Despite the buzz surrounding Tesla's disruptive potential in the electric cars segment, the company only started to make a profit in 2020. In 2019, it incurred a loss of US$665 million before tax on total revenues of US$24.6 billion. The year before, the loss was even greater at over US$1 billion on revenues of just over US$21.5 billion. In 2022, its stock fell 65%, thereby eroding over US$700 billion off its market valuation.

Similarly, BMW's electric car division is also making losses with the company not keen on developing a successor to its flagship model i3. Its investments in new electric vehicle technologies, including self-driving cars and ride-hailing business models is putting a significant strain on its bottom line. Stefan Juraschek, vice president of BMW's electric powertrain development says that it will take about 7 years to double the amount of energy stored in a battery, and BMW would have to figure out ways to save more money on producing battery-powered cars until then.

Moreover, Rivian, which had the biggest IPO for a U.S. company since Facebook, revealed large losses as part of the IPO process. According to company officials, these losses were mainly a result of the company's large capital investments and no current sales.

The high costs of manufacturing electric vehicles is one of the main challenges facing the industry currently. Even though operating costs for electric vehicles are much lower compared to internal combustion engine cars, upfront costs can be a lot higher. This is also because electric vehicles are still in the early stages of the product adoption curve and the industry has still not reaped the benefits arising from economies of scale and other efficiencies.

One of the main factors resulting in high vehicle costs are the costs of components and batteries, with the battery in an electric vehicle currently accounting for approximately 50% of the total price of the vehicle. Even though battery prices have been falling sharply over the last few years, they are still far away from becoming cost competitive with internal-combustion engine cars. According to a 2019 survey conducted by Shell with over 1,000 respondents in the UK, 80% of them cited high purchase costs as the biggest barrier towards owning an electric vehicle.

Sources: Bmwblog; Bloomberg; Tesla annual reports; Shell

"Mass adoption of electric cars in India will not happen unless the gap in up-front prices of electric and ICE vehicles is brought down."

Shantanu Jaiswal, Head of Research
Bloomberg New Energy Finance, 2020

Lack of consumer knowledge and concern regarding EVs

Consumer knowledge and perception

A 2020 survey in the UK by the car servicing and repair company Kwik Fit revealed that just 8% of vehicle owners expected their next car to be electric and that the pandemic had played a major role in altering vehicle purchase intentions. According to a 2022 study by J.D. Power, almost 30% of U.S. consumers cited a lack of relevant information as the main reason for rejecting an EV purchase. Further, a 2018 worldwide study by KPMG of over 2,000 people revealed that 24% would not consider purchasing an electric vehicle due to perceived charging issues, whilst 12% stated that uncertainty regarding future technology developments was keeping them away. These studies show that even though the general perception regarding electric vehicles has improved significantly over the years, the industry still faces challenges from a consumer awareness point of view, especially when concerning range and safety. Two of the primary reasons for this are, lack of proper education on the latest technological developments and misconceptions arising from a history of negative connotations

A broad acceptance of electric vehicle technologies depends primarily on consumer sentiment. Electric vehicles have a long history of negative connotations that have clouded people's perceptions and slowed down adoption.

For example, rechargeable batteries have been known to overheat and catch fire and are, therefore, considered unsafe. Additionally, low ranges offered by battery packs in the past have led to the coining of a new term, 'range anxiety', which refers to the feeling of fear drivers experience from knowing that their battery could run out of charge and leave them stranded far from a recharging station. This is even though today's electric vehicles are comfortably able to handle the average driver's daily needs. An increase in consumer education and a change in global consumer perception is paramount if the electric vehicle industry is to break away and garner mainstream adoption. This is also because mass consumer acceptance—based greatly on various psychological factors—can go a long way in influencing policies designed to promote the rapid adoption of electric vehicles.

According to a 2022 survey by Statista(1) of over 10,000 respondents in the U.S., 64% would consider purchasing a gasoline-powered car, while only 23% would consider one with an electric propulsion. According to Michael Austin, VP at BYD America, people need to become comfortable with 'opportunity charging' their vehicles, just as they did with their cell phones. It took about a decade for the complete transition from landlines to mobile telephony, and Austin predicts that a 'battery-based' energy revolution from gasoline to electric transportation will happen.

Notes: (1) "Which of these propulsion types do you consider when buying a car"?; Multi pick; U.S.: n=7,609

Sources: Kwik Fit; Energy and Industrial Strategy; KPMG; Ford; Statista Consumer Insights, as of April 2022

Oil companies and OEMs lobby against fast adoption of EVs

Oil companies & car manufacturer lobby

In October 2021, the CEOs of major oil companies such as BP, Chevron, ExxonMobil, and Shell were accused by the Committee on Oversight and Reform in the U.S. of spreading misinformation about the impact of hydrocarbons on global warming. American Petroleum Institute is yet another organization that has intensified its anti-green measures, including those against electric vehicles. Moreover, top automobile manufacturers have also started lobbying against changes to government climate policies. In fact, according to InfluenceMap, a UK-based independent think tank, Toyota ranks third on the list of “negatively influential” global companies on Paris-aligned climate policy, followed by BMW at 18, Daimler at 24, and Hyundai at 25.

Accelerating the electrification of transportation infrastructure would be resoundingly negative for the oil sector’s credit profile. According to a 2021 study by IHS Markit, U.S. oil demand could drop by as much as 25% or more between 2019 and 2050, depending on government policies and EV incentive schemes. Moreover, the strong growth of the global electric vehicle market over the last few years also poses a threat to other sectors such as automotive and electric utilities that use biofuels such as gas and coal. Therefore, oil and car companies have upped their lobbying efforts against the proliferation of electric vehicles.

Koch Industries, which has considerable interests in the oil industry, has increased its efforts to promote the use of fossil fuels, having spent over US$147 million between 1997 and 2018 to directly finance 90 anti-climate change groups. A total of 15 U.S. states, including Minnesota, San Francisco, and Rhode Island, have recently sued the company for a "30-year campaign of deception"' about the impacts of climate change.

Further, Volkswagen and Shell have been accused of trying to curtail the adoption of electric vehicles in the EU by pushing for greater use of biofuels and CO2 labelling as more efficient ways of mitigating climate change. According to Ulrich Eichhorn in 2016, VW’s head of research and development, even though hybrids and other electric vehicles are ‘building blocks’ of the future, modern diesel and natural gas engines would be mandatory to achieve C02 emissions targets.

Moreover, a 2016 study by consulting firm Roland Berger and commissioned by companies such as BMW, Daimler, Honda and Toyota, highlights the prohibitive costs involved in fuel efficiency improvements and the benefits of using biofuels instead. This is in contrast to an EU study which found biofuels such as palm oil and soybean oil producing up to three times as much emissions as diesel oil.

Sources: Bloomberg New Energy Finance; Newsweek; InfluenceMap

Incentives cuts can slow down market growth, mainly in Europe

Incentive cuts

As the adoption of electric vehicles gains momentum throughout North America, Europe, and Asia-Pacific, some governments have begun withdrawing related incentives. They believe they have done enough to spur market growth at the nascent stages and that manufacturers should shoulder the responsibility of continuing to improve vehicle safety, performance and quality.

China, with the world's largest market for electric vehicles, is leading this charge by reducing new energy incentives by 30% in 2022 and by scrapping all subsidies by the end of 2022. Previously, in 2021, the country had announced a new EV subsidy policy which included a 20% year-on-year reduction, reducing the subsidy from US$2,480 in 2020 to US$2,013 per vehicle. India has reduced the subsidy provided under FAME-II (Faster Adoption of Manufacturing of Electric Vehicles in India) to 15% from the previous 40%.

In Europe, the cuts have been even more severe: on two occasions in 2021, the UK reduced grants for electric vehicles. The subsidy is now only £1,500, half of what it was at the beginning of the year. Moreover, the upper price limit for eligible car models has been reduced to £32,000, down from £50,000 in March 2021. Meanwhile, the Valais region in Switzerland has totally cut subsidies for PHEVs, citing their minimal role in curbing climate change.

Even though Germany has extended its various incentives for a year, some incentives such as funding for private wall boxes for electric vehicle charging will be removed once the year is over. The country's new government has also stated that beginning 2023, it will only support those electric vehicles that have a demonstrably positive impact on climate protection. Additionally, France has scrapped its incentives from July 2022 onwards.

The U.S. is yet another example, with the Treasury Department completely scrapping tax credits for major automobile manufacturers like BMW and Nissan and reducing them by 50% for Tesla's base Model 3.

These cuts in incentives and grants are expected to slow market growth as evidenced by China. When the government started to discourage electric vehicle subsidies in 2019, sales declined for five consecutive months and sharply plummeted due to the COVID-19 pandemic.

It is anticipated that growth in Western Europe will slow down over the short term due to cuts in incentives, semiconductor shortages, and a greater push among automobile manufactures to sell vehicles with internal combustion engines before regulations destroy their profitability.

Sources: Strategy&; Forbes

CHAPTER 4

Trends

Thanks to easier integration and component control, it is easier to realize self-driving cars using electric vehicles rather than vehicles with internal-combustion engines. Despite the challenges, lithium-ion batteries are still expected to dominate the battery market for electric vehicles. Due to their low operating costs, electric vehicles are also part of the ride-sharing movement. Moreover, the U.S. and Europe are expected to gain more control over the lithium-ion supply chain. Interestingly, quantum computing is expected to significantly disrupt the electric vehicle industry resulting in higher battery ranges, new product launches and autonomous driving. Due to their low operating costs, electric vehicles are also part of the ride-sharing movement. Moreover, demand for related electronics and software is expected to grow over the next few years.

Autonomous driving likely to be closely connected to EV cars

Autonomous cars: Overview (1/2)

In the 2017 annual Consumer Electronics Show in Las Vegas, most of the prototype and concept cars demonstrating autonomous capabilities had electric powertrains. Full autonomous driving, which is expected to be commercially available over the medium to long-term, is perhaps the most captivating development in the entire automotive industry.

What is most interesting is that even though manufacturers of both electric vehicles and internal combustion engines are investing significantly to adopt this technology, its penetration is likely to be stronger in the electrical vehicle segment.

This is mainly because of the following factors:

- Easy integration: It is simply easier to integrate autonomous features on an electric car as compared to one with an internal-combustion engine. The self-driving capability of a car draws heavily from its electrical subsystem for its multiple sensors and advanced computing hardware. Therefore, an electric vehicles' high voltage battery is more suitable and provides more design freedom while implementing the autonomous driving features.
- Component control: According to Levi Tillemann-Dick in 2016, managing partner at Valence Strategic, a technology consulting firm, it is also simpler to control the components that make up an electrical vehicle as compared to the internal-combustion engine. The electrical vehicle has fewer moving pieces – the battery, inverter and the electric motor – whereas the internal combustion engine has about 2,000 small pieces that need to be lubricated for fear of breaking, thereby making the process a lot more complicated.
- Collective market maturation: Even though electrical vehicle sales have been increasing at a strong pace, they still make up only 2.5% of the entire automobile market. The market is still very much in a product innovator phase. At the same time, full autonomous technology is also in its early stages of development. These two technologies are expected to reinforce and accelerate one another, witnessing collective mainstream adoption by 2030.

Sources: DesignNews

33 million autonomous cars expected to be on the road by 2040

Autonomous cars: Overview (2/2)

Ride-sharing: The shift away from internal-combustion engines is steadily being accompanied by a change in the way people view ownership of cars, with pollution control playing a big role in it. According to the Statista Market Insights: Mobility, the global ride-hailing and taxi market is expected to grow from US$227 billion in 2022 to over US$359 billion in 2027. Mark Fields, CEO of Ford, also admitted in 2016 to an ever-growing change in people's mindsets from owning vehicles to owning and sharing. Interestingly, it is not only ride-sharing companies such as Uber, Lyft, and Nutomy, but also legacy auto makers such as BMW and Volkswagen, who are focusing on launching a fleet of autonomous electric cars.

With more and more traditional automobile manufacturers and technology companies investing heavily in autonomous driving, the market is primed for robust growth over the next few decades. According to a study by research company IHS, annual sales of self-driving cars are expected to reach approximately 33 million units by 2040, with nearly 76 million vehicles with some level of autonomy sold by 2035. In value terms, the Boston Consulting Group estimates the market of autonomous vehicles to stand at US$42 billion by 2025 and to increase to US$77 billion by 2035. It also estimates as much as 25% of new sales to be vehicles with some degree of autonomy by 2035.

Definition of automation levels

Level 1	Level 2	Level 3	Level 4	Level 5
Driver assistance	Partial automation	Conditional automation	High automation	Full automation
The vehicle can assist the driver in selected functions, e.g. steering or acceleration/ deceleration	Driver can disengage from some tasks with the vehicle taking over but must always be ready to take control and is responsible for most safety functions	The vehicle is in full control of driving respon-sibilities under certain specified conditions, but a driver is expected to take control when required	These vehicles are designed to perform all safety-critical functions and respond to many dynamic driving situa-tions, requiring minimal human intervention	Vehicle can perform all aspects of driving under all circumstances that are usually managed by a human driver, without a driver being present

High | Human intervention | No intervention

Sources: Boston Consulting Group

While the U.S. pioneers self-driving cars, China will be the market leader

Autonomous cars: Key highlights

The U.S. pioneers autonomous vehicle deployment

The U.S. is expected to be the global leader in the initial deployment and adoption of autonomous vehicles, with the total volume in the country expected to reach 7.4 million units in 2040. Europe and Mainland China are next in line with many models scheduled for release over the next few years. However, many such scheduled launches have been postponed in the past due to various technology limitations.

Mainland China is a market leader

Favorable regulations, strong domestic demand, heavy private sector investment, and rapid advancements in artificial intelligence are four factors propelling Mainland China to the top of the table in terms of total units sold. According to IHS, 14.5 million autonomous vehicles will be sold in the country on an annual basis by 2040. Moreover, McKinsey estimates revenue from sales of autonomous vehicles and mobility services to exceed US$500 billion by 2030.

First use by technology firms

Companies such as Alphabet, Uber, and Lyft will be the first to deploy autonomous vehicles as part of their mobility services fleets. This is expected to provide consumers with actual hands-on experience with the technology and reduce overall skepticism.

European demand to be driven by private ownership

As opposed to mobility services driving demand in the U.S., Europe is expected to witness more instances of individual ownership of autonomous vehicles, mainly due to unfavorable regulations for public use. IHS estimates annual sales of 5.5 million in 2040.

Late deployment and limited adoption in other countries

Factors such as strong local automotive industries, strict regulations governing autonomous driving/mobility services and unconducive driving conditions are expected to limit adoption and deployment in a few countries. Exceptions to this are countries such as Japan, South Korea, Australia, and Canada.

Sources: Boston Consulting Group; Fortune; IHS

"The advanced sensing and computing hardware on an autonomous vehicle needs a lot of electric power. Compared to an internal combustion engine, an all-electric battery pack acts as a more stable power source that can enable higher-powered AV components."

Why All AVs Should be EVs, General Motors
2023

Mobility services and technology investments drive the market

Autonomous cars: Key drivers

Mobility services

Mobility services such as ride-hailing introduced by companies such as Uber and Lyft are the primary drivers of industry growth and will be directly responsible for the mainstream adoption of autonomous cars, much before individual ownership gathers momentum.

Technology investment

Huge investments in transportation technologies by auto manufacturers, providers of mobility services and technology companies will result in new partnerships. A technology enabled ecosystem and new business models will drive further growth. Subsequently, technology advancement will enhance the ability of OEMs to scale up and alleviate many of the current supply chain limitations.

Pollution control initiatives

As stated before, governments around the world are increasingly implementing policies to phase out ICE vehicles in favor of the more environmentally friendly hybrids and electric vehicles. The fact that most autonomous cars will have an electric power train is expected to further drive the market.

Reduced mortality and spending on public safety

An Intel study also concluded that increased use of autonomous cars would result in the saving of many lives, which would lead to cost savings on public safety of over US$234 billion between 2035 and 2045.

Economic benefit

According to estimates by the World Economic Forum, driverless cars are expected to generate over US$1 trillion worth of 'economic benefits to consumers and society'. Another study by Intel and Strategy Analytics claims that autonomous vehicles will be responsible for US$7 trillion worth of economic activity and new efficiencies annually by 2050. This will include about US$4 trillion from driverless ride-hailing and US$3 trillion from driverless delivery and business logistics.

Smart infrastructure

With the influx of more AVs on the roads, municipal bodies will start enhancing transportation infrastructure by modernizing highways and thoroughfare with smart technology for road signs, traffic lights, and merge lanes. Better infrastructure will rapidly accelerate autonomous car adoption.

Sources: Boston Consulting Group; Credit-Suisse; Fortune; HIS; MIT

Deep learning making fully autonomous cars a reality

Autonomous cars: Deep learning

Even though the required hardware such as sensors, cameras, radars, and ultrasound systems have contributed heavily to making autonomous cars a reality, it is really the developments in artificial intelligence technologies that are playing the most pivotal role.

Deep learning architectures enable cars to learn from their experiences and adapt to real-time situations without human intervention. This is particularly important because it is impossible for software engineers to write programs to cover every variable or driving situation a car may face. In fact, deep learning is solely responsible for the evolution of cars from driver assist technologies to fully autonomous vehicles.

For deep learning to be successful, it is imperative that the algorithms are fed with large amounts of data. One of the most important trends driving automation in the industry is the growth in the number of connected cars. As autonomous cars share driving experiences and readings with each other, algorithms use that data to adapt to various situations without having to experience them firsthand.

Google, the global leader in self-driving technology, launched the testing phase of its self-driving car called Waymo in 2017. Since then, its autonomous vehicles have driven 20 million miles on public roads and over 10 billion miles in computer simulation. Waymo also started a self-driving taxi service in Arizona in 2018. Tesla has also rolled out the Model 3 with full self-driving capability, equipped with its own custom chip (ASIC), after replacing Nvidia’s AI system that uses deep learning to teach the car to handle itself.

Even though Google and Tesla are the most visible brands chasing driverless technology, a host of auto manufacturers and other technology companies are also partnering with each other to develop cars with varying levels of autonomy. A few key examples can be found in the following table.

Sources: Company sources

"Deep learning is the best enabling technology for self-driving cars. You hear a lot about all these things on a car: the sensors, the cameras, the radar, and LIDAR. What you need are the brains to make an autonomous car work safely and understand its environment."

Sameep Tandon, CEO and co-founder
Drive.ai

Overview on autonomous car models

Autonomous cars: Autonomous car models

Company	Model	Autonomy level	Range in miles	Launch year
Alphabet	Waymo	Level 4	N/A	2018
Audi	aicon	Level 5	500	Undecided
	A9 e-tron	Level 4	311	2024
	Q6 e-tron	Level 4	310	2022
	Elaine	Level 4	311	Concept
Baidu-BAIC Group	Apollo Moon	Level 4	N/A	2024
BMW	7 series	Level 3	435	2022
Faraday Future	FF91	Level 4	300	2022
Fisker	Emotion	Level 4	400	Undecided
Byton (Previously Future Mobility Corp)	Byton	Level 4	250	Undecided

Company	Model	Autonomy level	Range in miles	Launch year
General Motors	Cruise Origin	Level 4	-	2023
Jaguar Land Rover / Waymo	Jaguar I-Pace	Level 5	298	Undecided
Kia	Niro EV	Level 2	239	2018
Mercedes-Benz	EQS	Level 3	480	2022
Navya	Autonom Cab	Level 4	N/A	2018
Porsche	Mission E	Level 4	310	Concept
Renault	SYMBIOZ	Level 4	N/A	Concept
	Easy Drive	Level 2	N/A	2019
	EZ-ULTIMO	Level 4	N/A	Concept
Toyota	Concept-i	Level 5	186	Concept

statista

Sources: Autocar Professional; Carwow; Bloomberg; CNN; The Verge; Greentech Media; Digital Trends; Businessinsider; Green Car Congress; Top Gear

Cruise is the market leader in terms of disengagement

Autonomous cars: Disengagement (1/2)

With the development of autonomous vehicles still in a nascent stage, companies around the world are urged by their respective governments to carry out tests to assess their potential for successful integration with other means of public transport. Over the last few years, these tests were required to be carried out on public roads and have mostly proved to be successful, with only a few accidents reported.

California Department of Motor Vehicles (DMV) released a disengagement report on all licensed entities testing autonomous vehicles on public roads in the state for the year 2022. Disengagement is defined as the situation when the autonomous feature in a vehicle is deactivated due to a mechanical or operational failure, forcing the driver to take control.

Companies testing self-driving cars in California are required to submit an annual report on the number of miles their vehicles were successfully deployed in autonomous mode and how often the backup driver had to take control. According to the DMV, out of the 50 registered companies, only 24 reported testing in 2022 although around 6 million miles were driven, reflecting a sharp increase over the previous two years.

Interestingly, even though 50 companies have valid permits to test autonomous vehicles on Californian roads, only seven of them can transport passengers. These include Apollo, AutoX, Cruise, Nuro, Waymo, WeRide, and Zoox.

Waymo reported the highest number of autonomous miles driven at 2.9 million, up from 2.3 million miles in 2021. Its disengagement rate improved considerably from 1 for every 7,200 miles in 2021 to 1 for every 17,060 miles in 2022. In 2020, only 21 disengagements or 0.033 per 1,000 miles were registered over the course of the year.

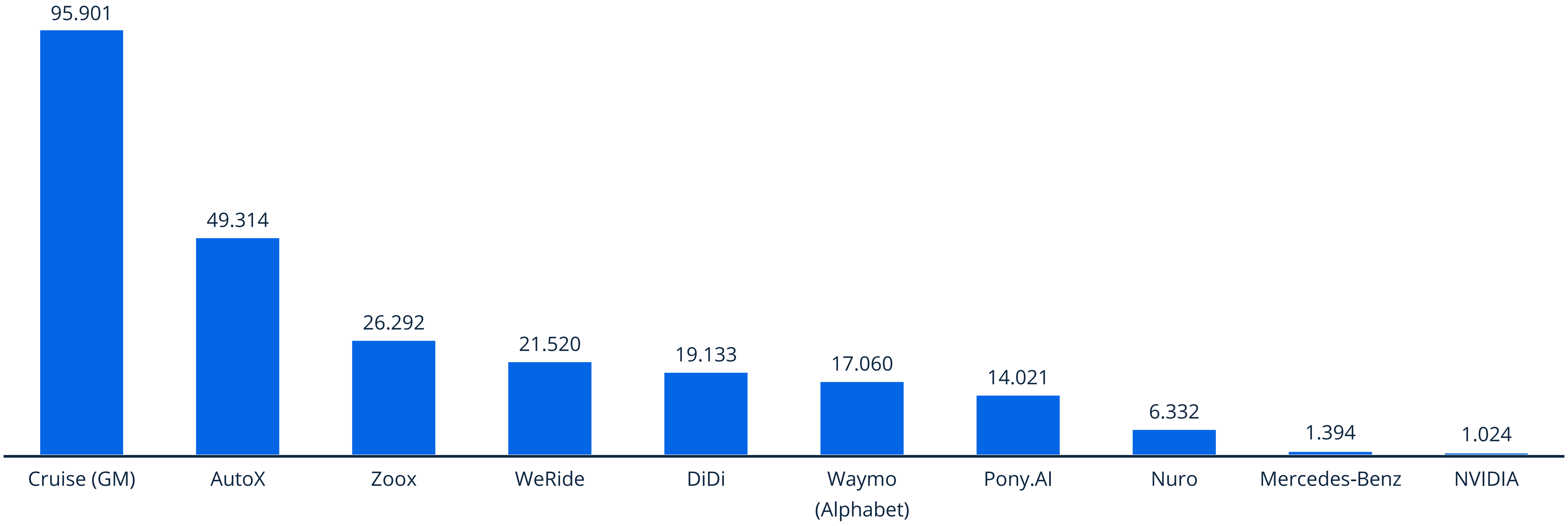
Cruise, which is backed by Honda, and Zoox ranked second and third for the most autonomous miles driven: 1.7 million and 552,133, respectively. Their disengagement rates were 1 per 95,901 miles and 1 per 26,292 miles, respectively.

Sources: Disengagement Reports 2018; The Last Driver License Holder; The Verge

Cruise cars average nearly 30k miles before being disengaged

Autonomous cars: Disengagement (2/2)

Miles before a disengagement for leading companies in 2022[(1)]



Notes: (1) Between Dec 2021 and Nov 2022

Sources: DMV California

Large OEMs work on car-sharing models with electric vehicles

Shared cars: Overview

The current proliferation of electric vehicles is being accompanied by the rise of the car-sharing model. Electric vehicles are simply better suited to car-sharing than a car with an ICE. This is primarily because the operational costs of running an electric vehicle are lower than those for a gas-powered one. Therefore, the payback on the price premium for an electric vehicle will be realized more quickly in case of shared fleets, as opposed to if it's used by just an individual. According to Morgan Stanley estimates, vehicles in car-sharing fleets have the potential to be utilized at a rate of about 50% a day compared with 4%, or less than an hour a day, for most privately owned vehicles.

Ride-sharing services being deployed by companies like Uber, Lyft, Kuaidi Dache, and Ola are disrupting the current ownership model that leaves cars significantly under-utilized. Global governments are coming out in favor of these companies in order to reduce congestion-related pollution and the need for additional road infrastructure. The positive environmental impact is potentially the biggest winner, and the induction of shared electric vehicles only multiplies this effect. Large auto manufacturers such as Ford, Toyota, Volkswagen, and BMW are also launching electric car-sharing operations, as they seek new ways to adapt to congestion and changing consumer attitudes.

Below is a list of OEMs and independent companies that launched electric car-sharing programs:

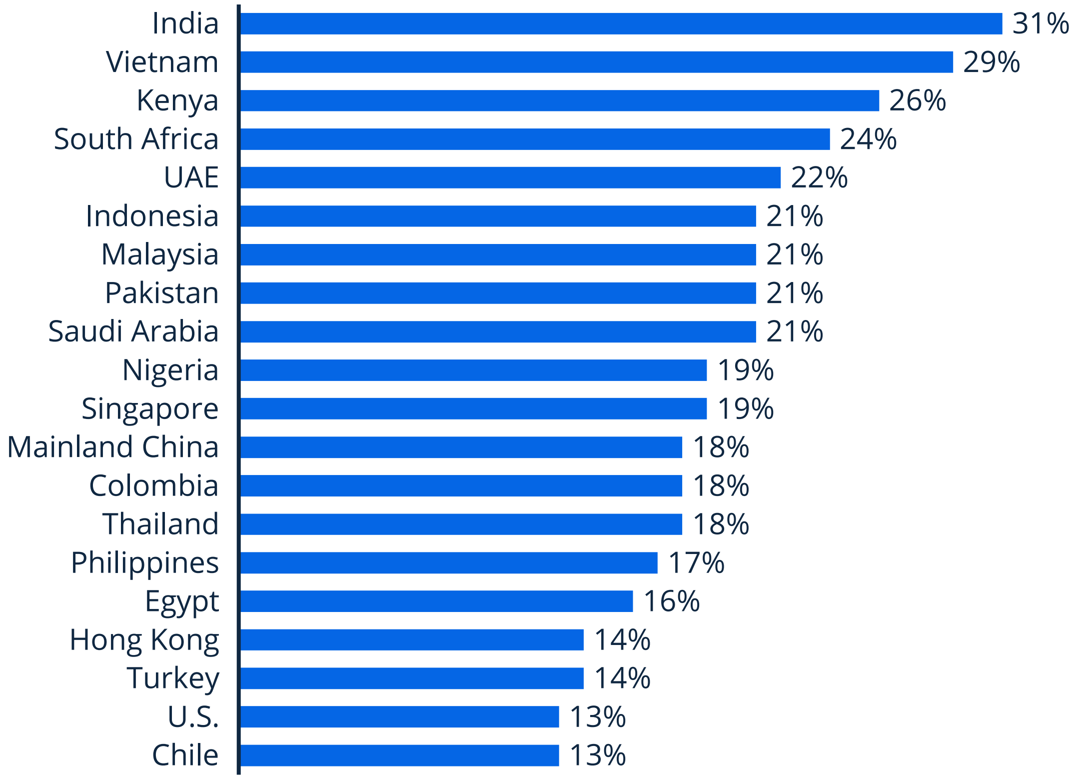
- BlueSG: A unit of France's Bollore Group launched an electric car-sharing program in Singapore in December 2017 with an initial deployment of 80 cars and 32 charging stations. It currently has a fleet of 667 shared electric Bluecar vehicles and 1,487 charging stations, spread across 374 locations around the country.
- Share Now: Launched in 2011 as BMW DriveNow, the program merged with Daimler's car2go in November 2019. It uses the i3 along with fuel-powered variants of models such as the 1 series and Mini.
- Honda: Launched the NeuV (New Electric Urban Vehicle) for the ride-sharing market. The two-seat vehicle uses AI technology to study the driver's reactions and patterns and makes recommendations on music and tips on daily driving habits.
- Volkswagen: In 2019, Volkswagen launched its electric car-sharing service WeShare in Berlin and extended operations to Hamburg in 2021. However, the business was sold to car-sharing startup Miles Mobility in 2022.

Sources: Company sources; Electrek

India leads the game in terms of car-sharing use with 34% usage

Shared cars: Consumer insights (1/2)

Share of respondents who booked car-sharing[1] in the last 12 months



When it comes to the use of car-sharing, Indians lead the way with 31% usage. Statista's Global Consumer Survey, comparing 56 countries[2] based on interviews with more than 60,000 consumers, shows that Vietnam and Kenya follow with 29% and 26% car-sharing use, respectively.

The U.S., which is usually the leader in new business models, is in 19th place with 13%. Generally, the field is dominated by Asian and African countries. This is not surprising, as car makers have many car-sharing alliances in the Asia-Pacific region.

Looking at user demographics, there are quite a few differences depending on the country. In India, for example, car-sharing users are young and from middle to high income households.

In the U.S., the age profile of car-sharing users is similar. However, the percentage of females using car-sharing services in the country are lesser, as compared to India.

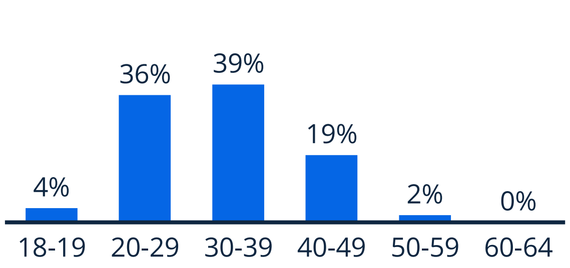
Notes: (1) Short-time car rentals (2) Only a selected few countries are shown in the graph; "Which of these services have you booked online (website or app) in the past 12 months?"; Multi Pick; Statement: "car-sharing (short-time)"; n=39,281

Sources: Statista Consumer Insights, as of April 2022

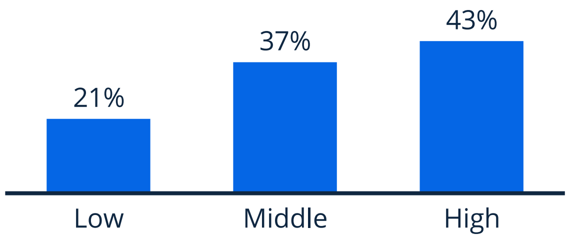
Car-sharing user demographics in India and the U.S.

Shared cars: Consumer insights (2/2)

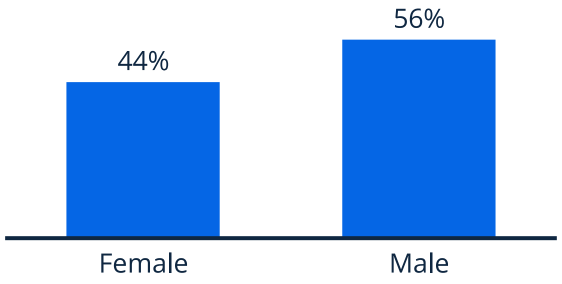
Users by age in India



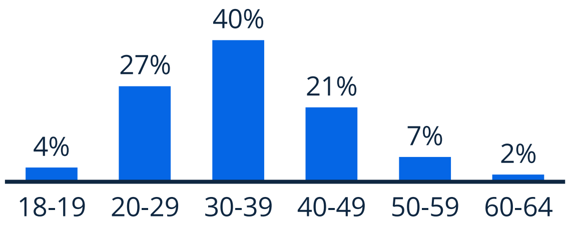
Users by income[1] in India



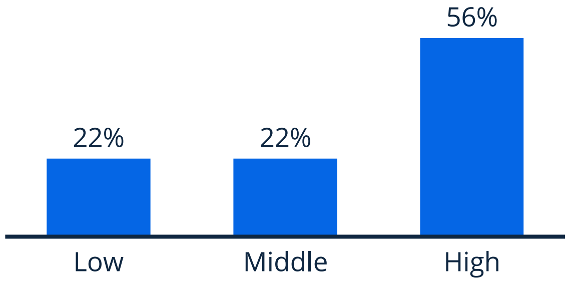
Users by gender in India



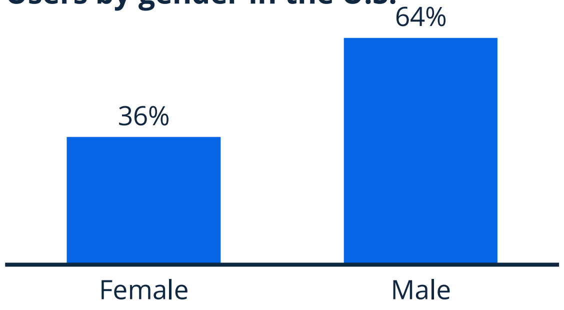
Users by age in the U.S.



Users by income[1] in the U.S.



Users by gender in the U.S.



Notes: (1) Low income depicts bottom 33% of households, medium income depicts mid 33% of households, high income depicts top 33% of households
"Which of these services have you booked online (website or app) in the past 12 months?"; Multi Pick; Statement: "car-sharing (short-time)"; India: n=1,236; the U.S.: n=1,309

Sources: Statista Consumer Insights, as of July 2023

China has the largest number of EV sharing alliances

Shared cars: Car-sharing

OEM origin country	OEM	Car-sharing affiliate	Availability
Mainland China	BAIC	BAIC Mobility	China
	BYD	Didi Chuxing	China
	Chery	Gofun Chuxing	China
	Geely Group	Microcity	China
	JAC Motors	1byongche	China
	Kandi	Microcity	China
	Lifan	Pand-Auto	China
	SAIC	Evcard	China
Germany	Volkswagen	Zoomcar	India
India	Mahindra & Mahindra	Zoomcar	India

OEM origin country	OEM	Car-sharing affiliate	Availability
Japan	Nissan	Choimobi	Yokohama, Japan
		E-Share mobi	Japan
	Subaru	DriveMyCar	Australia
	Toyota	Ha:mo	Japan, Thailand
South Korea	Hyundai	Deal Car	South Korea
		Green Car	South Korea
	Kia	WiBLE	South Korea
		Green Car	South Korea
U.S.	Ford	Zoomcar	India
		Carhood	Australia

Sources: Bloomberg New Energy Finance

Europe and U.S. to play a key role in the li-ion battery supply chain

Battery supply chain (1/2)

China currently dominates the global lithium-ion battery supply chain, largely due to its robust domestic demand which was valued at 280GWh in the first half of 2022 alone, as well as huge public and private investments, and favorable policies. It also controls 80% of global raw material refining, 77% of cell capacity, 90% of anode and electrolyte production, and 75% of overall battery cell manufacturing capacity. According to a 2021 study by Bloomberg New Energy Finance (BNEF), this capacity is expected to more than double over the next five years.

Interestingly, Europe, Canada, and the U.S. are expected to play more important roles in this supply chain in the years to come. A boom in European electric vehicle demand is expected to drive cell production closer to home, especially considering the COVID-19 pandemic which has emphasized the importance of local supply chains and the ability for trade-free tariff in the region. As a result, European countries such as Germany, Sweden, Finland, and Norway have already been placed in the top ten countries of 2022 in terms of lithium-ion battery supply chain ranking according to the 2022 BNEF study.

The U.S., which placed second in the 2021 study, has dropped to third in 2022, but is still one of the strongest countries in this space. The industry received a major boost due to Joe Biden's victory in the U.S. presidential election, which bodes well for the adoption of electric vehicles in the country. In fact, within hours of assuming office Biden re-signed the Paris Agreement for climate change, which had been previously repealed by the Trump administration. Moreover, initiatives such as Tesla's commitment to aggressive lithium mining, and increased participation and cooperation of private and public sectors, are expected to move the country up the lithium-ion supply chain, with an estimated overall ranking of three and a ranking of one in cell component manufacturing, by 2025.

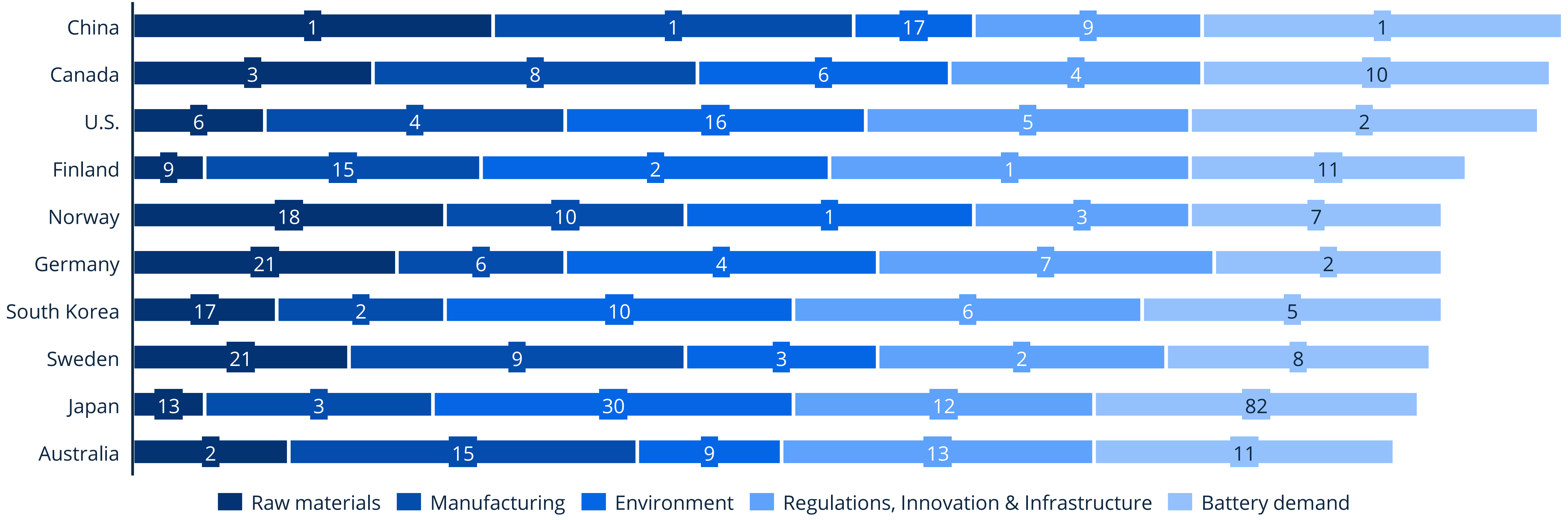
Surprisingly, Canada rose to number two in the 2022 rankings due to its large raw material resources and mining activity, as well as its favorable positioning in environmental, social, and governance factors (ESG).

Sources: Bloomberg New Energy Finance; Utility Dive

China leads the global lithium-ion battery supply chain

Battery supply chain (2/2)

Global lithium-ion battery supply chain ranking 2022



Sources: BNEF

"China's dominance of the industry is to be expected given its huge investments and policies the country has implemented over the past decade. Chinese manufacturers, like CATL, have come from nothing to being world-leading in less than 10 years. The next decade will be particularly interesting as Europe and U.S. try to create their own battery champions to challenge Asian incumbents who are already building capacity in both places."

James Frith, Head of Energy Storage
BNEF, 2020

Quantum computing could deliver higher range batteries

Quantum computing (1/2)

Quantum computing involves the use of qubits, which are essentially sub-atomic particles such as electrons and photons, to deliver significantly higher amounts of processing power, compared to conventional computers. Recent advancements such as IBM's latest quantum computer Q System One, and D-Wave Technologies' C chip with 5,000 "qubits" have opened-up various possibilities for potential applications across industries.

Industry experts estimate the automotive industry to be one of the leaders in the adoption of quantum technology over the medium to long-term. In fact, according to McKinsey estimates, almost 10% of all current potential use cases under exploration are expected to be ideal for automobile manufacturers and other players across the value chain. Listed below are some of the key application areas in the electric vehicle industry:

Higher range batteries

One of the main impact areas of quantum computing in the electric vehicle industry is the development of higher range batteries. Daimler is currently using the technology to further research the development of lithium-sulfur (Li-S) batteries, that are not only more powerful and long lasting but also cheaper compared to lithium-ion batteries. This involves the creation of accurate simulations of molecular events in a battery to more precisely determine their fundamental behavior and find a compound's most stable configuration. Since this process involves complex calculations to track the interaction between all particles in a molecule, it is not possible to use standard computers.

In addition, Hyundai, in partnership with quantum computing company IonQ, is using the technology to improve lithium-ion batteries. Using chemical simulation and computational acceleration provided by quantum computing, the company hopes to increase the capacity and durability of the batteries. The partnership is pivotal to Hyundai's Strategy 2025, which includes selling over 550,000 electric vehicles annually and launching over 12 new models. Additionally, quantum computing also enables researchers to get a better understanding of the quantum weirdness of elements, often described as quantum entanglement[1].

Notes: (1) Entanglement is a property of quantum mechanics, in which, when one particle changes its state, so does its entangled 'partner,' simultaneously.

Sources: The Quantum Daily; McKinsey; Forbes

Quantum computing could be the key to achieving level 4 and 5 autonomy

Quantum computing (2/2)

New product development

Suppliers will be able to use the technology to simulate processes related to areas such as chemical manufacturing and fluid dynamics, thereby enabling them to improve the kinetic properties of materials such as lightweight structures and adhesives. Further, manufacturers of fuel tanks and tubing can use their expertise in liquid storage and transportation systems to produce cooling circuits for batteries. Therefore, companies across the value chain are making robust investments to develop their quantum computing capabilities. An example is Bosch's 2019 investment in the Harvard quantum computing spinout called Zapata Computing to improve its expertise in sensor technology and cryptography.

Autonomous driving

Despite the progress made by EV manufacturers over the last decade, they haven't been unable to achieve level 4 or level 5 autonomy. Industry experts have tipped quantum computing as the missing link to develop a completely autonomous vehicle, owing to its much higher processing power and minimal error rates. It is not only expected to facilitate faster analyses of roadway data but to also deliver 'quantum sensors' with the ability to 'see' further than conventional sensors.

Sources: The Quantum Daily; McKinsey; Forbes

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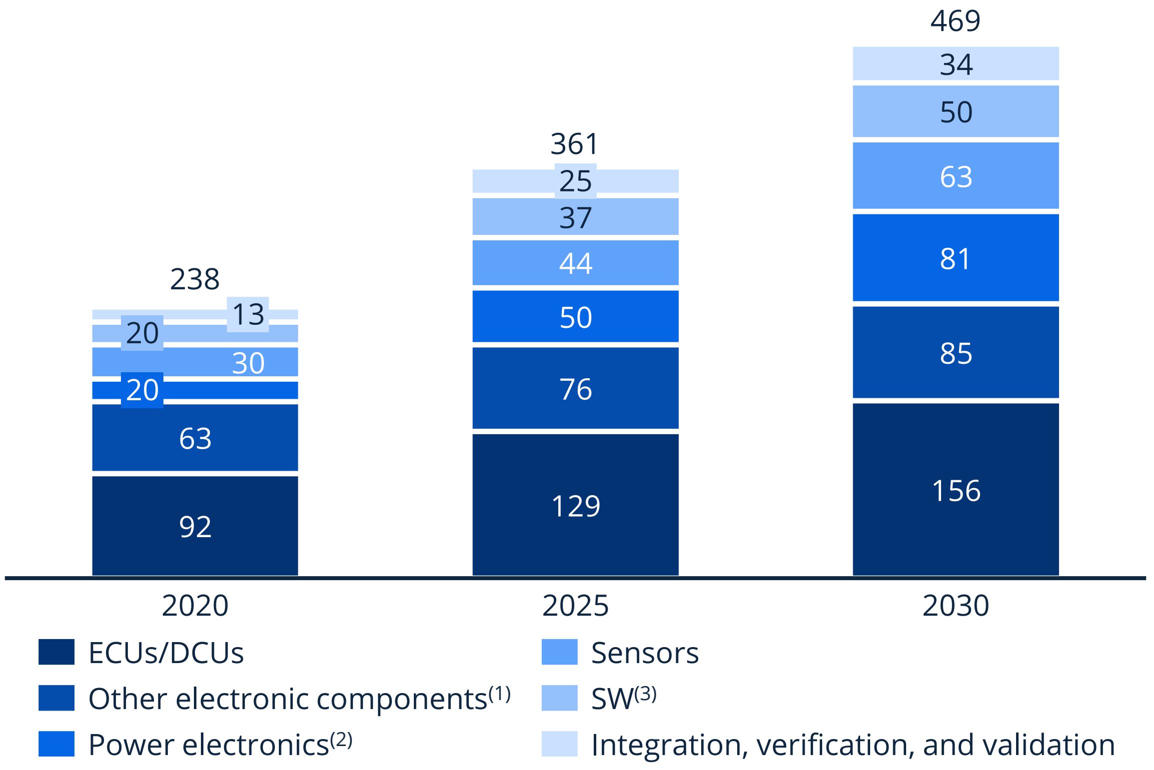
Strong demand for automotive electronics and software

Automotive electronics and software

The global automotive industry is currently at an inflection point, gradually moving from a decentralized architecture where functions run on dedicated and independent electronic control units (ECUs) to a more centralized one with dedicated domain controllers. The future is expected to usher in an era of fifth generation virtual domains, where independent control units control the functions of different domains. This shift, which in turn is being driven by the growing popularity of autonomous, connected, electric, and shared (ACES) vehicles, is expected to create demand for related software and electronic components such as domain control units (DCUs), ECUs, harnesses, switches, smart sensors, displays, and software. In fact, a 2019 McKinsey study estimates the global market for automotive software and electrical and electronic components to almost double from US$238 billion in 2020 to as much as US$469 billion in 2030.

The highest revenue generating segment is expected to be ECUs/DCUs, followed by components such as harnesses, controls, switches and displays, power electronics (excluding battery cells), sensors, software and finally integration, verification, and validation services. The power electronics segment, however, is expected to witness the strongest growth over 2020-2030 at a CAGR of 15%, followed by integration, verification and validation services (10%), software (9%), and sensors (8%).

Automotive software and electronic components market in billion US$



Notes: (1) Includes harnesses, controls, switches and displays (2) Excluding battery cells (3) Includes functions, OS and middleware

Sources: The Quantum Daily; McKinsey; Forbes

CHAPTER 5

Battery technology

Lithium-ion batteries dominate the market mainly because they deliver the highest range at the lowest cost when compared to any other battery.

However, due to limitations such as long charging times, the battery's size, and heavy weight, as well as limited battery capacity, companies such as Toyota, Volkswagen, Nissan, and Tesla are now investing in solid-state, lithium-sulfur, and zinc-air batteries for their future models.

Further, universities, technology companies, and independent battery start-ups are collaborating to develop other types of batteries, such as aluminum-ion, smart membranes, and graphene-based supercapacitors to enable faster charging times and longer life cycles.

Innovations in battery technologies are key to widespread EV adoption

Overview

The battery is the most important and expensive component in an EV and currently accounts for roughly half its cost. A study by Bloomberg New Energy Finance (BNEF) estimates this share to fall to 18% of the cost by 2030. The same study also estimates that battery prices will have to fall by more than half before EVs can compete with ICE prices.

Companies and research organizations all around the world are undertaking large scale innovation projects to improve their chemistries in order to achieve longer ranges, faster charging times, and increased safety.

The lithium-ion (Li-ion) family of batteries - the most widely used in EVs globally, mainly relies on a combination of cobalt, manganese, nickel, graphite, and other primary components. Other battery types include solid-state, aluminum-ion, lithium-sulphur, lithium-iron, graphene-based supercapacitors, and lithium-air. Some of these are already in production while others are in various stages of development.

Despite their popularity, high costs and the limited range available on a single charge have been the main barriers preventing widespread adoption of li-ion powered EVs, even though their operating costs are much lower than those of ICEs.

However, the last few years have witnessed a steep decline in price as manufacturers increase their production scale and develop more cost-effective manufacturing methods. Various experts believe that a major adoption hurdle will be eliminated when EV batteries are able to deliver a range of 400-500 miles on one charge at a cost of around US$100 per kWh. Interestingly, this is already happening in China with the price of battery packs for electric buses. According to BNEF's 2021 Battery Price Survey, the average battery pack price is expected to fall below the US$100 per kWh mark by 2024.

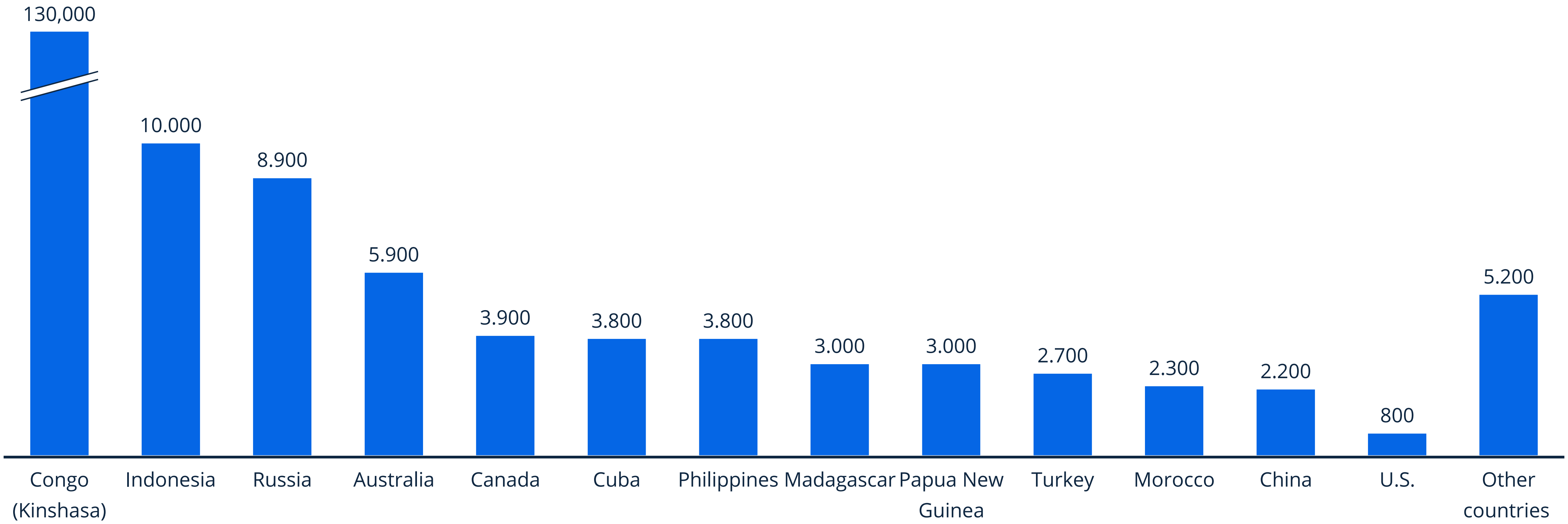
Nevertheless, one of the most important challenges facing battery manufacturers are the limited global reserves of lithium and cobalt, the key elements that go into making lithium-ion batteries. According to the U.S. Geological Survey, lithium-ion batteries in cell phones and the growing electric car industry make up about 49% of the global cobalt demand. However, with a majority of global cobalt reserves located in Congo - a politically unstable region where conducting business is often unpredictable and unethical - manufacturers face an uphill task in the years to come.

Sources: Bloomberg New Energy Finance; Battery University

Congo produces the most cobalt...

Global cobalt production and reserve (1/2)

Cobalt production in 2022[1] in metric tons



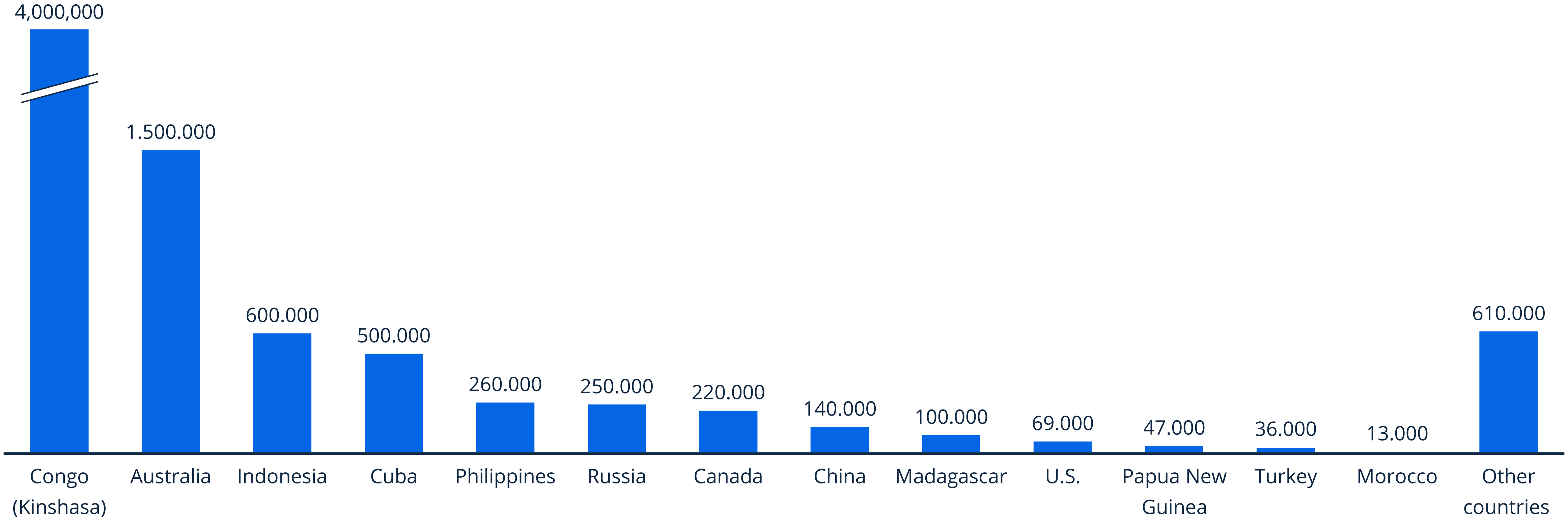
Notes: (1) Estimated figures

Sources: U.S. Geological Survey

...and also has the highest reserves

Global cobalt production and reserve (2/2)

Economically viable cobalt reserve in 2022 in metric tons



Sources: U.S. Geological Survey

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Many breakthroughs are made to improve lithium-ion batteries

Lithium-ion battery (1/2)

Lithium-ion batteries are the most widely used energy storage systems in electric vehicles globally. This is simply because they deliver the maximum range at the lowest cost, compared to all other currently available technologies.

The battery chemistry includes a positive electrode, typically made of lithium-cobalt oxide or lithium iron phosphate, and a negative electrode, usually made of carbon (graphite). The electrolyte between them is usually liquid but new research is focusing on polymeric electrolytes, which are more stable.

The main areas where they score over other batteries are:

- High cyclability(1)
- Lower maintenance
- Low self-discharge rate
- Rapid technological advancements due to widespread adoption

Technological breakthroughs

- In December 2016, Watt Laboratory, part of Huawei's Central Research Institute, launched a graphene-assisted lithium-ion battery, which allows them to be functional in a 60-degree Celsius environment—10 degrees higher than the existing limit. According to the company, this allows the batteries to operate for twice as long as ordinary lithium-ion batteries.
- In October 2017, Toshiba launched a next-generation lithium-ion battery with a new anode material called titanium niobium oxide. This doubled the capacity of the anode of current batteries and is expected to give EVs a 320 km range—three times the distance possible after only six minutes of ultra-rapid charging.
- In March 2023, the U.S. Department of Energy's Argonne National Laboratory announced the development of a lithium-air battery that uses a solid electrolyte instead of a liquid to increase the battery's energy density by up to four times.
- In July 2023, researchers at Rice University replaced the traditional anode material with silicon to bond with more lithium ions, thereby increasing the battery's lifespan by as much as 44%.

Notes: (1) High cyclability is the number of times the battery can be recharged while still maintaining its efficiency

Sources: Company sources; Press releases

Many breakthroughs are made to improve lithium-ion batteries

Lithium-ion battery (2/2)

Technological breakthroughs

- In February 2018, researchers in Shinshu University, in Japan announced the development of a new means to improve lithium-ion battery efficiency. This was done by growing a cubic crystal layer to create a thin and dense connecting layer between the electrodes of the battery.
- In February 2020, researchers at the WMG department at the University of Warwick claimed to have developed a new technology that enables lithium-ion batteries to be charged up to five times faster than current limits.
- In July 2020, scientists at the Texas A&M University's College of Engineering introduced carbon nanotubes into the electrode of a lithium metal battery which has the potential to drastically reduce charging times.
- Lithium-ion batteries use graphite anodes instead of silicon anodes, despite the latter's significantly greater energy density (10x). Silicon anodes have a higher degree of volatility that makes them unstable. In September 2021, engineers at the University of California found a way to overcome this shortcoming in silicon anodes by replacing the liquid electrolyte with sulfide-based solid electrolyte.

Sources: Company sources; Press releases

Volkswagen & Toyota planning on using solid-state batteries

Solid-state battery

Almost every electric vehicle in the market today is powered by lithium-ion batteries. However, these batteries have their limitations including charge times, weight, size and the amount of charge they can hold. Therefore, automotive companies such as Bolloré, Volkswagen, Toyota and the Renault Nissan alliance and technology companies such as Sakti3 and QuantumScape are investing heavily in solid-state batteries.

Solid-state batteries make use of a solid material instead of the liquid electrolyte currently used in lithium-ion cells. This reduces the chances of electrolyte leaks and fires, increases battery lifetime, and decreases the need for expensive and heavy cooling systems.

Bolloré, Sakti3 and QuantumScape are current examples of companies investing in solid-state batteries for electric cars. Toyota plans to have these batteries in all its production vehicles by 2025.

Technological breakthroughs

- In February 2017, John Goodenough, the co-creator of the lithium-ion cell, announced the creation of a glass-electrolyte solid-state battery with three times the energy density of a regular lithium-ion battery. It is also expected to be lower in costs because it would allow for the use of cheaper sodium extracted from seawater for the electrolyte, rather than the more expensive lithium used in other solid-state batteries.
- In May 2021, researchers at Harvard University announced that they had developed a lithium metal solid-state battery that could be charged and discharged at least 10,000 times. This technology could extend the lifetime of electric vehicles to around 10-15 years, without replacing the battery even once, while also achieving full charge within 10-20 minutes.
- In June 2023, researchers at Osaka Metropolitan University claimed to have achieved an advanced level of stabilization of the high-temperature phase of Li_3PS_4—a critical material for all-solid-state batteries—thereby attaining significantly improved ionic conductivity even at room temperature.

Sources: Company sources; Press releases

Aluminum-ion batteries catch up with regards to their lower density

Aluminum-ion battery

Aluminum-ion batteries offer many advantages over the commonly used lithium-ion batteries in terms of safety, charging time and cycle life.

In April 2015, a team of researchers at Stanford University working on advanced battery packs developed an aluminum-ion battery that reduced the chances of catching fire compared to lithium-ion batteries. The aluminum-ion battery also features fast charging capabilities, has a longer life cycle and does not pollute the environment.

One of main disadvantages until recently was the low energy density, making it unusable for the electric vehicles. However, in March 2016, a Chinese research team achieved substantial progress in developing an aluminum-graphite, dual-ion battery (AGDIB), that offers a higher energy density along with other benefits such as reduced weight, volume and fabrication cost.

According to Tang Yongbing, leader of the research team, the AGDIB has the following advantages compared to conventional lithium-ion batteries:

- Ca. 50% lower production costs
- Ca. 1.3-2.0 times higher specific density
- Ca. 1.6-2.8 times higher energy density

More recently, in June 2021, the Australian company Graphene Manufacturing Group (GMG) claimed to have developed graphene aluminum-ion battery cells that charged 60 times faster than contemporary lithium-ion cells and could hold three times the energy of the best aluminum-based cells. These cells were created using nanotechnology developed by the University of Queensland.

Sources: Stanford; ScienceDaily; Light Metal Age

Lithium-sulphur batteries may still achieve a higher cycle life

Lithium-sulphur battery

Lithium-sulfur (Li-S) batteries, which are yet to enter mainstream production for use in electric vehicles offer twice the energy density of lithium-ion batteries and are expected to provide a range of 450 kilometers on a single charge. Other key advantages of these batteries are that sulphur is non-toxic, safe, and inexpensive.

Until now the main problem with these batteries was that they would deteriorate after only a few charges. However, a research team at the Lawrence Berkeley Labs in California have modified these cells using graphene oxide as an electrolyte. This has enhanced their capacity to at least 1,500 cycles, without deterioration.

Technological breakthroughs

- UK based OXIS Energy has made significant advancements in its commercial development of an Li-S battery with successful testing of over 400 watt-hours per kilogram in October 2016.
- In November 2016, scientists at the University of Cambridge developed a new prototype battery that uses a Li-S cell to provide up to 5 times the energy density of a lithium-ion battery. The design of this battery is inspired by human intestines.
- In January 2020, researchers at Monash University reconfigured the design of sulfur cathodes to accommodate higher stress loads without a drop in overall capacity, or performance. This has the potential to enable an electric vehicle to travel 1,000 kilometers without needing to recharge.
- In April 2020, researchers at the Cockrell School of Engineering at the University of Texas at Austin created an artificial layer containing tellurium inside the battery in-situ and on top of lithium metal to make it last four times longer.
- In July 2020, energy technology company Brighsun New Energy announced that it had developed a technology that would prevent the generation of polysulfide on the sulfur cathode of a battery, thereby suppressing dendritic growth that hampers battery functioning. According to company researchers, this process allows the Li-S battery to keep 91% of its initial capacity even after 1,700 cycles.
- In March 2023, scientists at the U.S. Argonne National Laboratory announced that they had created a porous sulfur-containing layer within the battery that can help protect the materials from the dendrite destruction. This would enable the battery to charge and discharge 700 times, making it competitive with today’s lithium-ion batteries.

Sources: Company information; Press releases

Smart membranes to prevent charge leaks in EV batteries

Smart membrane

Batteries losing charge over time is a major concern for the battery pack manufacturers, as the membrane that conducts the charge and physically separates the anode and the cathode often fails to prevent the charge leak.

In August 2016, researchers at the Ohio State University developed a thin plastic membrane that stops rechargeable batteries from discharging when not in use, while at the same time allowing for rapid recharging.

The technology, which is inspired by the characteristics of living cell membranes that transport proteins in the body without losing their efficiency, controls how charge flows inside the battery. The 'smart' membrane is expected to result in the development of 'redox transistor batteries' that will enable EVs to achieve higher battery ranges. The new battery pack will store energy in a liquid electrolyte which people can refill as they would refill a gas tank.

In January 2022, scientists at the University of Michigan claimed to have developed a biologically inspired membrane which could increase the charge capacity of electric vehicle batteries by as much as 400%. The membrane is made using recycled Kevlar, which is then transformed into a network of nanofibers similar in structure to a cell membrane.

Sources: Press releases

“Achieving record levels for multiple parameters for multiple materials’ properties is what is needed now for car batteries. It is a bit similar to gymnastics for the Olympics – you have to be perfect all round including the sustainability of their production.”

Nicholas Kotov, Professor of chemical sciences and engineering at the University of Michigan

Study published in Nature Communications, 2022

Graphene-based supercapacitors still lack energy storage capacity

Graphene-based supercapacitors

Also called electrochemical double layer capacitors (EDLCs), the supercapacitors are made up of two layers of graphene with an electrolyte layer in the middle. The graphene-based supercapacitor film, which is only one atom thick can fit into multiple areas in a vehicle, as opposed to ordinary batteries that take up a lot of space.

Besides its size, it also scores higher than traditional batteries in terms of faster charging times, longer life cycles, and the ability to function optimally at low temperatures.

However, one of its current limitations that has made it unviable for mainstream EV use is its low storage capacity: it can store only 5% of the energy that lithium-ion batteries can.

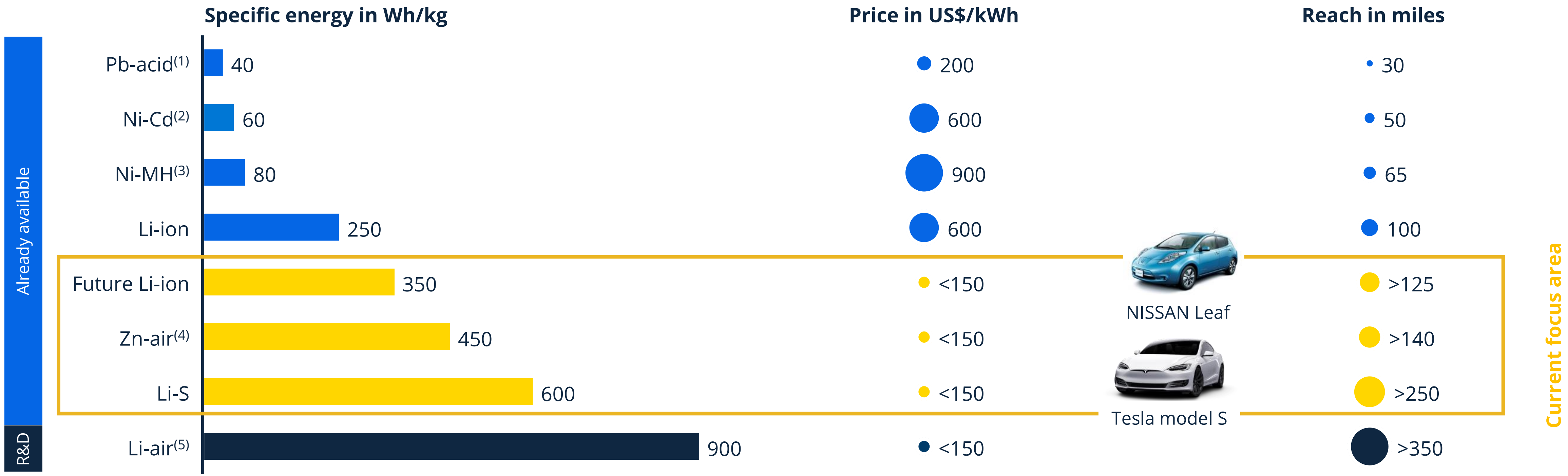
- In November 2017, Samsung announced that it had developed a technology using a 'graphene ball' with the potential to boost battery capacity by as much as 45% and charging speeds by 500%.
- In August 2020, scientists at the Integrated Nano Systems Lab (INSys Lab) in the Centre for Clean Energy Technology announced that they had found a way to improve the performance of supercapacitors, which have historically been prone to leakages due to the fabrication with liquid electrolytes. Developing these electrolytes together with carbon-based electrode materials, such as graphene, graphene oxide, and carbon nanotubes has resulted in improved energy storage performance.
- In June 2021, researchers from Imperial College London and University College London announced that they had developed a cheaper, more sustainable, and energy-dense electrode material for supercapacitors, which would lead to more advanced battery charging technology. The team used lignin, a bio-based by-product derived from the paper industry, to create free-standing electrodes with better energy storage capacity.
- In April 2023, the Indian Institute of Science announced that it had developed the smallest micro-supercapacitor yet using the two-dimensional materials graphene and molybdenum disulfide (MoS_2). The resulting device has a capacitance of 1.8 millifarad per square centimeter (mF/cm^2).

Sources: Iflscience; Science Daily; Phys.org

Tesla Models S currently with best battery specifications

Battery comparison (1/2)

Battery technologies: reach, price, specific energy, and development stage



Notes: (1) Lead-Acid batteries (2) Nickel-Cadmium batteries (3) Nickel–metal hydride battery (4) Zinc–air batteries (5) Lithium-Air batteries

Sources: University of Illinois at Chicago

Comparison of selected battery pack performance factors

Battery comparison (2/2)

Battery	Energy density in Wh/kg	Costs in US$/kWh	Avg. lifespan in # discharge cycles	Safety
Lead-Acid	30–42	250-260	500-800	Environmental concerns
Nickel-metal hydride	60–140	-	180-2000	Environmental concerns
Lithium-ion	100 –265	273	Ca. 400–1200	Flammable materials, requires careful disposal
Solid-state	2x that of lithium -ion batteries	N/A (cheaper than li-ion)	ca. 10 years	Nonflammable
Aluminum-ion	1,060	250	>7,500	Nonflammable, non-hazardous
Lithium-sulphur	500	NA (cheaper than li-ion)	>1500	Nonflammable

Sources: University of Illinois at Chicago

CHAPTER 6

Electrification of public transport

Rising pollution levels, potential operational cost savings, and heavy dependence on public transportation are the three major factors driving the gradual switch from hydrocarbon-based to electrified public transport.

The total number of electric buses in the world is expected to witness a 235% increase from 800,000 in 2022 to about 2.7 million in 2030, with Mainland China accounting for a share of more than 96%.

Financial support from the government, a large urban population and the resultant pollution, a lack of legacy transportation infrastructure, global trade, and increased public awareness are the five key reasons for Mainland China’s dominance.

Public transportation is another major application for EVs

Overview

One major application of electric driving technology besides cars are buses and other transportation vehicles in the public transportation system. Rising pollution levels, potential operational cost savings, and heavy dependence on public transportation are the three major factors driving the gradual switch from hydrocarbon-based to electrified public transport. According to the 2023 Electric Vehicle Outlook report by Bloomberg New Finance (BNEF), the global e-bus market is changing quickly as cities make increasingly ambitious fleet electrification commitments. By 2032, almost half of the global bus fleet will be battery powered, and this number is expected to increase to 75% by 2045.

Rising pollution

Tailpipe emissions from internal-combustion engines are one of the major sources of harmful pollutants such as nitrogen oxides and particulates. According to World Health Organization estimates, road transportation is responsible for up to 30% of particulate emissions in Europe and up to 50% in OECD countries—mostly due to diesel vehicles.

Cost savings

Even though e-buses are more expensive to acquire than internal-combustion engine buses, lower long-term operating costs in terms of fuel, maintenance expenses, and falling battery prices, add to the cost competitiveness of electric buses.

According to a study conducted by Bloomberg New Energy Finance, all-electric bus configurations will become cost competitive with diesel buses in just a few years.

Dependence on public transport

Most of the urban population worldwide is now heavily dependent on public transportation and governments across the world are beginning to invest in and make significant commitments to more sustainable and cost-effective transportation options. The rapid rise of eCommerce and related logistics is also contributing majorly to the growth in this segment. In fact, according to the 2010 BNEF report over one-third of all commercial vehicles on the road are expected to be either electric or fuel-cell by 2040.

Sources: Bloomberg New Energy Finance

Mainland China dominates the global e-bus market

Mainland Chinas‘ e-bus dominance (1/3)

According to the International Energy Agency (IEA) report, the total number of electric buses in the world is expected to witness a 235% increase from 800,000 in 2022 to about 2.7 million in 2030, with Mainland China accounting for a share of more than 96%. Total sales of electric buses in the country increased over five-fold from 23,188 units in 2014 to 122,332 in 2017, before falling sharply to 60,446 units in 2020. This is mainly due to a gradual subsidy phase out from 2016 and a decline in the overall bus market. However, the electric buses sales regained momentum in 2021 with 85,902 units, an increase of around 42% over 2020 sales. As of 2022, E-buses make up around 14% of the total Chinese bus fleet, with pure electric buses clearly dominating over plug-in hybrid buses. The five main reasons behind Mainland China’s dominance are:

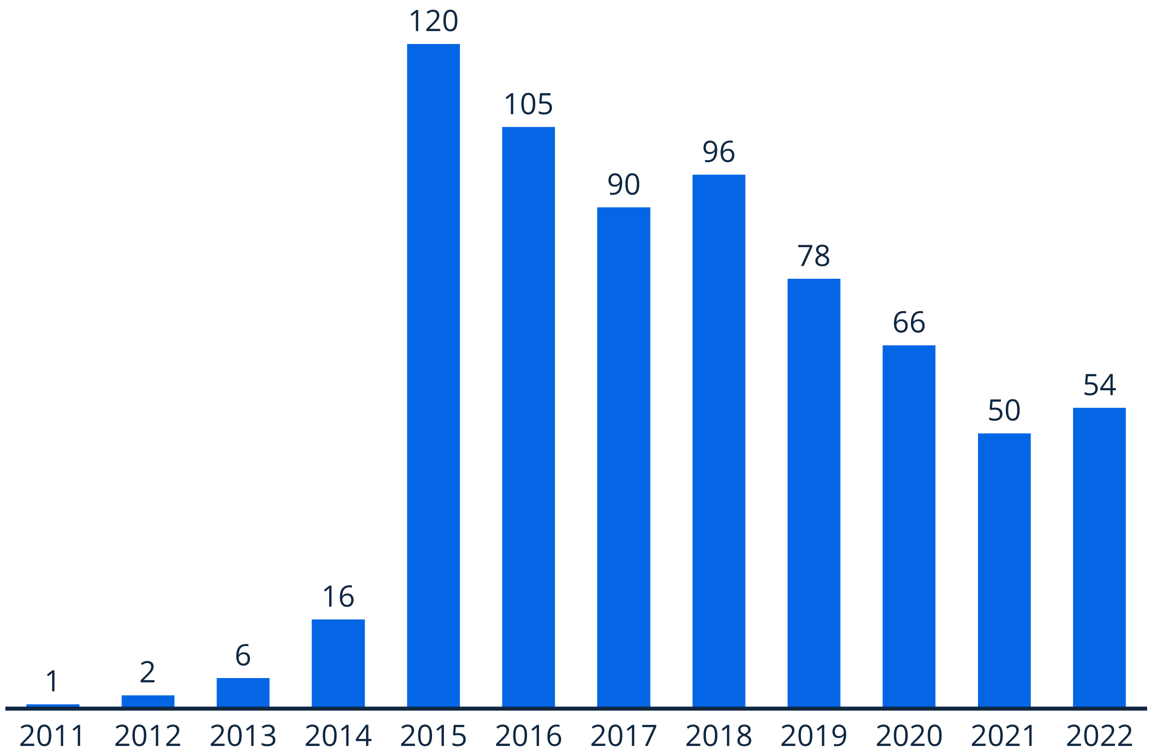
- Financial support: Robust government support in the form of subsidies helped to bring the total cost of an electric bus below that of a similar diesel variant, thereby resulting in increased adoption.
- Global trade: The Chinese government’s robust support for the industry also stems from their desire to create domestic companies which are able to be market leaders in foreign markets as well.
- Large urban population and the resultant pollution: The sheer scale of Mainland China’s public transportation network due to its large urban population, was the major contributor to the country’s rising pollution levels. The politicization of this issue resulted in quick government intervention and the passing of policies favorable for the electrification of the entire public transportation infrastructure.
- Lack of legacy transportation infrastructure: While Europe and the U.S. try and incorporate electric buses into their complex existing public transportation infrastructure, many Chinese cities have the luxury of building entirely new public transportation networks, which makes the task much easier.
- Increased public awareness: While Mainland China has been taking steps to curb air pollution for several years now, public awareness of air pollution in Europe gained traction only after the Volkswagen diesel emissions scandal. Cities such as Shanghai and Shenzhen have already stopped purchasing new ICE buses.

Sources: Bloomberg New Energy Finance; International Energy Agency (IEA)

Mainland China’s e-bus sales started to increase in 2015

Mainland Chinas‘ e-bus dominance (2/3)

Electric bus sales in Mainland China in thousands



Selected municipal e-bus fleet projects in Mainland China

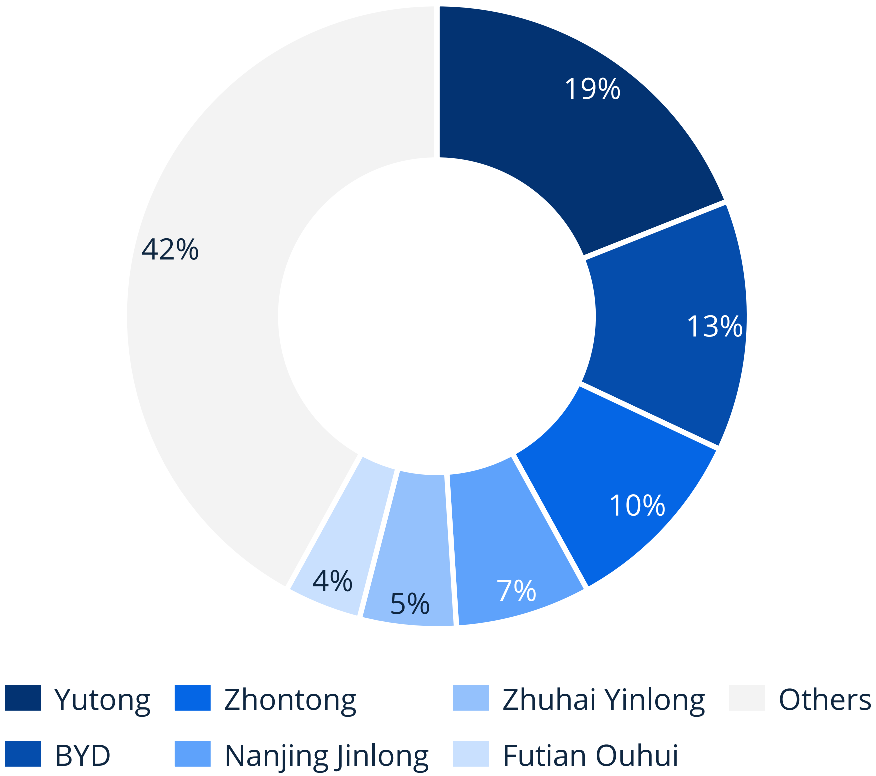
City	#e-buses	Year	Manufacturer	Status
Beijing	1,426	2017	Zhongtong	Delivered
	2,120	2020	BAIC Foton	Delivered
	2,790	2020	Foton	Delivered
Qingdao	347	N/A	Zhongtong	Announced
Shangqiu	635	2016	Yutong	Delivered
	100	N/A	Yutong	Announced
Shenzhen	1,000	2012	BYD	Delivered
	3,600	2016	BYD	Delivered
	16,500	2017	N/A	Delivered

Sources: International Energy Agency (IEA); Bloomberg New Energy Finance; China Buses

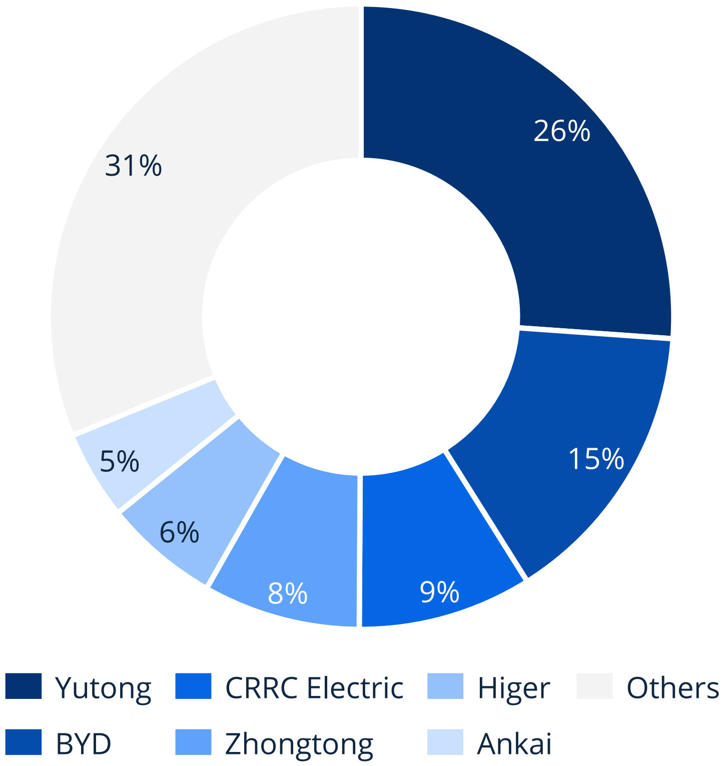
Yutong holds the largest market share in 2020, followed by BYD

Mainland Chinas‘ e-bus dominance (3/3)

Market shares of pure electric bus producers in Mainland China in 2017



Market shares of pure electric bus producers in Mainland China in 2020



Sources: Bloomberg New Energy Finance; Sustainable Bus

Municipal e-bus fleet projects (1/3)

Municipal e-bus fleet projects

Country	City / transit agency	#e-buses	Year	Manufacturer (model)	Status
Egypt	Alexandria / Passenger Transport Authority	15	2018	BYD (K9)	Delivered
France	Paris / RATP	23	2016	Bollore (Bluebus)	Delivered
		4500	2025	Bollore (Bluebus)	Announced
	Strasbourg/ Compagnie des Transports Strasbourgeoi	12	2019	Alstom Aptis	Delivered
		49	2021	Irizar ie	Delivered
Germany	Cologne	8	2015	VDL (Citea SLF)	Delivered
	KVB Cologne	51	2021	VDL	Announced
	BVG Berlin	15	2020	Mercedes	Delivered
		107	2020	Solaris	Delivered

Country	City / transit agency	#e-buses	Year	Manufacturer (model)	Status
Germany	Hamburger Hochbahn	530	2021-2025	Daimler, MAN, and Solaris	Delivery in progress
	Hamburg/Verkehrsbetriebe Hamburg-Holstein (VHH)	53	2022	MAN Truck & Bus	Announced
	Düsseldorf/ Rheinbahn	10	2019	Irizar ie	Delivered
Hungary	Budapest	20	2016	Evopro	Delivered
Israel	Haifa	17	2017	BYD	Delivered
Netherlands	Eindhoven	43	2016	VDL	Delivered
	Rotterdam public transport operator	55	2018	VDL	Delivered
	Amstelland-Meerlanden	100	NA	VDL (Citea SLF)	Delivered
		18	NA	VDL (Futura)	Announced

Sources: University of Illinois at Chicago; Sustainable Bus

Municipal e-bus fleet projects (2/3)

Municipal e-bus fleet projects

Country	City / transit agency	#e-buses	Year	Manufacturer (model)	Status
Netherlands	Den Haag HTM	5	NA	VDL (Citea SLF120)	Delivered
Norway	Trondheim	35	2019	Volvo (7900), Heuliezes	Delivery in progress
Poland	Trondheim	11	2020	Heuliez GX	Delivered
	Krakow	17	2017	Solaris (Urbino 12)	Delivered
		3	2017	Solaris (Urbino 18)	Delivered
	Warsaw	130	2019	Solaris	Delivered
Sweden	Gotheburg	157	2018	Volvo	Delivery in progress
United Kingdom	London	14	2017	BYD/ADL (Enviro 200EV)	Delivered
		105	2018	BYD/ADL (Enviro 400EV)	Delivered

Country	City / transit agency	#e-buses	Year	Manufacturer (model)	Status
United Kingdom	London	36	2018	NA	Announced
		56	2019	NA	Announced
	Manchester	32	2020	Stagecoach	Delivered
United States	Stockton / San Joaquin Regional Transit District	12	2017	Proterra (EcoRide)	Delivered
		5	2018	Protera (Catalyst E2)	Delivered
	Los Angeles County / Metropolitan Transportation	35	2020	New Flyer	Announced
		60	2021	BYD	Announced
		2200	2030	NA	Announced
	Los Angeles / Department of Transportation	25	2019	Proterra (Catalyst)	Delivered

Sources: University of Illinois at Chicago; Sustainable Bus

Municipal e-bus fleet projects (3/3)

Municipal e-bus fleet projects

Country	City / transit agency	#e-buses	Year	Manufacturer (model)	Status
United States	Los Angeles / Department of Transportation	359	2030	NA	Announced
	San Francisco / Municipal Transit Agency	185	2019	New Flyer8 (XT40)	Delivered
	Pomona, San Gabriel Valleys / Foothill Transit	361	2030	NA	Announced
	Albuquerque	20	2017	BYD	Delivered
	Clemenson Area Transit (South California)	10	NA	Proterra (Catalyst E2)	Delivered
	Porterville	10	2019	GreenPower Motor (EV350)	Delivered
	Park City	6	2017	Proterra (Catalyst FC+)	Delivered
Qatar	Lusail, Al Khor, Doha, Al Rayyan, Al Wakrah/Mowasalat	741	2022	Yutong	Delivered

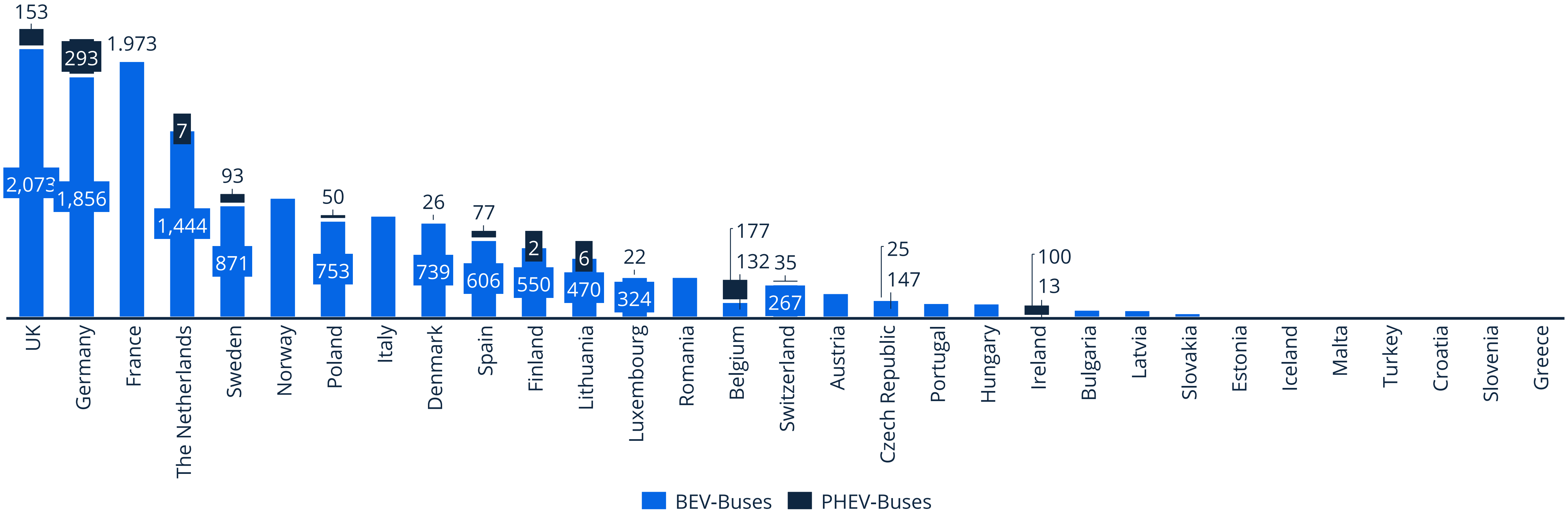
Country	City / transit agency	#e-buses	Year	Manufacturer (model)	Status
Chile	Santiago de Chile	100	2018	BYD	Delivered
	Santiago de Chile	100	2018	Yutong E12	Delivered
Colombia	Medellín	64	2019	BYD	Delivered
	Bogota	470	2020	BYD	Delivered
	Bogota	406	2022	BYD	Delivered
Italy	AMT Genoa	10	2019	Rampini	Delivered
	AMT Genoa	14	2020	Irizar ie	Delivered

Sources: University of Illinois at Chicago; Sustainable Bus

UK had the largest fleet in Europe in 2022, with 2,226 e-buses

E-bus fleet: Europe (1/2)

E-bus fleet in Europe in 2022

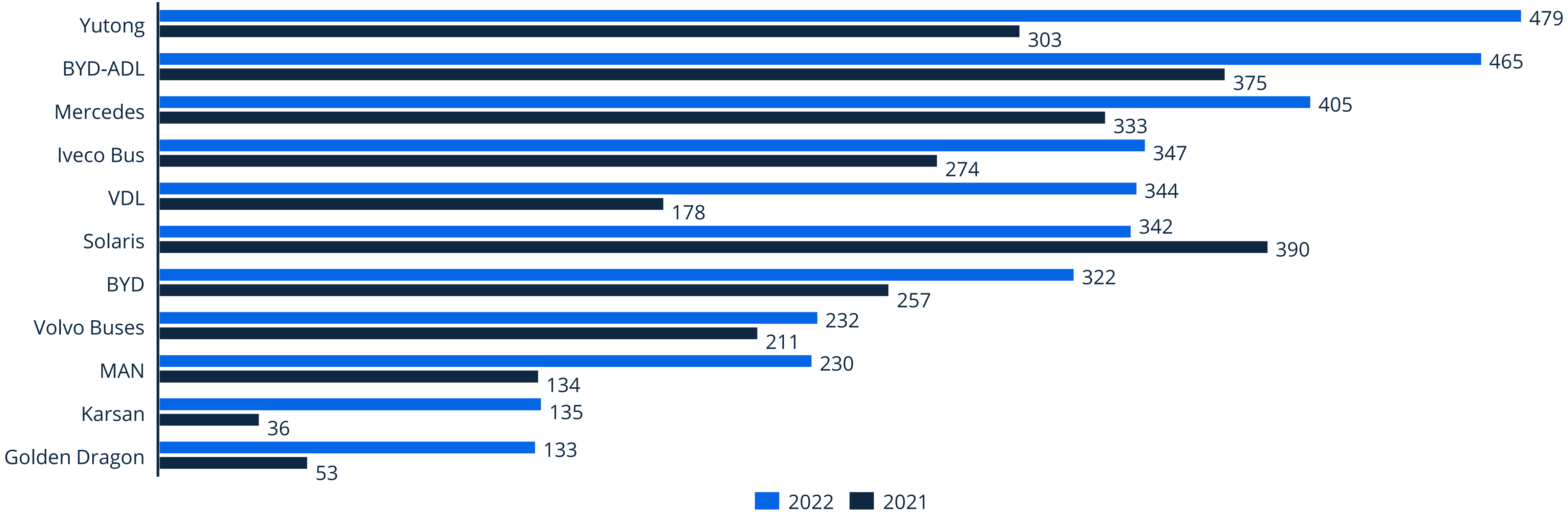


Sources: European Alternative Fuels Observatory

Yutong sold the highest number e-buses in 2022

E-bus fleet: Europe (2/2)

E-bus registrations in Europe



Sources: Sustainable Bus

Major e-bus manufacturers and their flagship models in China

E-bus models: Mainland China

Company	Model	Battery in kWH	Battery type	Battery Supplier	Range in km	Charging	Units sold
BYD	12m (China)	324	LFP[1]	BYD	250	Plug-in at depot at a rate 2x40kW	NA
	12m (Overseas)	422	LFP[1]	BYD	450	Plug-in at depot at a rate 2x40kW	NA
	18MLE	563	LFP[1]	BYD	250	Plug charging (CCS), pantograph charging	80 in Europe
	Double Decker	345	LFP[1]	BYD	330	Plug-in at depot at a rate 2x40kW	20,500 in China for 2015-2016
BYD-ADL	Enviro 200EV	348	LFP[1]	BYD	250	Choice of dual plug 2×40kW AC charging and single plug 102kW DC charging	51
Yutong	Yutong E12	295	LFP[1]	CATL	320	Plug-in at depot	35,000 in 2015-2016
Zhongtong Bus	LCK6122E VG	230	LFP[1]	China First Brand	414	Plug-in at depot	20,000 in 2015-2016

Notes: (1) Lithium iron phosphate battery

Sources: University of Illinois at Chicago

Major e-bus manufacturers and their flagship models (1/4)

E-bus models: Global (1/4)

Company	Model	Battery in kWH	Battery type	Battery Supplier	Range in km	Charging	Units sold
ADL	Enviro 400VE	61	NMC(1)	Akaso	30	NA	3
Bollore Group	Bluebus	240	LMP(2)	BlueSolutions	180	Plug-in at depot	23
Bozankaya	Sileo S10 and S12	200-260	LFP(3)	Bozankaya BC&C	235-260	Plug-in at depot	8
	Sileo S18	450	NA	NA	260	Plug-in at depot	NA
	Sileo S24	380	NA	NA	250	Plug-in at depot	NA
Carrosserie Hess	TOSA	70	LTO(4)	ABB	30	Conductive pantograph	1
DCGT	Temsa MD9	200	NMC(1)	Mitsubishi	230	CCS Combo2	NA
	Temsa Avenue	360	NMC(1)	Microvast	50	CCS Type 2	NA
Ebusco	Ebusco 12m	350	LFP(3)	Ebusco	700	Plug-in at depot	NA
	Ebusco 18m	500	LFP(3)	NA	700	Plug-in at depot	NA

Notes: (1) Lithium Nickel Manganese Cobalt Oxide battery (2) Lithium-Metal-Polymer battery (3) Lithium Iron Phosphate battery (4) Lithium–Titanite battery

Sources: Bloomberg New Energy Finance

Major e-bus manufacturers and their flagship models (2/4)

E-bus models: Global (2/4)

Company	Model	Battery in kWH	Battery type	Battery Supplier	Range in km	Charging	Units sold
Evopro	ModuloC68e	144	LFP(1)	Valence	200-230	Conductive	20
	ModuloC88e	84	LFP(1)	NA	120-140	NA	NA
Heuliez Bus	GX337 ELEC	349	NMC(2)	Foresee	200	NA	1
	GX437 ELEC	106	LTO(3)	NA	NA	NA	NA
Hybricon Bus System	ArcticWhisper	40-120	LTO(3)	Altair-Nano	30-55	Pantograph	NA
	City BusHCB	38-265	NMC2	BMZ	NA	Pantograph	9
Irizar	Irizar I2e	376	NaNiCl (ZEBRA)(4)	FIAMM	250	Plug-in at depot, Combo2	13
Optare	Solo EV	138	LiFeMgPO4(5)	Valence	270	Depot charging	56
	Metrocity EV	NA	NA	NA	205	NA	13
	Versa EV	NA	NA	NA	NA	NA	13

Notes: (1) Lithium Iron Phosphate battery (2) Lithium Nickel Manganese Cobalt Oxide battery (3) Lithium–Titanite battery (4) Sodium–Nickel Chloride battery (5) Lithium Iron Phosphate battery

Sources: Bloomberg New Energy Finance

Major e-bus manufacturers and their flagship models (3/4)

E-bus models: Global (3/4)

Company	Model	Battery in kWH	Battery type	Battery Supplier	Range in km	Charging	Units sold
Optare	Metrodecker	200	NA	NA	NA	Depot charging	NA
Proterra	Catalyst FC	79-105	LTO(1)	Toshiba	80-100	Pantograph, SAE J1772 CCS connector	100
	Catalyst bus XR	220-330	NMC(2)	LG Chem	220-310	Pantograph, SAE J1772 CCS connector	NA
	Catalyst E2	440-660	NA	NA	405-560	Plug-in at depot or pantograph	NA
Solaris	Urbino 8.9	160	LFP(3)/LTO(1)	Solaris	200	Plug-in at depot or pantograph	5
	Urbino 12	300	LFP(3)/LTO(1)	NA	266	Plug-in at depot or on-route charging	93
	Urbino 18	550	LFP(3)/LTO(1)	NA	185	Plug-in at depot or on-route charging	5
Van Hool	Exqui.City 18m	215	LFP(3)	BFFT	120	Plug-in and inverted pantograph	40
VDL Bus & Coach	Citea LLE-99	180	NMC(2)	Multiple	100-150	Pantograph, depot charging, fast charging	67
	Citea SLF120	63-240	NMC(2)	Akasol, Durapower, Microvast	NA	Pantograph, Combo2	NA

Notes: (1) Lithium Iron Phosphate battery (2) Lithium Nickel Manganese Cobalt Oxide battery (3) Lithium–Titanite battery

Sources: Bloomberg New Energy Finance

Major e-bus manufacturers and their flagship models (4/4)

E-bus models: Global (4/4)

Company	Model	Battery in kWH	Battery type	Battery Supplier	Range in km	Charging	Units sold
VDL Bus & Coach	Citea SLF-180	63-180	NMC(1)	Akasol, Durapower, Microvast	NA	Pantograph, Combo2	NA
Volvo Bus	Volvo7900E	76	LFP(2)	SAFT	96	ABB OppCharge	11
	Volvo7900 (PHEV)	330	LFP(2)	SAFT	8.1	On-route charging (OC)	39

Notes: (1) Lithium Nickel Manganese Cobalt Oxide battery (2) Lithium–Titanite battery

Sources: Bloomberg New Energy Finance

CHAPTER 7

E-scooters

E-scooters recently gained popularity and are believed to be the solution to the problem of last-mile transportation in many global markets.

Even though the need to restrict environmental damage caused mainly by polluting vehicles is the overarching reason behind the development of various alternate fuel technologies, the e-scooter industry specifically is driven by the rise in micro-mobility, which aims to transform urban transportation through the use of cheaper and quicker alternatives to cars, especially in dense urban areas in the U.S., Asia, and Latin America.

E-scooters represent version 2.0 of the ride-sharing industry

Overview (1/3)

A few years ago, many cities around the world started promoting bicycle sharing services and bike lanes to reduce carbon emissions and offer users a quicker and more convenient way of travelling short distances. The recent popularity of e-scooters, which are believed to be the solution to the problem of last-mile transportation in many global markets, is mainly an offshoot of that.

There are currently two types of e-scooters in the market: dockless and the 'Vespa-like' ones, with the former being more popular in the U.S. and other western countries and the latter in Mainland China. The dockless e-scooters have an average top speed of around 15 miles per hour, are equipped with GPS trackers and wireless connectivity, and can be accessed and operated simply by using an app. They cost about US$3-US$4 per ride, with people using them mainly for short distances. The 'Vespa-like' scooters on the other hand are meant for longer distances, have a higher top speed, and usually cost more to ride.

The main companies operating dockless scooters are all U.S. based and include Bird, Lime and Spin (recently acquired by Ford), Goat, Scoot, and Skip. Bird, which started business in late 2017, is currently in around 75 U.S. cities, while Lime is in around 55 cities.

Types of e-scooters

Vespa-like

Dockless

Sources: Bloomberg; CNBC; Engadget; TechCrunch; Venture Beat; Risester

Rise in micro-mobility to drive the industry growth

Overview (2/3)

They have also expanded to markets in Europe such as Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Netherlands, Norway, Portugal, Romania, Spain, and Switzerland. Until now, Bird has received a total funding of US$916 million, while Lime has managed US$1.5 billion. Both the companies are expected to go public, which is a sign that investors are feeling more optimistic about the long-term survival of the e-scooter industry in a post-pandemic world. The major companies making more conventional or 'Vespa-like' e-scooters include Gogoro (Taiwan), Terra Motors (Japan), Vmoto (Australia), Jiangsu Xinri Electric Vehicle Company (Mainland China), Amego Electric Vehicles (Canada), and Govecs Group (Germany).

Drivers

Even though the need to restrict environmental damage caused mainly by polluting vehicles is the overarching reason behind the development of various alternate fuel technologies, the e-scooter industry specifically is driven by the rise in micro-mobility which aims to transform urban transportation through cheaper and quicker alternatives to cars. This is especially the case in dense urban areas in the U.S., Asia and Latin America. The lack of an incumbent industry which ride-hailing companies like Uber and Lyft had to deal with, is also driving market growth.

Challenges

In spite of such strong growth, the market has faced many challenges from authorities and consumers alike. For example, when Bird, Lime and Spin launched in San Francisco without a permit in March 2018, it led to their subsequent ban from the city in June. Also, governments in other cities in the U.S. have limited the number of e-scooters vehicles on the streets(1), thereby restricting market growth. Some consumers have also protested against their use because of the lack of proper parking spaces and the physical dangers they pose to pedestrians. The dockless system is regularly discarded on the sidewalk resulting in blocked doorways and congestion and can also result in an accident as they are used mostly on sidewalks. Further, the cost of maintaining the vehicles including changing their batteries daily, lack of adequate charging stations, low prices and lack of customer loyalty are other factors affecting business viability.

The E-scooter company Skip is the latest casualty in this market, having filed for Chapter 7 bankruptcy in August 2021. It hopes to sell off its assets to repay up to US$50 million in liabilities. Other notable insolvencies in the micro-mobility sector are Unicorn and Boosted, which went bankrupt in 2019 and 2020, respectively.

Nots: (1) San Francisco currently doesn't allow more than 2,500 e-scooters on the streets at any on time.

Sources: Ernst & Young; CultureMap; Bloomberg; Smart Cities Dive

Incumbents are wary of Uber and Lyft's entry

Overview (3/3)

Uber and Lyft

Even though market pioneers such as Lime and Bird are growing, they are also keeping an eye on Uber and Lyft, both of whom have now entered the e-scooter market. In September 2018, Lyft launched its first e-scooter sharing service in Denver, Colorado and then expanded to Santa Monica, California, Atlanta, Georgia and Nashville, Tennessee. However, the Covid-19 pandemic has adversely impacted its business leading to a shutdown of operations in Austin, San Jose and Oakland and a pause in business in Miami. Going forward, Lyft scooters will only be available in Denver, Los Angeles, San Diego, Santa Monica and Washington, D.C. Uber entered the market through the acquisition of Jump Bikes and is now in more cities than Lyft including San Diego, Los Angeles, San Francisco, Sacramento, Santa Monica, Santa Cruz, Austin and New York among others. It has also invested US$170 million in Lime. According to Bloomberg, Uber is also now manufacturing its scooters instead of buying the from Mainland China, thereby signaling its long-term interest in this market.

Manufacturing

Even though e-scooter ride-sharing is growing at a fast pace in the U.S. and Europe, it is a less known fact that most of these vehicles are procured in Mainland China and more specifically, Beijing based Ninebot. In fact, Ninebot is now the single largest supplier of e-scooters deployed in the U.S. According to the company's CEO Gao Lufeng, its e-scooter sales grew at a rate of 600% in FY2018, as compared to the year before. However, in spite of such robust growth, the company is facing unexpected challenges in the form of vehicle recalls over safety issues. In October 2018, Lime called back 2000 scooters for fear of them catching fire, thereby posing a question on the company's and indeed the industry's ability to churn products out in large numbers, with the industry being nascent.

Sources: Bloomberg; CNBC; Engadget; TechCrunch; Venture Beat

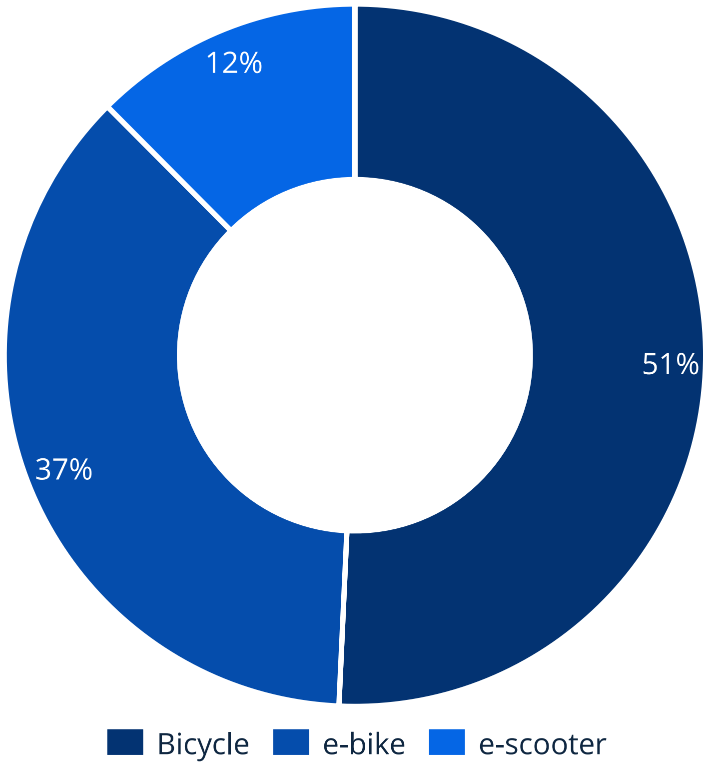
E-scooters seen as a solution for last-mile transportation

Barriers & preferences

Traffic congestion and growing pollution are among the biggest issues globally with many studies resting the blame on last-mile travel. In fact, according to a study conducted by Forbes, in the U.S., cars commuting for less than three miles are responsible for as much as 46% of all traffic on the roads. This is one of the major drivers of the shared mobility market, especially e-scooters and e-bikes, with data collected by Lime showing that 30% of riders in the U.S. are now opting for e-scooters rather than cars on their recent trips. Another factor pointing towards the industry's rapid growth is the enormous success enjoyed by e-scooter start-ups Lime and Bird, both of which have achieved over billion-dollar valuations within just a year of starting up.

However, despite the success, the e-scooter market in the U.S. has much room for growth as is evident from Statista's survey[1], which shows the acceptance rate of bicycles and e-bikes to be 51% and 37% respectively as opposed to just 12% for e-scooters. With Mckinsey estimating the U.S. micro-mobility market to value between US$200-300 billion by 2030, there seems to be plenty of room for growth in the medium to long-term. Moreover, a 2020 BCG study showed that 750 cities across the U.S. and Europe were well positioned to support large scale micro mobility.

Preference regarding shared mobility systems in %



Notes: (1) "Which of the following means of transportation in shared mobility systems do you prefer?"; Single Pick; n=481 respondents who have used a shared bicycle system at least once

Sources: Forbes; McKinsey; Deloitte; Statista Survey E-bikes and Shared Bicycle Systems in the U.S. 2019

Inexperienced riders are at higher risks of accidents with e-scooters

Accidents

Electric scooters are light, compact and ideal for quickly traveling through busy urban areas, especially when used together with public transport. They have become one of the hottest trends in the U.S. and many rental companies offer them for as little as US$1 per hour with a few cents added on for each minute of usage.

Unfortunately, even though these scooters may seem to be ideal to navigate through the ever-increasing traffic congestion, especially in major cities, they can also prove to be dangerous for inexperienced riders. There are no official numbers on global e-scooter deaths, but fatal accidents have been reported in a host of cities worldwide including Singapore, London, and Los Angeles. According to a 2020 study published in the JAMA Surgery journal, there was a 222% jump in the number of related injuries between 2014 and 2018.

Given these heightened safety fears about the severity of e-scooter accidents, researchers in the U.S. have published a new study about injuries from these mishaps for the first time. The analysis was carried out by the University of California Los Angeles (UCLA) and published in the medical journal; the JAMA Network Open.

Focusing on two emergency departments between September 2017 and August 2018, it found that 249 people involved in e-scooter accidents required medical care with a third of them brought to hospital by ambulance. Falls, collisions, and getting struck by moving vehicles or objects were the most common accidents documented. The resulting injuries were severe with 40% of accidents involving bone fractures, 32% head trauma, and 28% cuts, sprains and bruises.

Poignantly, the study found that only 4% of riders were wearing a helmet when their accident happened. Most e-scooter companies recommend wearing a helmet but there seems to be a very low adherence to this basic safety guideline. That lack of safety, coupled with increasing numbers of e-scooters in circulation has led to greater scrutiny of the situation. There is now talk of a ban unless safety protocols are strictly followed. As the discussion gets louder, the days of people riding without a helmet could thankfully be numbered.

Sources: Statista; University of California Los Angeles via JAMA Network

Development of autonomous e-scooters in its nascency

Autonomous e-scooters

The growing popularity of e-scooters is addressing the need to shrink the physical footprint required to help people commute over short distances. Even though this trend is still in its infancy, technology companies, lured by the vehicles' low-cost, potential return on investments and the need to address various pain points, have already started creating new products and business models.

One such development is the creation of autonomous e-scooters. In January 2019, Uber announced that it had already begun developing its own line under a new division called Micro-mobility Robotics. These scooters can drive themselves to charging stations, to locations where riders need them or to maintenance depots, thus eliminating the need for expensive manual intervention. In 2018, e-scooter company Bird spent almost half its gross revenue per ride on paying individual contract workers to charge its e-scooters and another 14% of the revenue to carry out repairs.

The Beijing based company Segway-Ninebot Group, has already unveiled an AI powered autonomous scooter called KickScooter T60, which can be controlled remotely via the cloud. According to a company statement, ride-sharing companies such as Uber and Lyft are being considered as potential customers, when the product is launched.

One of the main challenges facing manufacturers of autonomous e-scooters is the price. Any self-driving vehicle makes use of multiple sensors to perceive the world around it, with AI powered computers making sense of it. Even if they don't use Lidar, which is the most expensive and advanced sensor in the market today, the vehicle is still expected to cost much more than the traditional scooters. The KickScooter T60 is expected to sell at a price of around USS$1,420, which is four times the cost of the company's range of traditional scooters (US$100 to US$300).

Sources: Deloitte; Medium; Reuters

Major e-scooter manufacturers and their flagship models (1/2)

E-scooter models (1/2)

E-scooter Models	Type	Battery Range	Charging Time	Battery Used
Gotrax GXL V2	Dockless	12.5 miles	4 hours	Lithium-ion
Glion Dolly XL	Dockless	30 miles	5.5 hours	Lithium-ion
Glion SNAPnGO	Dockless	15 miles	3.5 hours	Lithium-ion
Hero Electric Photon LP	Vespa-like	56 miles	5 hours	Lithium-ion
Hero Electric Optima CX 2.0	Vespa-like	55 miles	4.5 hours	Lithium-ion
Hero Electric Nyx HS500 ER	Vespa-like	86 miles	4.5 hours	Lithium-ion
Hero Electric Flash LX	Vespa-like	53 miles	4.5 hours	Lithium-ion
Hero Electric Optima CX 5.0	Vespa-like	84 miles	6.5 hours	Lithium-ion
Hero Electric Eddy	Vespa-like	53 miles	5 hours	Lithium-ion
Hero Electric Atria LX	Vespa-like	53 miles	5 hours	Lithium-ion

E-scooter Models	Type	Battery Range	Charging Time	Battery Used
Kymco Like-EV	Vespa-like	-	-	Lithium-ion
Lightning Motorcycles LS-218	Vespa-like	188 miles	2 hours	Lithium-ion
NIU NGT	Vespa-like	56 miles	6 hours	Lithium-ion
NIU MQi+Sport	Vespa-like	40 miles	9 hours	Lithium-ion
NIU N Series	Vespa-like	45 miles	7 hours	Lithium-ion
NIU MQi GT	Vespa-like	56 miles	6 hours	Lithium-ion
Novoku 6.5 A3 Electric Scooter	Dockless	25 miles	-	Lithium-ion
Novoku 8 B2 Electric Scooter	Dockless	43 miles	-	Lithium-ion
Okinawa Praise PRO	Vespa-like	50 miles	3 hours	Lithium-ion
Razor Power E200 Electric Scooter	Dockless	6.2 miles	12 hours	Lithium-ion

Sources: Company websites; News articles

Major e-scooter manufacturers and their flagship models (2/2)

E-scooter models (2/2)

E-scooter Models	Type	Battery Range	Charging Time	Battery Used
Razor E300	Dockless	10 miles	-	Lithium-ion
Razor E-Prime	Dockless	7.5 miles	-	Lithium-ion
Razor EcoSmart Metro	Dockless	12 miles	-	Lithium-ion
Razor Power A2	Dockless	6 miles	-	Lithium-ion
Razor Power Core 90	Dockless	10 miles	-	Lithium-ion
Razor Power Core E90	Dockless	12 miles	-	Lithium-ion
Razor Power Core E100	Dockless	11 miles	-	Lithium-ion
Razor RX 200	Dockless	8 miles	-	Lithium-ion
Sunra Robo	Vespa-like	40 miles	4 hours	Lithium-ion
Sunra Robo-S	Vespa-like	61 miles	4 hours	Lithium-ion

E-scooter Models	Type	Battery Range	Charging Time	Battery Used
Sunra Mike Super	Vespa-like	65 miles	4 hours	Lithium-ion
Sunra Miku Max	Vespa-like	23 miles	4 hours	Lithium-ion
Swagtron Swagger 5	Dockless	12 miles	3.5 hours	Lithium-ion
SXT 1000 Turbo electric	Dockless	20 miles	-	Lithium-ion
Vectrix VX-1	Vespa-like	174 miles	3 hours	Lithium-ion
Vectrix VX-2	Vespa-like	62 miles	3 hours	Lithium-ion
Zero Motors-S	Vespa-like	89 miles	1.1 hours	Lithium-ion
Zero Motors-SR	Vespa-like	169 miles	1.4 hours	Lithium-ion
Zero Motors-DS	Vespa-like	82 miles	1.1 hours	Lithium-ion
Zero Motors-FX	Vespa-like	91 miles	1.3 hours	Lithium-ion

Sources: Company websites; News articles

CHAPTER 8

E-bikes

E-bikes are essentially conventional bicycles equipped with a rechargeable battery and motor, which helps them gain momentum faster and achieve speeds of up to 30 miles an hour. They look and function just like a traditional bicycle and give riders the option to use the pedal as and when they desire.

They can be classified according to their functionality (mountain bikes, road bikes, hybrid bikes, folding bikes, and utility bikes) or according to their design (Pedal Assist/Pedelec, Throttle, and Speed Pedelec).

The growing popularity of e-scooters around the world has piqued interest in e-bikes. The first e-bike was manufactured in Japan in 1993, with Yamaha launching its pedal assist bicycle.

E-bikes are classified according to functionality and design

Overview (1/3)

E-bikes are essentially conventional bicycles equipped with a rechargeable battery and motor which helps them gain momentum faster and achieve speeds of up to 20-30 miles an hour, depending on one's location. They look and function just like a traditional bicycle, and also give riders the option to use the pedal as and when they desire.

They can be classified according to their functionality – mountain bikes, road bikes, hybrid bikes, folding bikes and utility bikes – or according to their design – Pedal Assist/Pedelec (Class 1), Throttle (Class 2) and Speed Pedelec (Class 3).

Mountain bikes have more power on an average, with a maximum battery capacity of 700wh which supports riding through rough terrain. Road bikes are meant for moving around cities and towns; and for navigating through traffic easily. Hybrid bikes can handle rough roads and occasional park tracks which make riding more difficult due to the presence of gravel. Folding bikes, as the name suggests, fold up and are much easier to transport around and store. Utility bikes have cargo carrying capacities.

- Pedal Assist/Pedelec (class 1): This is the most common e-bike in the market allowing the rider to pedal normally while a motor increases the power transmitted to the rear wheel. Therefore, the pedaling requires far less effort even in higher gears. A class 1 e-bike in Europe cannot provide assistance over 15 miles per hour (mph), while in the U.S. the speed limit is 20 mph. These bikes are mostly used alongside regular bikes and do not require any additional licensing.
- Throttle (class 2): These e-bikes are more like motorcycles and scooters in that a throttle propels the bike forward without much input from the rider. They are much less common as compared to the class 1 bikes with many countries prohibiting them entirely. They're mostly available in the U.S. and Mainland China with the European Union (EU) completely disallowing their use.
- Speed Pedelec (class 3): These bikes are similar in design to a standard pedelec or class 1 but allow for a higher top speed of around 28 mph. Many countries require riders of these bikes to carry an additional license on account of them being motorized.

Sources: BikEeurope; European Cyclists' Federation (ELECTROMOBILITY FOR ALL, Financial incentives for e-cycling); Montague; The Royal Society for the Prevention of Accidents

Mainland China is the largest market for e-bikes

Overview (2/3)

The batteries used in e-bikes vary in chemistries, with the most common being lead-acid, nickel-metal hydride (NiMH), or lithium-ion (Li-ion). The low-cost bikes usually have a sealed Valve Regulated Lead-Acid (VRLA) battery, while the more expensive ones have either a nickel-metal hydride or lithium-ion battery. The type of batteries used also vary according to the country with Chinese companies using lead-acid and those in Europe using mostly nickel-metal hydride and lithium-ion.

Giant Manufacturing (Taiwan), Merida (Taiwan), Yamaha (Japan), NYCeWheels (U.S.), Robert Bosch (Germany), Accell Group (Netherlands), Derby Cycle (Germany), and Aima Technology (Mainland China) are some of the top manufacturers of e-bikes in the world. Giant Group is the largest in terms of revenue, with a total revenue of nearly US$3 billion in 2022.

The growing popularity of e-scooters around the world has piqued interest in e-bikes. The first e-bike to be launched ever was the Zike by Sinclair Research in 1992, but it was a commercial failure selling only 2,000 units. The first commercially successful e-bike was manufactured in Japan in 1993, with Yamaha launching its pedal assist bicycle equipped with its proprietary PAS (Power Assist System) technology. The bike had a lead battery and a range of 20 kms, with Yamaha selling 30,000 units in the first year alone. Even though regular updates to the PAS models had a positive effect on the market, it was only the revision of regulations governing a bicycle’s motor and road safety in 2008 that triggered mainstream adoption in the country. Today Japan is among the leading users of e-bikes, with Yamaha and Panasonic dominating the market.

Mainland China made the development of e-bikes an official technology goal in 1991 and is currently the largest manufacturer and user of e-bikes in the world. According to the China Bicycle Association (CBA), the country currently has around 700 companies manufacturing e-bikes with the top 10 accounting for about half of the total production.

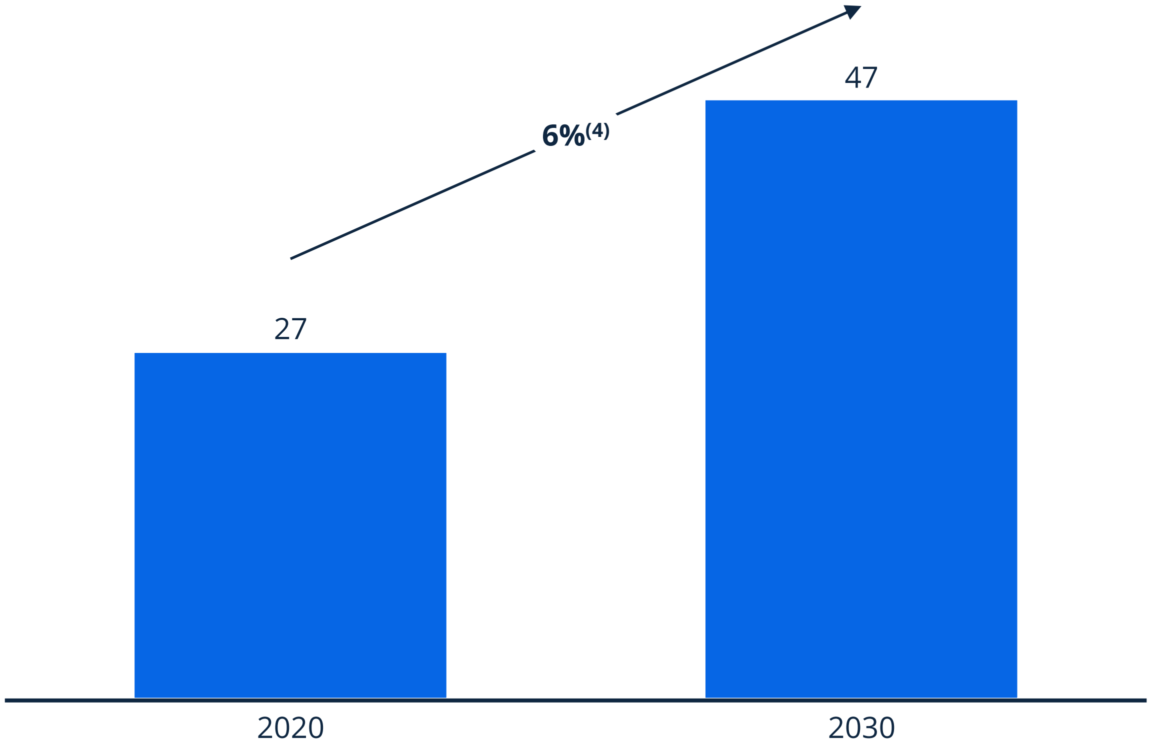
Sources: BIKEeurope; China Bicycle Association; European Cyclists’ Federation (ELECTROMOBILITY FOR ALL, Financial incentives for e-cycling); Montague; The Royal Society for the Prevention of Accidents

Mainland China is the largest market for e-bikes

Overview (3/3)

Even though Europe and North America were late adopters of this technology, their markets have experienced strong growth over the last few years. Belgium, the Netherlands, and Germany are the major markets in Europe. According to various studies conducted in these countries, their respective market shares for e-bikes as a proportion of total bikes currently stand at approximately 50%(1), 40%(2) and 23.5%(3). Further, Giant reported that Europe was its fastest growing market in the first half of 2018, with sales mainly driven by e-bikes. According to estimates by Navigant Consulting and Bloomberg, the global market for e-bikes was valued at US$15.7 billion in 2016 and is expected to increase to US$24.3 billion in 2025 at a CAGR(4) of 5%.

Global market for electric bicycles in billion US$



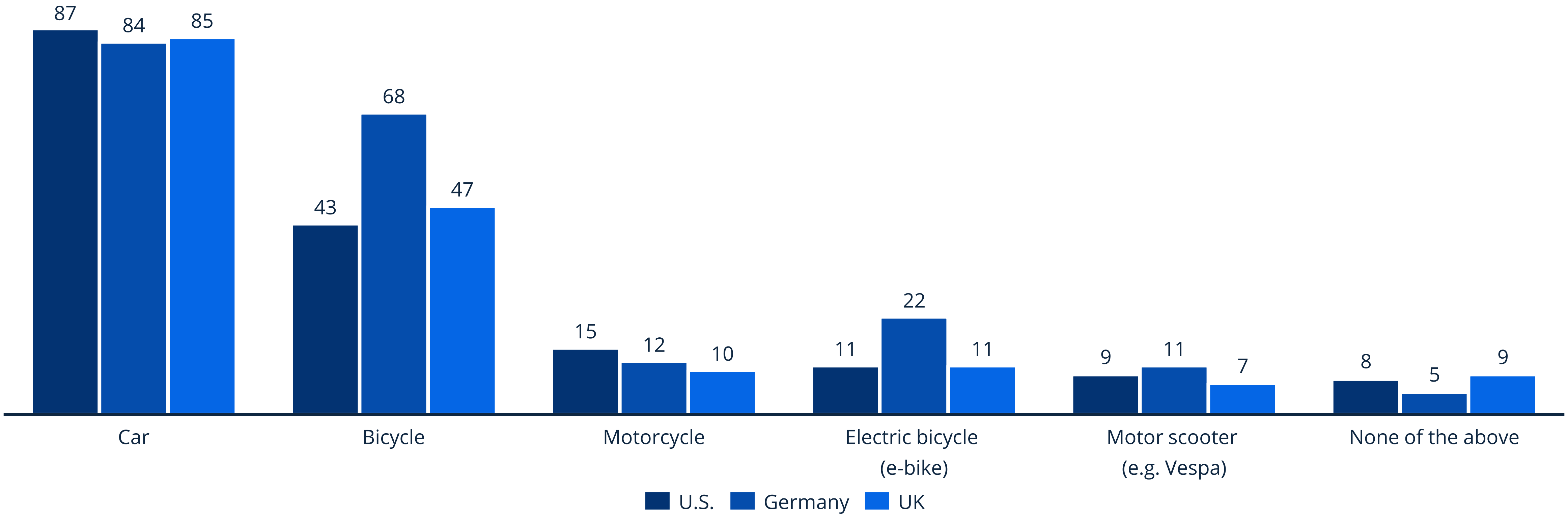
Notes: (1) Velofollies, a bicycle trade fair (2) RAI Vereniging, a trade association (3) Zweirad-Industrie-Verband, a trade association (4) CAGR: Compound Annual Growth Rate

Sources: BIKEeurope; Bloomberg; China Bicycle Association; European Cyclists' Federation (Electromobility for all, Financial incentives for e-cycling); Montague; The Royal Society for the Prevention of Accidents; Guidehouse

In Germany, 22% of households owned an e-bike in 2022

E-bike ownership

Type of vehicle ownership in %



Notes: "Which of these items do you permanently have available in your household?"; Multi Pick; U.S.: n=10,011, UK: n=4,027, Germany: n=6,004; Residential online population, all respondents

Sources: Statista Consumer Insights, as of July 2023

Evolution of e-bikes: timeline (1/2)

Evolution

1895 Ogden Bolton patented the first battery-powered bicycle

1897 Hosea W. Libbey patented the bicycle with a double electric motor

1898 John Schnepf patented the electric motor with a roller wheel

1900s Bicycle models with torque sensors and power controls became available

1992 Zike, the first ever modern commercial e-bike was launched

1993 Yamaha launched its first pedal assisted bicycle with a lead battery and range of 20 kms; it sold 30,000 units in the first year

1998 Over 50 new models were launched globally

2000s Yamaha and Panasonic begun mass producing e-bikes for the global market

2005 Mainland China begins exporting e-bikes to countries in the EU

2016 32.8 million e-bikes were sold in the Asia-Pacific, which was 30 times more than Western Europe, the second largest market at the time

2017 Size of the global market for electric bikes was ascertained at US$16.34 billion

2019 Uber started developing autonomous e-bikes

2020 Harley Davidson launched its line of e-bikes under the Serial 1 brand
Jeep launched its line of e-bikes

2021 BMW launched a highspeed e-bike with a range of 186 miles
Alibaba launched a US$750 three-passenger e-bike
The U.S. announced US$900 tax credits for e-bikes

Sources: Company information; Press releases

Evolution of e-bikes: timeline (2/2)

Evolution

2022 Harley-Davidson's electric vehicle arm, LiveWire, unveils the S2 Del Mar LE electric motorcycle in the U.S.

2023 Decathlon launches its Decathlon Elops LD 920 electric bike for sale in some countries such as France and the Netherlands, with plans to further expand in the EU

Sources: Company information; Press releases

New technologies and celebrity endorsements are driving the market

Drivers (1/2)

Faster alternative or short or mid-range travel

According to a report by the European Cyclists' Federation, e-bikes are faster than cars for distances of up to 10 km, with the time difference for longer distances (up to 20 km) being marginal. Another study by Mobike, a Chinese bike-sharing company, found that 90% of the people using a combination of bikes and public transportation in New York reached destinations under 5 kms (3.1 miles) faster than those who used only cars.

Technological advancements

The e-bike industry has experienced several technological breakthroughs, and this is the primary reason for their recent proliferation:

- Battery: The lithium-ion battery, which is the most commonly used on e-bikes now, weighs only 6 pounds and provides around 1,000 cycles of charge/discharge. Moreover, the recent addition of Graphene nanotechnology to lithium batteries is also expected to result in improved energy density.
- Insulated-Gate Bipolar Transistors: They achieve motor speeds of over 4,500 rpm resulting in higher torque.
- Durable Electric Motors: The recent addition of brushless permanent-magnet DC motors consisting of neodymium rare-earth magnets, have not only resulted in enhanced durability and power but have also made the automotive starters much smaller.

Celebrity endorsement

The e-bike industry has gained much visibility from several key celebrity endorsements. For example, Olympic gold medalist Victoria Pendleton launched her own e-bike in 2018, while Olympic gold medalist Sir Chris Hoy has spoken up about the advantages and entertainment value of riding an e-bike on many occasions. Non-athletes who have advocated the use of e-bikes include Charles, Prince of Wales, who was spotted riding a Spencer Ivy, Leonardo di Caprio riding an A2B Ultra-Motor, and Miley Cyrus riding a Pedego.

Sources: Cycle Volta; European Cyclists' Federation; INSG Insight

Cargo transportation and new target audiences are also driving the market

Drivers (2/2)

Cargo transportation

Electric cargo bikes (electric utility bikes) make it possible to transport heavier goods as compared to conventional bikes. This is not only beneficial for individuals doing their private shopping but also retail and logistics companies looking for a faster last-mile delivery solution. In fact, companies such as Amazon, Swiggy (India), Grofers (India) and IKEA have already started using electric bikes for deliveries. Additionally, a 2021 study by the University of Westminster found that compared to deliveries in city centers by van, those made with electric cargo bikes were 60% faster. They had a higher average speed and dropped off ten packages per hour as compared to six for vans. Moreover, electric cargo bikes are more environmentally friendly with carbon emissions 90% lower than diesel vans and a third lower than electric vans.

New target audience

The introduction of e-bikes opened up a new segment of target customers who haven't cycled previously because of their physical condition or because of a lack of perceived convenience. A good example is elderly people, who can now overcome natural obstacles like hills or headwinds more easily as compared to using a conventional bike.

Sources: Cycle Volta; European Cyclists' Federation; INSG Insight

CHAPTER 9

E-LCV

As the electric drive of vehicles gradually gains momentum across the world, the next phase of growth is expected to be driven mainly by vans and trucks.

The need to switch to cleaner engines is far greater for these larger vehicles, given that they pollute more than cars. Even though less than 5% of vehicles in Europe are commercial vehicles or heavy-duty trucks, they contribute to almost 20% of greenhouse gas emissions.

One of the main reasons why the light commercial vehicles (LCV) industry is witnessing electric disruption at such a fast pace is its high and predictable use rate.

Electric light commercial vehicles (e-LCVs) witness increasing adoption

Overview (1/3)

As the electrification drive of vehicles gradually gains momentum across the world, the next phase of growth is expected to be driven mainly by vans and trucks. The need to switch to cleaner engines is far greater for these larger vehicles, given that they pollute more than cars. According to the IEA, tailpipe CO_2 emissions from heavy-duty vehicles have risen by an average of 2.2% annually since 2000. In fact, commercial trucks and buses account for nearly 25% of CO_2 emissions in the U.S., according to the Bureau of Transportation Statistics.

One of the main reasons why the light commercial vehicles (LCV) industry is witnessing electric disruption at such a fast pace is due to its high and predictable use rate. These vehicles are not only driven for long periods, but also on predictable routes and for almost the same number of hours each day. This makes it easy to set up charging stations either at home or at work because that's mainly where they charge. Moreover, since they mainly transport goods within a city or town, most often a single charge is enough to operate them for the whole day.

This is in contrast to heavy trucks and buses which usually travel intercity and thus require an extensive charging station infrastructure. Logistics firms are therefore increasingly finding it more economical to convert their fleets to electric vehicles, especially for urban routes and 'last-mile' deliveries.

This trend has also witnessed government support in many countries around the world in the form of laws, grants and exemptions. You can find some examples below:

- UK: The government's maximum grant for electric LCVs amounts to £2,500 for small vans and £5000 for large vans. In addition, large fleet operators will be limited to 1,000 van grants per year. Moreover, there is no vehicles excise duty for 100% electric vans.
- Germany: From July 2018, German OEMs can apply for government grants ranging from €12,000 to €40,000 depending on the trucks' weight, to a maximum of €500,000 per company. These vehicles are now also exempt from any form of road tax.
- Norway: In Norway, the TCO of the e-LCV is already lower than that for a diesel vehicle mainly because of its favorable taxation system. UK conditions are a mixed bag, with a competitive TCO for only some of the vehicles. In the Netherlands on the other hand, the TCO of the e-LCV is relatively higher partly due to insurance premiums being based on vehicle weight (batteries make e-LCV's heavier).

Sources: Hitachi Capital; J.P. Morgan; Medium

EU countries have the most generous grants and incentives

Overview (2/3)

- India: Plans to expand the freight category to include electric LCVs in its latest draft EV policy. This will include a generous allotment of funds mainly collected as pollution cess and road tax among other environment taxes.
- France: In 2009, the French government introduced a new bonus scheme of €5,000 for e-LCVs emitting less than 60g CO2/km—automatically covering all EVs. The bonus scheme ran until the first 100,000 low-carbon vehicles were purchased in 2012. Now, pure e-LCVs get up to €6,000 but PHEVs are no longer included in the list. Those looking to scrap a vehicle whilst purchasing an EV can expect up to an extra €2,500.
- Spain: e-LCVs purchases will be subsidized with government payouts of €5,000 while automakers, importers, or dealers must also offer a minimum discount of €1,000 on each vehicle. Consumers wishing to purchase an e-LCV with such subsidies must scrap their existing vehicle if it is more than 10 years old.
- Netherlands: Electric vehicles are fully exempt from BMP or private tax until 2024, while plug-in hybrid vehicles will be subject to a lower BMP from 2026. Publicly used electric vehicles will be granted purchase subsidies: €2,030 per vehicle starting in 2021 and dropping to €1,830 in 2024.
- Sweden: Sweden introduced a bonus-malus system for the purchase of light-trucks and buses. These pure EVs receive a purchase incentive bonus of 60,000 Swedish krona (€5,700), so long as the climate bonus does not exceed 25% of the vehicle's value. For companies buying a climate bonus vehicle, the bonus must not exceed 35% of the difference between the new vehicle price and a comparable petrol or diesel vehicle's new price. The bonus is paid directly to the owner six months after the vehicle is registered, preventing the vehicle being sold within that time period. For every gram of CO2 above zero and up to 60g/km, the bonus gets reduced by 833 Swedish krona per g/km.
- Austria: In June 2020, Austria updated their subsidy packet from €3,000 to €5,000 for electrified vehicles, with the automotive industry contributing €2,000 towards the subsidy. Moreover, as per the new policy, home-charging stations and intelligent charging cables are also eligible for a €600 grant.

Sources: International Energy Agency (IEA); WardsAuto; Volkswagen; Autovista Group

DHL deploys e-LCVs for its last-mile delivery

Overview (3/3)

2018 was the breakout year for e-LCVs with the introduction of many models such as Mercedes eVito and eSprinter, Nissan e-NV200 2018, and the Renault Master ZE. With advancements in battery capacity, improving efficiencies and restrictive policies on diesel vehicles, electricity is fast becoming the favored source of fuel for LCVs all around the world.

What is particularly encouraging is that this change is now being witnessed even in countries like India, which have historically been slow in electric vehicle adoption. For instance, in May 2022, Tata Motors launched the Ace EV, a small commercial vehicle with an aim to fulfill green intra-city deliveries for logistic service providers such as Flipkart and Amazon.

In spite of a bright forecast, the main challenge the industry is likely to face in the short to medium term is to present an economically viable business case to convince fleet owners to switch to an electric powertrain. For this, the total cost of ownership (TCO) of an e-LCV needs to be lower than that of a diesel variant and this is already happening in a few countries.

DHL – from logistics to manufacturing

In 2013, when DHL wanted to buy electric LCVs to make its last-mile delivery more environmentally friendly, it couldn't find an OEM which would provide it with the required vehicles. It then decided to develop its own vehicle instead and strategically acquired StreetScooter, a startup focused on manufacturing commercial electric vehicles. However, in February 2020, the company announced its decision to stop production by the end of the year, due to heavy financial losses. One of the main reasons for this was the lack of an ideal strategic partner who could help DHL scale up production capacity.

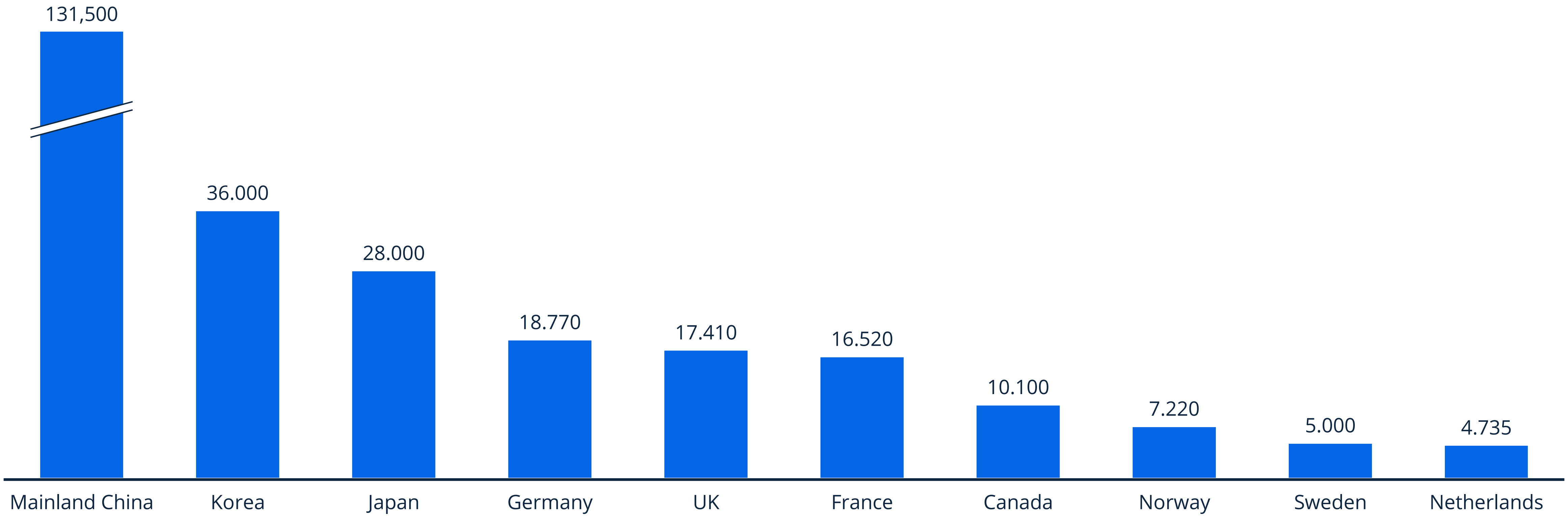
The company has now deployed approximately 100 Lightning eMotors electric Ford Transit vans. The Transit 350HD Class 3 model includes proprietary telematics and analytics software to help with route optimization, driver training, and vehicle efficiencies. More recently in January 2022, DHL also deployed three new BYD-made electric vans that can travel up to 155 miles on a single charge while bearing/ transporting a load of up to 3.5 cubic meters. These developments are part of the company's sustainability roadmap that will result in an investment of over €7 billion in climate control logistics by 2030.

Sources: DHL; Hitachi Capital; J.P. Morgan; Medium

Top 10 leading countries in terms of new E-LCV sales in 2022

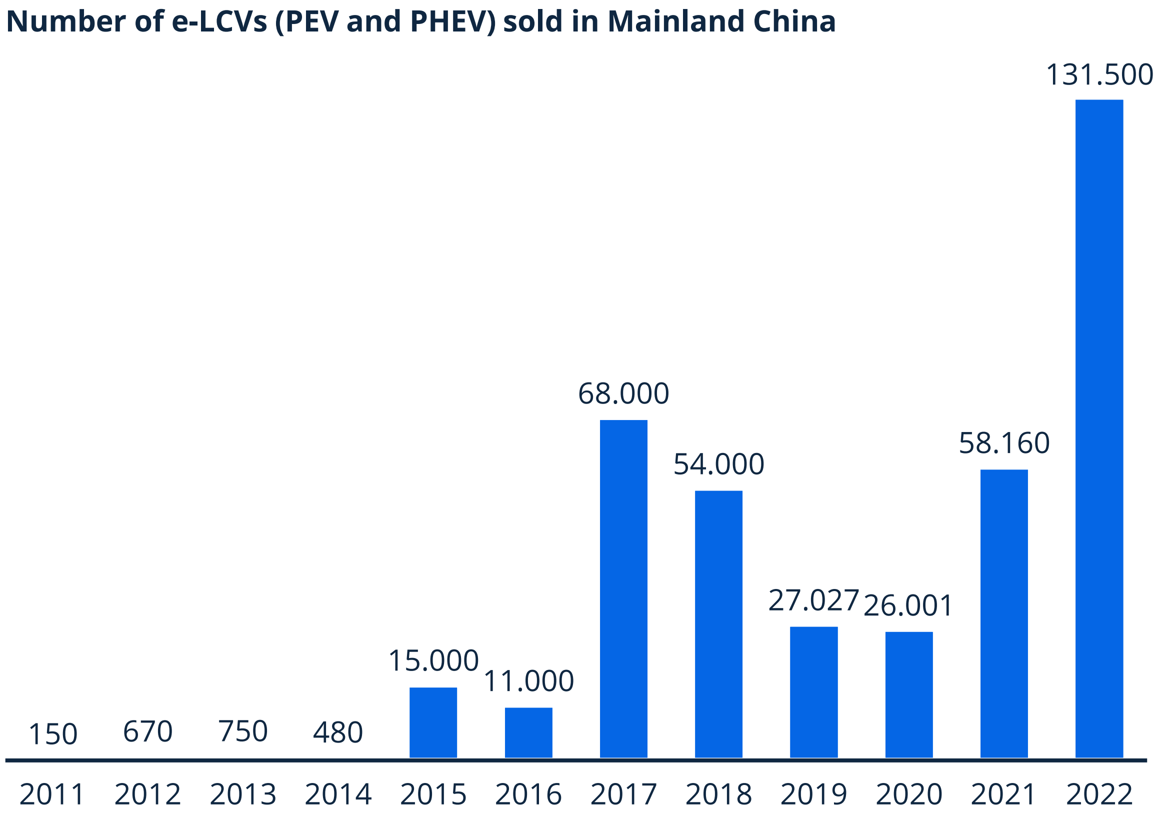
E-LCV sales

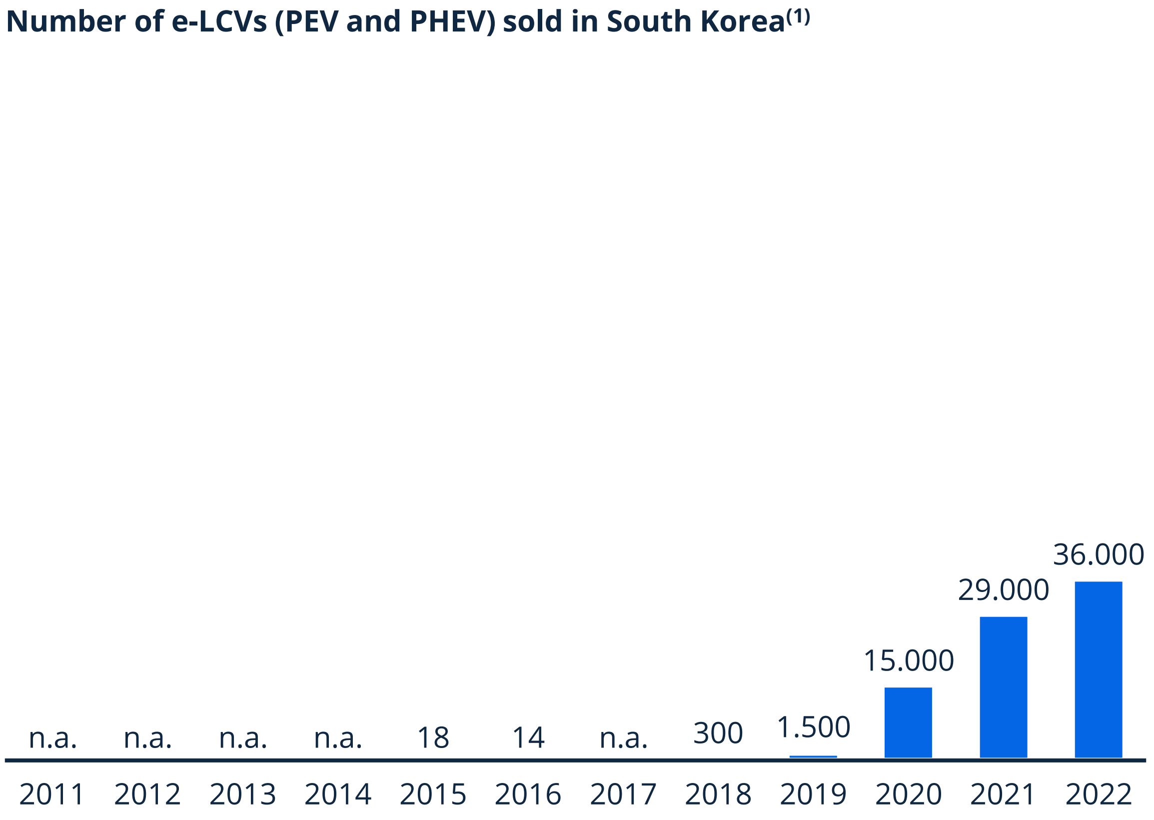
Top 10 leading countries in terms of new e-LCV sales in 2022



Sources: International Energy Agency (IEA)

Top 10 leading countries: New E-LCV Sales (1/5)



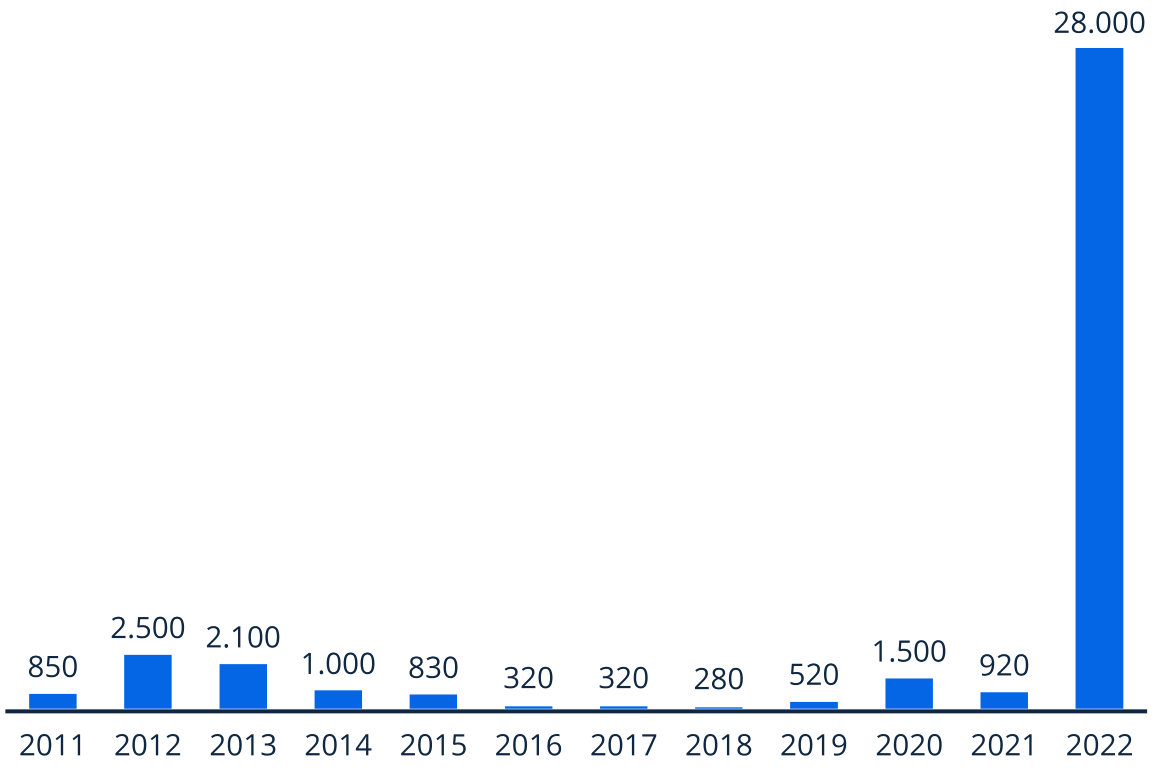


Notes: (1) 2011-2014, and 2017 data not available

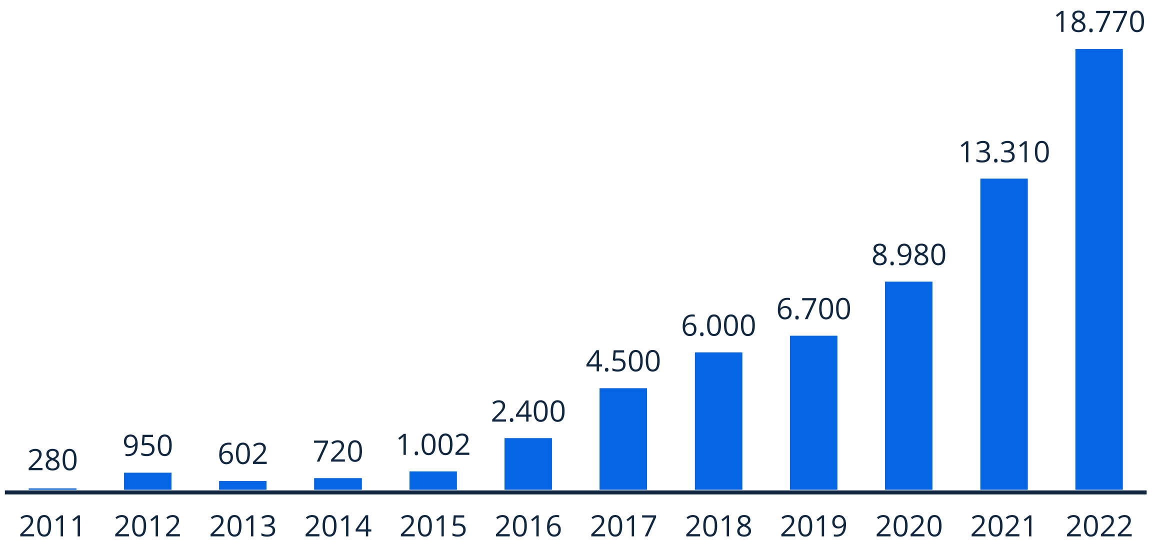
Sources: International Energy Agency (IEA)

Top 10 leading countries: New E-LCV Sales (2/5)

Number of e-LCVs (PEV and PHEV) sold in Japan



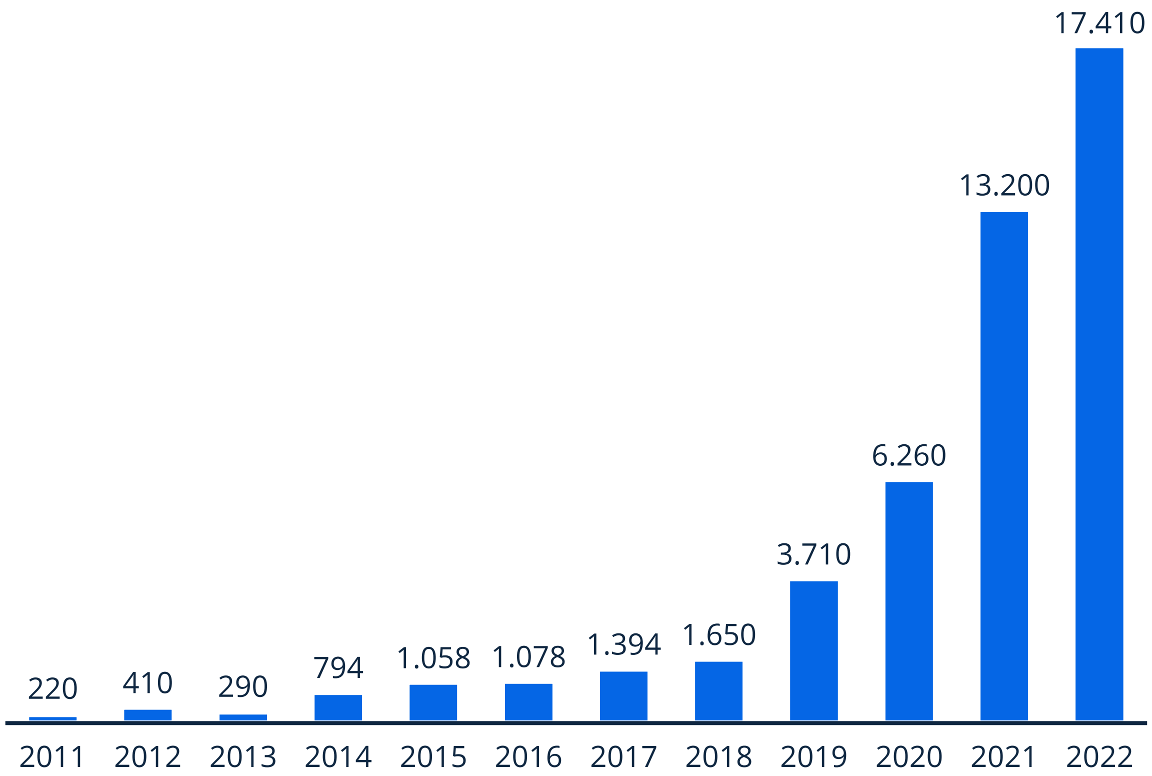
Number of e-LCVs (PEV and PHEV) sold in Germany



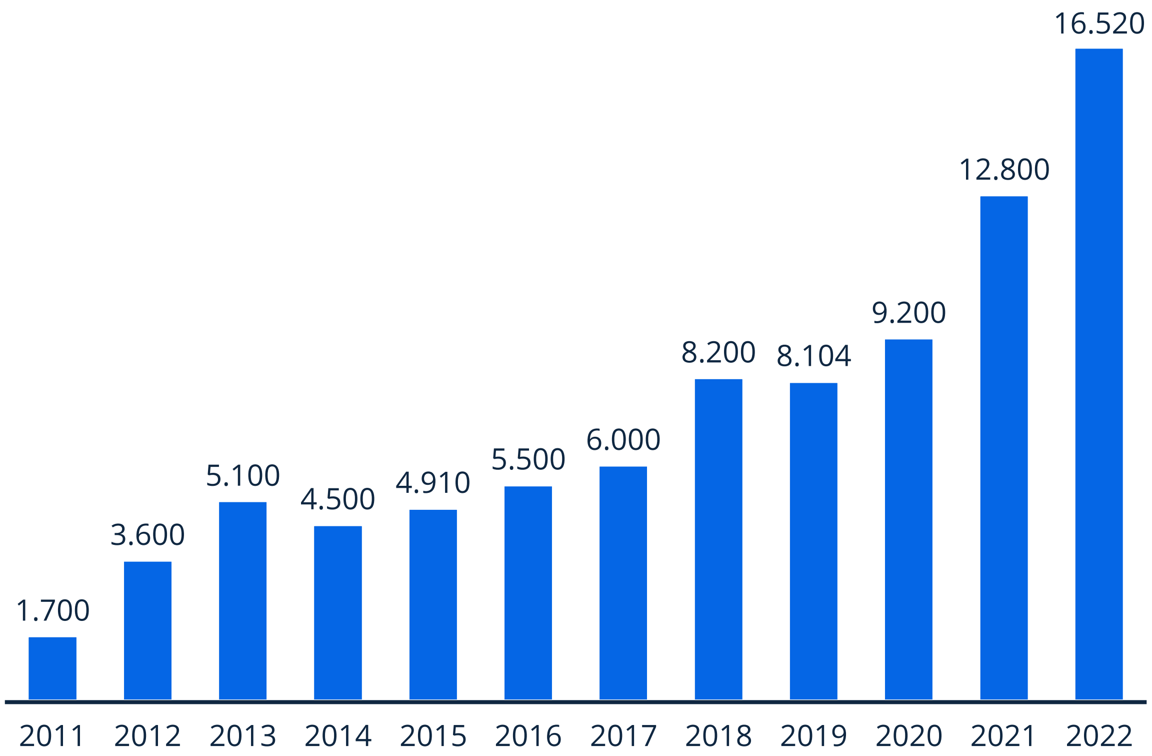
Sources: International Energy Agency (IEA)

Top 10 leading countries: New E-LCV Sales (3/5)

Number of e-LCVs (PEV and PHEV) sold in the UK



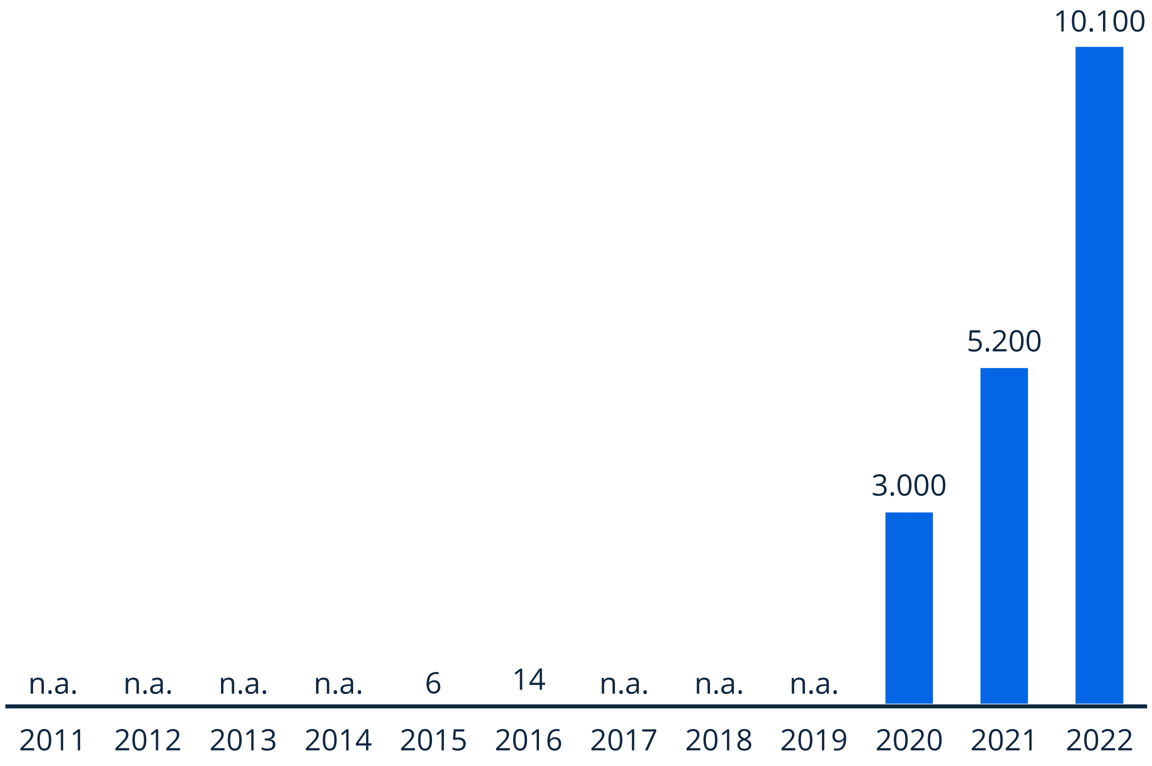
Number of e-LCVs (PEV and PHEV) sold in France



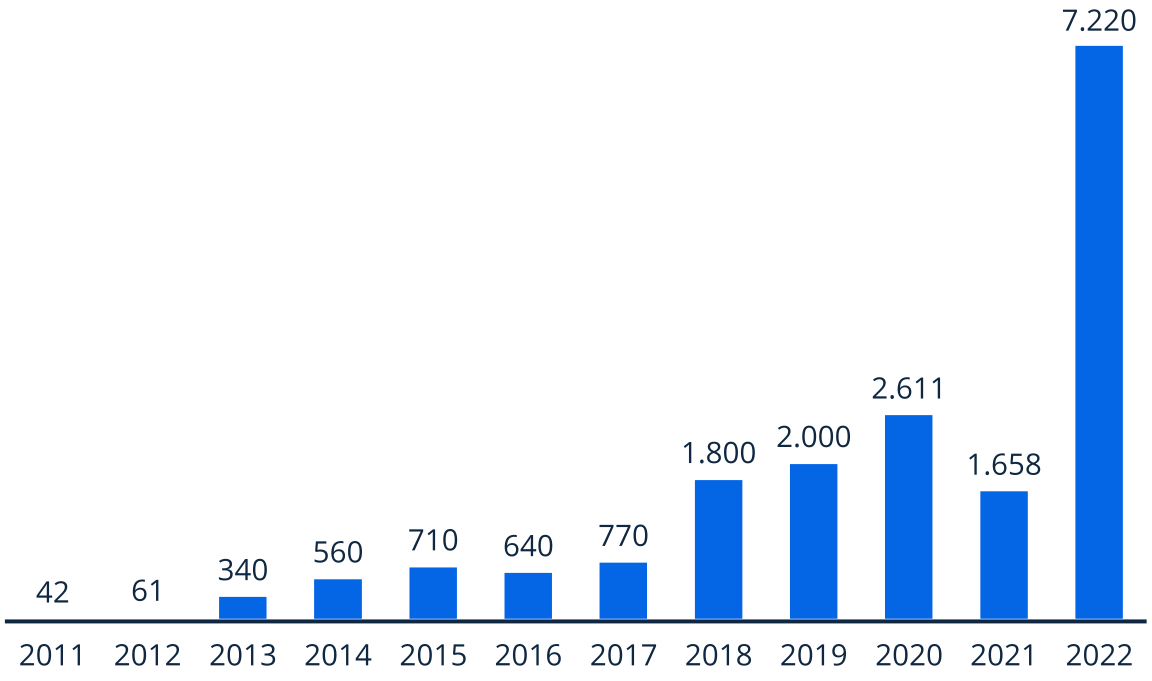
Sources: International Energy Agency (IEA)

Top 10 leading countries: New E-LCV Sales (4/5)

Number of e-LCVs (PEV and PHEV) sold in Canada(1)



Number of e-LCVs (PEV and PHEV) sold in Norway

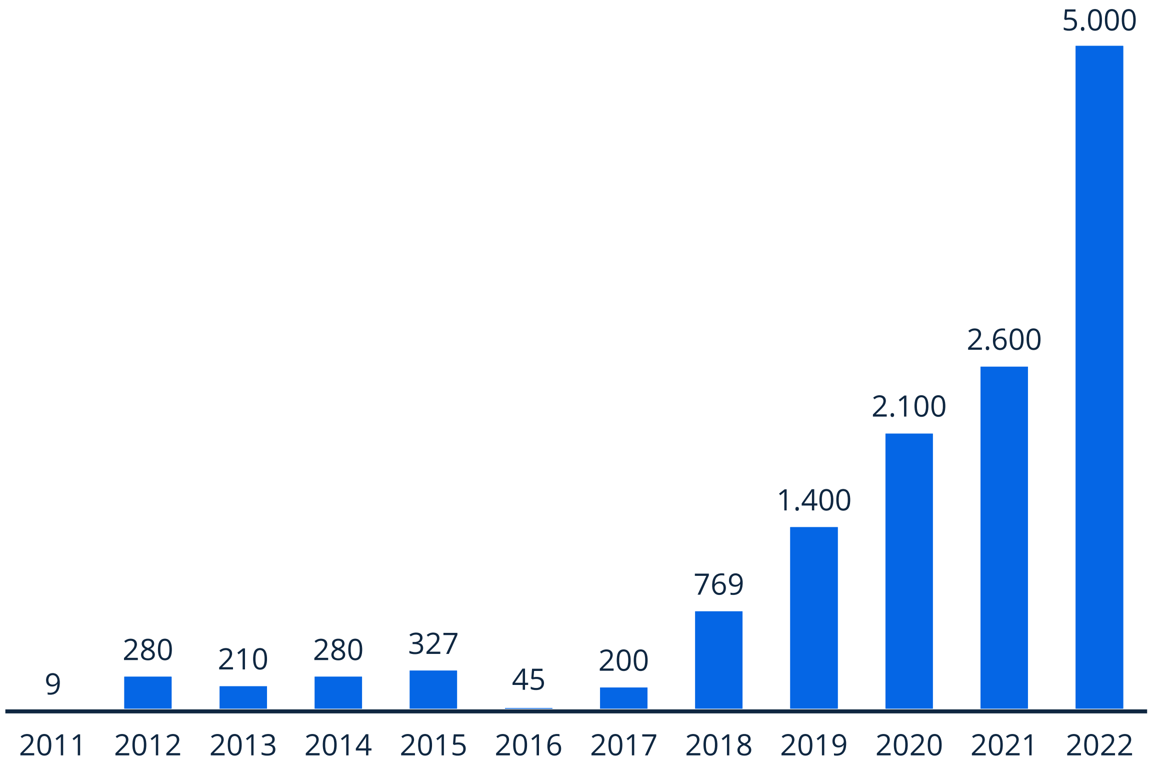


Notes: (1) 2011-2014, and 2017-2019 data not available

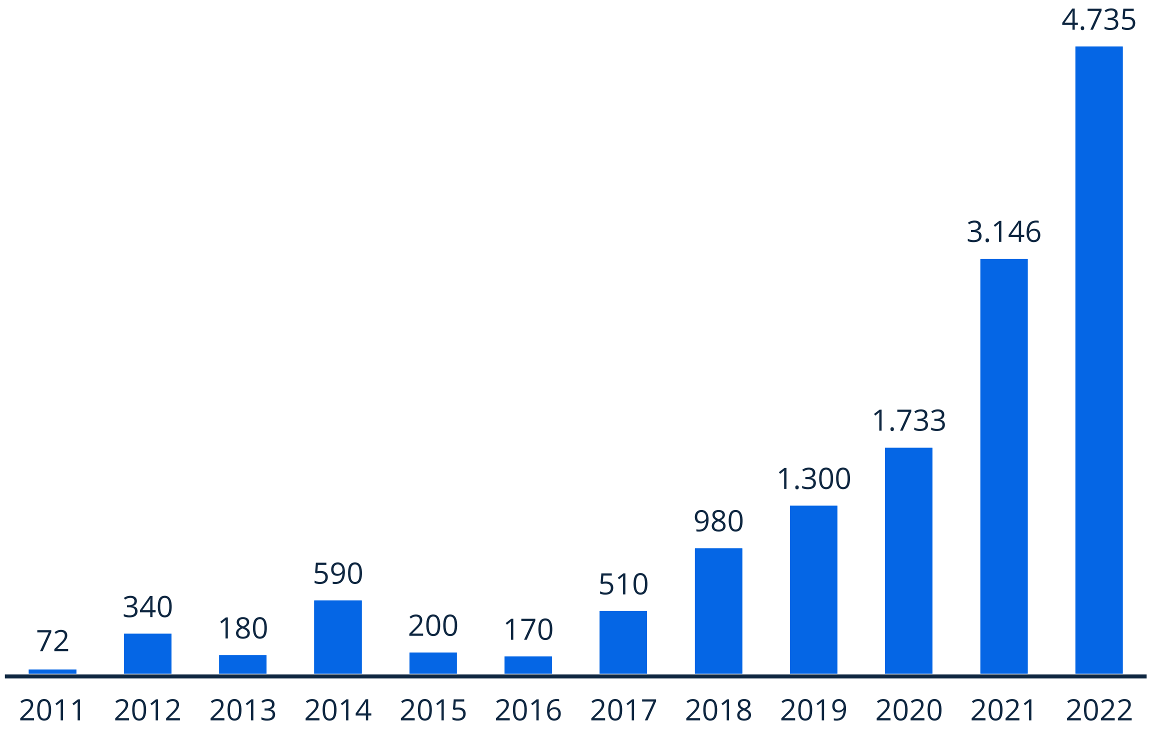
Sources: International Energy Agency (IEA)

Top 10 leading countries: New E-LCV Sales (5/5)

Number of e-LCVs (PEV and PHEV) sold in Sweden



Number of e-LCVs (PEV and PHEV) sold in the Netherlands

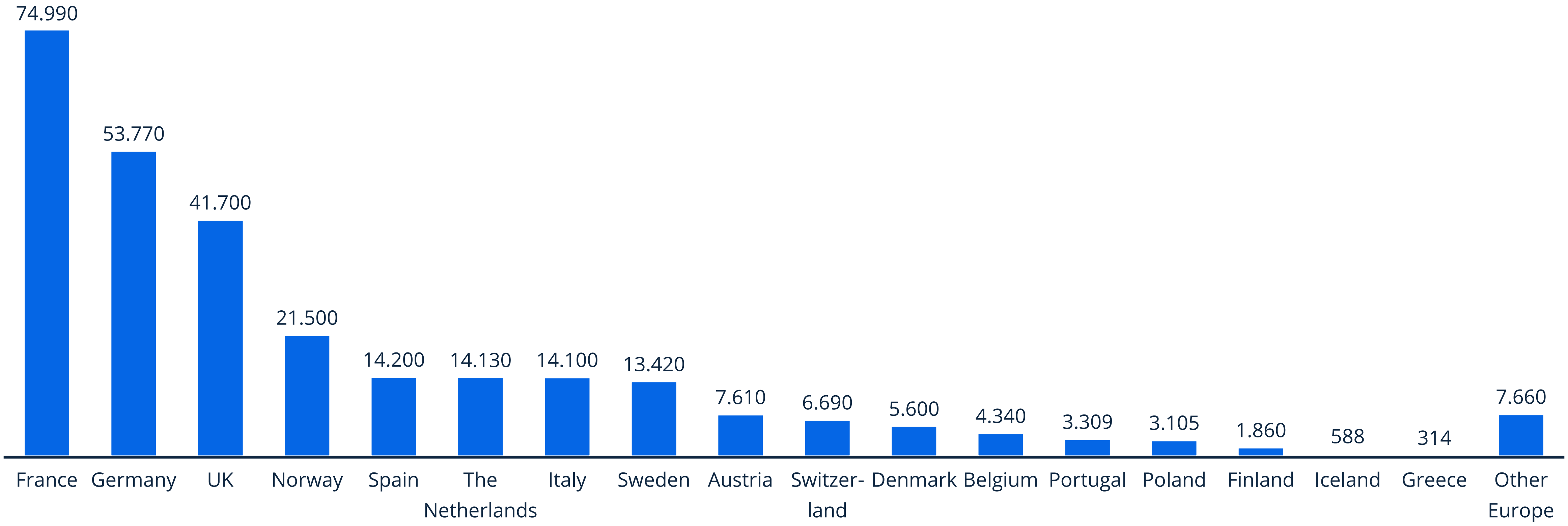


Sources: International Energy Agency (IEA)

France has the highest number of e-LCVs in Europe

E-LCVs fleet in Europe

E-LCV fleet in Europe in 2022



Sources: International Energy Agency (IEA)

statista

CHAPTER 10

Consumer insights

Consumer insights show that gasoline and diesel lead in terms of drives in respondents' primarily used car in the U.S., the UK, and Germany. While gasoline is still the most probable drive in a future car, hybrids and electric drives are catching up.

Gasoline and diesel lead in terms of drives in the primarily used car

Electric cars: Overview (1/3)

The Statista survey on mobility conducted between July 2022 to June 2023 focused on the residential online population in the U.S., Germany and the U.K. who have a car in their household and/or plan to purchase one in the next 12 months.

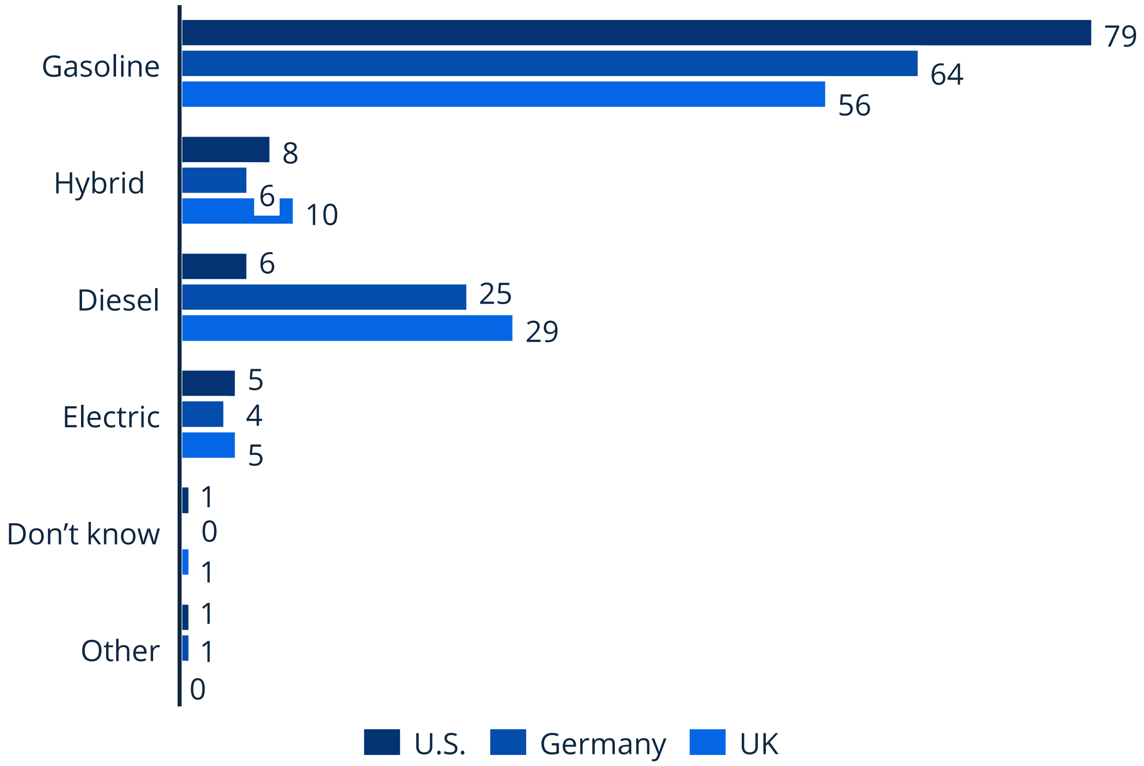
It covers the following topics: general information about the car in the household, usage, brands, drives and their typology, alternative drives and eMobility in particular, public transport, car-sharing and attitudes.

More exciting results of this survey can be found for the U.S., the UK and Germany.

The most common drive types currently are gasoline and diesel. While U.K. has the strongest presence of diesel cars in the sample, hybrids[1] are more common in the U.S. than diesel cars. Electric drives are still very uncommon.

Looking at the drive people would consider in their next car purchase, hybrids and electric drives are preferred to diesel drive. The survey also shows that the preference for gasoline as a drive is marginally reducing.

Drive in primarily used car in %

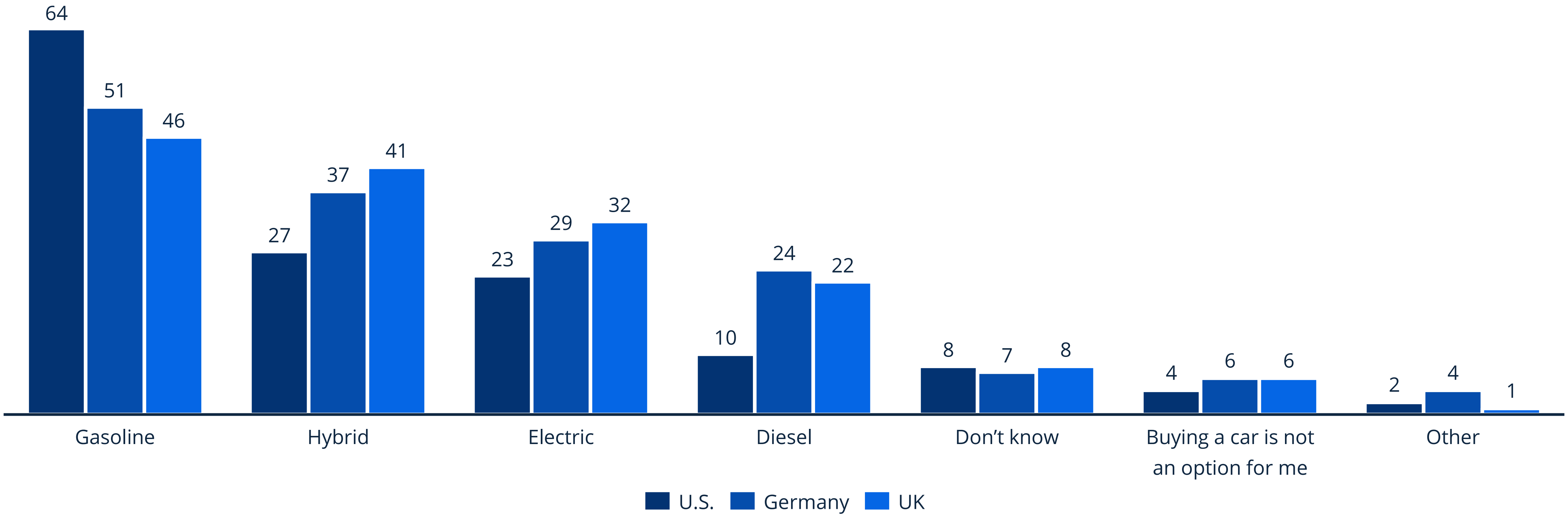


Notes: (1) Combination of combustion and electric drive
"Which of these propulsion types does your primarily used car use?"; Single Pick; U.S.: n=8,723, UK: n=3,435, Germany: n=5,051; Residential online population, who have a car available in their household
Sources: Statista Consumer Insights, as of July 2023

Gasoline still the most probable drive for future car purchases

Electric cars: Overview (2/3)

Probable drive in a future car in %



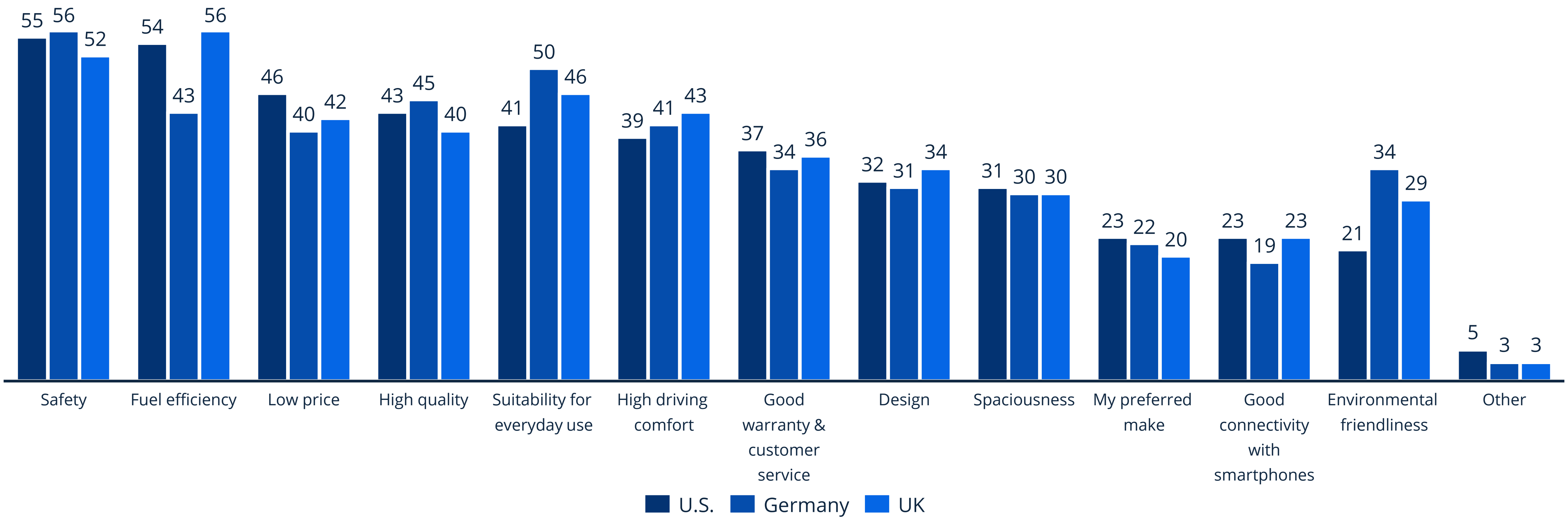
Notes: "Which of these propulsion types do you consider when buying a car" Multi Pick; U.S.: n=10,011, UK: n=4,027, Germany: n=6,004; Residential online population, all respondents

Sources: Statista Consumer Insights, as of July 2023

Safety is the most important criteria for a new car in the U.S.

Electric cars: Overview (3/3)

Purchase criteria for new cars in %



Notes: "Which of these characteristics are especially important to you when you decide on a new car?"; Multi Pick; U.S.: n=10,011, UK: n=4,027, Germany: n=6,004; Residential online population, all respondents

Sources: Statista Consumer Insights, as of July 2023

CHAPTER 11

Competitive landscape

Tesla is the most recognized electric vehicle (EV) brand in the world: in 2022, combined sales of the Model 3 and Model Y totaled 1,247,146 units. Tesla's success is primarily attributed to its aesthetics and longer ranges compared to other EVs. BYD is one of the largest selling brands in Mainland China, but its focus on international markets is limited. The company's top-selling brand in 2022 was the Han with sales of over 274,015 units.

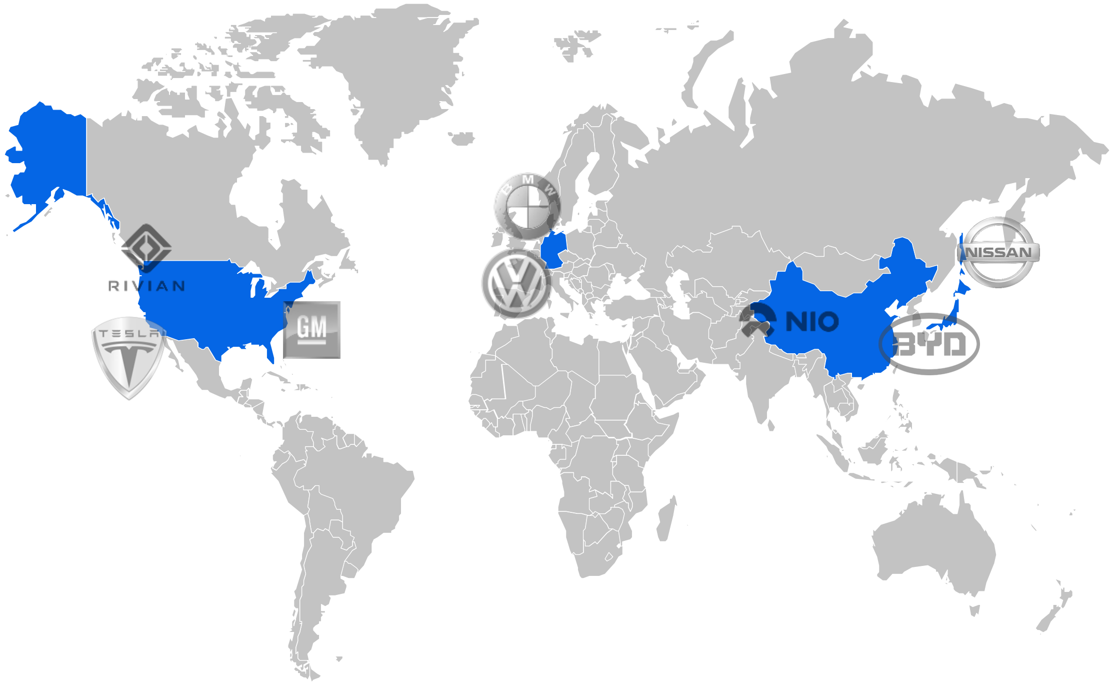
Volkswagen sold a total of 572,100 EVs in 2022, up 26% as compared to its 452,839 sold in 2021. The other European player, BMW, has 14 EV models in its portfolio and had over 2 million electric vehicles in circulation by the end of 2022.

In North America, General Motors has unveiled its plans to spend over US$35 billion on its electric and automated vehicle programs between 2020 and 2025. A relatively new player, Rivian is making its foray into the EV market and in November 2021, the company raised nearly US$12 billion though its IPO.

NIO and Rivian are the two biggest challengers to Tesla

Company comparison

Location of selected leading OEMs in EV development



Company	Headquarter	Selection of EV models	USP
BMW	Munich, Germany	• BMW iX, i4, I7 • BMW Mini Electric	• Sustainable/recycled interior • Special leasing/rental offers
BYD	Xi'an, Shaanxi, Mainland China	• BYD Han, Atto • BYD Qin, Tang	• Domestic market focus • Lower prices
General Motors	Michigan, U.S.	• Bolt EV • LYRIQ	• Futuristic projects (1) • Lower price compared to Tesla in >200 miles battery range
NIO	Shanghai, China	• eT5 and eT7 • ec6 • es6 and es8	• Battery-as-a-Service • Availability of rescue van service with integrated chargers
Nissan	Yokohama, Japan	• Nissan Leaf • Nissan Ariya	• Advanced dedicated IT system (2)
Rivian	California, U.S.	• R1T • R1S • EDV700	• Focus on pickup trucks and SUVs instead of cars • Distinctive styling
Tesla	California, U.S.	• Tesla Model S • Tesla Model 3 • Tesla Model X, Y	• Supercharger infrastructure • Cost-free charging • Over-the-air software updates
Volkswagen	Wolfsburg, Germany	• E-up! • E-Golf • ID.4	• US$100 billion EV spending until 2026 • Reliable battery supply chains

Notes: (1) Wireless and solar EV charging stations (2) Remote charging and status check via mobile apps

Sources: Annual reports; Corporate newsletters

BMW currently produces 22 electric models

BMW (1/2)

BMW is a German luxury vehicle, motorcycle, and engine manufacturing company founded in 1916. The company launched its first electric vehicle, the BMW i3, in 2013 and its current range of 22 electric vehicles includes fully electric and plug-in hybrid versions.

At the end of 2022, BMW had over 1.4 million electric vehicles including PEVs and PHEVs in circulation across the world and announced plans to double its PEV sales by 2025. The company's range of PEVs include the iX, iXM60, i4, i5, and the i7. BMW stopped the production of the i3 in June 2022, which had sold nearly 250,000 units since its launch in 2013 and 37,939 in 2021 alone.

- Year founded: 1916
- Number of employees: 149,475 (Dec 2022)
- Revenue (group): US$152.2 billion (Dec 2022)(1)
- Revenue (automotive): US$131.9 billion (Dec 2022)(1)
- Net profit: US$19.8 billion (Dec 2022)(1)
- Total cars sold: 2.4 million (Dec 2022)

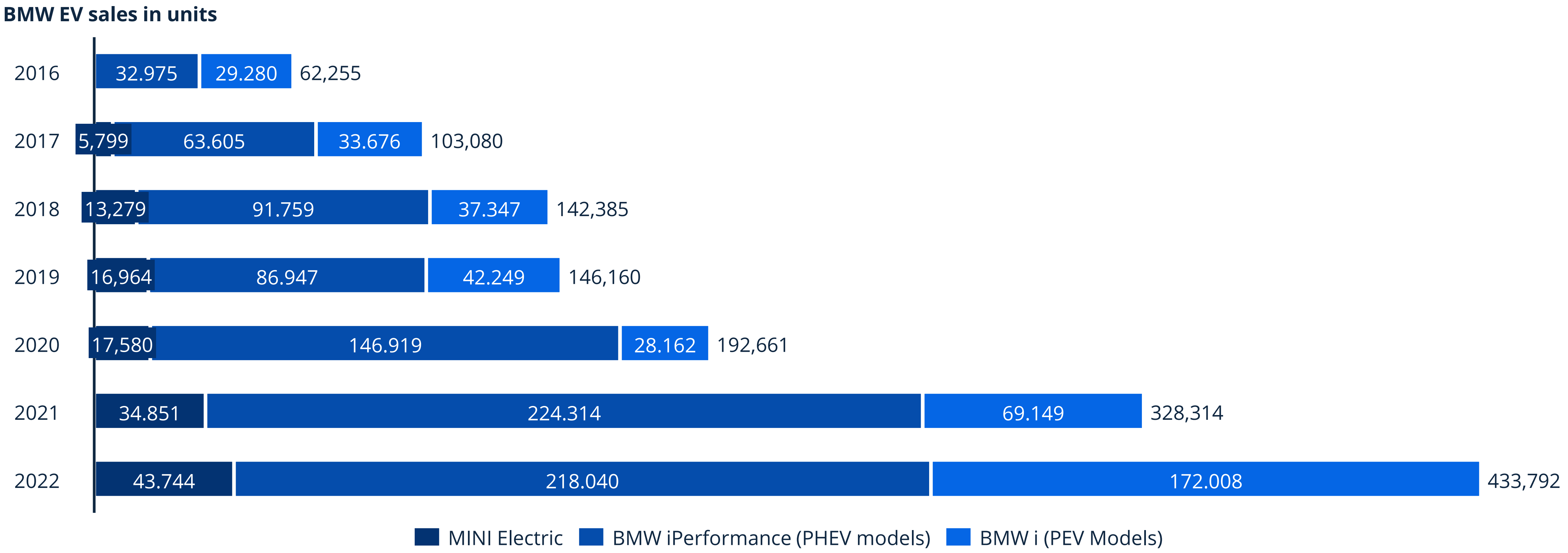
EV model	Type	Battery range	Battery used
BMW i7 xDrive60	PEV	387 miles	101.7 kWh lithium ion
BMW iX xDrive50	PEV	382 miles	105.2 kWh lithium ion
BMW i7 eDrive50	PEV	321 miles	101.7 kWh lithium ion
BMW i4 xDrive40	PEV	307 miles	81.1 kWh lithium ion
BMW i4 eDrive40	PEV	301 miles	81.1 kWh lithium ion
BMW iX M60	PEV	296 miles	105.2 kWh lithium ion
BMW i5 eDrive40	PEV	295 miles	81.2 kWh lithium ion
BMW iX3	PEV	286 miles	74 kWh lithium ion
BMW i4 eDrive35	PEV	276 miles	67 kWh lithium ion
BMW i4 M50	PEV	269 miles	81.1 kWh lithium ion
BMW iX xDrive40	PEV	264 miles	76.6 kWh lithium ion

Notes: (1) Converted from Euro to US$, exchange rate: EUR-US$ 1.0674 as of Dec 31, 2022 (Oanda)

Sources: Company sources; Annual report; Press releases; The Economic Times

BMW sales of electric vehicles amounted to more than 433,000 units worldwide in 2022

BMW (2/2)



Sources: BMW annual report 2017, 2019, 2021, 2022; ElectricVehicleWeb

BYD’s electric vehicles are among the top sellers of its kind in Mainland China

BYD (1/2)

BYD (Build Your Dreams) Auto Co., Ltd. is a Chinese automobile manufacturer based in Xi'an, Shaanxi Province and a fully owned subsidiary of BYD Company. The company unveiled its first plug-in hybrid concept car, the BYD F6DM, at the North American International Auto Show in January 2008. However, the car remained a prototype, and the company turned its focus towards the development of a smaller plug-in hybrid compact sedan called the F3DM, the all-electric e6, and the hybrid SUV S8DM. BYD started increasing its international footprint in 2009 and began to export its electric vehicles to Africa, South America, and the Middle East. In 2013, due to a decline in sales, the company replaced the F3DM with the new plug-in hybrid variant BYD Qin. In 2022, the company sold 1,857,379 EVs, including 911,141 PEVs and 946,238 PHEVs.

- Year founded: 2003
- Number of employees: 570,100 (Dec 2022)
- Revenue (group): US$61.2 billion (Dec 2022)[1]
- Revenue (automotive): US$46.9 billion (Dec 2022)[1]
- Net profit: US$2,557.5 million (Dec 2022)[1]

EV model	Type	Battery range	Battery used
BYD HAN	PEV	374 miles	76.9 kWh LiFePO4
BYD e6	PEV	250 miles	7 kWh LiFePO4
BYD Atto 3	PEV	261 miles	60.5 kWh LiFePO4
BYD Song Plus	PEV	314 miles	71.7 kWh LiFePO4
BYD Tang	PEV	328 miles	86.4 kWh LiFePO4
BYD Qin	PHEV	261 miles	56.4 kWh LiFePO4
BYD Qin EV300	PEV	261 miles	56.4 kWh LiFePO4
BYD Dolphin	PEV	211 miles	60.5 kWh LiFePO4
BYD Seal	PEV	354 miles	82.5 kWh LiFePO4
BYD Seagull	PEV	252 miles	38.9 kWh LiFePO4

Notes: (1) Converted from CYN to US$, exchange rate: CNY-US$ 0.1443 as of Dec 31, 2022 (Oanda)

Sources: Company sources; Annual report; Press releases

Han was BYD's top-selling electric vehicle in 2022

BYD (2/2)

BYD EV sales in 2022 in units

Sources: Inside EVs

General Motors started to develop electric vehicles in 1990

General Motors (1/2)

General Motors' foray into electric vehicles started in 1990 with the production of its concept car, Impact. The response to the prototype motivated the company to develop and produce the GM EV[1] electric car in 1996. However, the introduction of ultra low emission vehicles, natural gas vehicles, and hybrid cars in the late 90s forced the company to discontinue the production of its EV1 by 2002.

In 2010, GM debuted the Chevrolet Volt, a plug-in hybrid electric vehicle with gasoline-powered backup generators. In 2011, the company announced the production of the Chevrolet Spark EV, an all-electric version of the third-generation vehicle, the Chevrolet Spark. The Chevrolet Spark EV was later replaced by the Bolt EV. GM formed a joint venture in Mainland China with SAIC and launched Baojun E100 (an all-electric vehicle) in August 2017, followed by the E200 in September 2018. In February 2021, the company unveiled its all-electric Chevy Bolt EUV but was thwarted by battery defects.[1] Additionally, the company has also announced plans to spend over US$35 billion between 2020 and 2025 on its electric and automated vehicle programs, which includes a US$7 million battery plant in Michigan.

- Year founded: 1908
- Number of employees: 167,000 (Dec 2022)
- Revenue (group): US$156.7 billion (Dec 2022)
- Revenue (automotive): US$144.0 billion (Dec 2022)
- Net profit: US$9.7 billion (Dec 2022)

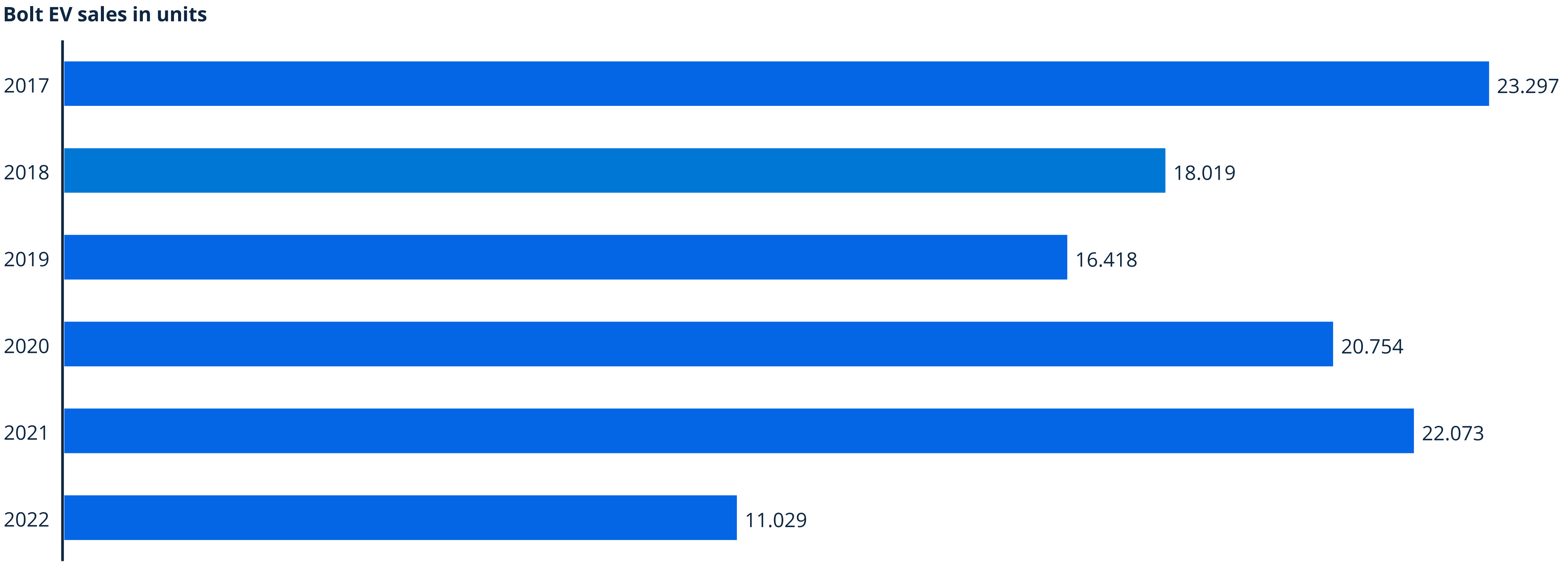
EV model	Type	Battery range	Battery used
Chevrolet Bolt EUV	PEV	247 miles	65 kWh lithium ion
Chevrolet Silverado	PEV	400 miles	200 kWh lithium ion
Chevrolet Bolt EV	PEV	259 miles	65 kWh lithium ion
Cadillac LYRIQ	PEV	300 miles	100 kWh lithium ion
GMC Hummer Truck	PEV	329 miles	200 kWh lithium ion

Notes: (1) GM's production of the Chevy Bolt EV and EUV was supposed to resume in January 2022 but there is no updated news on this.

Sources: Company sources; Annual report; Press releases; CNBC

U.S. unit sales of the Bolt EV in 2022 decreased by over 50%

General Motors (2/2)



Sources: Gmauthority

NIO currently has five electric vehicle models on the market

NIO (1/2)

NIO, previously Nextev, was founded in 2014 and is a manufacturer of premium electric vehicles and batteries. The company also provides battery charging and battery swap facilities through its Battery-as-a-Service (BaaS) offer.

NIO's first electric car, the EP9, was launched in 2016 and set the world record for the fastest all-electric car at Nürburgring's Nordschleife track (also known as "The Green Hell") in Germany. Subsequent launches included the ES8 seven-seater SUV in 2017, the six-seater ES8 in 2018, the ES6 SUV in 2018, the EC6 smart electric coupe SUV in 2019, and the ET7 electric sedan in 2021. By the end of 2022, the company had delivered a total of 289,556 vehicles, which included 122,486 in 2022 alone.

NIO has also established NIO Life, a lifestyle brand covering apparel, home and living, travel, consumer electronics, cars, food, and wine. By the end of 2020, the brand had delivered over 2.6 million products through its online and offline channels. The company's offices are located throughout the world: Beijing, Shanghai, Nanjing, Hefei, San Jose, Oslo, Oxford, and Munich.

- Year founded: 2014
- Number of employees: 26,763 (Dec 2022)
- Revenue (group): US$7.1 billion (Dec 2022)
- Revenue (automotive): US$6.6 billion (Dec 2022)
- Net loss: US$2,093.2 million (Dec 2022)

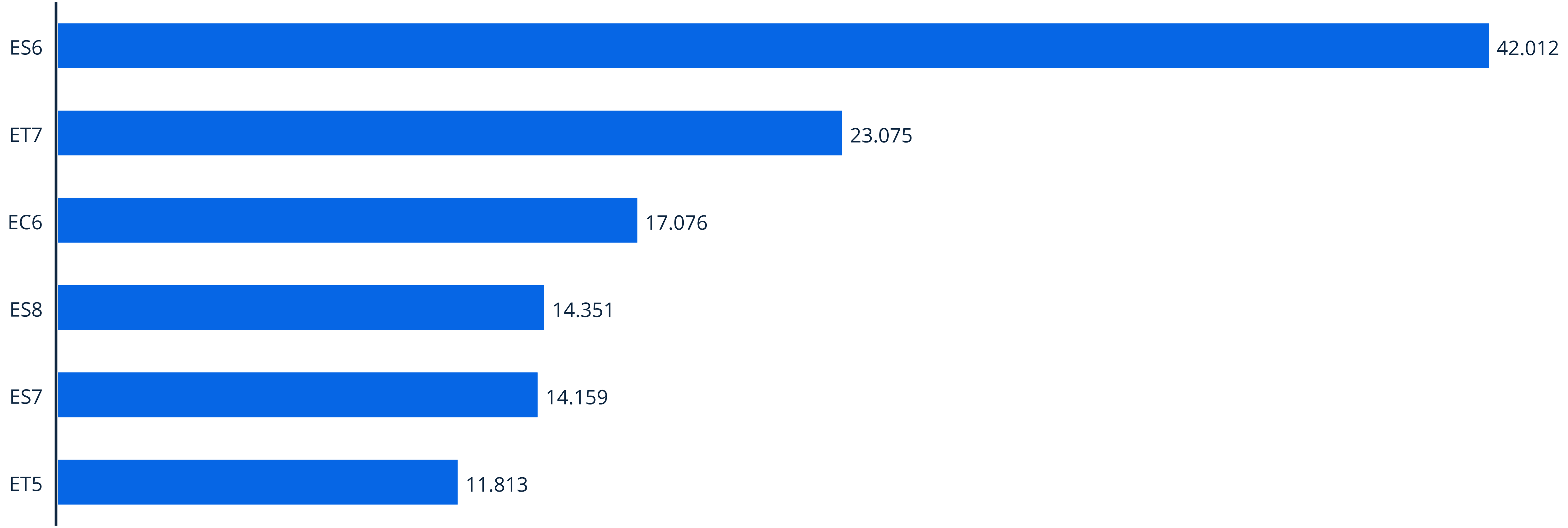
EV model	Type	Battery range	Battery used
eT5	PEV	621 miles	150 kWh lithium ion
eT7	PEV	621 miles	150 kWh lithium ion
eC6	PEV	615 miles	100 kWh lithium ion
eS8	PEV	360 miles	100 kWh lithium ion
eS6	PEV	379 miles	100 kWh lithium ion

Sources: Company sources; Annual report; Press releases; CNBC; Autoexpress

ES6 was Nio’s top-selling electric vehicle in 2022

NIO (2/2)

Nio EV sales in 2022 in units



Sources: Inside EVs

Nissan launched its first electric vehicle, the Tama, as early as 1947

Nissan (1/2)

Nissan Motor Company Ltd or Nissan, is a Japanese multinational automobile manufacturer headquartered in Nishi-ku, Yokohama. The company sells its cars under the Nissan, Infiniti, and Datsun brands. Nissan's Tama, its first EV and equipped with lead batteries, was launched in 1947. However, it was only after the launch of the Hypermini in 2000 that the company's EV division gained momentum. Nissan's flagship EV brand, Leaf, was launched in 2009. In 2014, global sales of Leaf surpassed the 100,000 mark and achieved a total of 450,000 units in 2020. The company also launched the Leaf e+, an upgrade to the existing Leaf model in January 2019. In July 2020, Nissan unveiled its first electric SUV, Ariya, deliveries of which will commence in the first half of 2022. The company plans to spend more than US$17 billion over the next five years to accelerate the rollout of electric vehicles featuring 23 new models by 2030.

- Year founded: 1933
- Number of employees: 134,111 (Mar 2022)
- Revenue (group): US$79.9 billion (Mar 2023)[1]
- Net income: US$1.8 billion (Mar 2023)[1]

EV model	Type	Battery range	Battery used
Nissan Leaf	PEV	226 miles	40 kWh lithium ion
Nissan Townstar Van	PEV	177 miles	44 kWh lithium ion
Nissan Ariya SUV	PEV	265 miles	87 kWh lithium ion

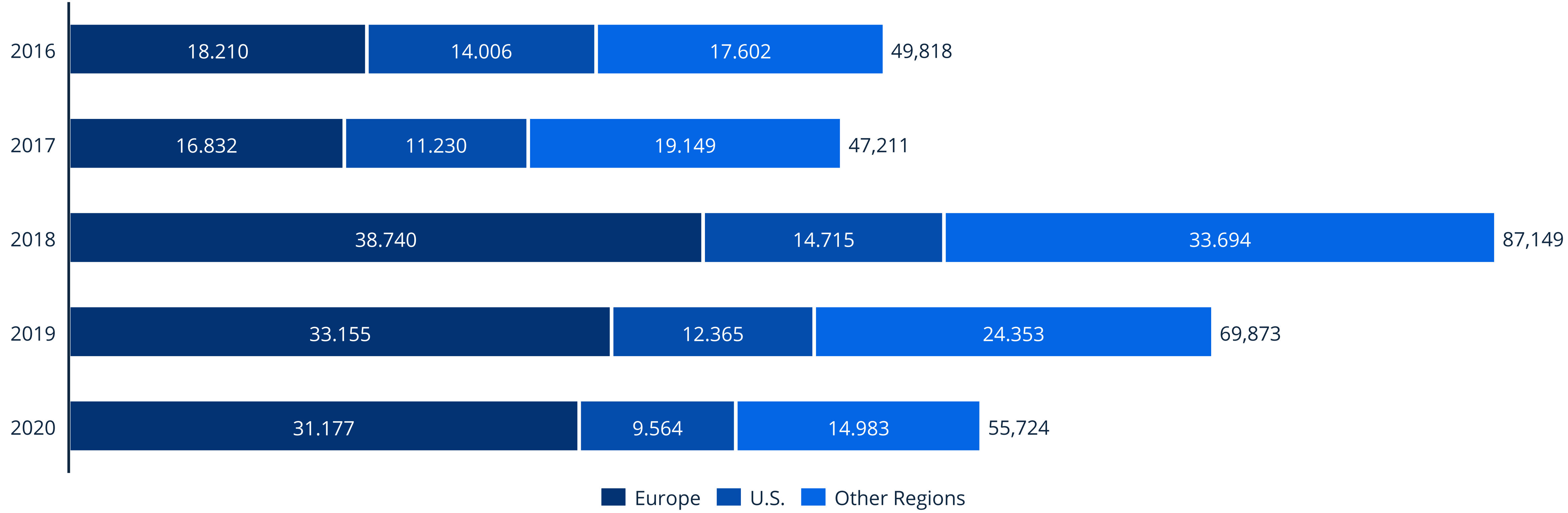
Notes: (1) Converted from Yen (JPY) to US$, exchange rate: JPY-US$ 0.00754 as of Mar 31, 2023 (Oanda)

Sources: Company sources; Annual report; Press releases; Hindustan Times; Inside EVs

Compared to 2019, sales of Nissan's Leaf decreased by 20% in 2020

Nissan (2/2)

Nissan Leaf EV sales in units



Sources: Carsalesbase; EV Obsession; Inside EVs; Seekingalph

Rivian's IPO toppled Facebook from its position among U.S. companies

Rivian (1/2)

Founded in 2009, Rivian Automotive is an American electric vehicle manufacturer. The company, whose investors include Amazon, Ford, and T. Rowe Price, among others, is currently manufacturing an electric pickup truck (R1T) and a sports utility vehicle (R1S). Production of the FF91 line of sedans is set to begin in 2022. Like Tesla, Rivian uses a skateboard platform, a flexible proprietary architecture that facilitates the seamless manufacture of different types of vehicles.

Although Rivian had made only 1,015 vehicles at its factory in Illinois by the end of 2021, plans are being made to ramp up production at its new US$5 billion factory just outside Atlanta, Georgia in 2024. At present, the company's largest order is to produce 10,000 electric delivery vans for Amazon by the end of 2022 and 90,000 more by the end of the decade.

In November 2021, Rivian raised nearly US$12 billion in what was the biggest IPO of the year and assigned the company a valuation of over US$100 billion. This was more than the valuations of General Motors, Ford, and Honda but far behind Tesla's. However, the company's market value has since dropped to approximately US$65 billion. Rivian plans to use these funds to produce 150,000-200,000 vehicles annually by 2023/2024.

Sources: Company sources; Electrek; Time; Fortune

Rivian's IPO toppled Facebook from its position among U.S. companies

Rivian (2/2)

- Year founded: 2009
- Number of employees: 14,122 (Dec 2022)
- Revenue (group): US$1.7 billion (Dec 2022)
- Revenue (automotive): N/A
- Net loss: US$6.8 billion (Dec 2022)

EV model	Type	Battery range	Battery used
R1T	PEV/Electric pickup truck	314 miles	135 kWh lithium ion
R1S	PEV/Electric SUV	316 miles	135 kWh lithium ion
EDV700(1)	PEV	201 miles	-
R1X(2)	PEV	-	-

Notes: (1) Rivian is making a total of 100,000 vans only for Amazon. Technical details of the vehicle are not out yet. (2) The R1X is expected to be manufactured sometime in the future. No technical details are available yet.

Sources: Company sources; Electrek; Time; Fortune; Annual report

Tesla currently has four electric vehicle models on the market

Tesla: Overview (1/2)

Tesla designs and develops fully electric vehicles and energy storage systems. The company also installs, operates, and maintains solar and energy storage products.

It currently sells four fully electric vehicles: the Model S sedan, the Model X sport utility vehicle (SUV), the Model 3 (a lower-priced sedan), and the Model Y SUV. In 2022, Tesla's Semi — first seen as a prototype in 2017 — will be brought to market, and the second-generation Roadster is expected to ship in 2023. The company's vehicles are sold through its own branded stores.

In addition to manufacturing electric vehicles, Tesla looks to leverage its expertise in batteries, power electronics, and integrated systems to manufacture and sell energy storage products. Its main manufacturing facilities are located in Fremont and Lathrop (California), Tilburg (the Netherlands), and Reno (Nevada).

- Year founded: 2003
- Number of employees: 127,855 (Dec 2022)
- Revenue (group): US$81.5 billion (Dec 2022)
- Revenue (automotive): US$71.5 billion (Dec 2022)
- Net profit: US$12.6 billion (Dec 2022)

EV model	Type	Battery range	Battery used
Tesla Model S	PEV	405 miles	100 kWh lithium-ion
Tesla Model X	PEV	348 miles	100 kWh lithium-ion
Tesla Model 3	PEV	333 miles	82 kWh lithium-ion
Tesla Model Y	PEV	330 miles	81 kWh lithium-ion

Sources: Company sources; Annual report; Press releases; CNBC; Autoexpress

In 2022, more than 1.3 million Tesla Model 3s and Model Ys were sold

Tesla: Overview (2/2)

Tesla EV deliveries in 2022 in units

Sources: Press releases

Tesla’s sole focus on electric vehicles pays off in technological superiority

Tesla: Technological superiority (1/2)

Before Tesla’s became a serious contender in the automobile industry, other major car manufacturers had more financial resources at their disposal. However, over the past few years, Tesla has been able to establish a more robust and advanced technological infrastructure. In the book Zero to One by Peter Thiel, the founder of PayPal, he acknowledges, “Tesla's technology is so good that other car companies rely on it.” That Daimler once relied on Tesla’s battery packs, Mercedes-Benz its powertrain, and Toyota its motor all demonstrate Tesla’s technological dominance in the global automotive industry.

One factor which places Tesla in a category of its own is its ability to produce large volumes of high-end electric vehicles. Its efforts are focused solely on continuously improving its technological expertise in all aspects of the value chain, ranging from battery range to autonomous driving.

Traditional automobile companies, by contrast, merely experiment with electric vehicles as most of their profits are earned from the production of ICE cars. If they were to start mass production of electric vehicles, they would risk cannibalizing their own market share and position. However, Tesla has more than its advanced technology working in its favor. It has also achieved mastery over managing and delivering its entire technology infrastructure.

Tesla’s proprietary operating system allows its technology to remain both highly flexible and secure. Furthermore, since the company has made most of its technology remotely transmittable, all cars can be instantly upgraded through regular updates to new operating systems. Some of Tesla’s innovative technologies include:

- AI powered fleet learning: The thousands of cars that make up Tesla’s entire fleet are now using AI and big data to transfer information between networked cars to improve the driving experience in terms of both safety and performance. Key to the company’s autonomous driving research is the uninterrupted cellular connection to its cars; every 10 hours, 1 million miles of self-driving data is made available. In August 2021, Tesla launched D1, a custom chip that trains AI networks in data centers to recognize various events from video feeds collected by cameras inside Tesla cars. These chips are expected to enhance Tesla’s Full Self-Driving Capability that enables vehicles to autonomously change lanes, navigate highways, and maneuver into parking spaces.

Sources: Company sources; Annual report; Press releases; CNBC; Autoexpress

Tesla’s sole focus on electric vehicles pays off in technological superiority

Tesla: Technological superiority (2/2)

- Battery innovation: Tesla is gradually moving away from the standard nickel cobalt aluminum oxide (NCA) cells to lithium iron phosphate (LFP) cathodes. Due to the dwindling supply of nickel at competitive rates, automobiles are becoming more expensive. The company is also producing the 4680 battery cell, a tabless cylindrical cell that is said to have 600% more power and 500% more energy capacity. Meanwhile, Tesla’s high-end Model S and Model X cars are powered by its 100 kWh battery pack with a range of 315 miles and 289 miles, respectively. The packs feature a novel design and a new way to cool the battery cells as they discharge energy.
- Radar technology: The radar processing technology available in its Autopilot software enables the system to see two cars ahead. Since it bounces underneath or around the vehicle, it has access to a view that a driver does not typically have. As a result, radar technology can predict an accident about two seconds faster than a driver. Tesla has dropped the radar technology for the Model Y and Model 3 vehicles sold in North America, but new Model S and Model X vehicles and all models built for other markets are still equipped with this technology.

Sources: Company sources; Annual report; Press releases; CNBC; Autoexpress

By centralizing the supply chain, Tesla is able to lower its costs

Tesla: Centralization of the supply chain (1/2)

Tesla's ability to centralize some crucial elements of the supply chain gives it the scale and efficiencies to improve performance, lower costs, and deliver a superior customer experience. It also allows the company to make quick changes to its custom manufacturing processes, prevent loss of patents, increase speed of innovation, and improve its speed-to-market. Some key features include:

- Battery production: The company's US$5 billion Gigafactory in Nevada is expected to reduce the cost of battery production by as much as 35% by streamlining labor, time, and transport. Experts in the industry have predicted that battery cost needs to come down to about US$100/kWh if electric vehicles are to witness mass adoption. The Gigafactory gives Tesla the best possible chance to achieve this reduction in cost by securing the benefits of manufacturing on a large scale.
- Charging network: Tesla has the most comprehensive and ubiquitous network of self-owned charging stations among all-electric vehicle manufacturers. At the end of 3Q2021, it had approximately 3,250 super-charging stations and over 29,250 charging points globally. Initially offered free of cost, customers who purchased a Tesla after January 1, 2017 must pay a "small fee" to recharge their cars. In turn, Tesla uses these fees to expand the network of charging stations.
- Unified computing architecture: Tesla's unified computing architecture has given the company a sizeable competitive advantage in the industry. Most notably, it has enabled Tesla to navigate the ongoing semiconductor shortage more effectively than other manufacturers that have had to endure production delays, suspended models, and resultant sharp price increases. By owning its own software, the company's AI engineers were able to access, modify, and rewrite the software according to their needs and thereby make use of available chips from other vendors. Unsurprisingly and whereas most other manufacturers struggled, Tesla sold almost twice the number of cars in 2021 as compared to 2020.
- Distribution network: In addition to battery production and a unified computing architecture, Tesla's entire distribution network is also in-house; the company sells directly to the end consumer via its website and company-owned showrooms. Even though this requires a high level of upfront investment, the company saves money in the long run by eliminating the factors of dealer markups and excess inventory.

Sources: Wired; Electrek; Harvard Business School; Torque News

Tesla's ambition: to control the entire battery supply chain

Tesla: Centralization of the supply chain (2/2)

In September 2020, Elon Musk announced Tesla's goals to build a US$25,000 mass-market electric car and to ramp up annual production to 20 million cars. Achieving these rather ambitious goals hinges on securing complete control of all elements of the battery supply chain process.

- Cathode production: To begin with, Musk intends to develop an independent cathode plant, with the benefits of reducing supply chain costs while simplifying production processes and eliminating many of the intermediate steps. These cathodes will be 76% less expensive compared to current prices and not generate wastewater. In February 2022, Tesla applied to build a new facility to manufacture cathode materials for batteries, next to its Gigafactory in Austin.
- Novel cell: Instead of buying cells from various suppliers, Tesla is now developing a proprietary '4680' cell for its pilot line on Kato Road in Fremont, California. This cell has 16% more range, an improved power-to-weight ratio, and much higher energy outputs. Its reduced number of connections —1,800 as compared to the current 8,800 — is expected to result in a 40% reduction in steel usage. The production of automotive-grade battery cells at consistently high volumes and quality is another sign of the importance of vertical integration to Tesla's strategy.

Sources: Wired; Electrek; Harvard Business School; Bloomberg

Tesla scores with aesthetics and range in the luxury EV segment

Tesla: Unique market positioning

One of the main reasons for Tesla's success is that it has managed to ride the electric vehicle wave with a unique market positioning. Tesla is currently the only electric vehicle brand to manufacture luxury, long-range cars on a large scale. Other companies such as Nissan, Chevrolet, and BMW either make low-frill electric cars with shorter ranges or expensive plug-in hybrids.

The Model S is currently the only car in the luxury long-range electric vehicle market with a range of 402 miles on a single charge and a top speed of 163 mph.

Aesthetics, which is especially important in industries of consumer electronics, fashion, and automotive, is another area where the Model S scores above every other electric car in the market today.

According to experts at the Harvard Business School and the Wharton School at the University of Pennsylvania, Tesla is bound to perform well based on its brand strength and distinctiveness from other car manufacturers.

Sources: Wired; Electrek; Harvard Business School

Tesla faced liquidity issues due to Model 3 manufacturing problems

Tesla: Model 3 manufacturing problems (1/2)

When Tesla Motors started accepting orders for the Model 3 in 2016, it received nearly US$10 billion in pre-orders in just two hours. With a base model price of US$35,000, the Model 3 was thought to be the electric car that would take the segment mainstream.

However, two years later, Tesla missed its production targets and also used up its budget in the process. The company fell far short of its original promise to manufacture 5,000 Model 3 automobiles every week by the end of 2017 and was able to deliver only 1,764 in the final two quarters of that year. However, things started turning around for the company and delivered 92,550 Model 3 cars in the fourth quarter of 2019 against a target of 87,900 cars.

Another major concern for the company was the cash burn it suffered between 2017 and 2019. At the end of 2019, Tesla announced a loss of US$775 million on revenues of US$24.6 billion. This prompted credit analysts to question the company's liquidity and speculate about its ability to raise more money from the financial markets amid declining investor confidence.

However, these concerns have now been laid to rest after Tesla's stock increased by over 740% in 2020 and by additional 50% in 2021 in spite of much global uncertainty. In fact, Tesla is now valued higher than the combined value of Toyota, Volkswagen, Daimler, General Motors, BYD, and NIO.

One of the main reasons behind the Model 3 delays was the company's problems with battery production at its Gigafactory in Sparks, Nevada.

According to statements given by Tesla's current and former employees, the company at the time could not to fully automate the battery manufacturing process. As a result, they had to produce them partly manually, which in turn created production delays. Moreover, mistakes were made by some external vendors who were responsible for two of the battery zones. Potential fire hazards caused by insufficient distances between lithium-ion cells were also reported to media sources.

Sources: Harvard Business School; Wharton; CNBC

Heavy reliance on robots resulted in production delays of the Model 3

Tesla: Model 3 manufacturing problems (2/2)

Another difficulty Tesla encountered with the Model 3 production was excessive automation. Whereas Tesla's future as a mass-market manufacturer of automobiles hinges mainly on the successful automated production of its Model 3, this is exactly where the company faced problems in 2018/2019.

In an April 2018 interview with CBS Good Morning, Elon Musk confirmed that the major reason behind the production delays of the Model 3 was Tesla's overreliance on robots in the assembly lines that had repeatedly malfunctioned.

At the time, industry analysts considered this ironic, as the use of automation and advanced technologies had been positioned as the primary factors differentiating Tesla from other automobile manufacturers.

According to analysts at the asset management company Alliance Bernstein, Tesla's overreliance on Kuka robots to not only automate the usual stamping, paint, and welding processes, but also the entire final assembly (including welding and battery pack assembly) resulted in a breakdown of many processes.

Therefore, even though the Model 3's design was overall much easier to build compared to Tesla's other models, the intensely automated production line and failure of one of the subcontractors made it necessary for Tesla to rewrite most of the software from scratch and redo the mechanical and electrical elements in one area of the plant.

Sources: CNBC; Mashable; Stuff; The Sydney Morning Herald

"Yes, excessive automation at Tesla was a mistake. To be precise, my mistake. Humans are underrated."

Elon Musk
Tesla, 2018

Repeated vehicle recalls suggest manufacturing defects

Tesla: Vehicle recalls

In March 2018, Tesla recalled 123,000 of its Model S cars to repair excessively corroded power steering bolts. Although the steering wheels continued to function, significantly more force was required. This made the car harder to drive at lower speeds and also made parallel parking more difficult. In January 2021, the National Highway Traffic Safety Administration asked the company to recall 158,000 Model S and Model X vehicles due to faulty display consoles that when inoperable, disconnected driver access to the car's backup camera, climate control systems, and the Autopilot driver assistance system.

In December 2021, Tesla recalled over 475,000 of its Model 3 and Model S cars in the U.S. and an additional 200,000 in China because rear-view camera and trunk issues had increased the risk of collisions.

These are not the only examples of Tesla recalling its cars due to manufacturing defects. In 2017, malfunctioning parking brakes and a faulty locking mechanism forced Tesla to recall 53,000 Model X and Model S vehicles.

In 2014, charging defects and fire hazards forced the company to recall 20,222 Model S sedans. This was followed by another recall on 90,000 vehicles from the same model resulting from a defect in the front seat belt assembly.

Both the Model S and the Model X have attracted media attention based on malfunctions in their self-driving feature. In August 2021, the U.S. government opened a formal investigation into Tesla's Autopilot system, after many collisions with parked emergency vehicles left 17 people injured and one dead. The investigation included Tesla's entire electric vehicle lineup (Tesla Model X, Tesla Model Y, Tesla Model S, and Tesla Model 3) sold in the period between 2014 and 2021. In another incident in 2019, a Tesla driver on Autopilot ran a red light, collided into another car, and killed two people.

These recalls and production delays both tarnished the company's image and drastically drove its stock prices down.

Sources: CNBC; Mashable; Stuff; The Sydney Morning Herald; NPR

Volkswagen is the market leader for electric vehicles in Europe

Volkswagen (1/2)

Volkswagen's (VW's) electric vehicle journey can be traced back to 1970 when it opened its Centre for Future Research to develop a powertrain for the future. A few years later, the company launched the electric T2 Camper with a 70 km range and the Golf I City-STROMer in 1981.

Since then, VW has become one of the leading electric vehicle manufacturers in the world and has the largest market share in Europe. In December 2021, the company announced an investment of over US$100 billion in electric mobility over the next five years and expects 25% of all vehicle sales in 2026 to come from EVs. This is the first time the company has allocated over half its total spending for electric vehicles.

2021 was an especially good year for the company; a total of 369,000 PEVs and PHEVs were purchased a 73% increase compared to 231,600 in 2020. Although the European region holds the top spot for VW's sales of electric vehicles, China remained the single largest market with 92,700 PEVs (up 319.5% on 2020) sold in 2021, followed by the U.S. with 37,200 PEVs (up 200.2% on 2020). VW also plans to set up an independent battery manufacturing company whose estimated sales total US$34 billion.

- Year founded: 1937
- Number of employees: 675,800 (Dec 2022)
- Revenue (group): US$298.1 billion (Dec 2022)(1)
- Net profit: US$16.9 billion (Dec 2022)(1)

EV model	Type	Battery range	Battery used
E-up!	PEV	159 miles	32.3 kWh lithium-ion
E-Golf	PEV	144 miles	35.8 kWh lithium-ion
ID.3	PEV	261 miles	62 kWh lithium-ion
ID.4	PEV	275 miles	82 kWh lithium-ion
Q4 e-tron	PEV	323 miles	77 kWh lithium-ion
Q4 e-tron Sportback	PEV	309 miles	77 kWh lithium-ion
Taycan	PEV	227 miles	83.7 kWh lithium-ion

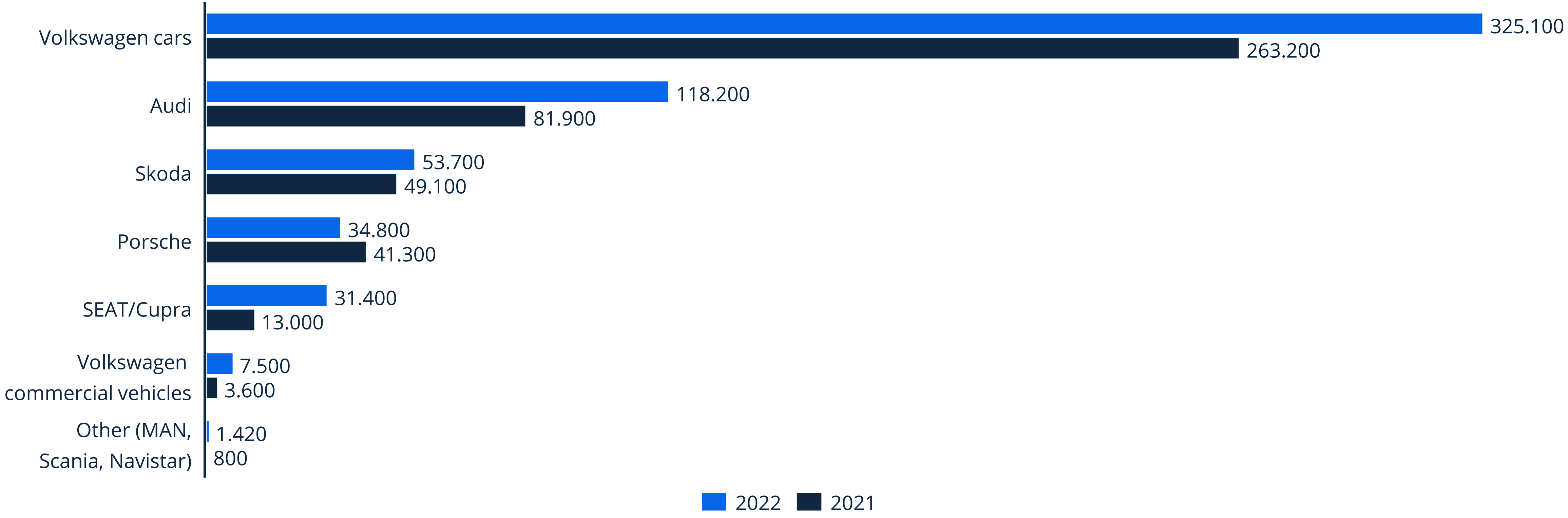
Notes: (1) Converted from Euro to US$, exchange rate: EUR-US$ 1.0674 as of Dec 31, 2022 (Oanda)

Sources: Company sources; Annual report; Press releases; CNN

Volkswagen sold over 572,000 electric vehicles in 2022

Volkswagen (2/2)

Volkswagen EV sales in units



Sources: Inside EVs

CHAPTER 12

Country analysis

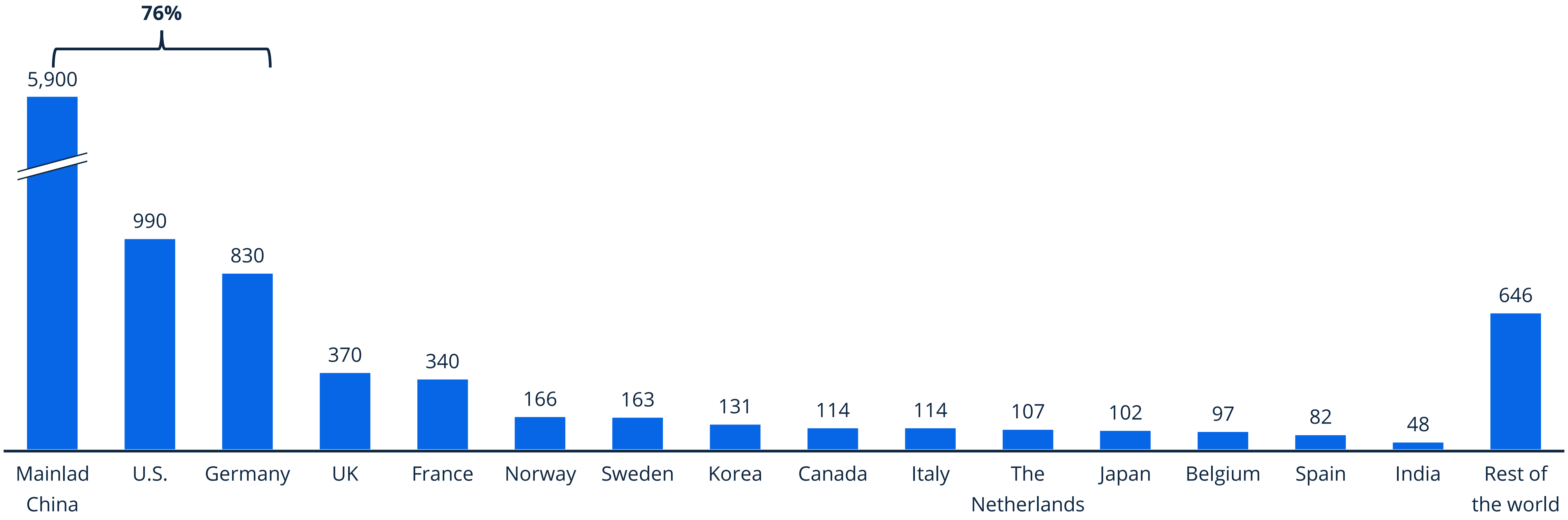
Mainland China, the U.S., and Germany were the three biggest markets for electric vehicles in 2022 and accounted for more than 76% of all electric vehicle sales globally in 2022. Most of the European countries witnessed robust sales in 2022 as compared to 2021. In Japan, electric vehicles sales increased in 2022 after the downward trend between 2018 and 2020.

In terms of charging infrastructure, Mainland China once again leads the pack with more than 1,760,000 publicly accessible charging points, followed by South Korea (approx. 201,000), the U.S. (approx. 128,000), and the Netherlands (approx. 124,300)

76% of 2022 sales were in Mainland China, the U.S., and Germany

Overview (1/2)

New electric cars registrations in thousands in 2022

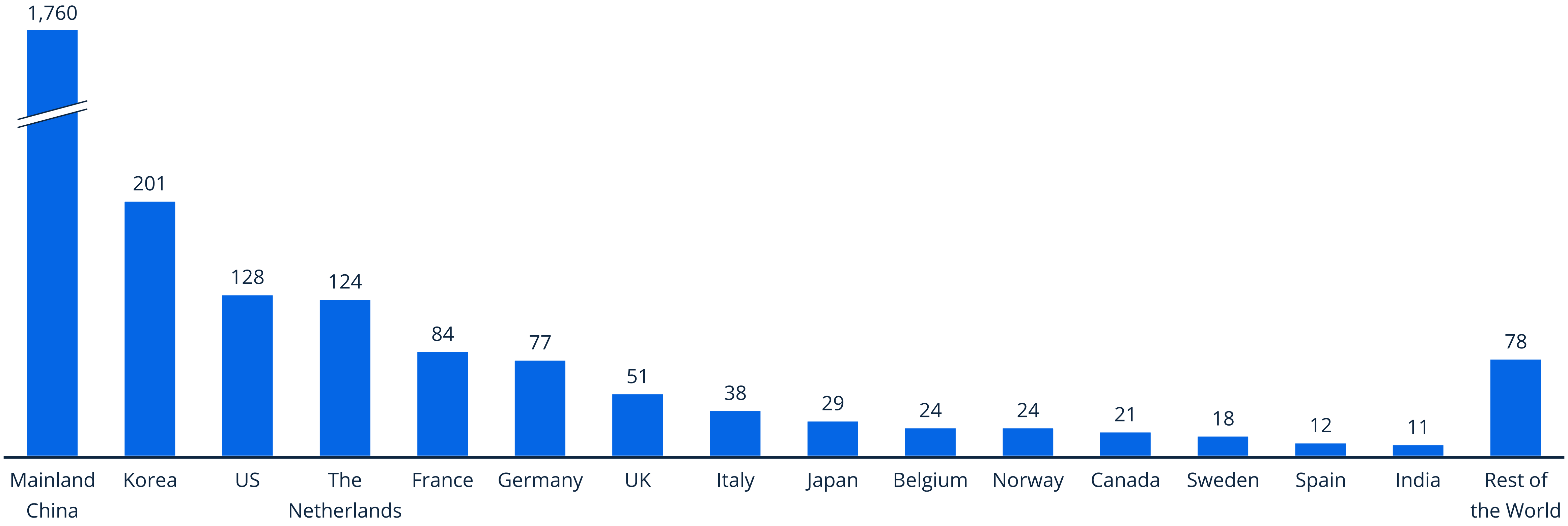


Sources: International Energy Agency (IEA)

Mainland China also leads the race in terms of EV charging points

Overview (2/2)

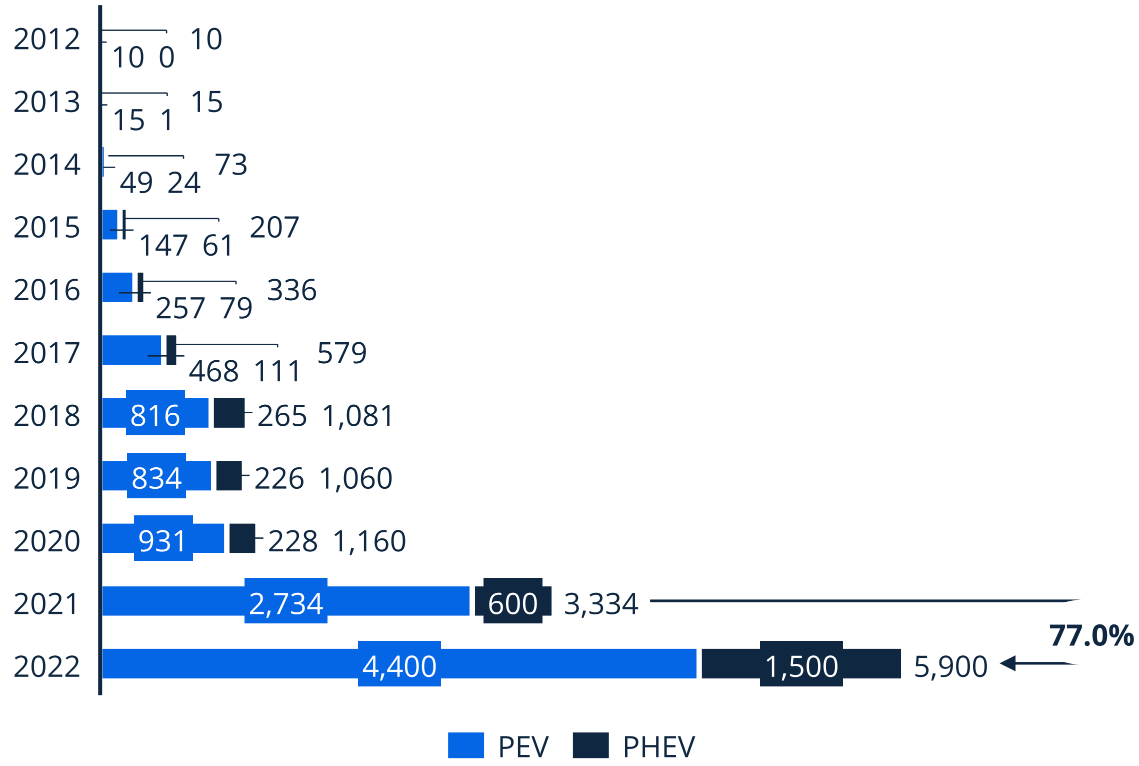
Number of publicly accessible charging points in thousands in 2022



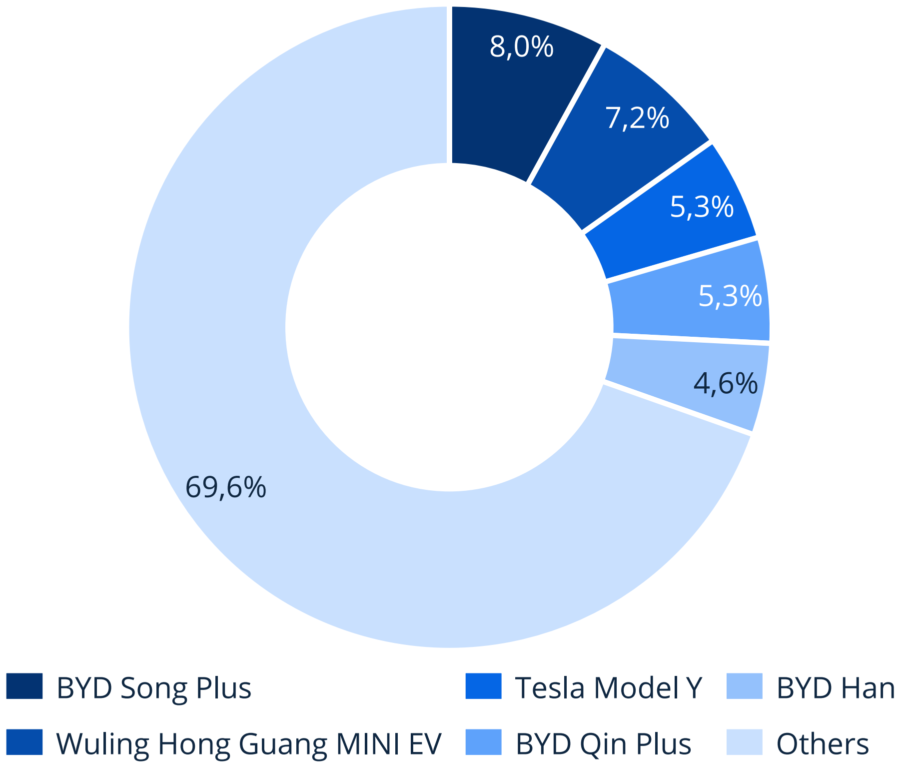
Sources: International Energy Agency (IEA)

Country analysis: Mainland China (1/2)

New electric cars registrations in thousands



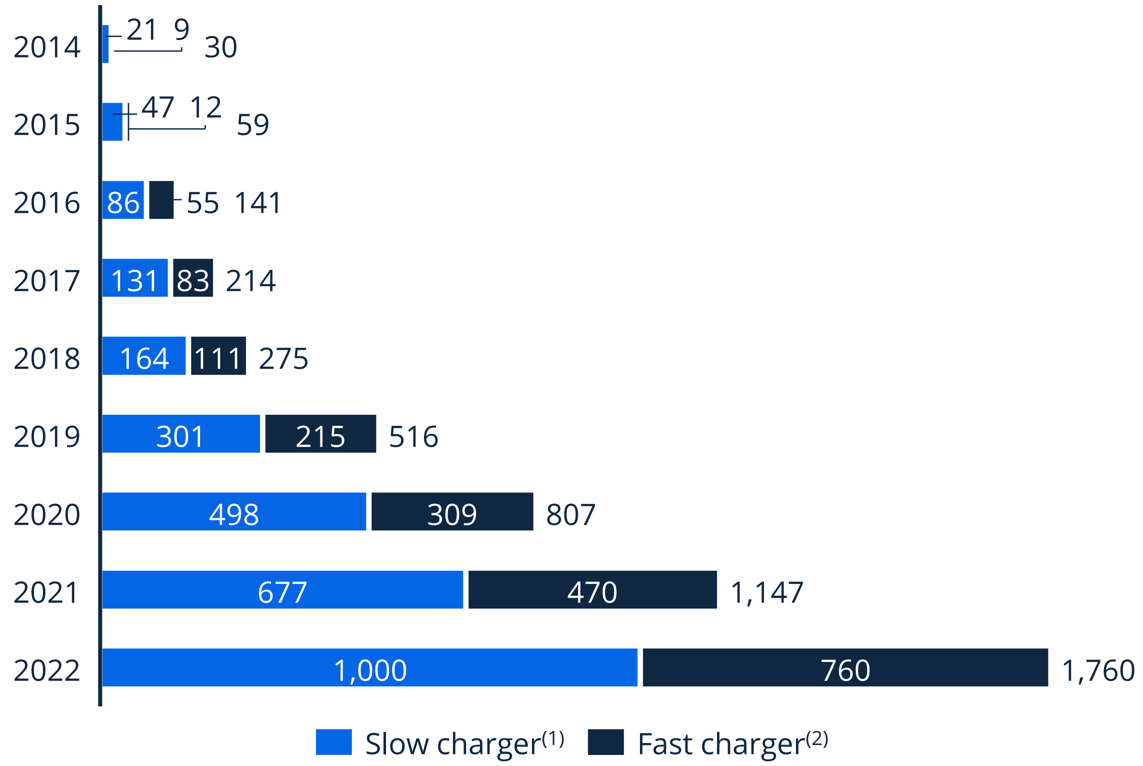
PEVs and PHEVs sales share by models in 2022



Sources: International Energy Agency (IEA); Inside EVs

Country analysis: Mainland China (2/2)

Number of publicly accessible charging points in thousands

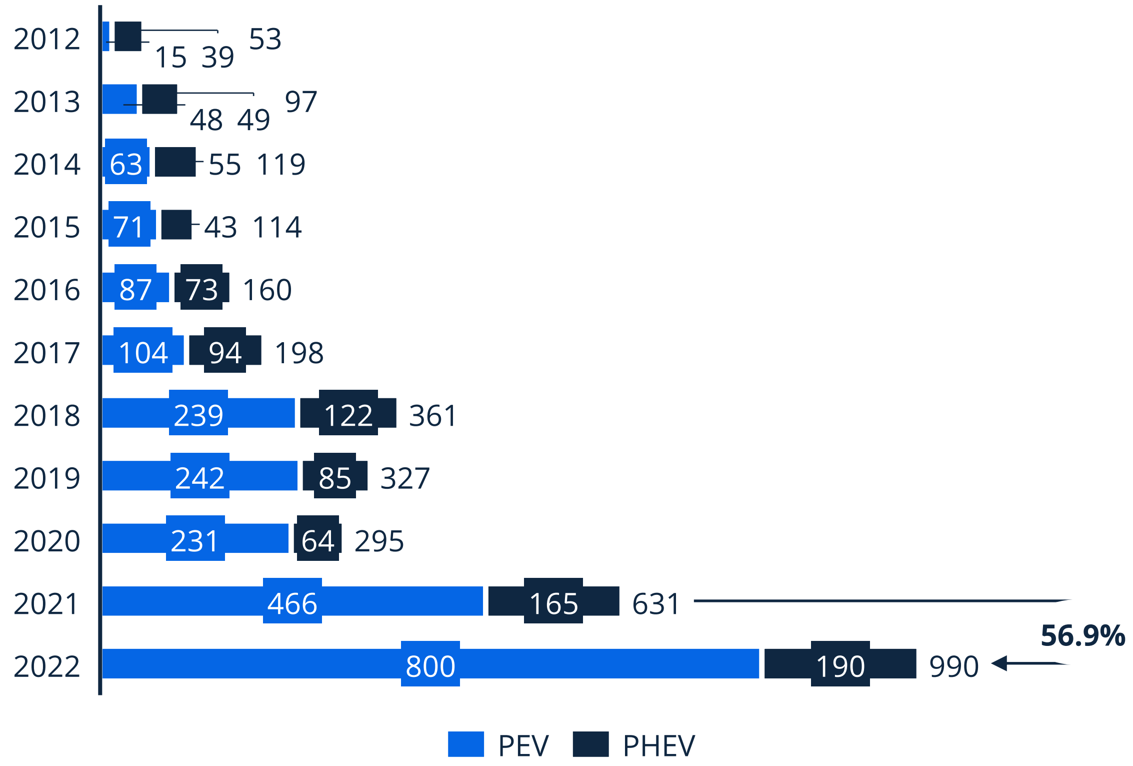


Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

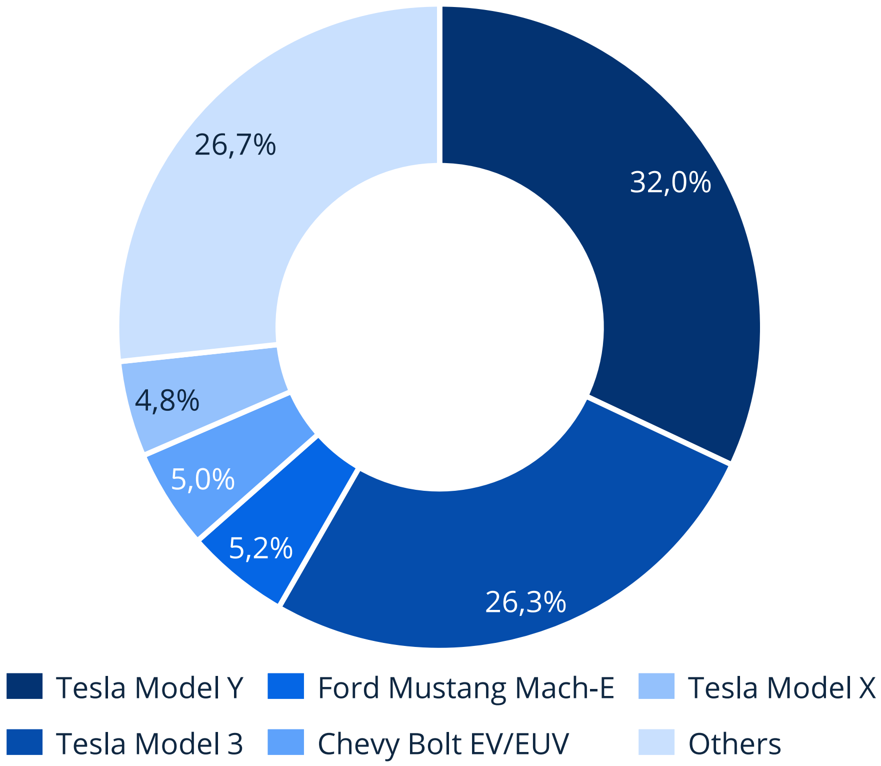
Sources: International Energy Agency (IEA)

Country analysis: U.S. (1/3)

New electric cars registrations in thousands



PEVs and PHEVs sales share by models in 2022

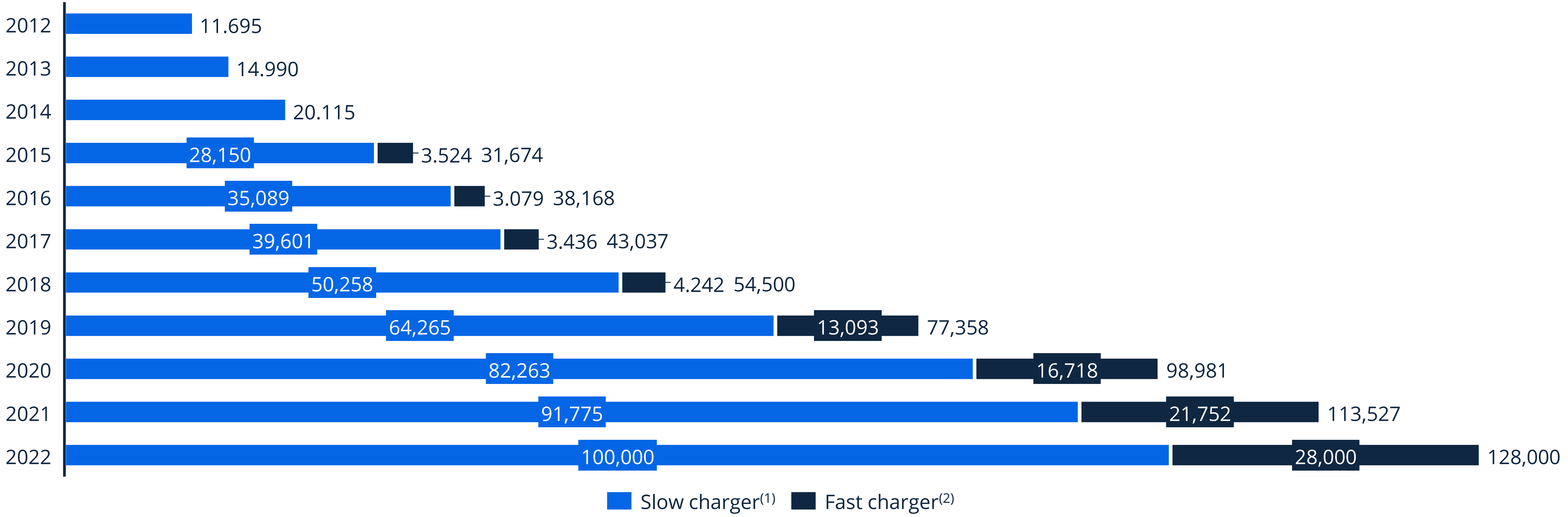


Sources: International Energy Agency (IEA); CleanTechnica

statista

Country analysis: U.S. (2/3)

Number of publicly accessible charging points



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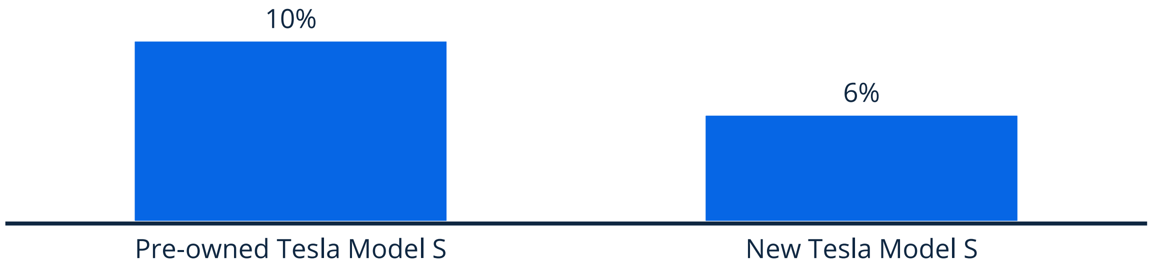
Sources: International Energy Agency (IEA); Inside EVs

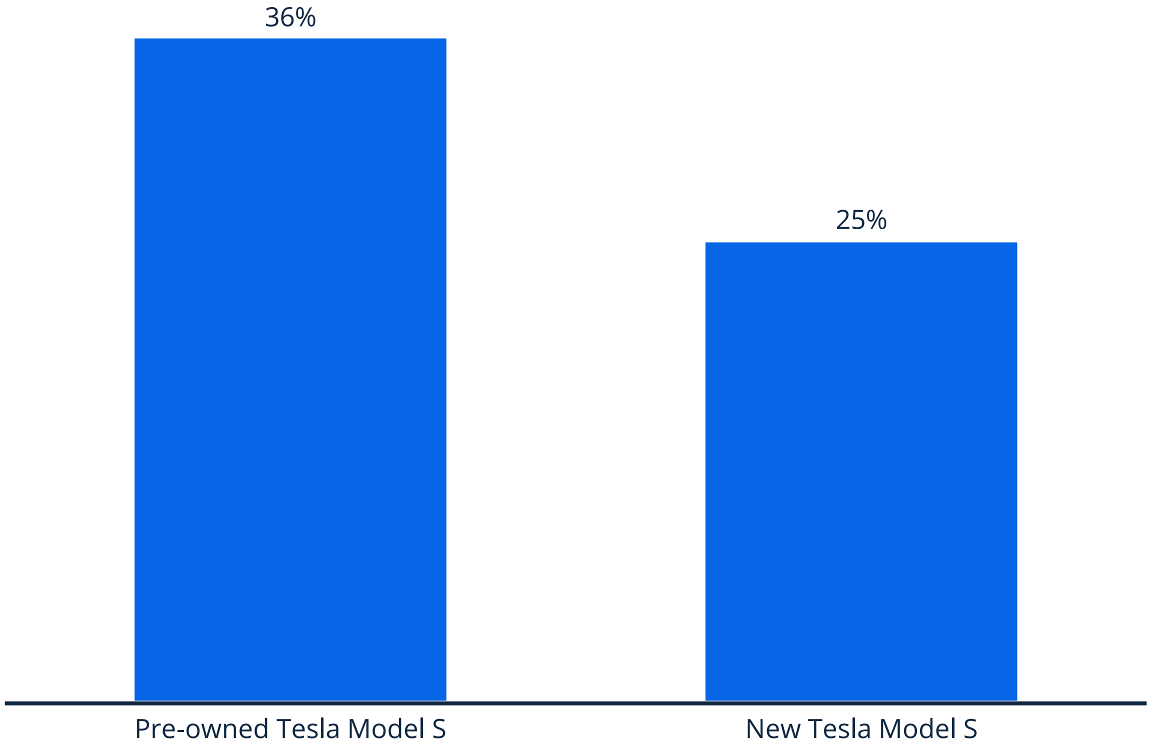
Country analysis: U.S. (3/3)

Consumer profile: Tesla model S

Share of 18-34 years old consumers



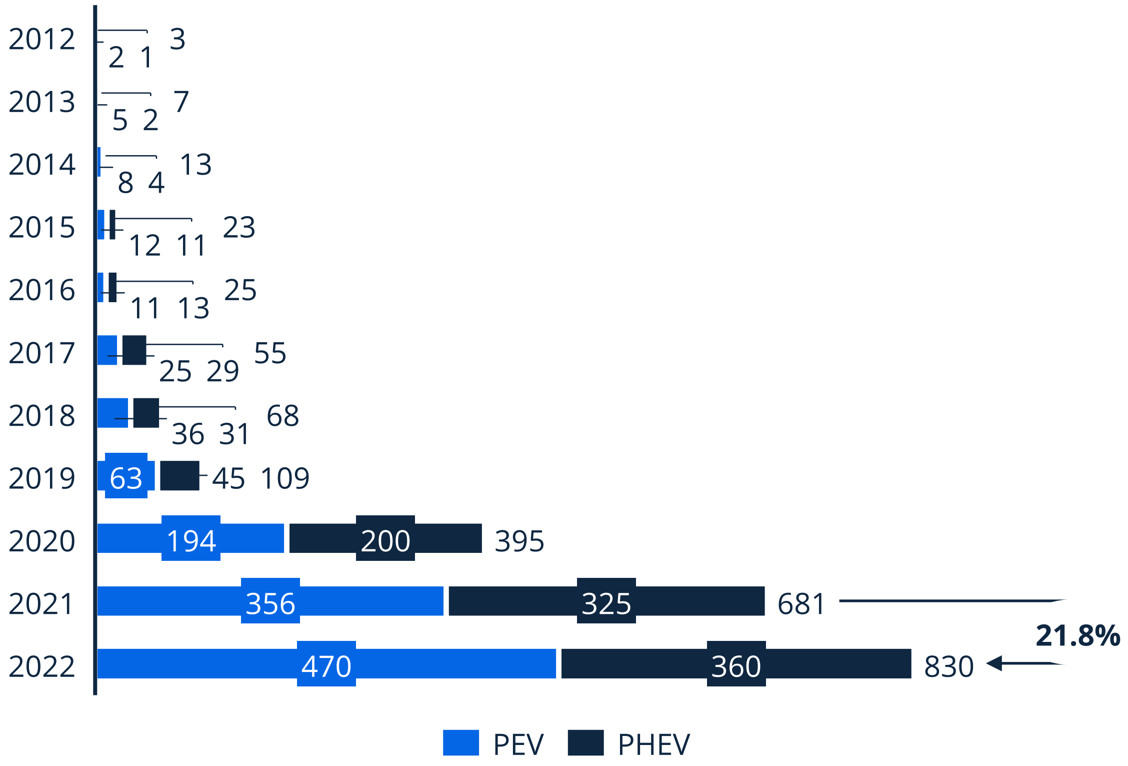
Share of consumers with an income of less than US$100,000 a year



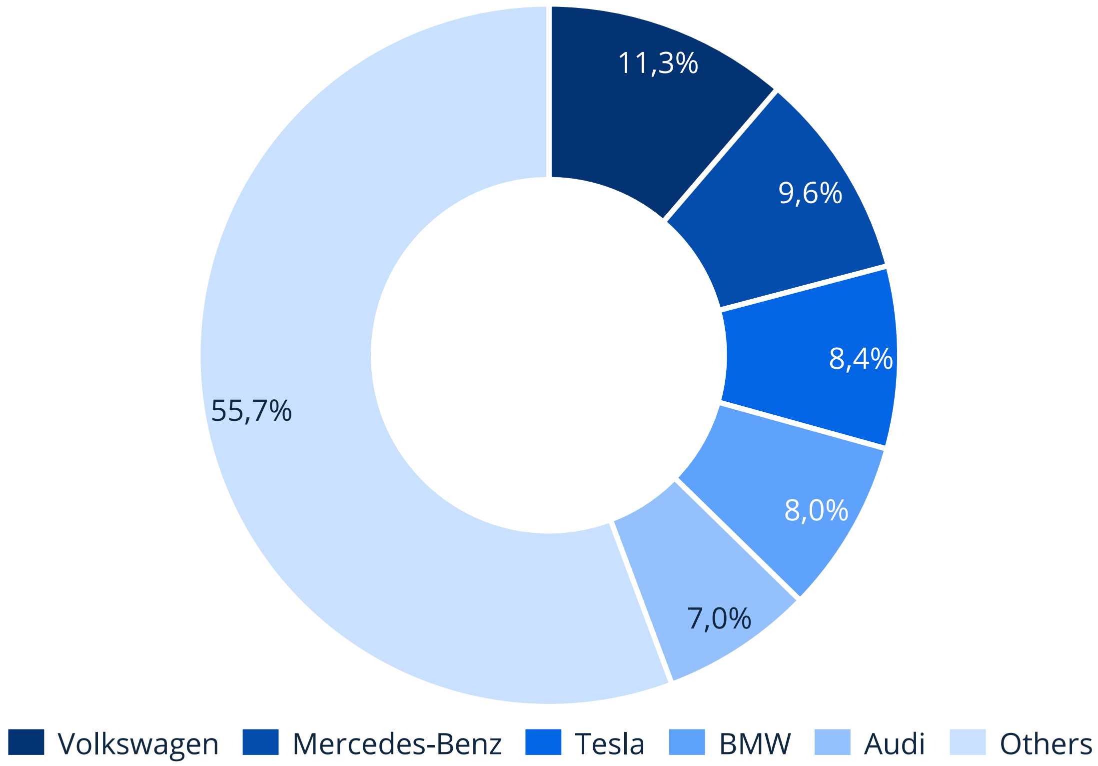
Sources: Automobile Propre; International Energy Agency (IEA)

Country analysis: Germany (1/3)

New electric cars registrations in thousands



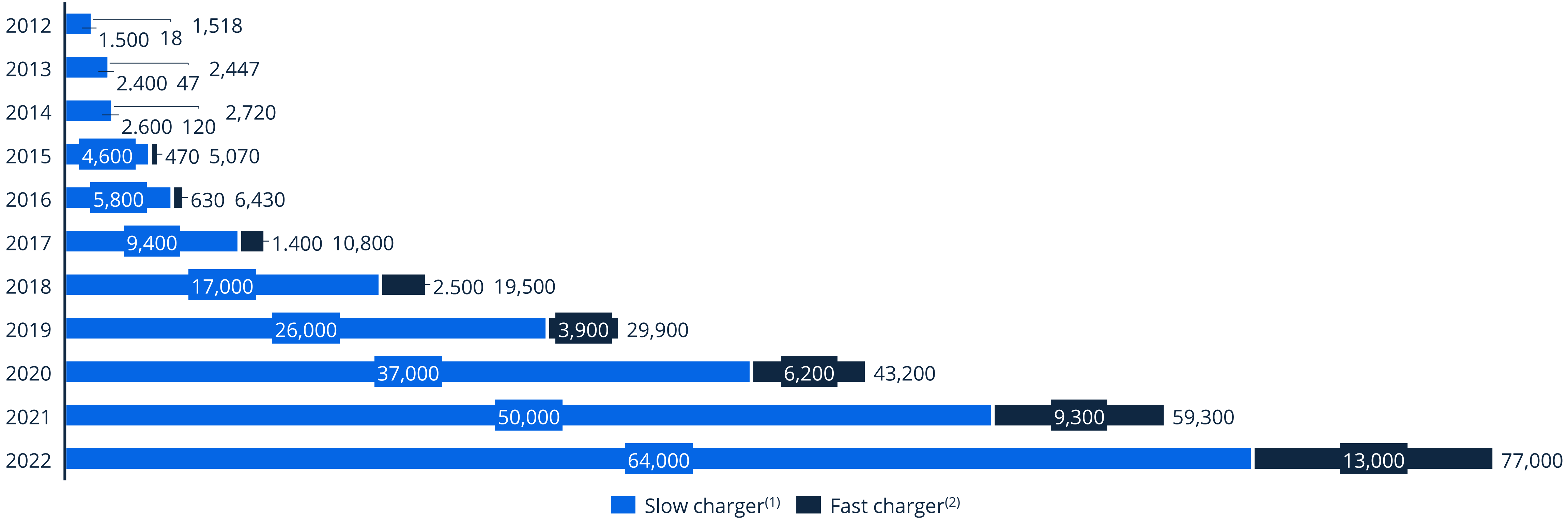
PEVs and PHEVs sales share by brands in 2022



Sources: International Energy Agency (IEA); Inside EVs

Country analysis: Germany (2/3)

Number of publicly accessible charging points



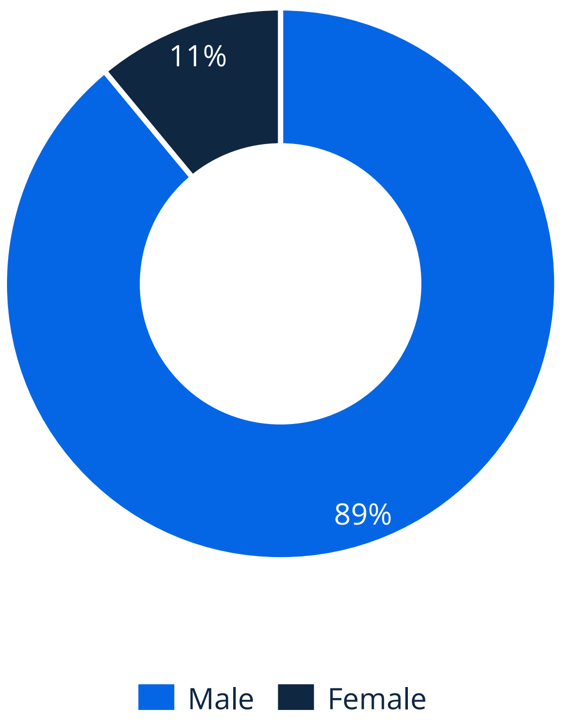
Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

Sources: International Energy Agency (IEA)

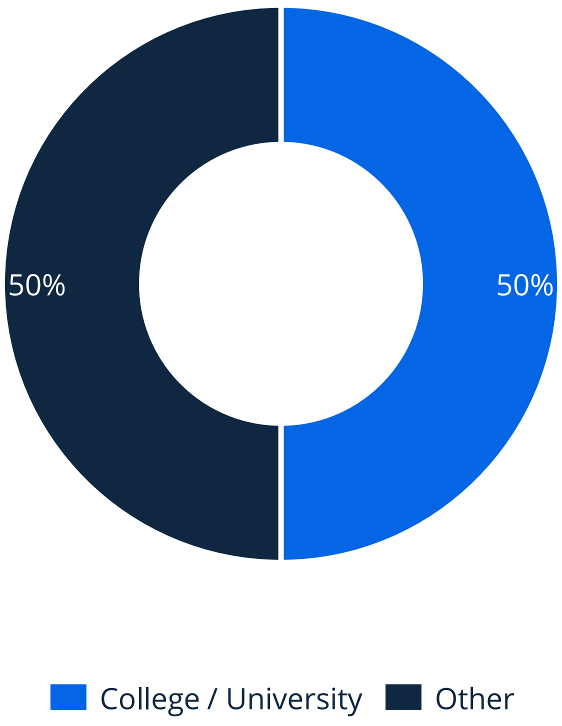
Country analysis: Germany (3/3)

Consumer profile: Electric vehicles

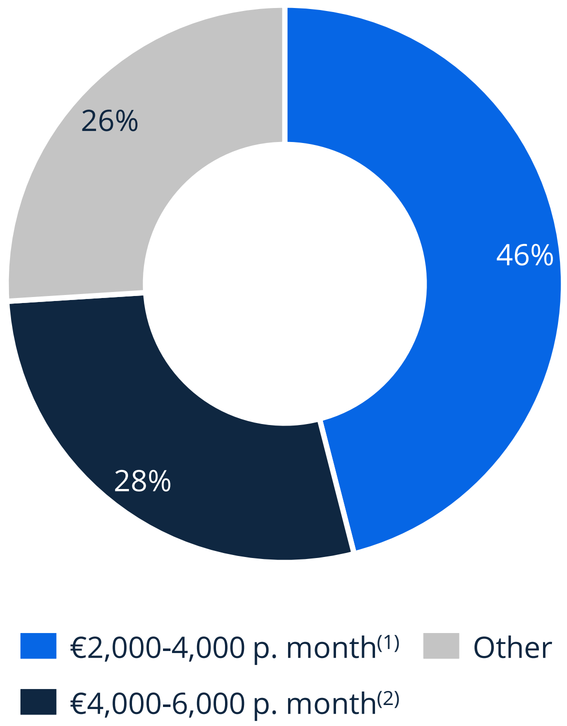
Gender



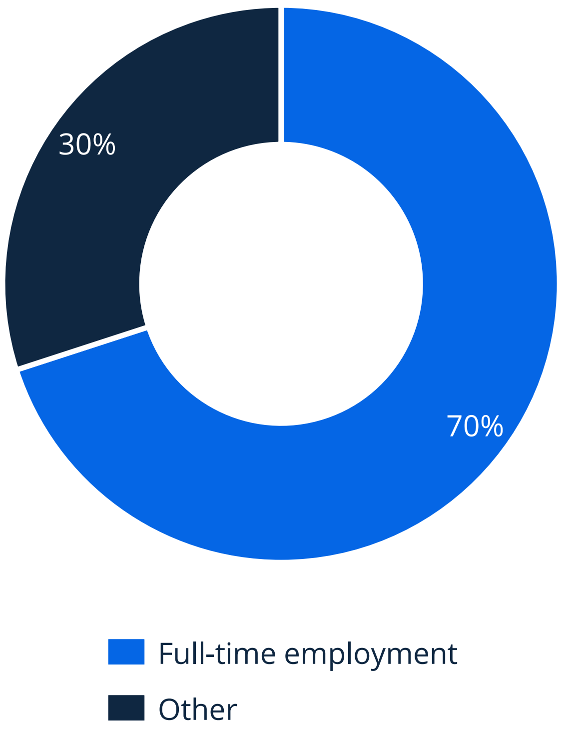
Education



Income



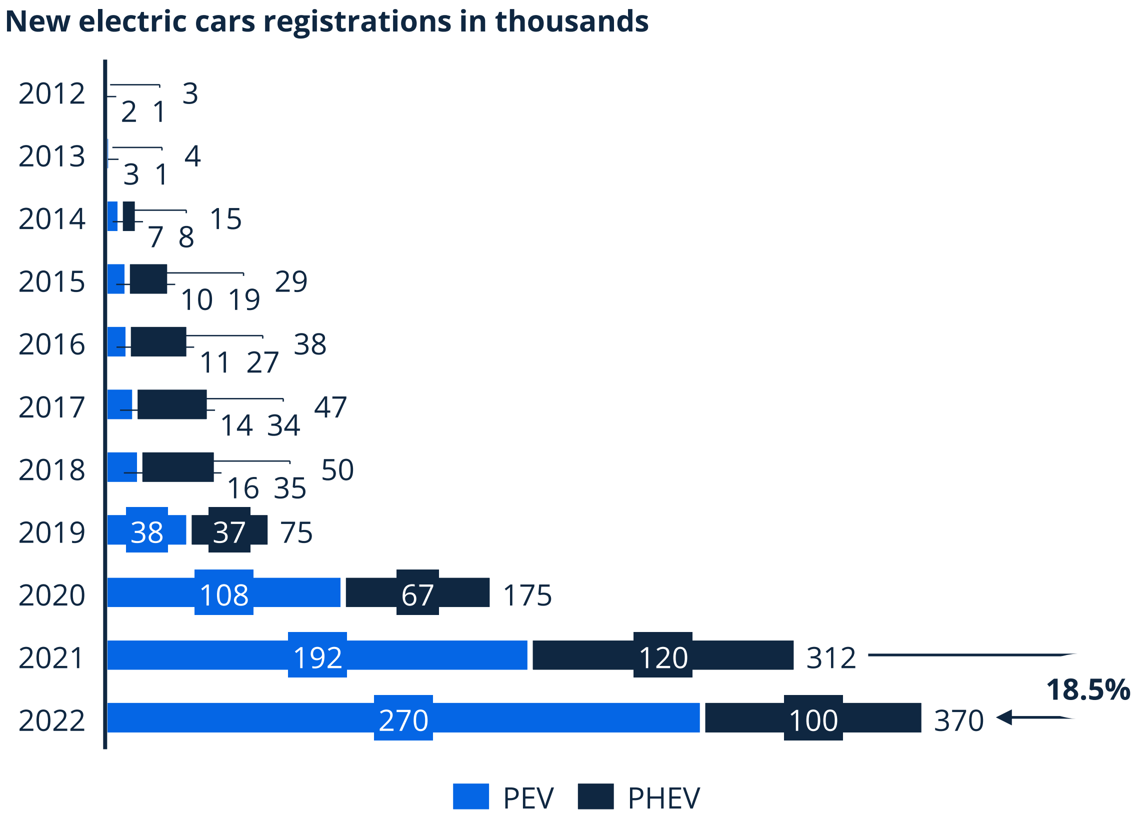
Employment

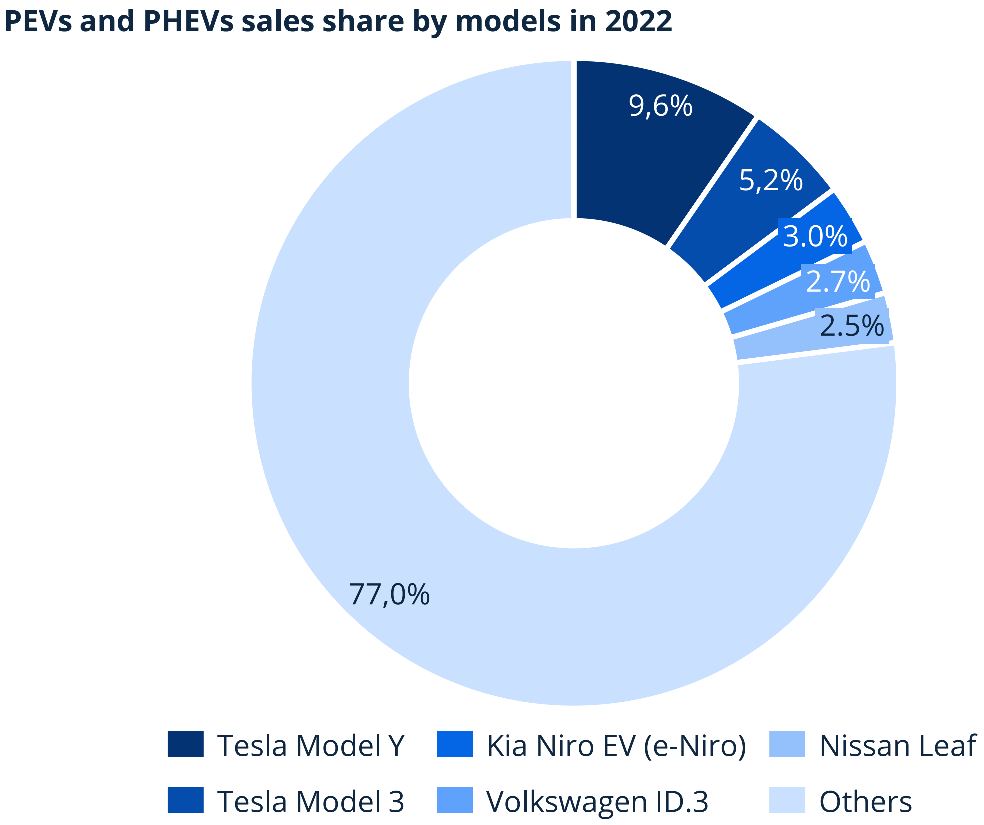


Notes: (1) US$2,360-US$4,720 (Oanda exchange rate 31st Sep 2017) (2) US$4,720-7,008 (Oanda exchange rate 31st Sep 2017)

Sources: Early adopters of electric vehicles in Germany unveiled, as of May 2015

Country analysis: UK (1/2)

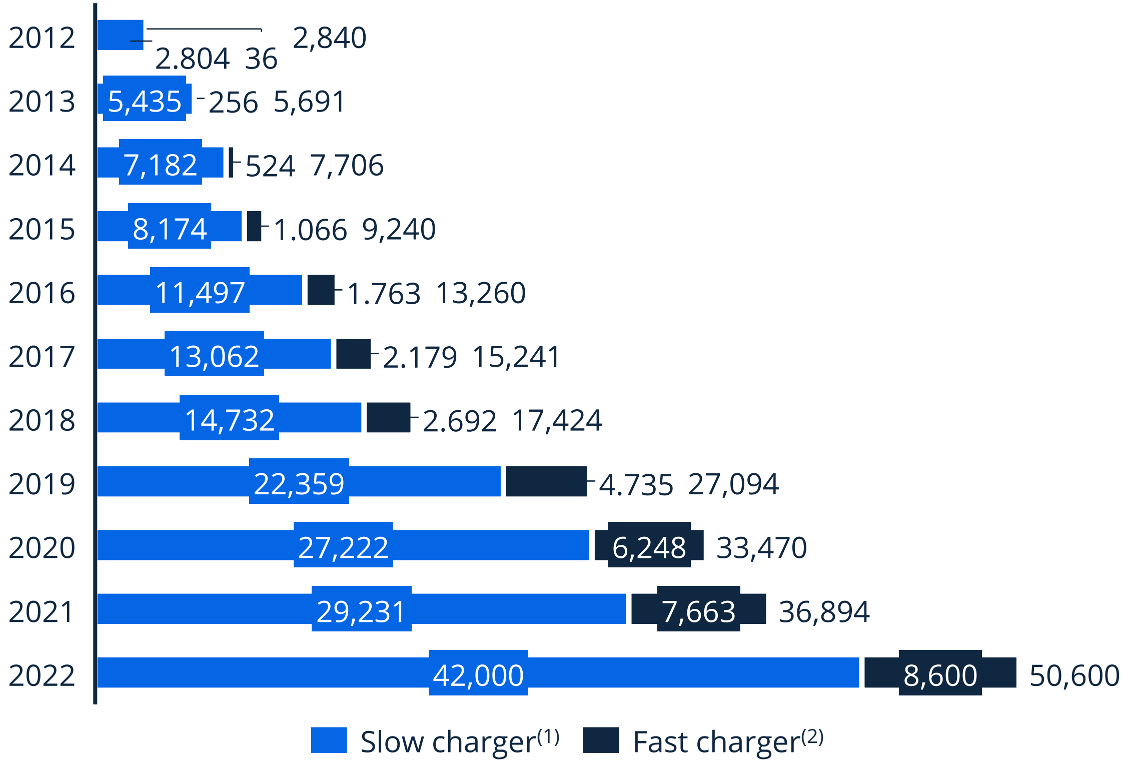




Sources: International Energy Agency (IEA); Inside EVs

Country analysis: UK (2/2)

Number of publicly accessible charging points



Consumer profile: electric vehicles

Research commissioned by the UK Government found that the sorts of people who tend to buy electric vehicles are

- Middle-aged
- Males
- Well-educated
- Affluent
- Live in urban areas with households containing two or more cars and with the ability to charge at home

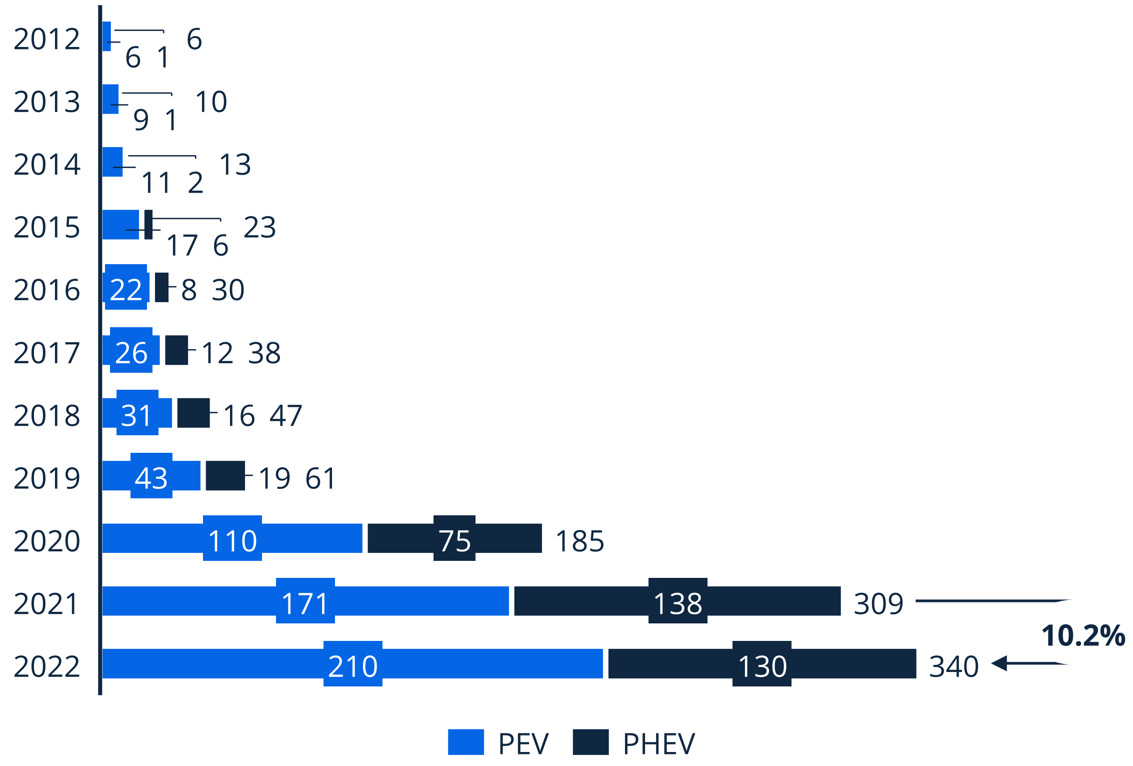
It also found that this socio-demographic profile of EV owners in the UK was "not likely to change significantly".

Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

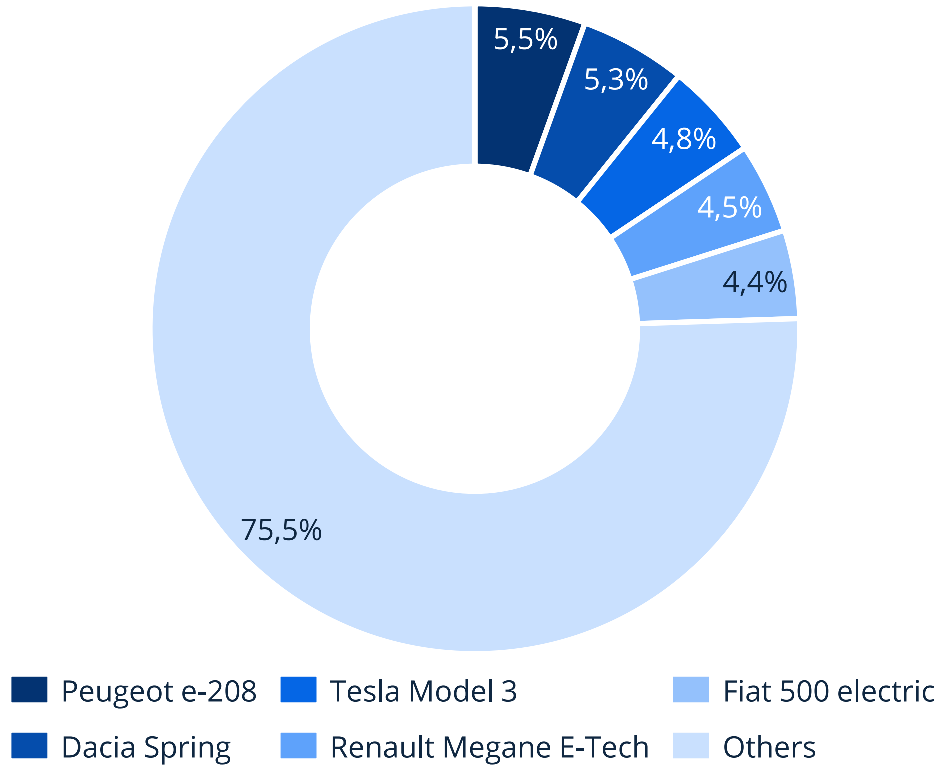
Sources: International Energy Agency (IEA); Briefing Paper on Electric vehicles and infrastructure – House of Commons Library, as of Dec 2016

Country analysis: France (1/2)

New electric cars registrations in thousands



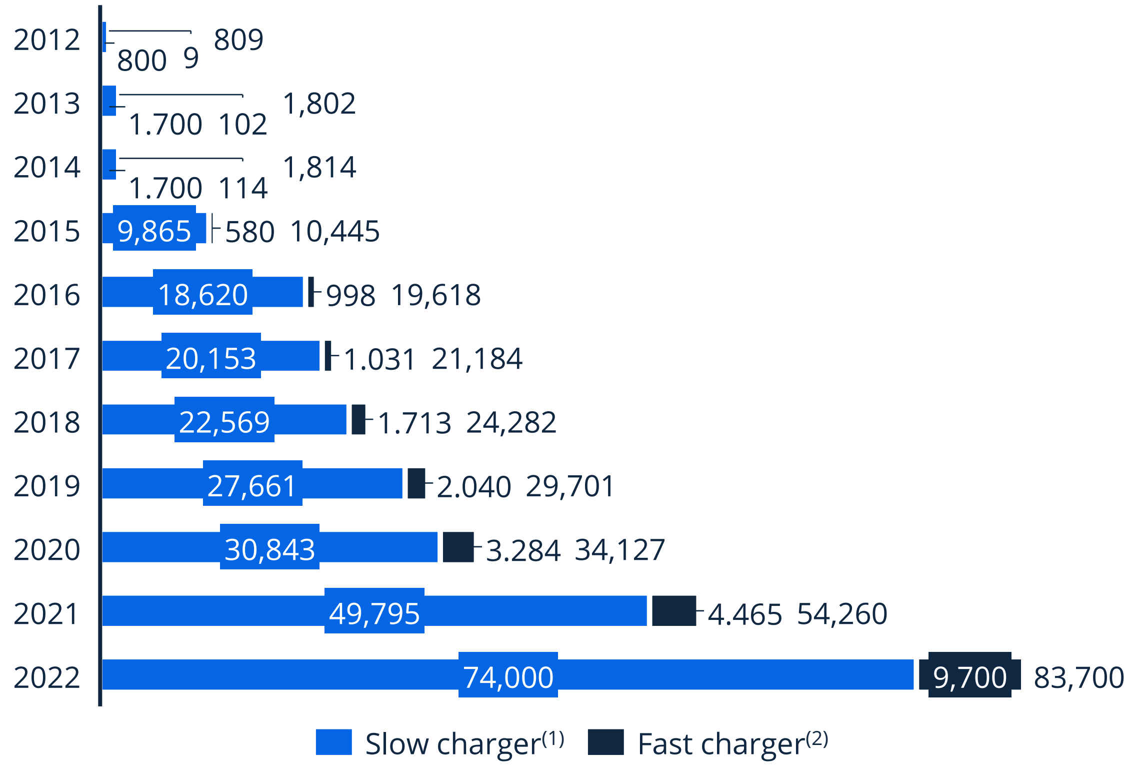
PEVs and PHEVs sales share by models in 2022



Sources: International Energy Agency (IEA); Inside EVs

Country analysis: France (2/2)

Number of publicly accessible charging points



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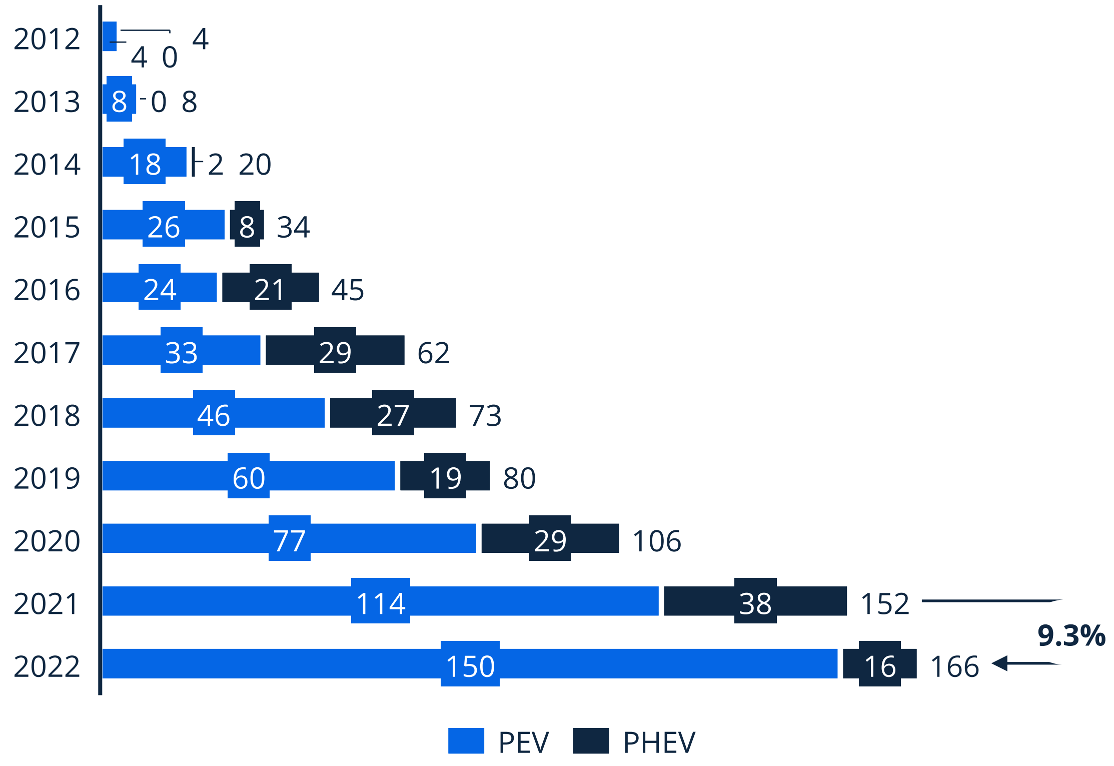
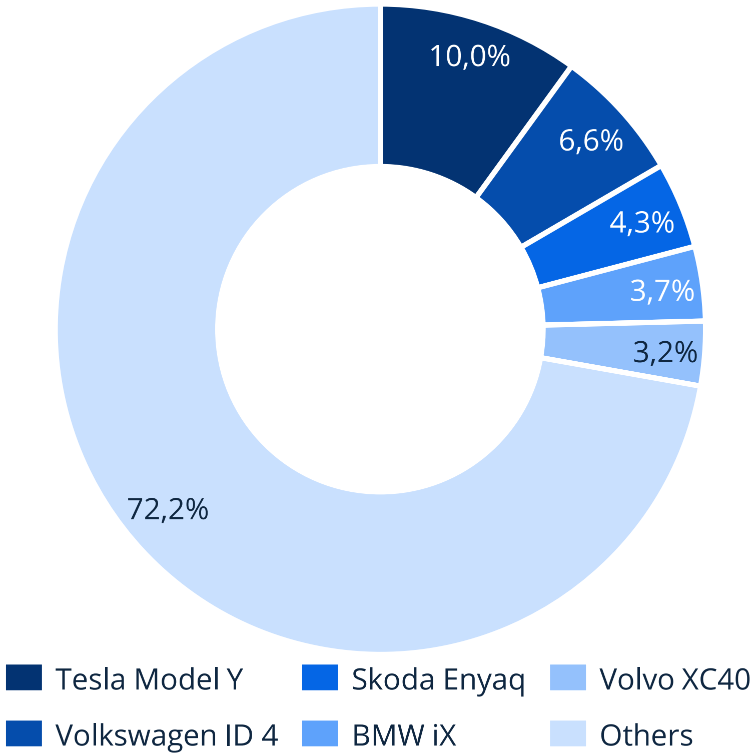
Sources: International Energy Agency (IEA)

Country analysis: Norway (1/3)

New electric cars registrations in thousands



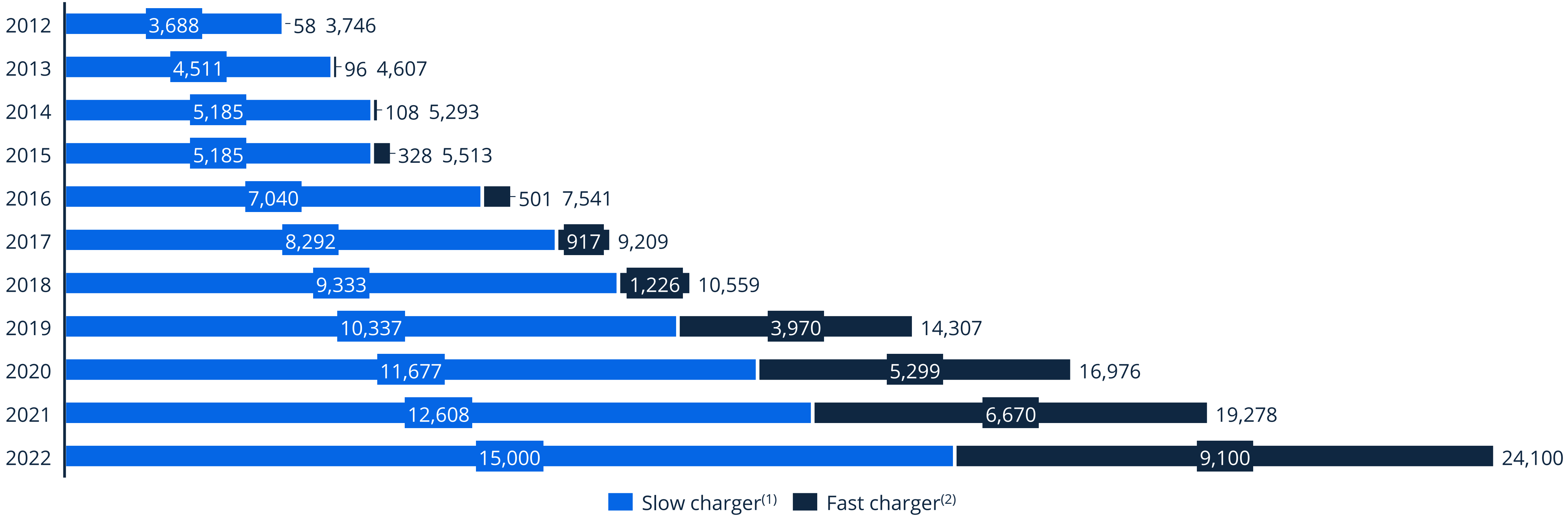
PEVs and PHEVs sales share by models in 2022



Sources: International Energy Agency (IEA); Inside EVs

Country analysis: Norway (2/3)

Number of publicly accessible charging points



Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

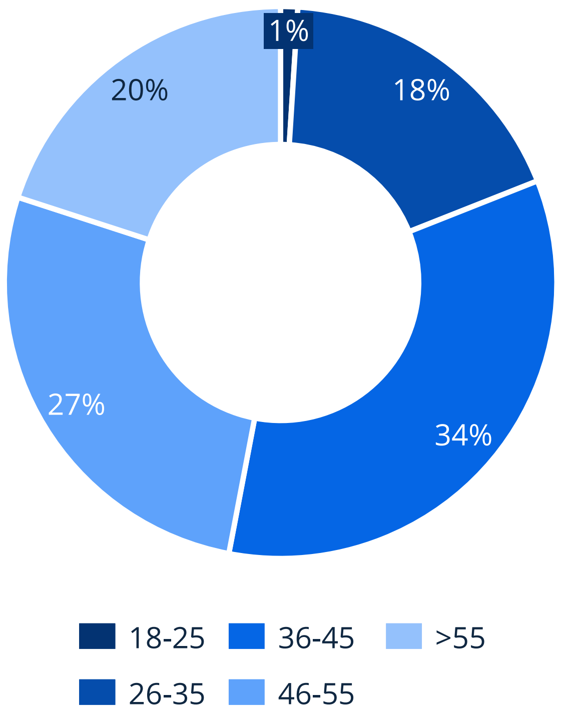
Sources: International Energy Agency (IEA)

statista

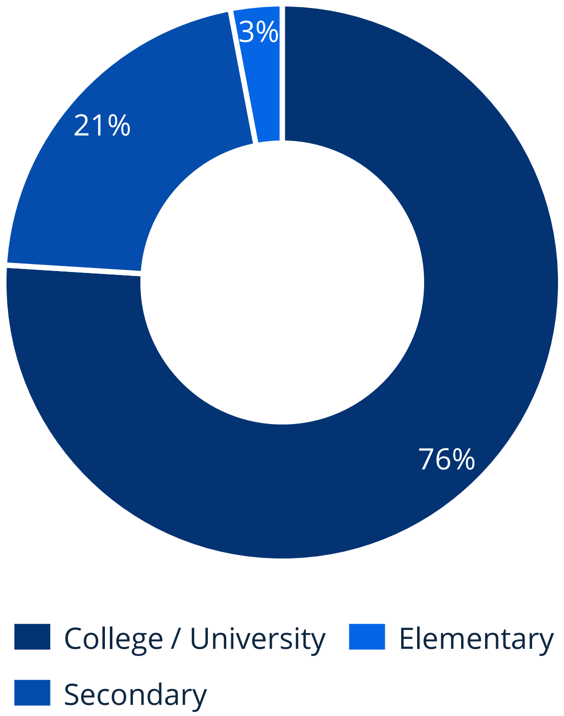
Country analysis: Norway (3/3)

Consumer profile: Electric vehicles

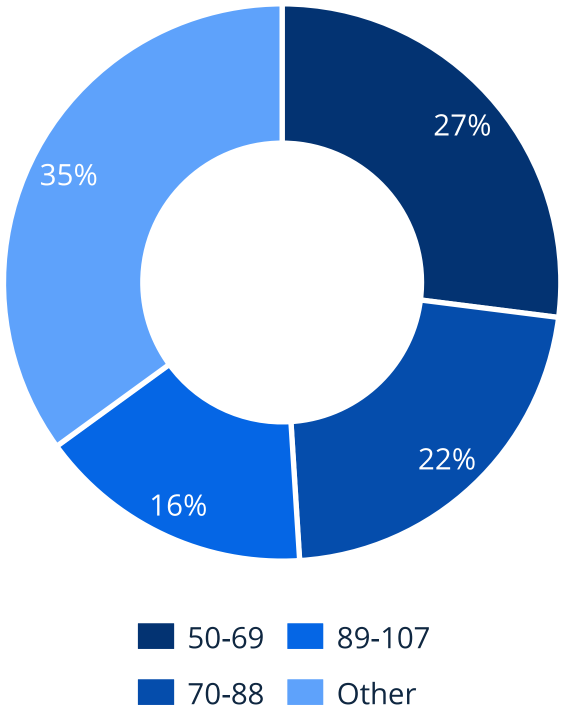
Age in years



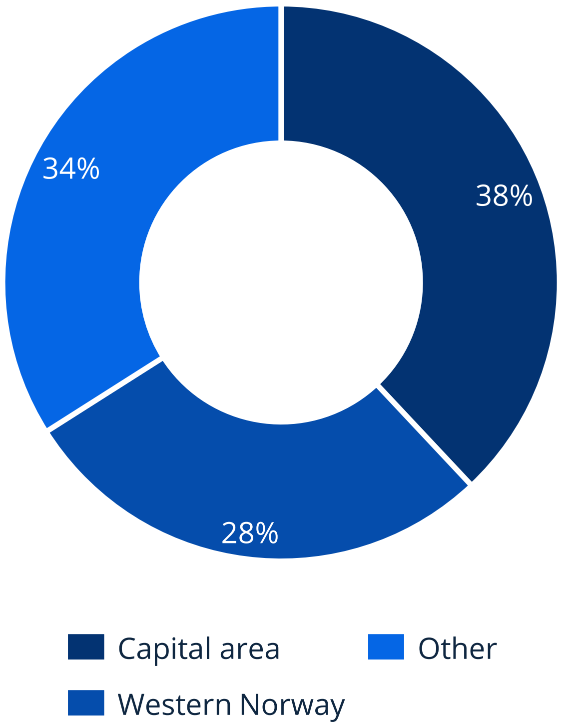
Education



Income in thousand US$ per year(1)



Region

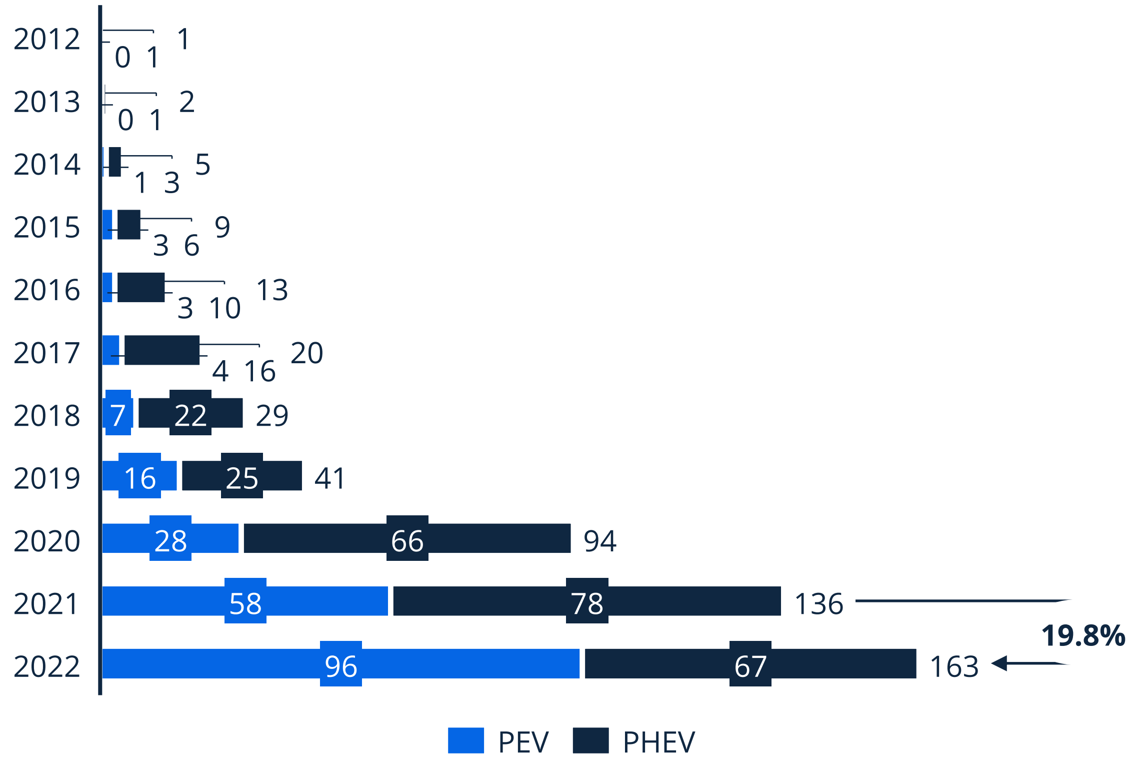


Notes: (1) Transferred from Norwegian krone to US$, exchange rate: NOK-USD 0.12562 as of 30th Sep 2017 (Oanda)

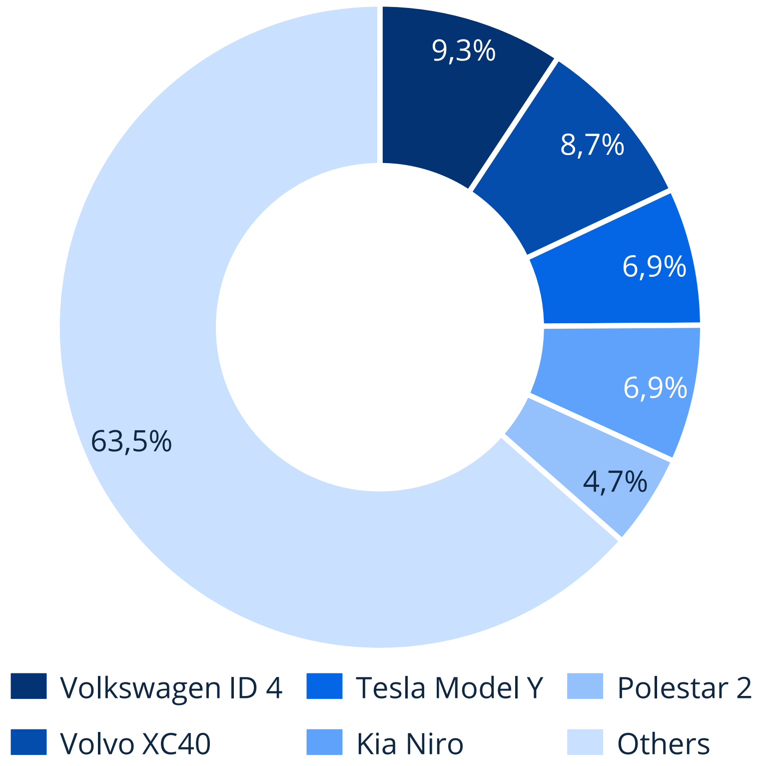
Sources: Transportation Research Part D, Incentives for promoting Battery EV adoption in Norway, as of Jan 2016

Country analysis: Sweden (1/2)

New electric cars registrations in thousands



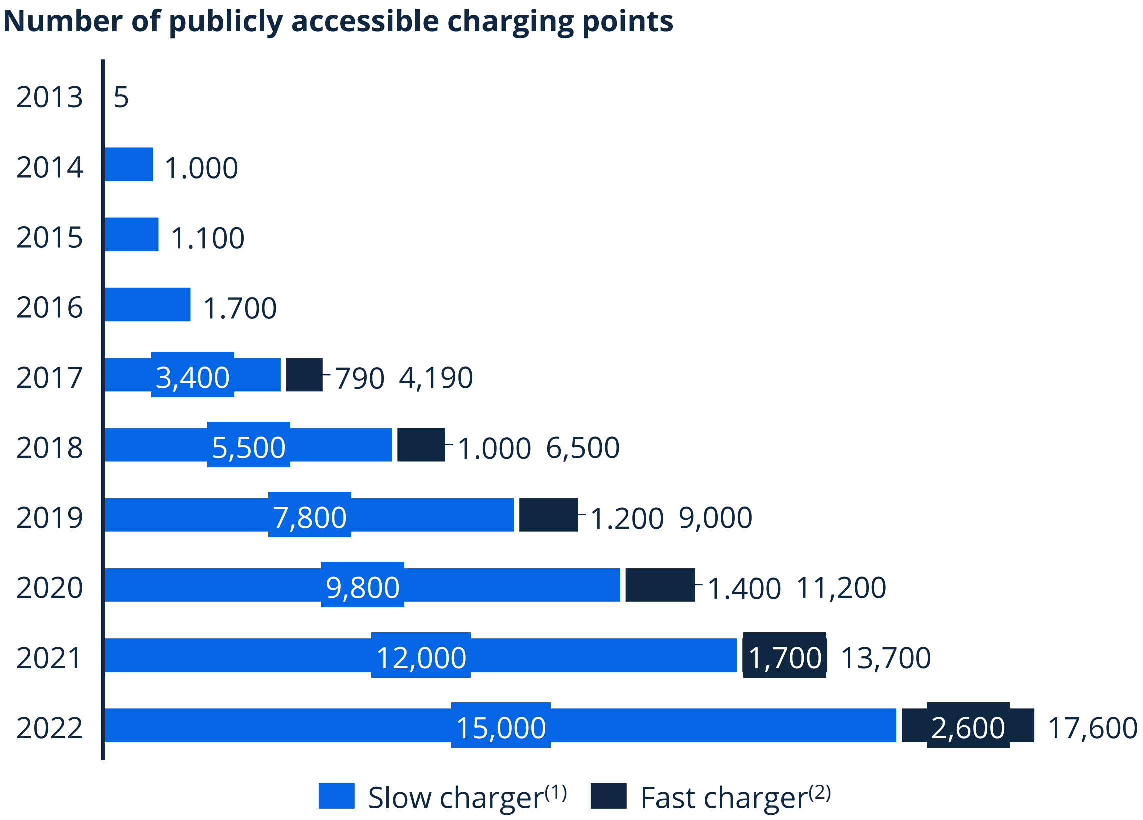
PEVs sales share by models in 2022



Sources: Automobile Propre; International Energy Agency (IEA); Inside EVs

statista

Country analysis: Sweden (2/2)

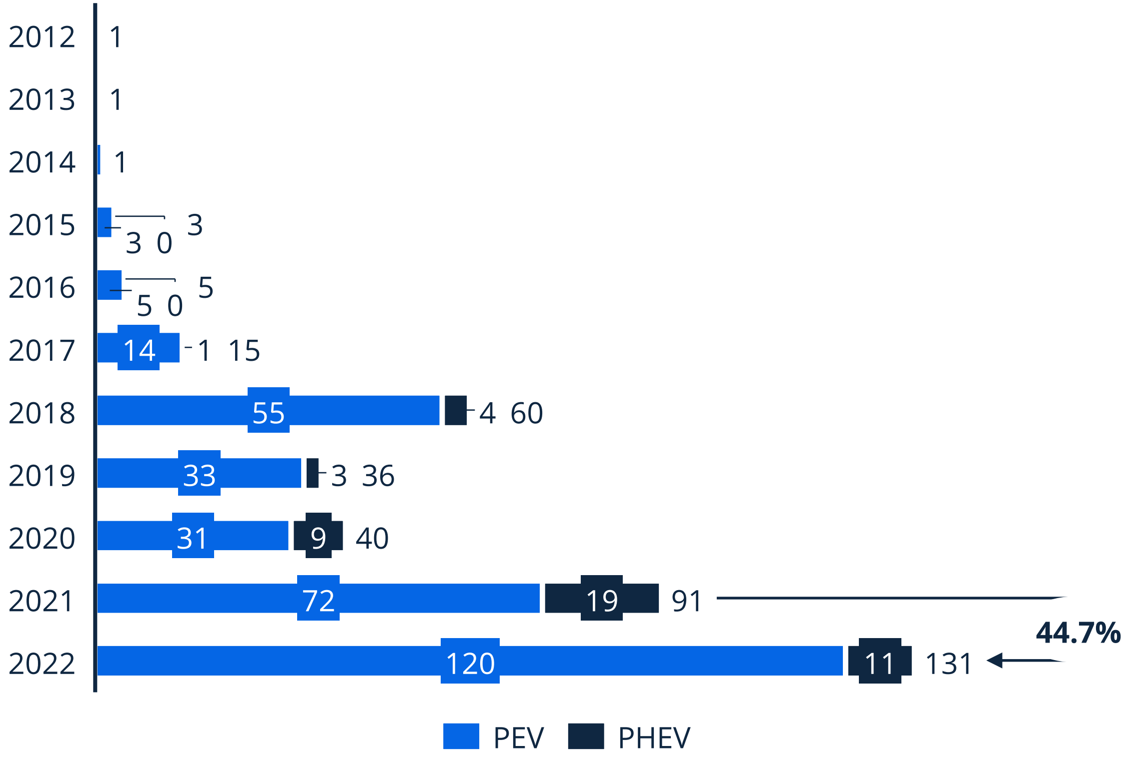


Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

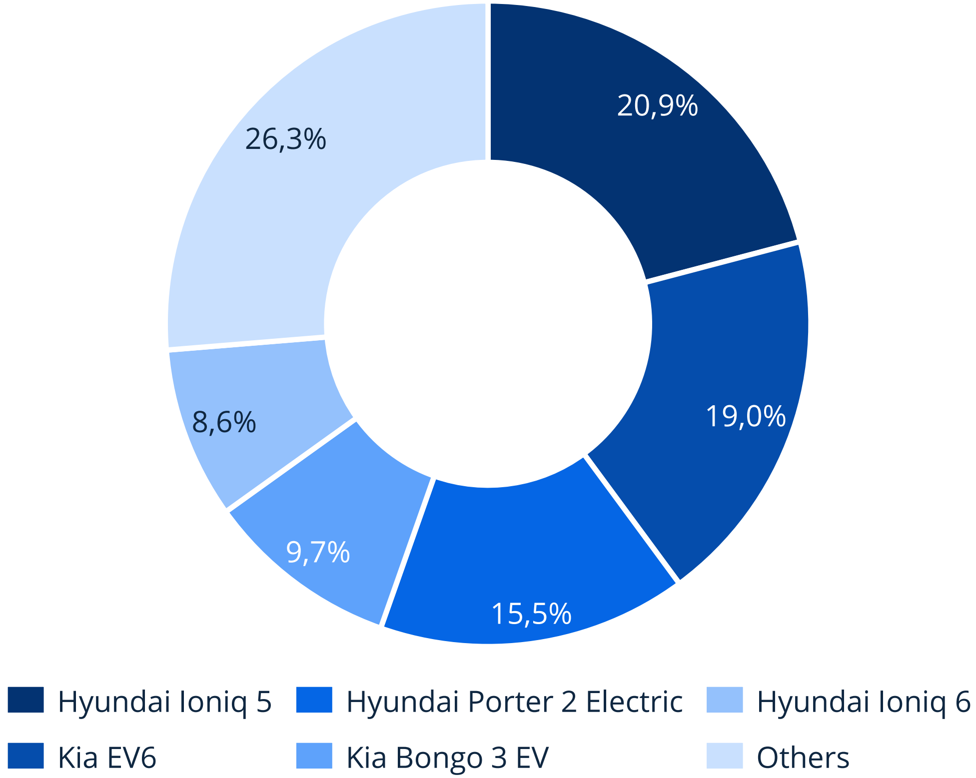
Sources: International Energy Agency (IEA)

Country analysis: South Korea (1/2)

New electric cars registrations in thousands



PEVs and PHEVs sales share by models in 2022

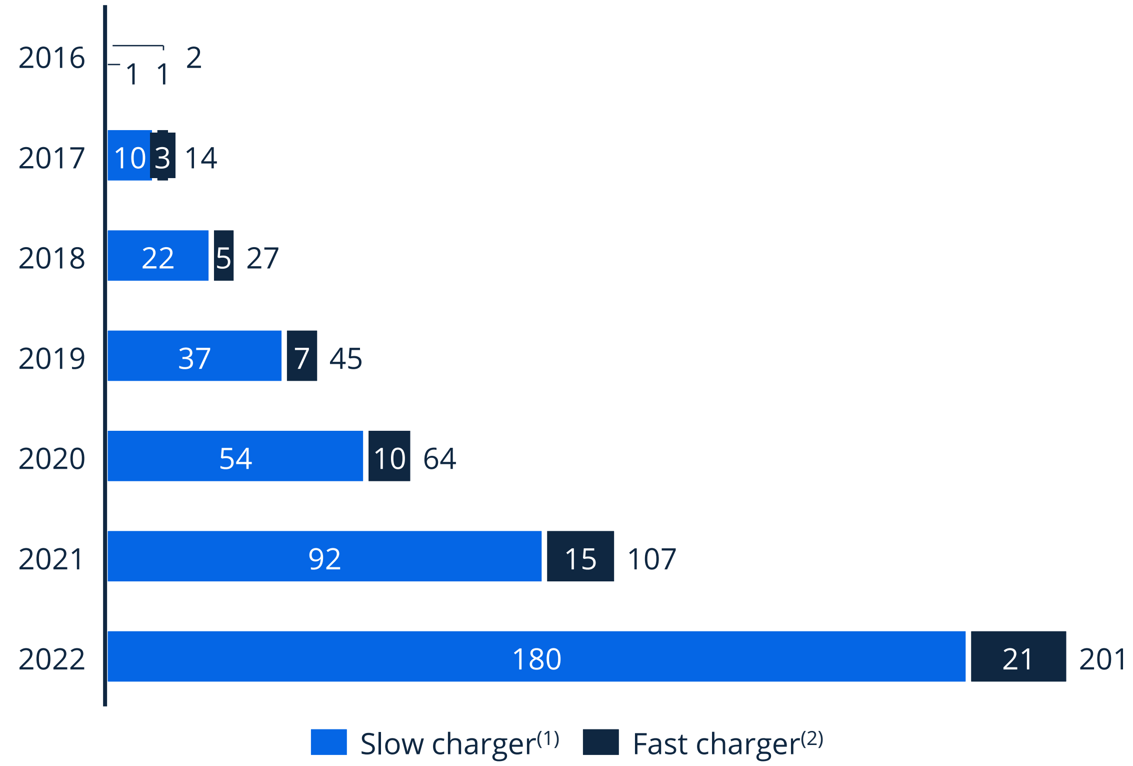


Sources: Bloomberg; International Energy Agency (IEA) ; Tago

statista

Country analysis: South Korea (2/2)

Number of publicly accessible charging points in thousands

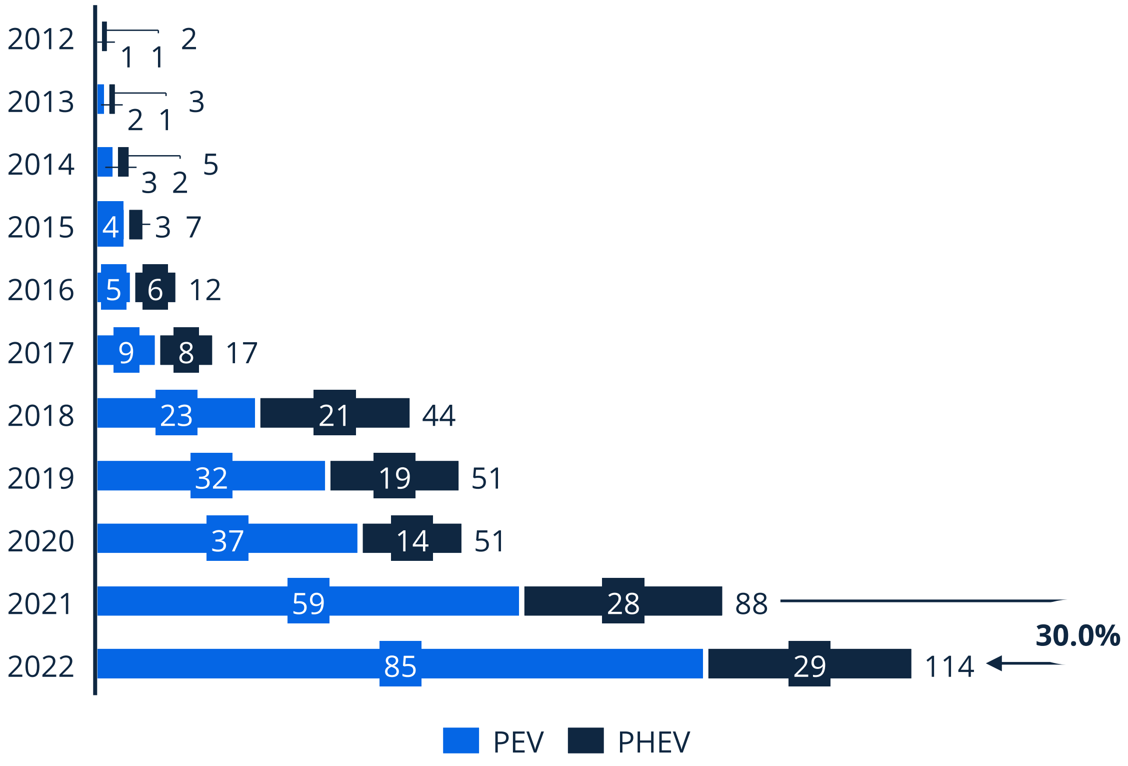


Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

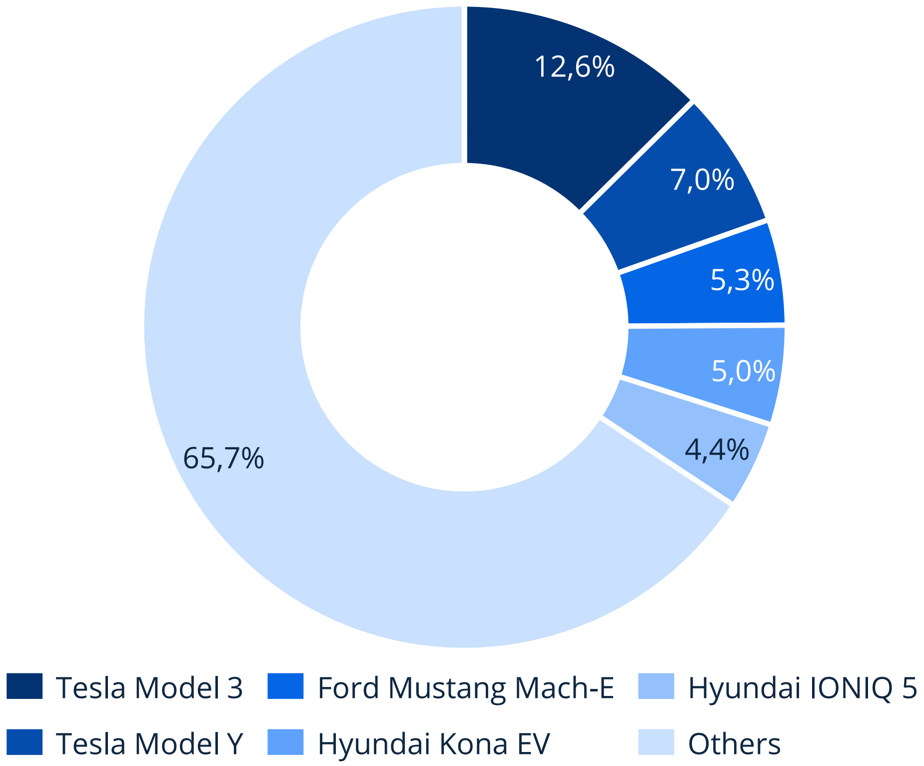
Sources: International Energy Agency (IEA)

Country analysis: Canada (1/2)

New electric cars registrations in thousands



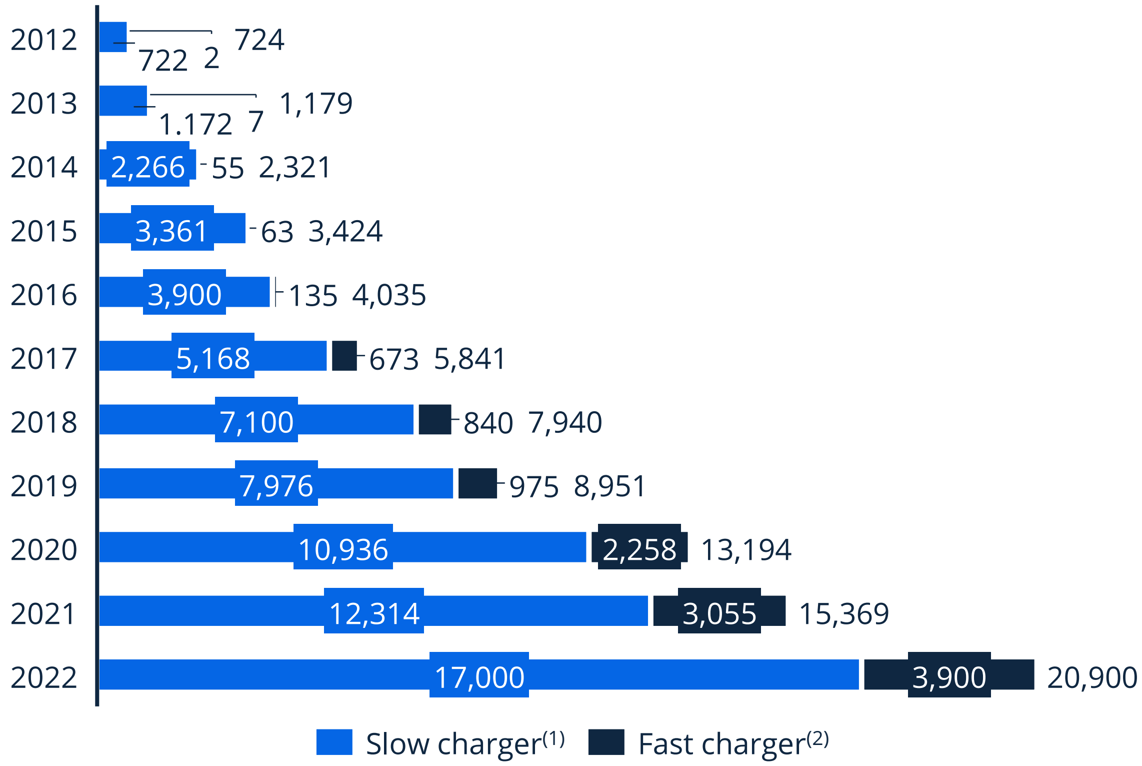
PEVs and PHEVs sales share by models in 2022

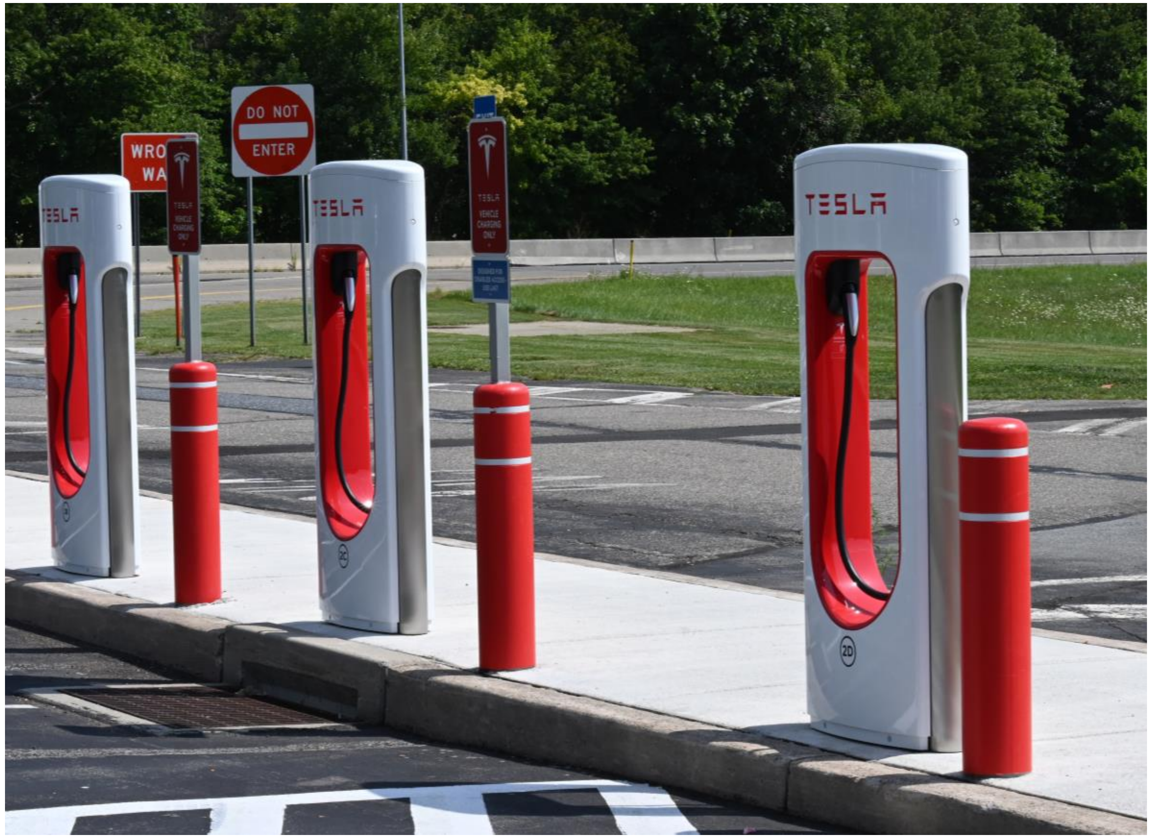


Sources: International Energy Agency (IEA); MotorIllustrated

Country analysis: Canada (2/2)

Number of publicly accessible charging points in thousands



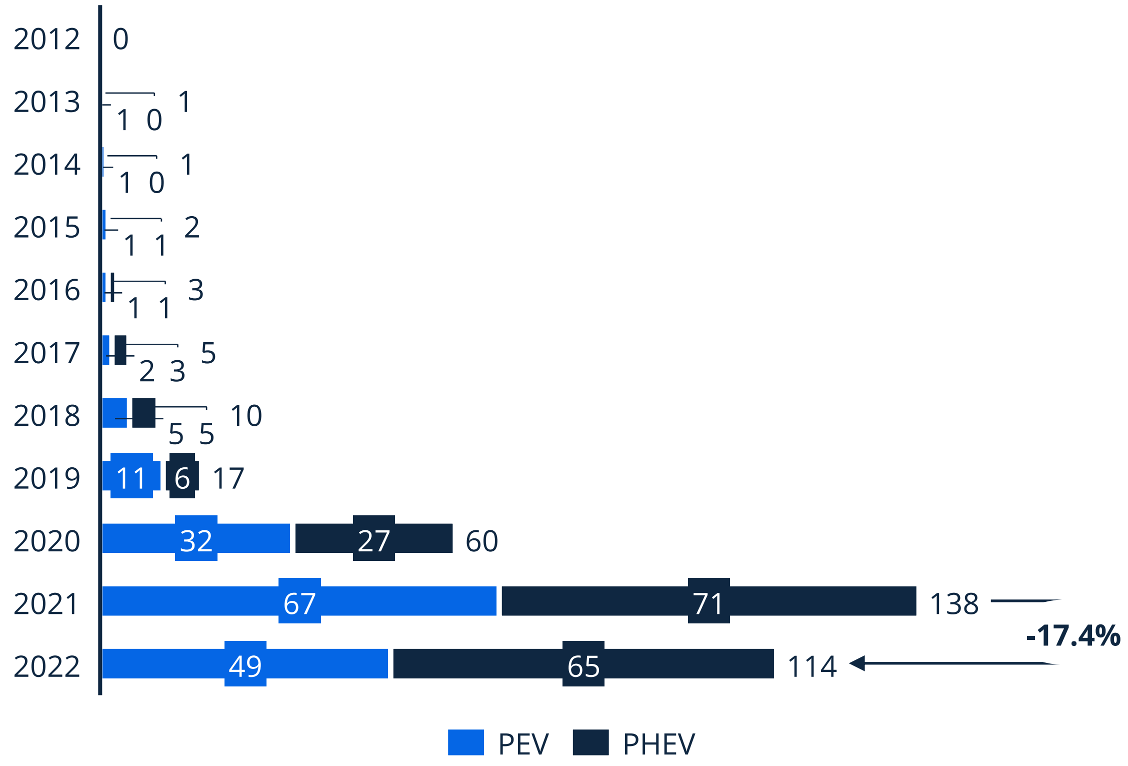


Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

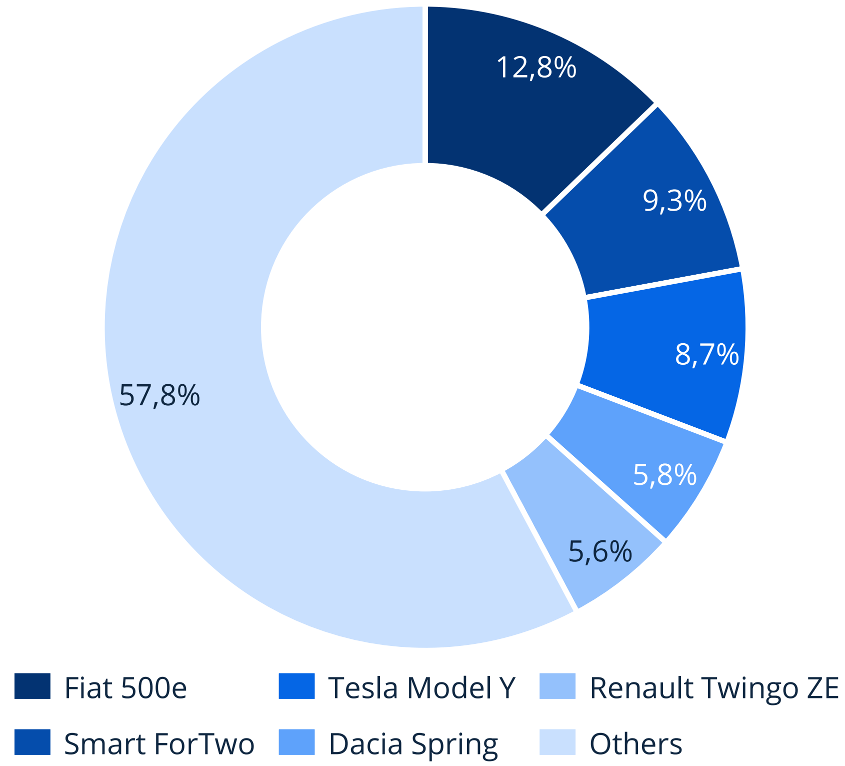
Sources: International Energy Agency (IEA)

Country analysis: Italy (1/2)

New electric cars registrations in thousands



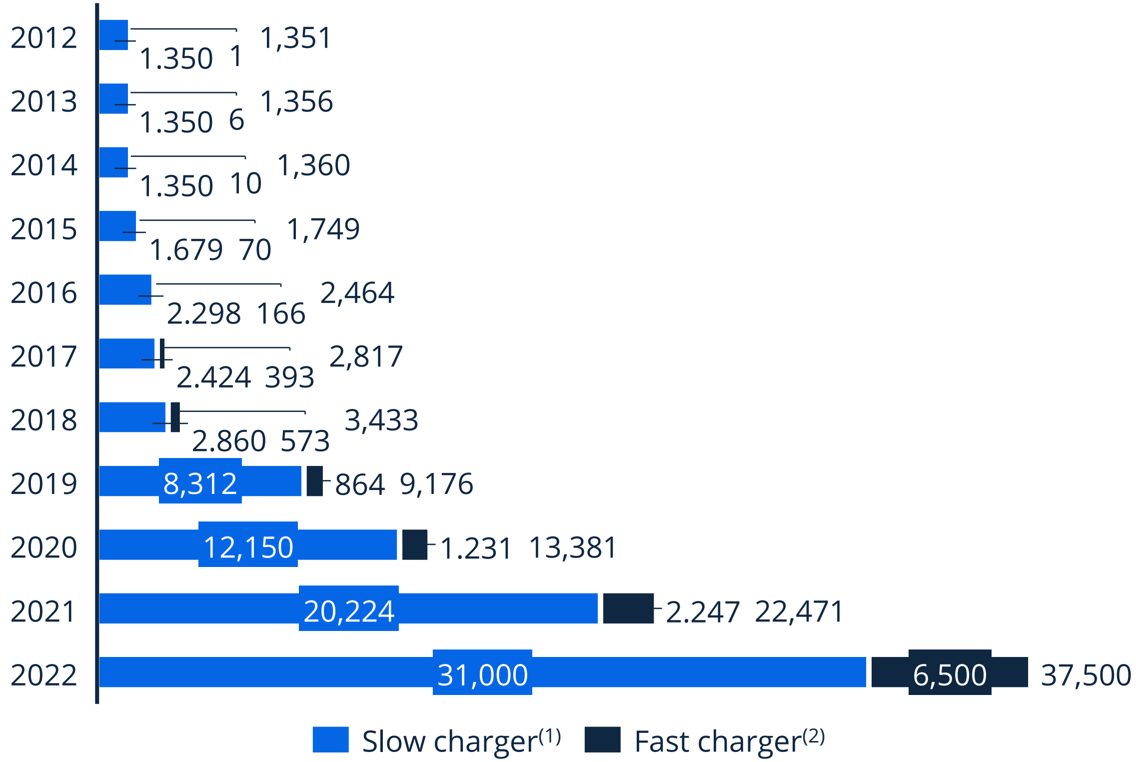
PEVs sales share by models in 2022



Sources: International Energy Agency (IEA); Inside EVs

Country analysis: Italy (2/2)

Number of publicly accessible charging points

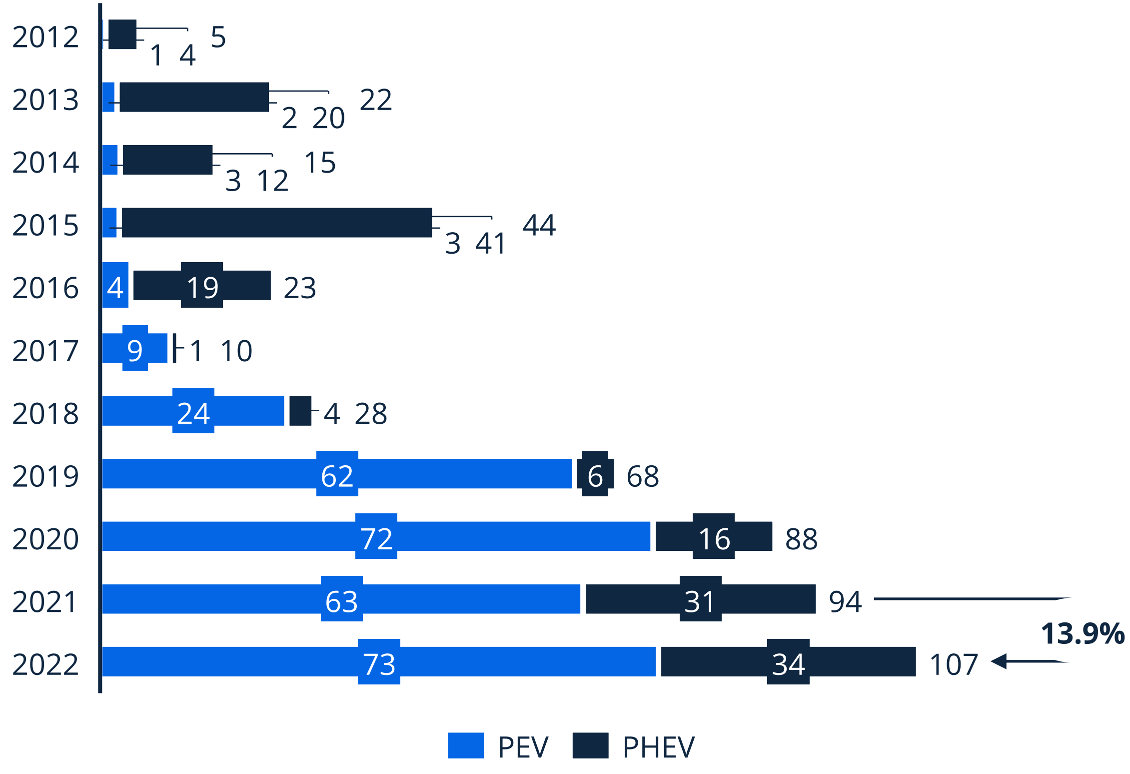


Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

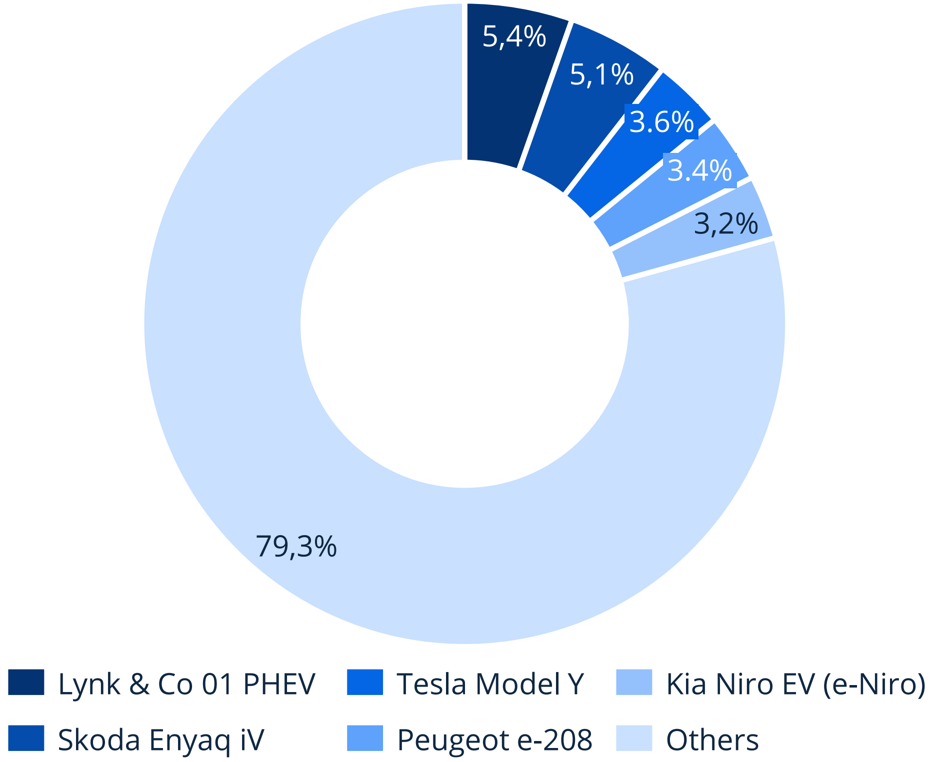
Sources: International Energy Agency (IEA)

Country analysis: The Netherlands (1/2)

New electric cars registrations in thousands



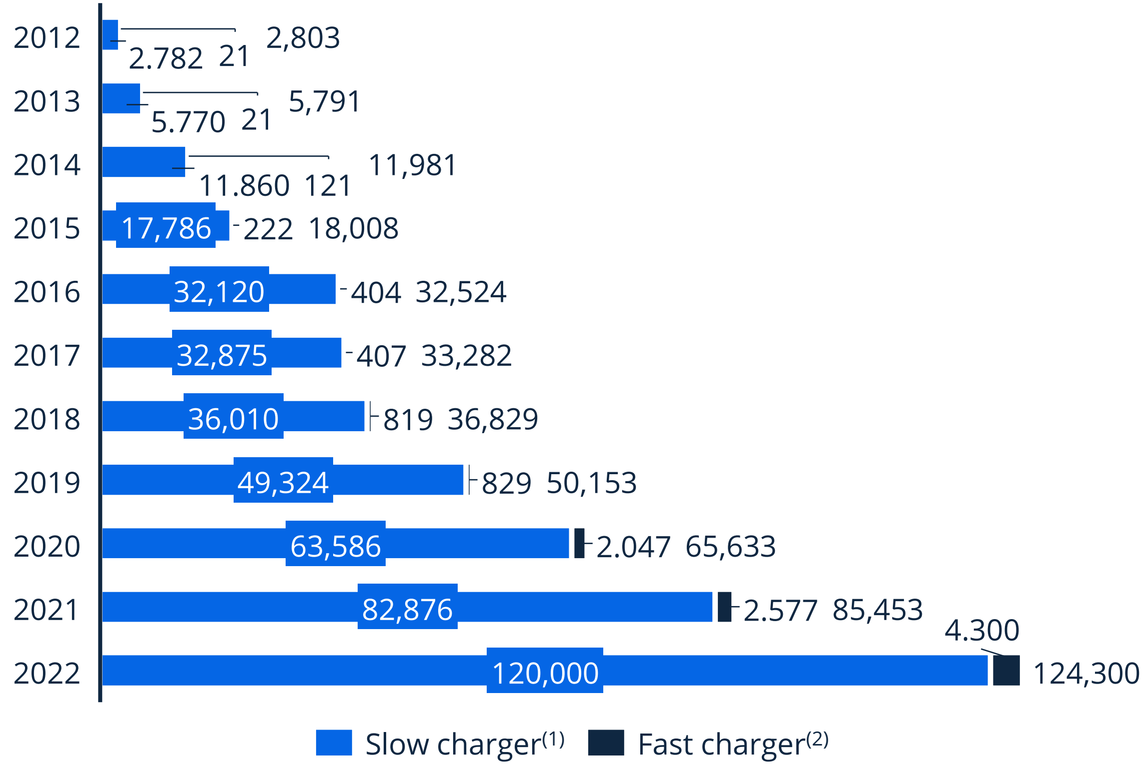
PEVs and PHEVs sales share by models in 2022



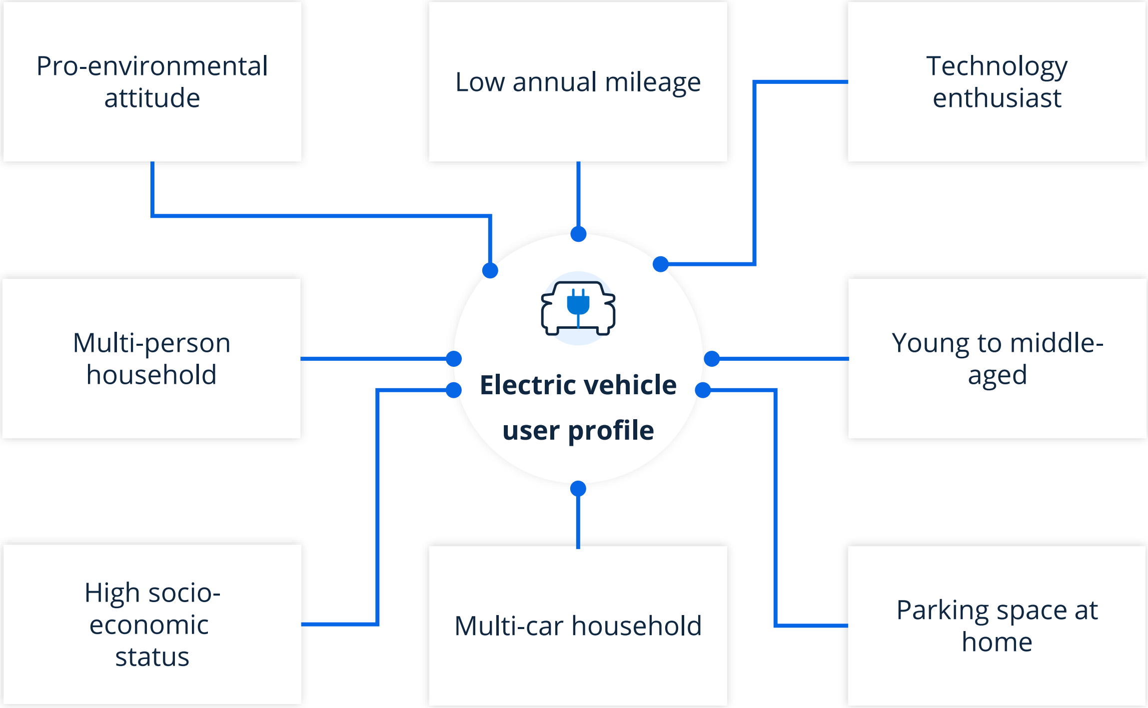
Sources: International Energy Agency (IEA); Inside EVs

Country analysis: The Netherlands (2/2)

Number of publicly accessible charging points



Consumer profile: electric vehicles

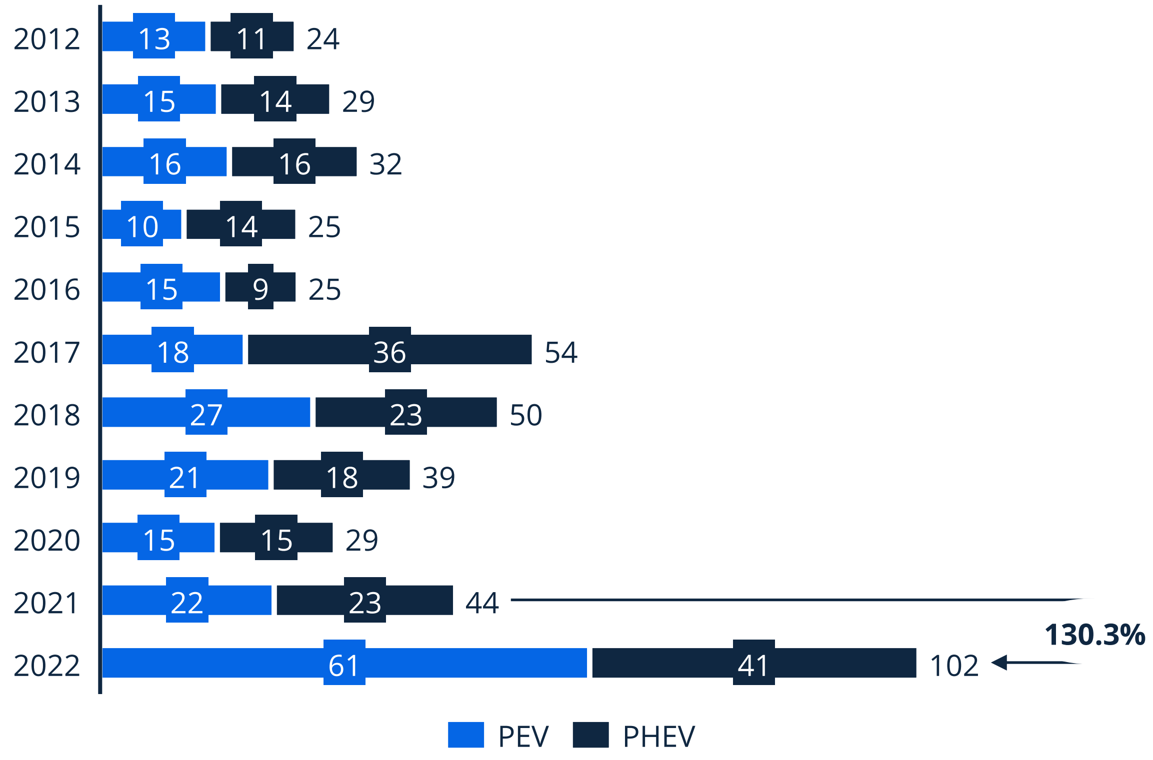


Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

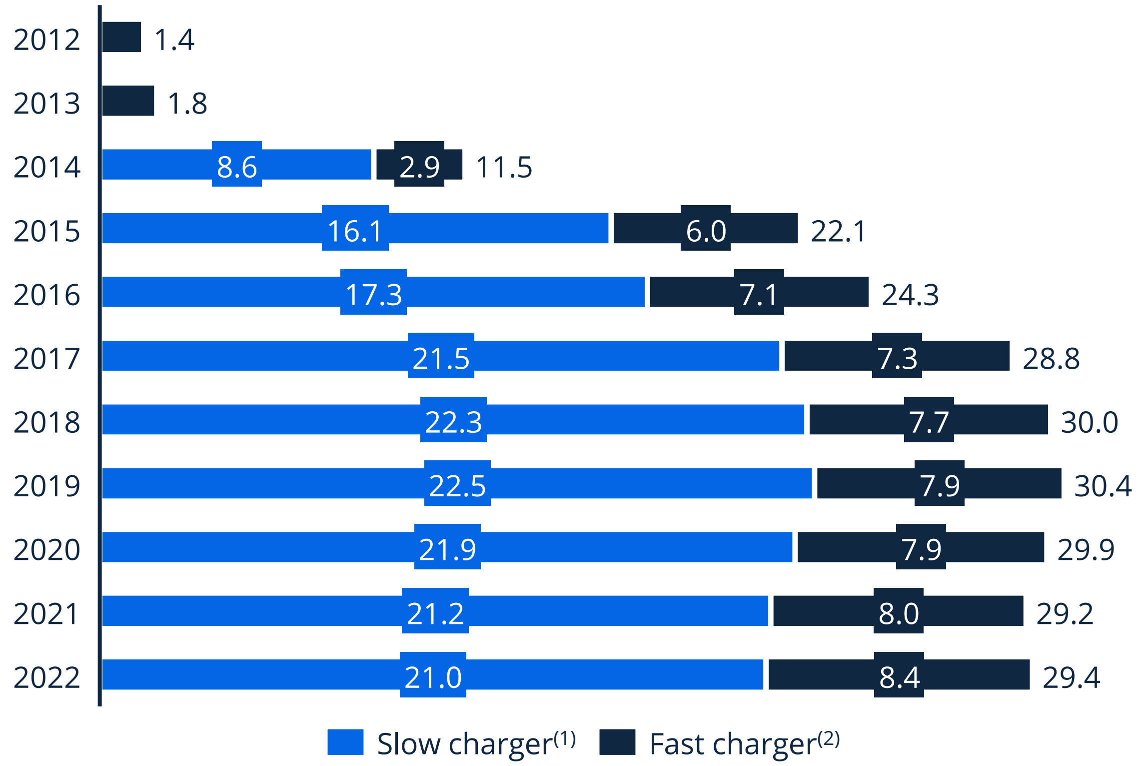
Sources: International Energy Agency (IEA); Early adopters of electric vehicles in Germany unveiled, May 2015

Country analysis: Japan

New electric cars registrations in thousands



Number of publicly accessible charging points in thousands

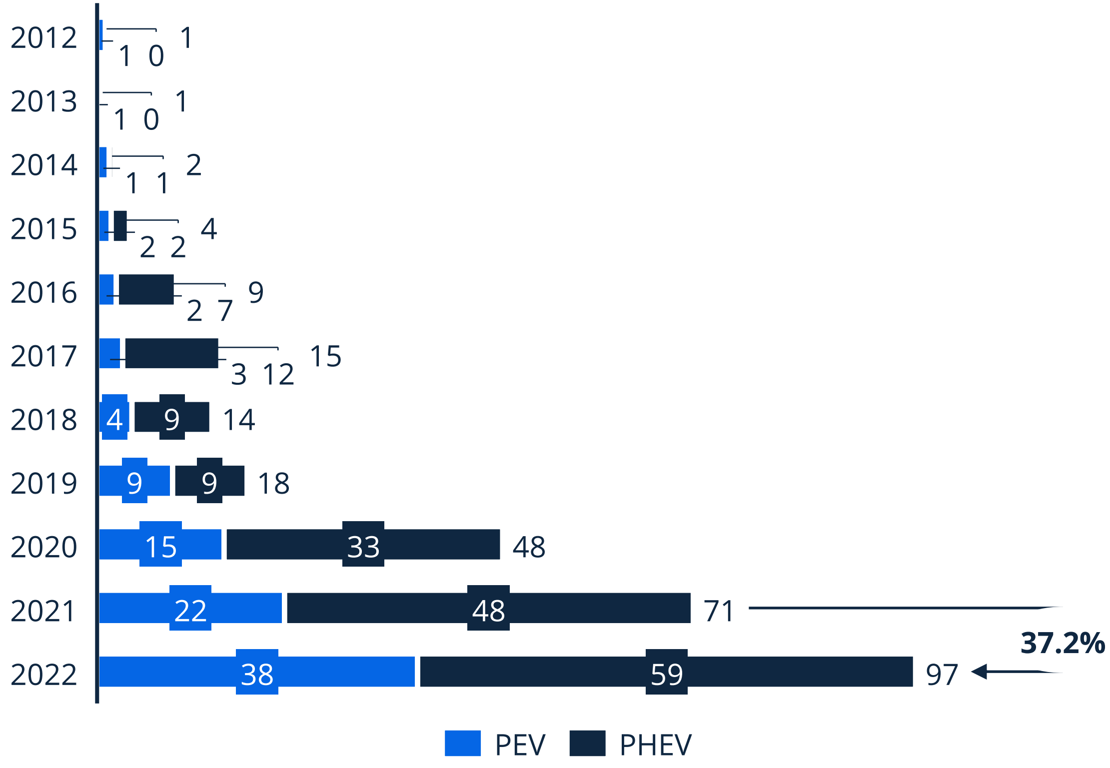


Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

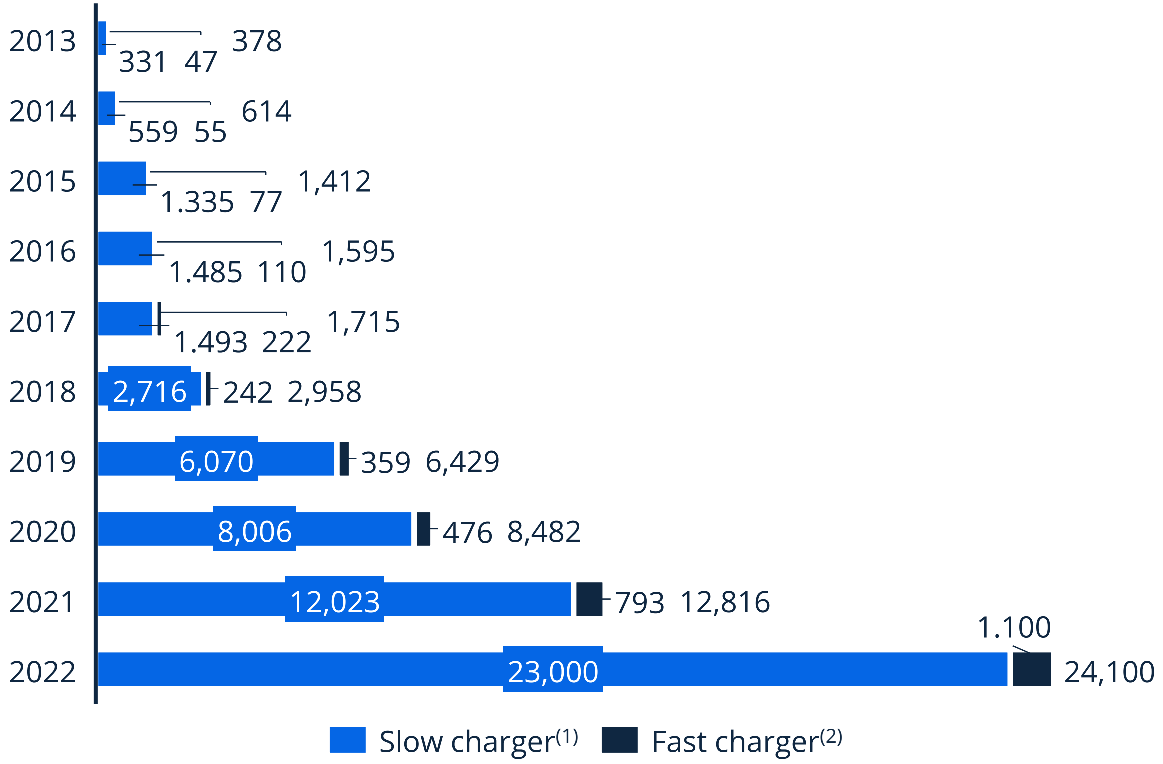
Sources: Automobile Propre; International Energy Agency (IEA)

Country analysis: Belgium

New electric cars registrations in thousands



Number of publicly accessible charging points

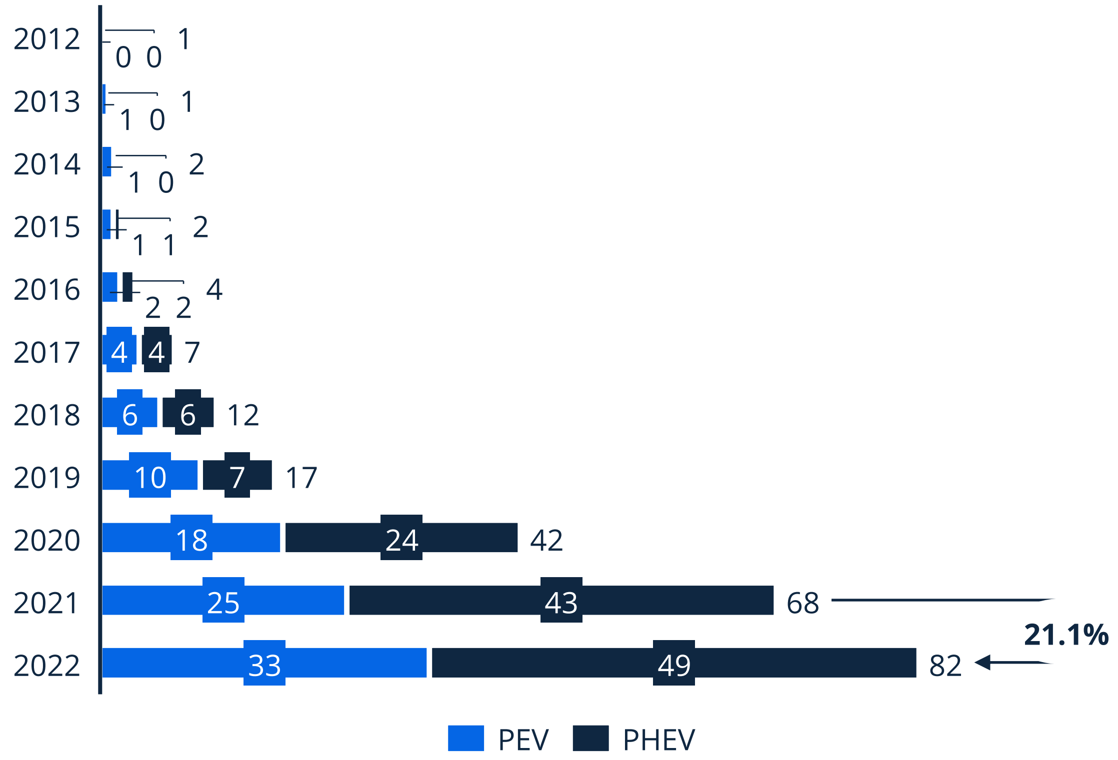


Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

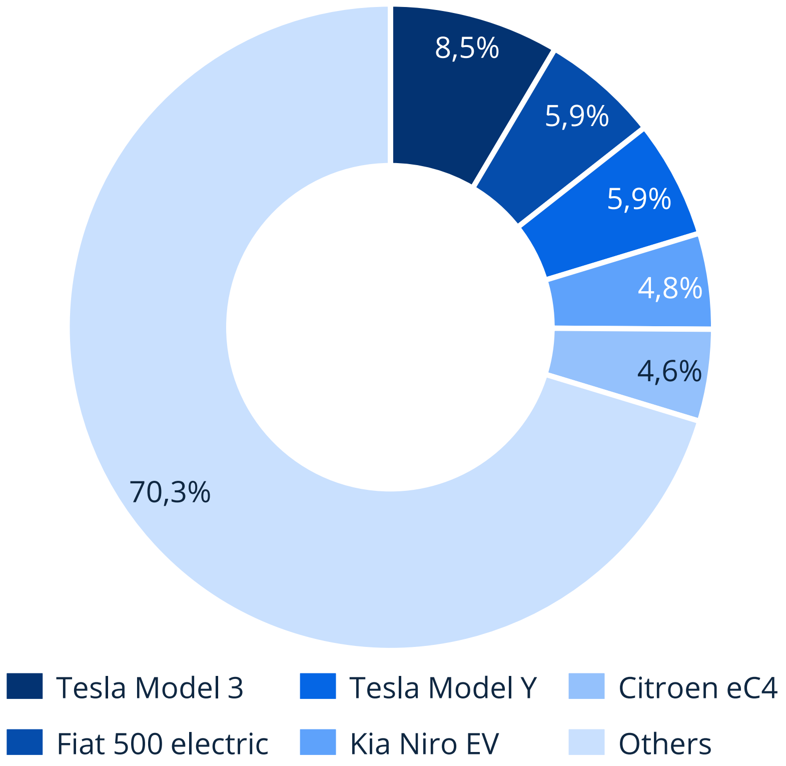
Sources: Automobile Propre; International Energy Agency (IEA); CleanTechnica

Country analysis: Spain (1/2)

New electric cars registrations in thousands



PEVs sales share by models in 2022

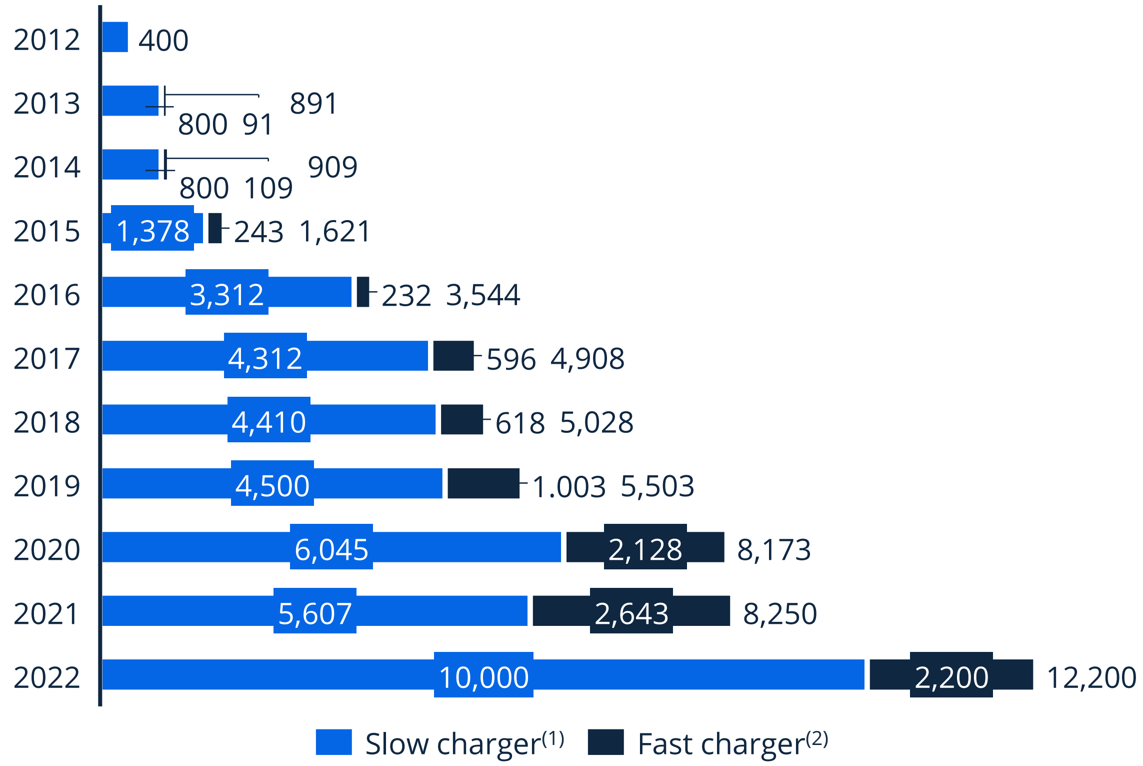


Notes:

Sources: Automobile Propre; International Energy Agency (IEA); Inside EVs

Country analysis: Spain (2/2)

Number of publicly accessible charging points

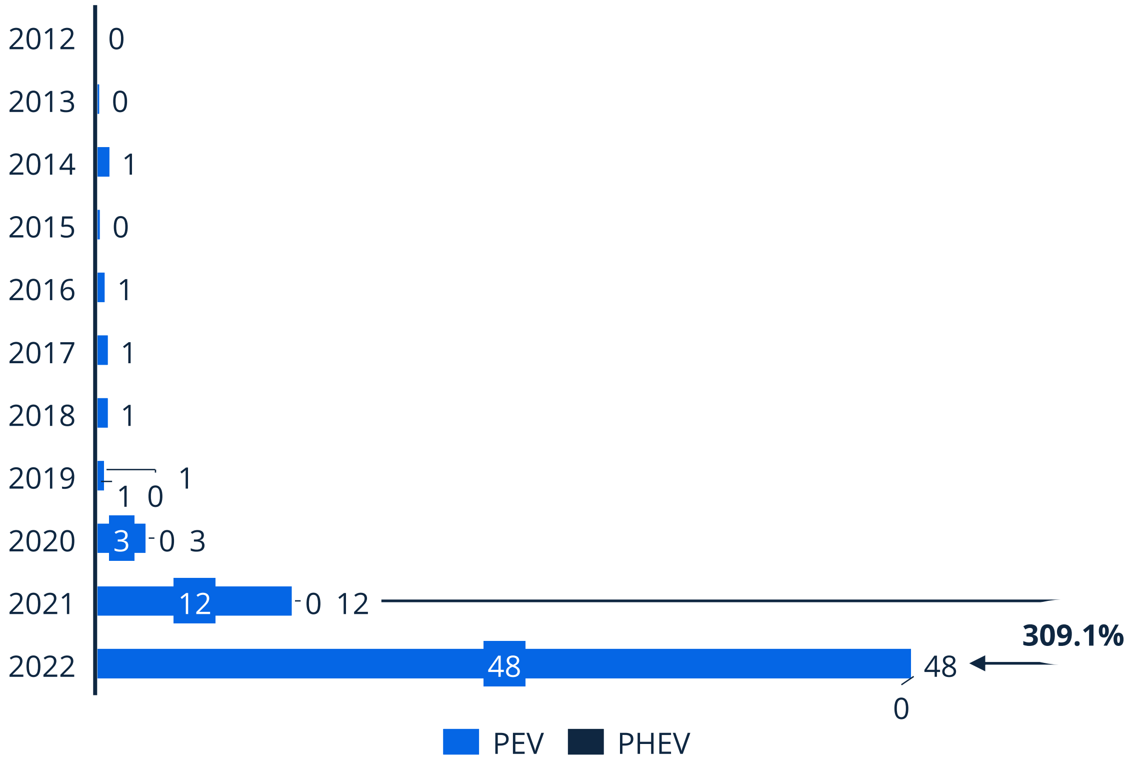


Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

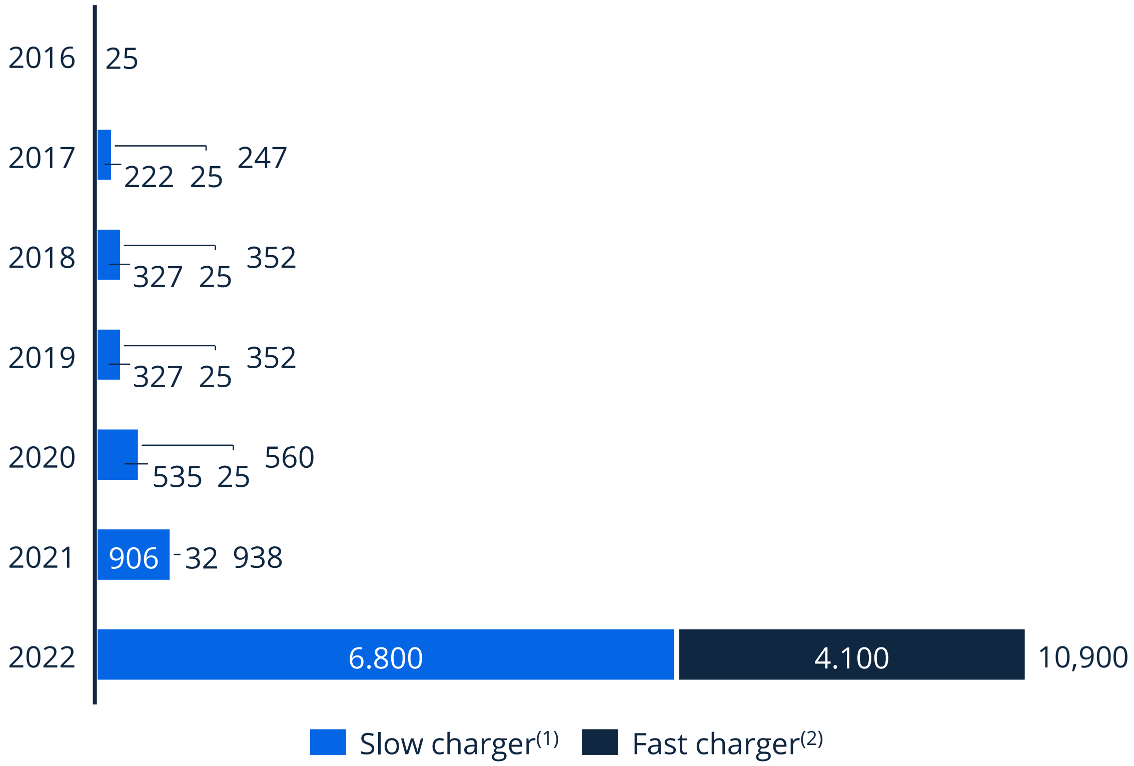
Sources: International Energy Agency (IEA)

Country analysis: India

New electric cars registrations in thousands



Number of publicly accessible charging points



Notes: (1) Slow chargers include AC level 1 (≤ 3.7 kW) and AC level 2 chargers (> 3.7 kW and ≤ 22 kW) (2) Fast chargers include AC 43 kW chargers, DC chargers, Tesla Superchargers and inductive chargers

Sources: Automobile Propre; International Energy Agency (IEA)

statista

CHAPTER 13

Special: EV sales in Europe

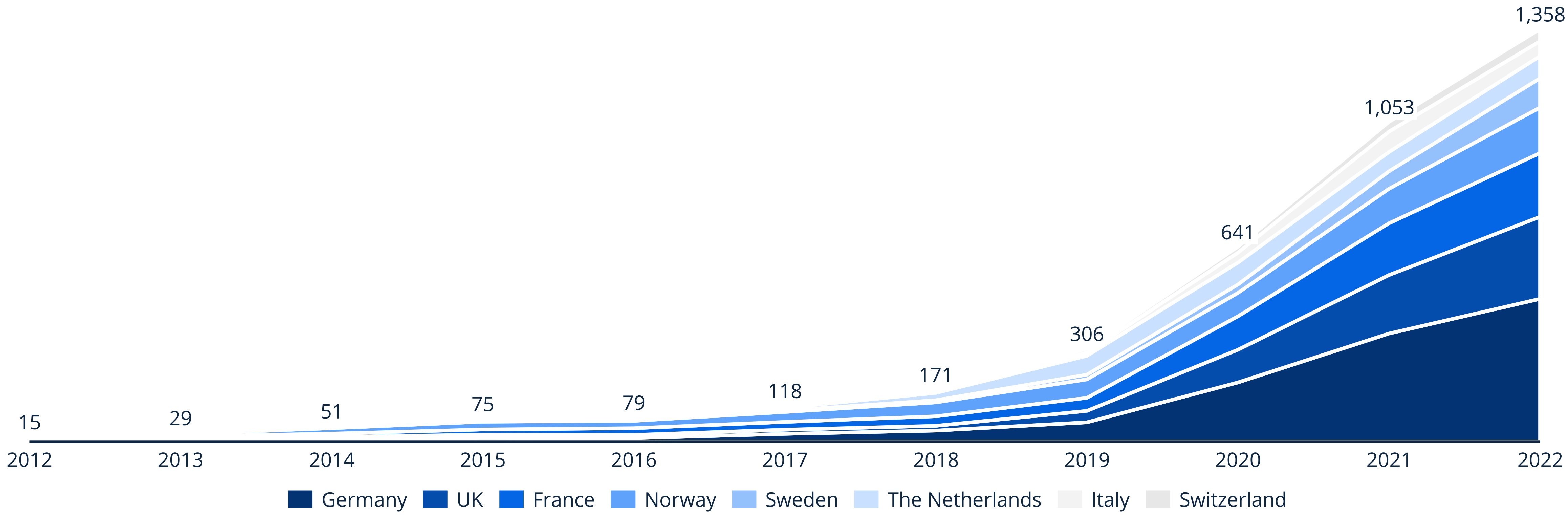
Since 2012, PEV sales have been steadily rising in Europe, with sales in the top eight countries amounting to over 1,358,000 units in 2022. The leading countries for 2022 include Germany, the UK, France, Norway, Sweden, the Netherlands, Italy, and Switzerland.

As for e-LCVs (including BEVs and PHEVs), Germany was the leading market in 2022 in terms of sales, followed by the UK, France, Norway, Sweden, the Netherlands, Italy, and Spain.

Development of PEV sales in Europe in number of cars

Development of PEV sales

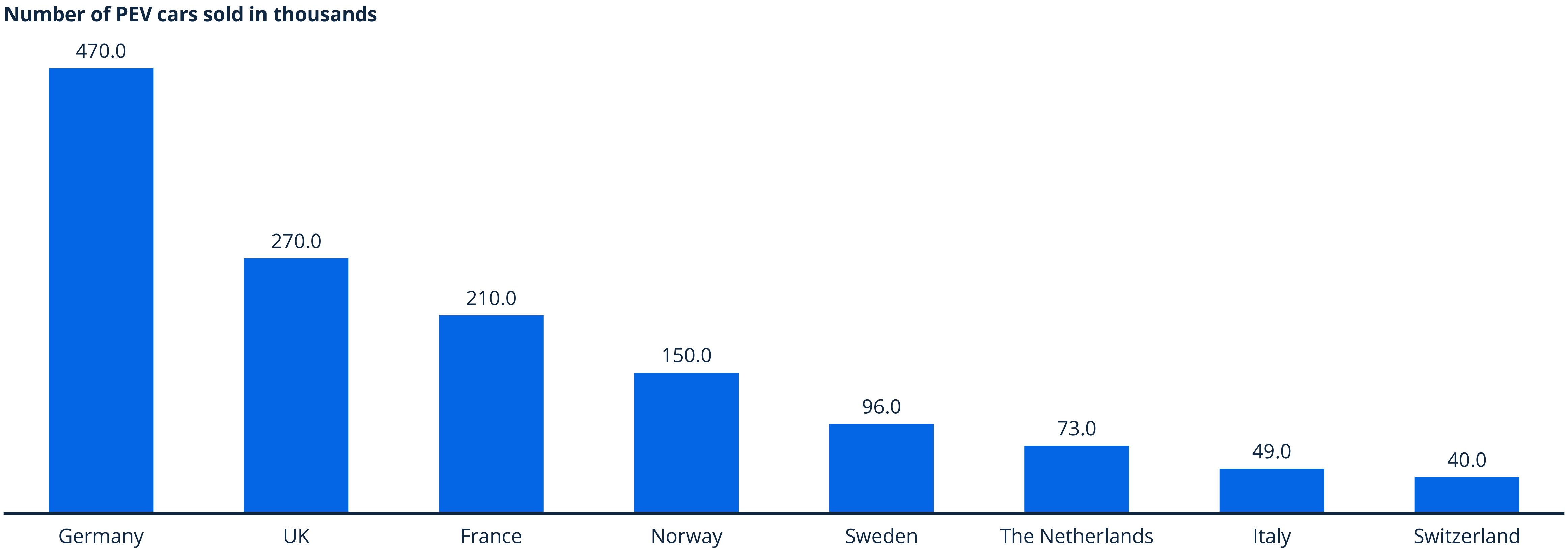
Development of PEV sales in thousands



Sources: International Energy Agency (IEA)

Number of PEVs sold in selected European countries in 2022

Country ranking (1/2)

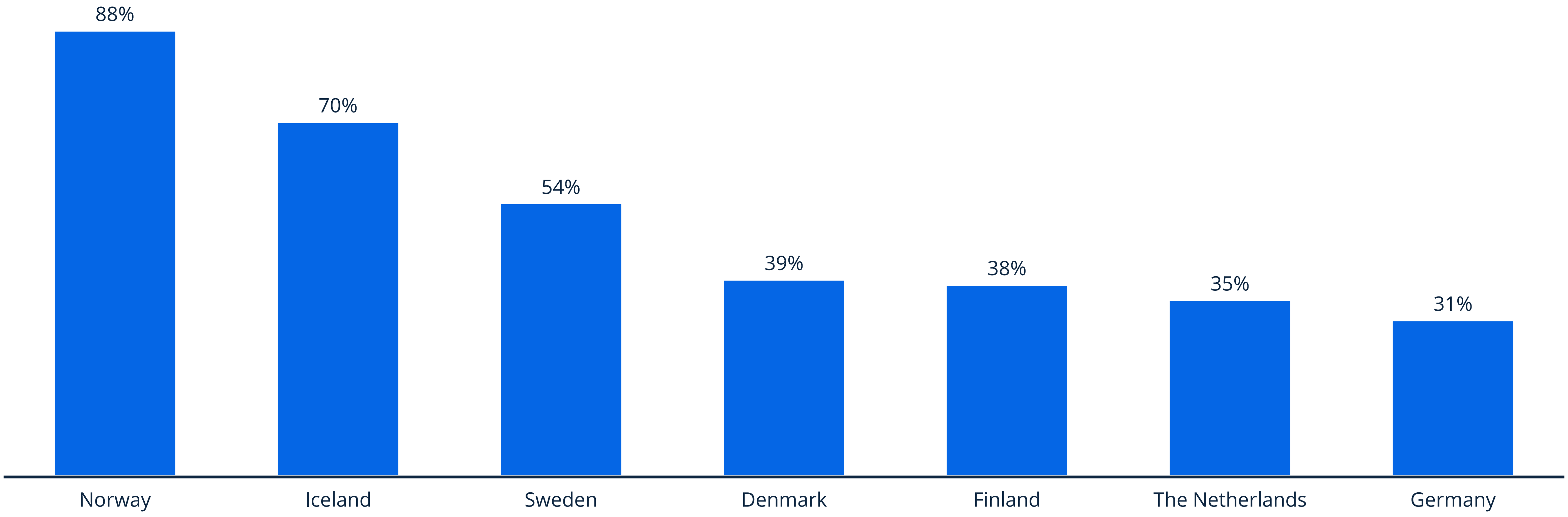


Sources: International Energy Agency (IEA)

EVs market share in selected European countries in 2022

Country ranking (2/2)

EVs(1) market share in 2022



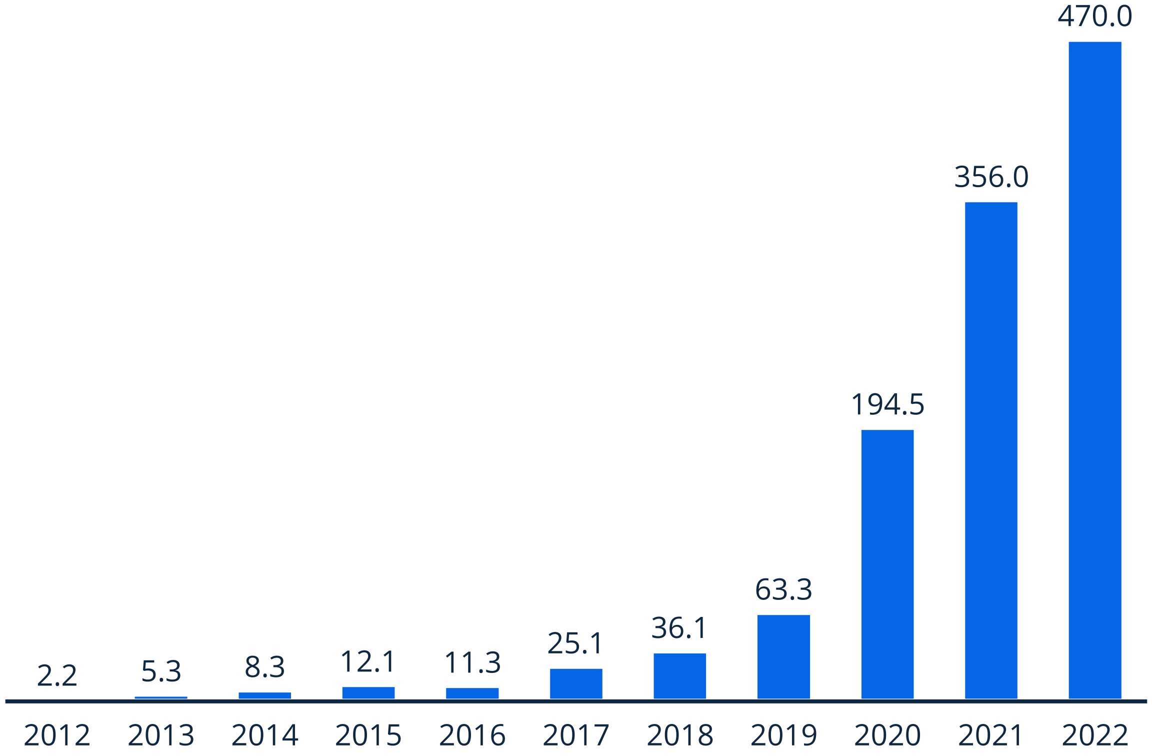
Notes: (1) EVs include PEVs and PHEVs

Sources: International Energy Agency (IEA)

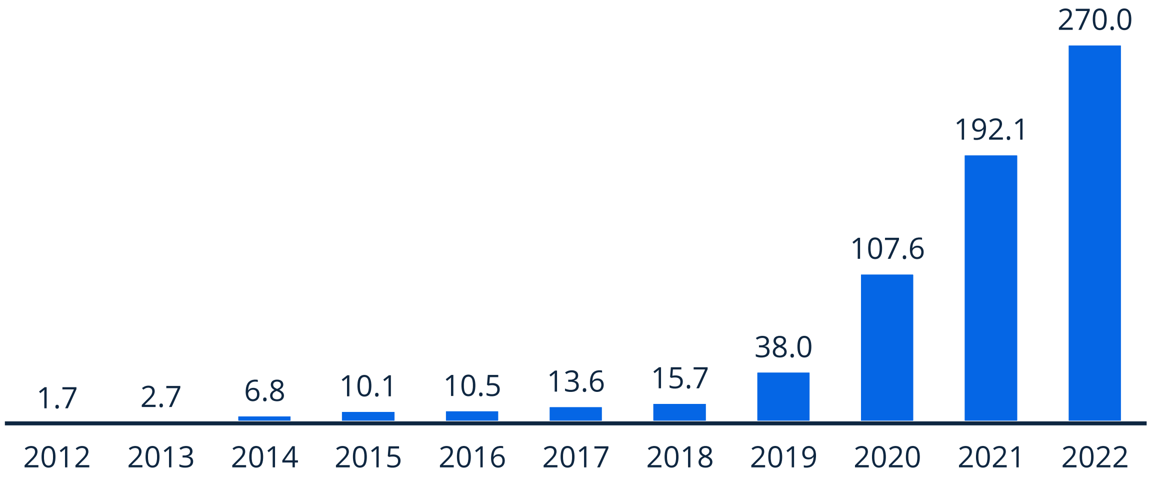
Top 8 countries in 2022: PEV sales in Europe (1/4)

Electric vehicles sales (1/4)

Number of PEV cars sold in Germany in thousands



Number of PEV cars sold in the UK in thousands

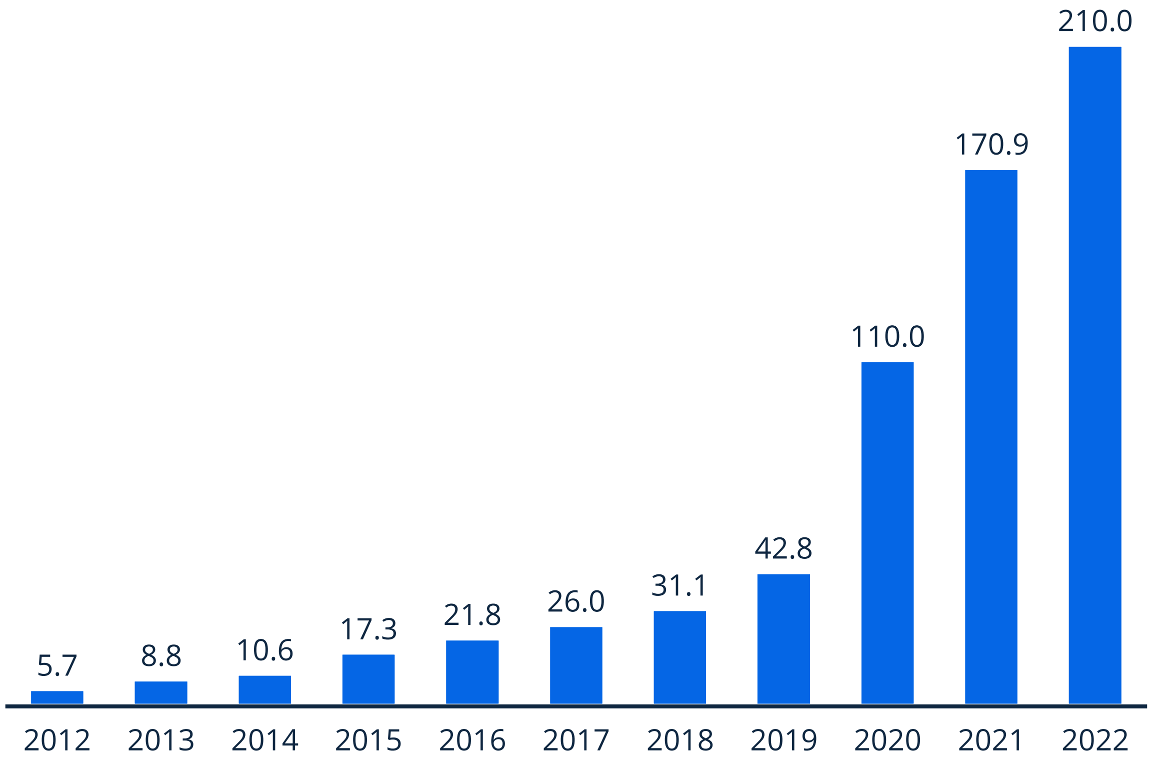


Sources: International Energy Agency (IEA)

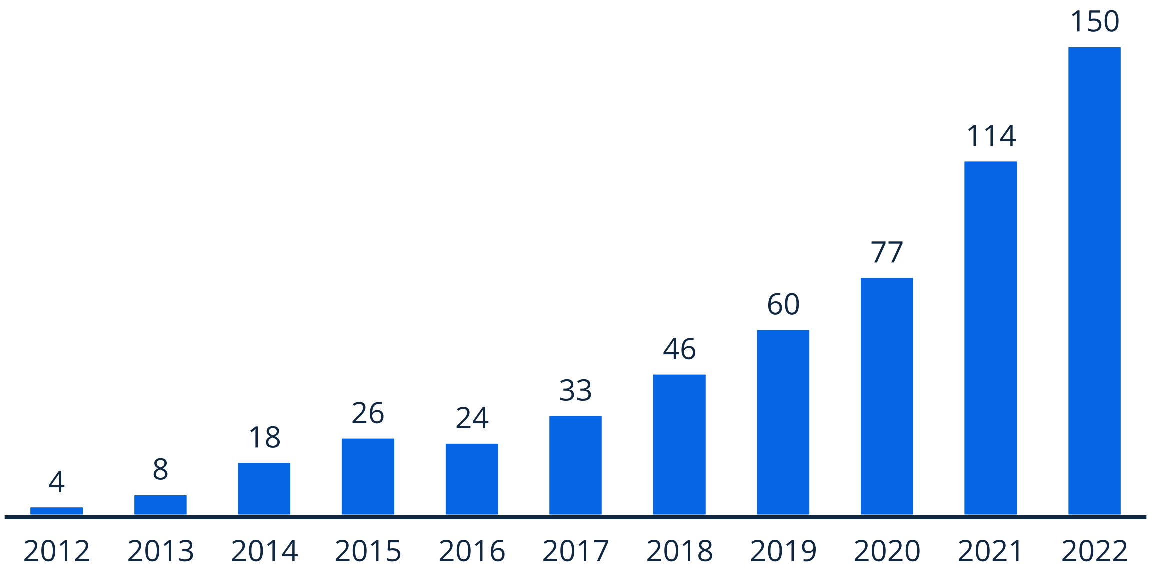
Top 8 countries in 2022: PEV sales in Europe (2/4)

Electric vehicles sales (2/4)

Number of PEV cars sold in France in thousands



Number of PEV cars sold in Norway in thousands

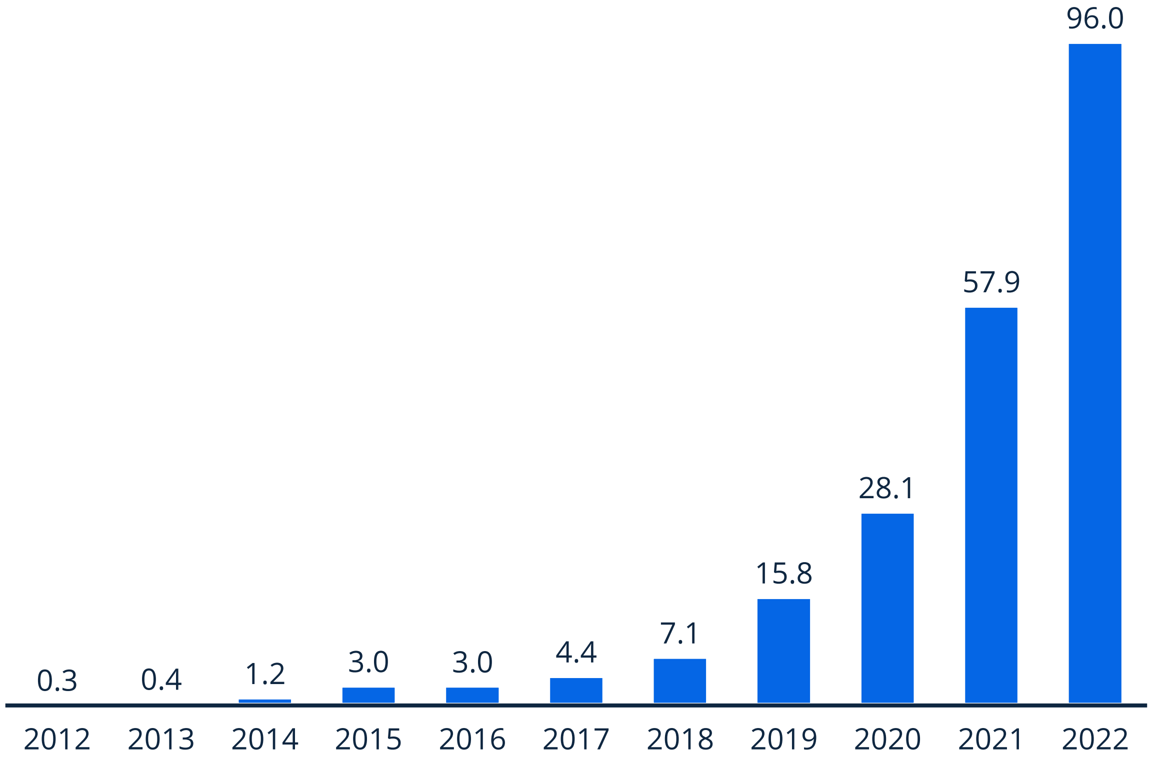


Sources: International Energy Agency (IEA)

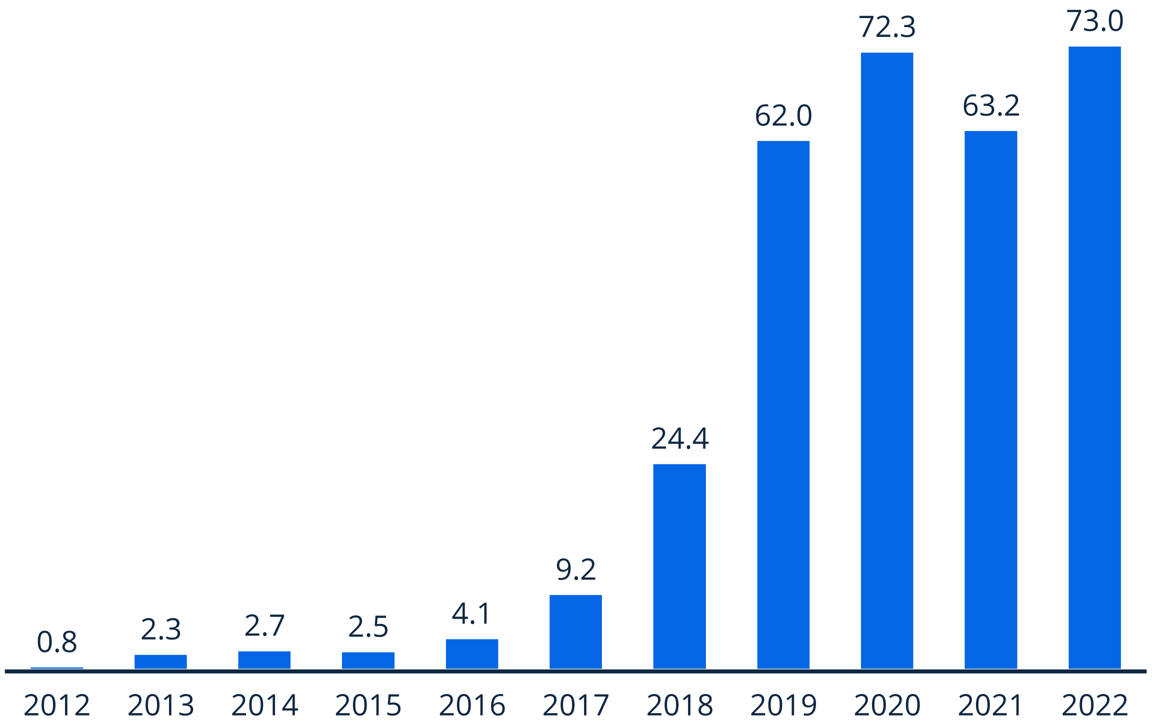
Top 8 countries in 2022: PEV sales in Europe (3/4)

Electric vehicles sales (3/4)

Number of PEV cars sold in Sweden in thousands



Number of PEV cars sold in the Netherlands in thousands

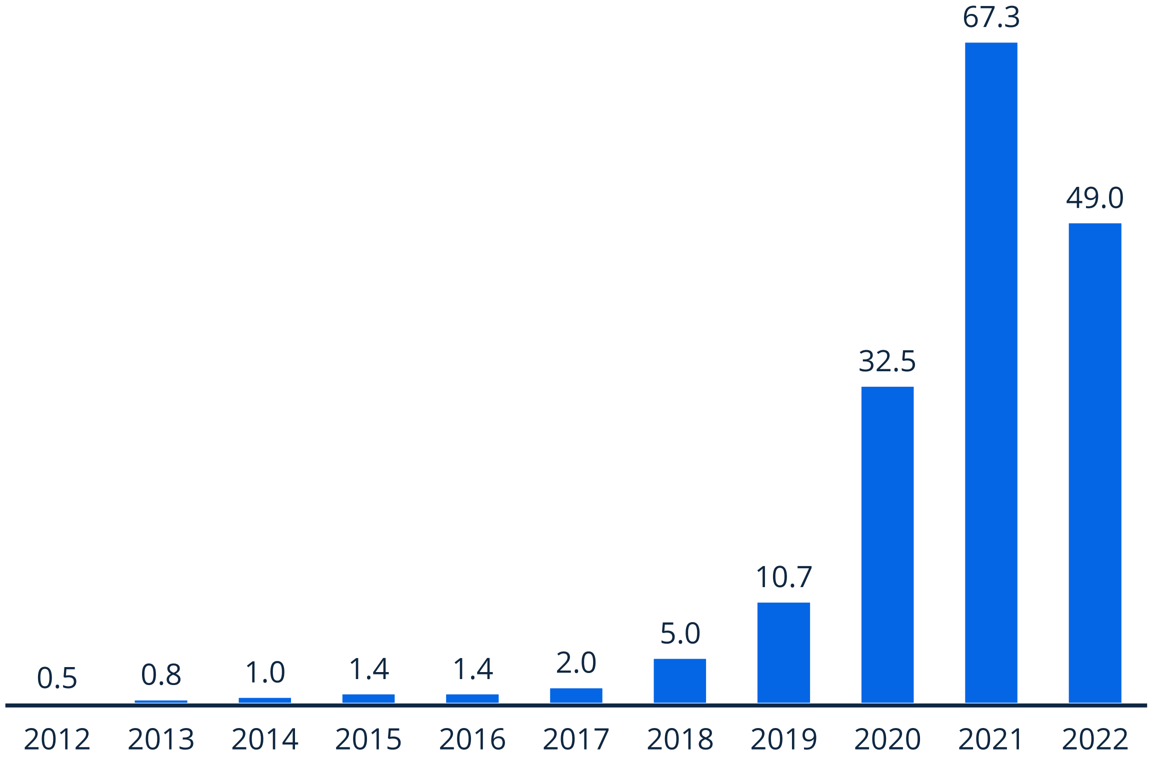


Sources: International Energy Agency (IEA)

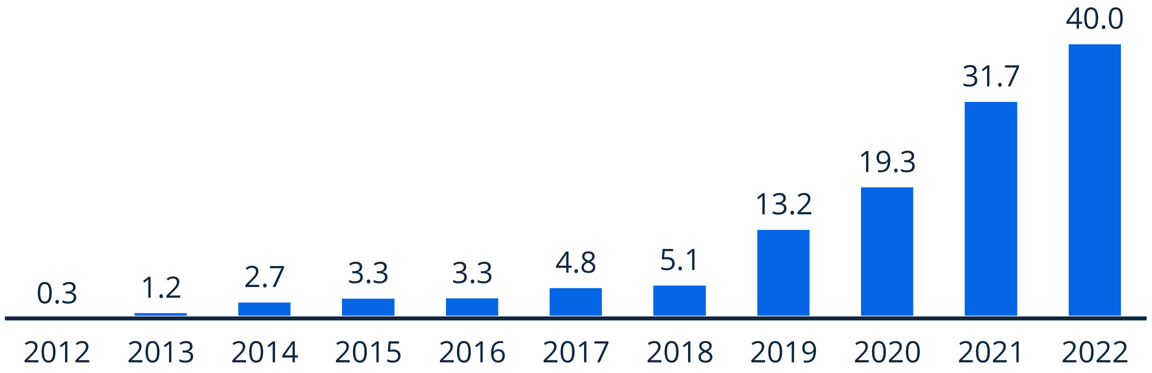
Top 8 countries in 2022: PEV sales in Europe (4/4)

Electric vehicles sales (4/4)

Number of PEV cars sold in Italy in thousands



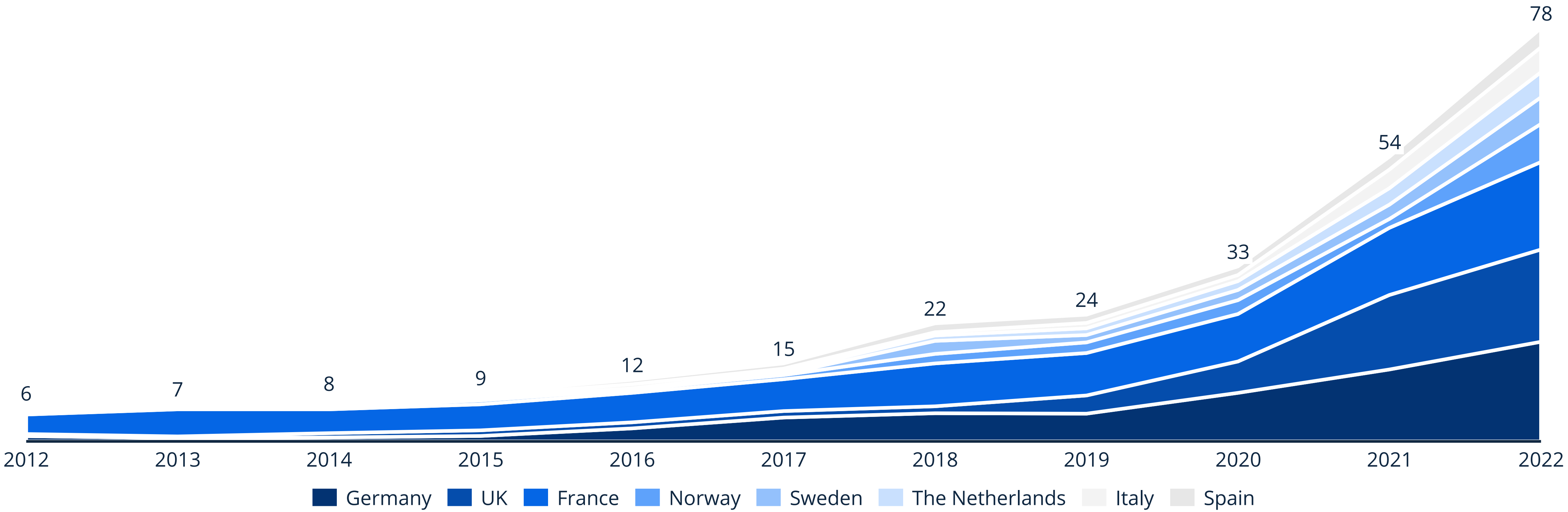
Number of PEV cars sold in Switzerland in thousands



Sources: International Energy Agency (IEA)

Development of e-LCV sales in Europe

Development of e-LCV[1] sales in Europe in thousands



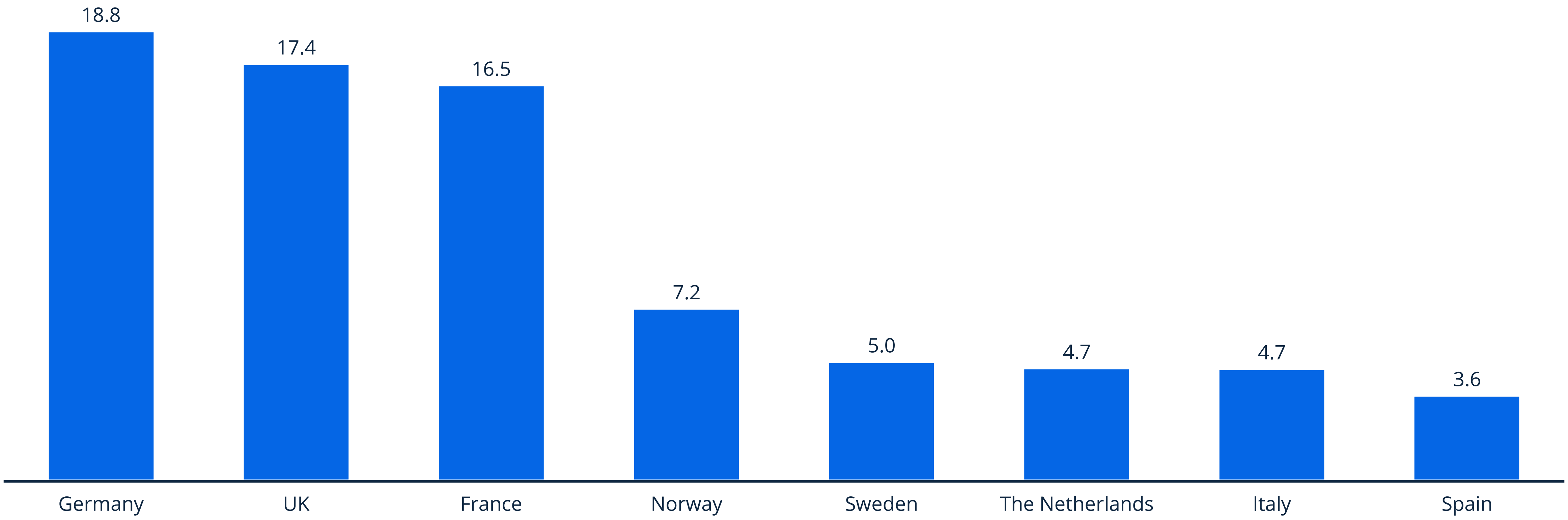
Notes: (1) Including BEV and PHEV vehicles

Sources: International Energy Agency (IEA)

Number of e-LCVs sales in selected European countries in 2022

Country ranking (1/2)

Number of e-LCVs[(1)] sold in thousands



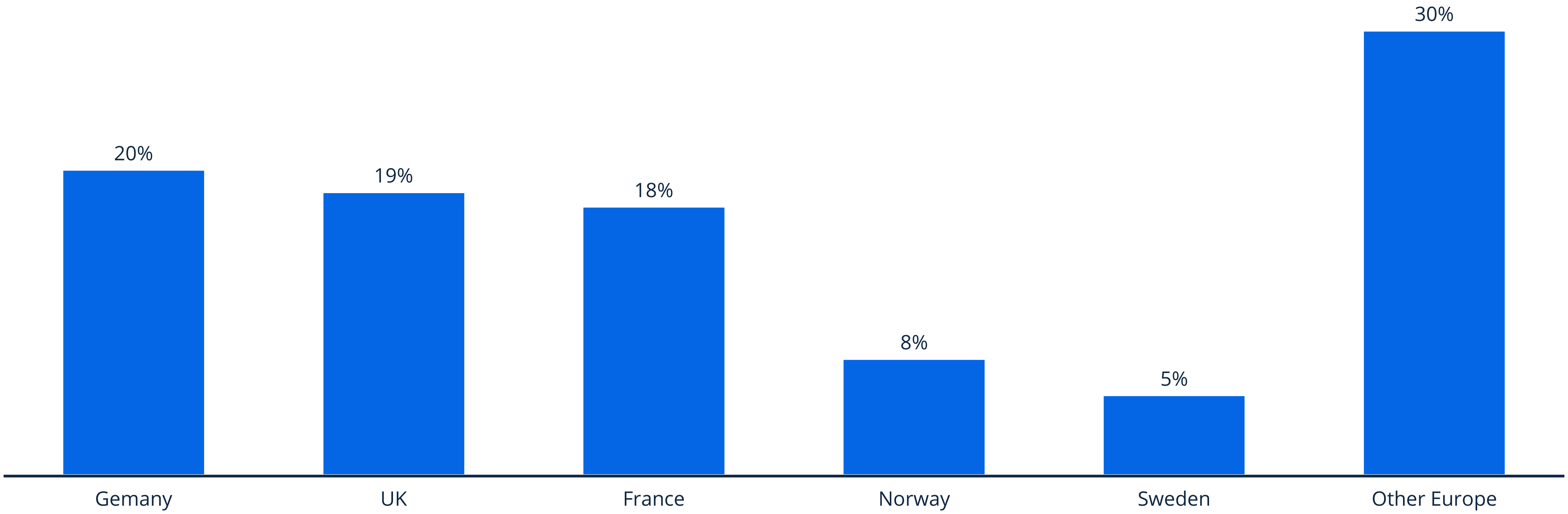
Notes: (1) Including BEV and PHEV vehicles

Sources: International Energy Agency (IEA)

e-LCVs market share in selected European countries in 2022

Country ranking (2/2)

e-LCVs(1) market share as % of total sales in Europe in 2022



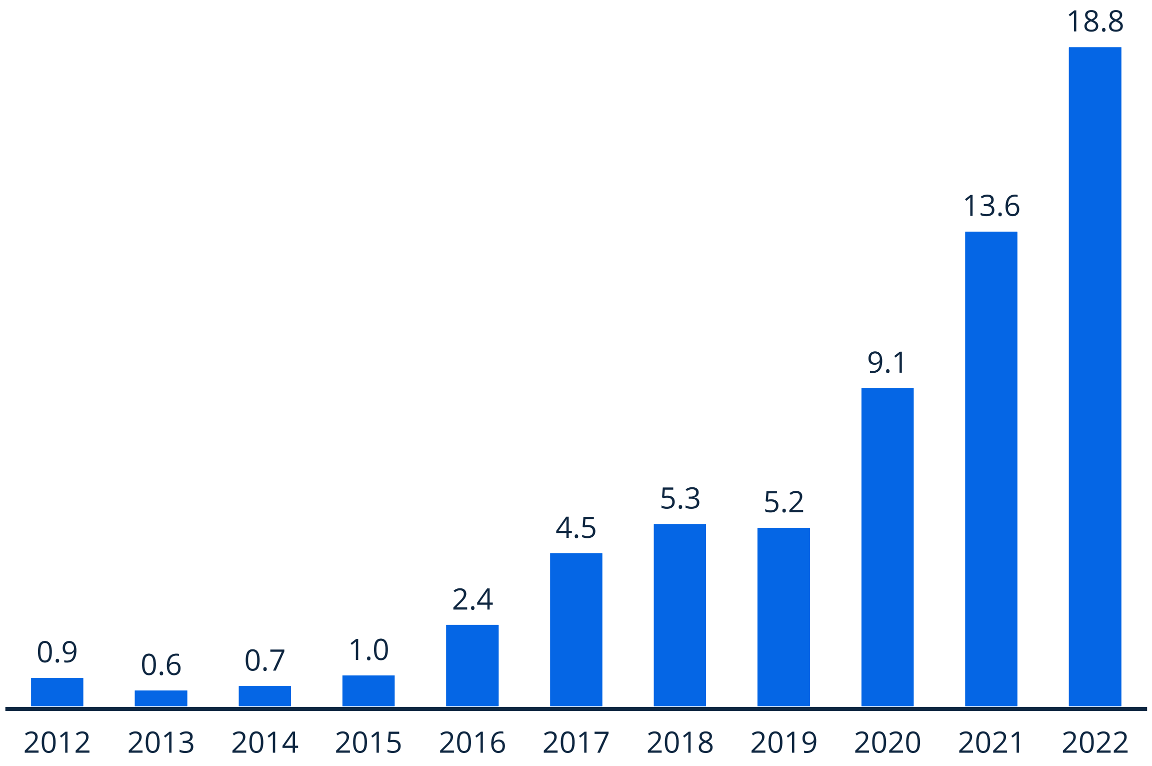
Notes: (1) Including BEV and PHEV vehicle

Sources: International Energy Agency (IEA)

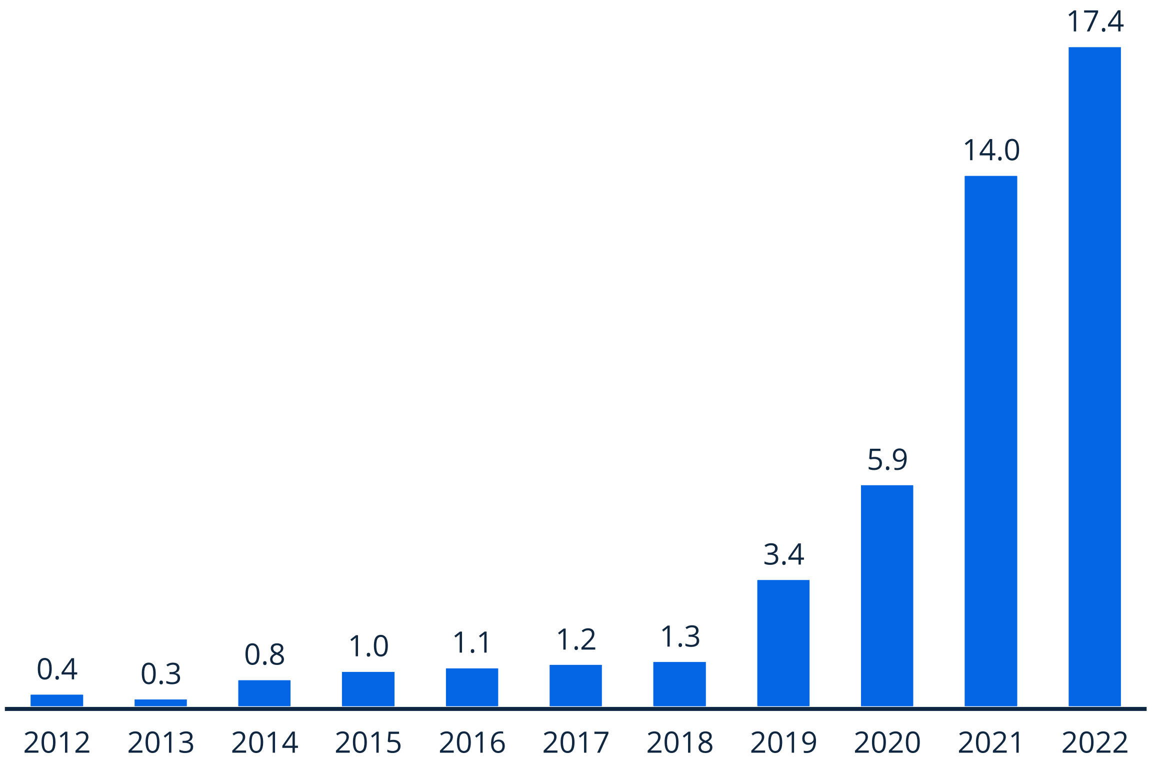
statista

Top 8 countries in 2022: e-LCV sales in Europe (1/4)

Number of e-LCVs[(1)] sold in the Germany in thousands



Number of e-LCVs[(1)] sold in UK in thousands

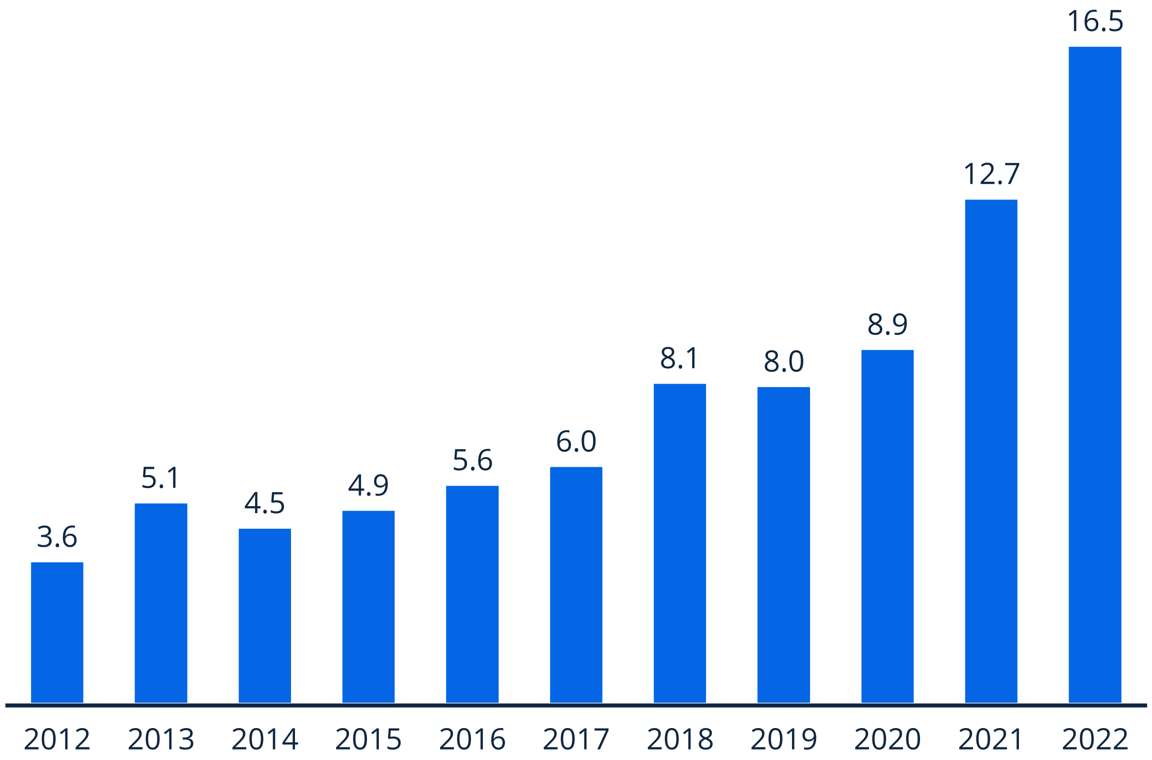


Notes: (1) Including BEV and PHEV vehicles

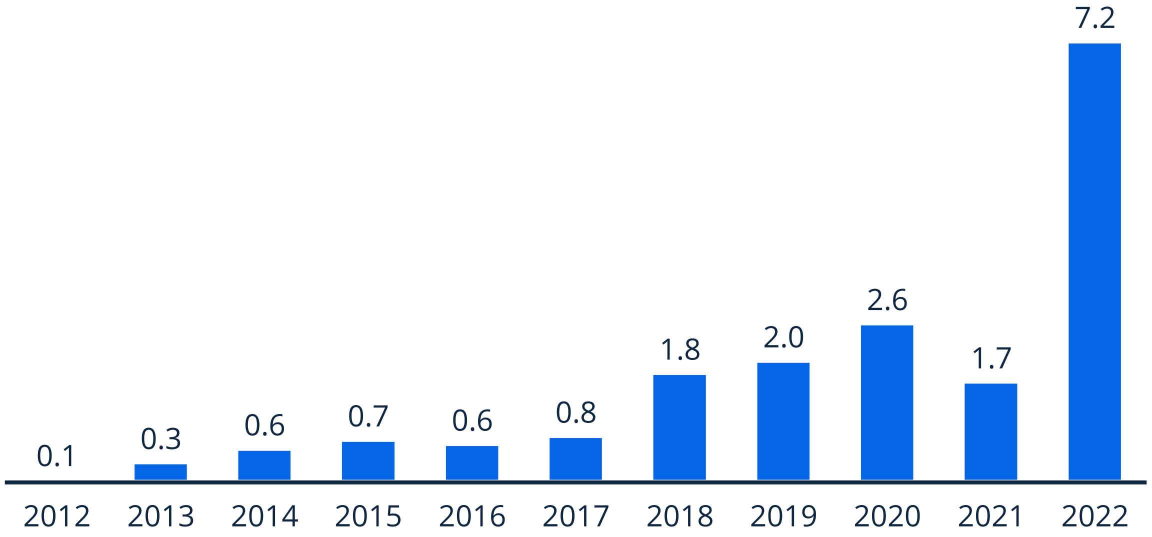
Sources: International Energy Agency (IEA)

Top 8 countries in 2022: e-LCV sales in Europe (2/4)

Number of e-LCVs[1] sold in France in thousands



Number of e-LCVs[1] sold in Norway in thousands

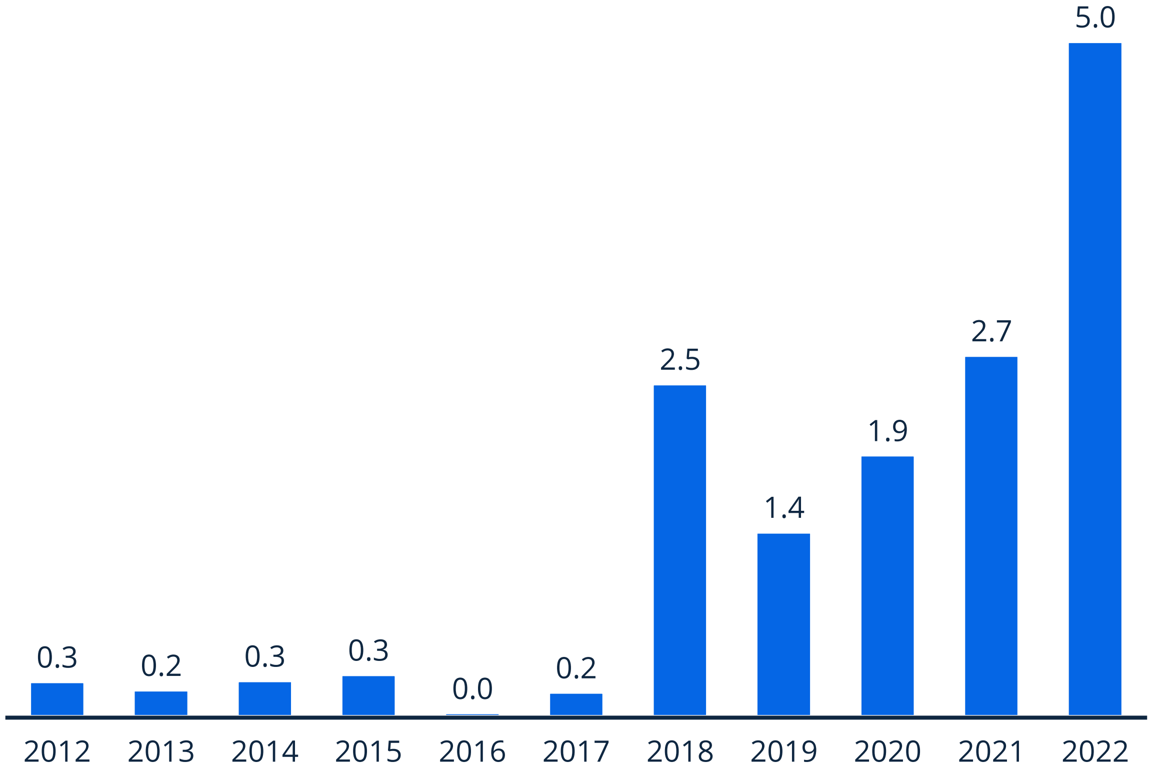


Notes: (1) Including BEV and PHEV vehicles

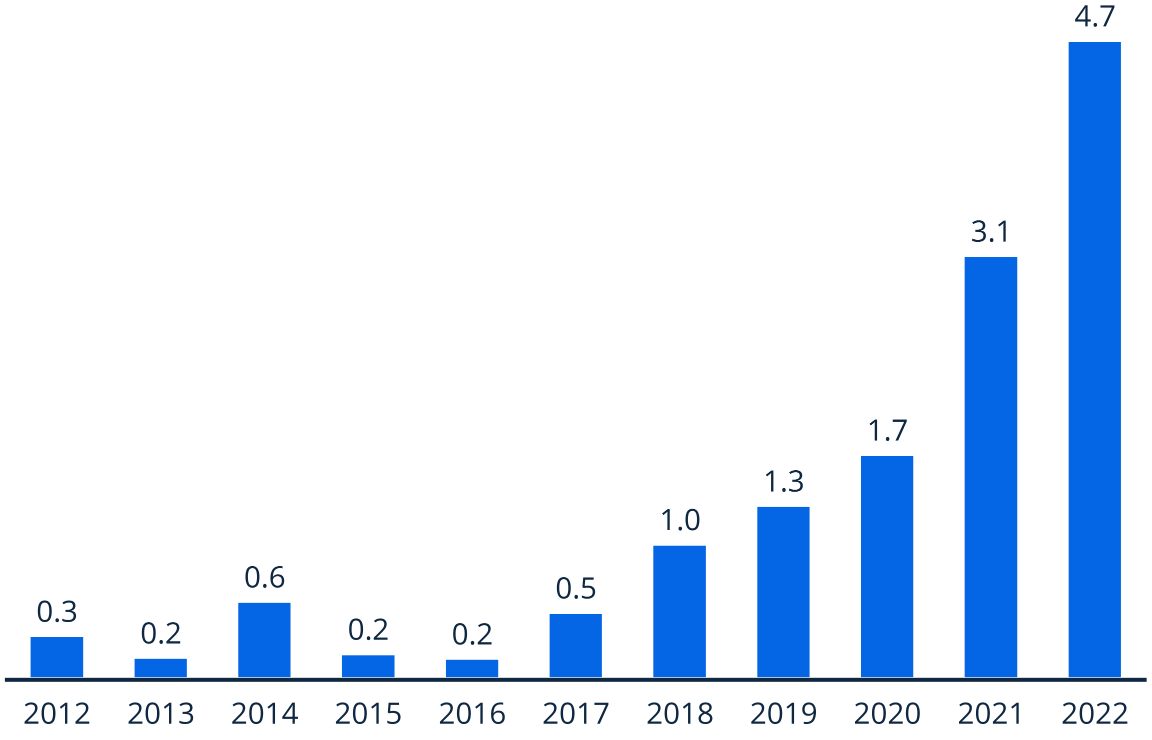
Sources: International Energy Agency (IEA)

Top 8 countries in 2022: e-LCV sales in Europe (3/4)

Number of e-LCVs[1] sold in Sweden in thousands



Number of e-LCVs[1] sold in the Netherlands in thousands

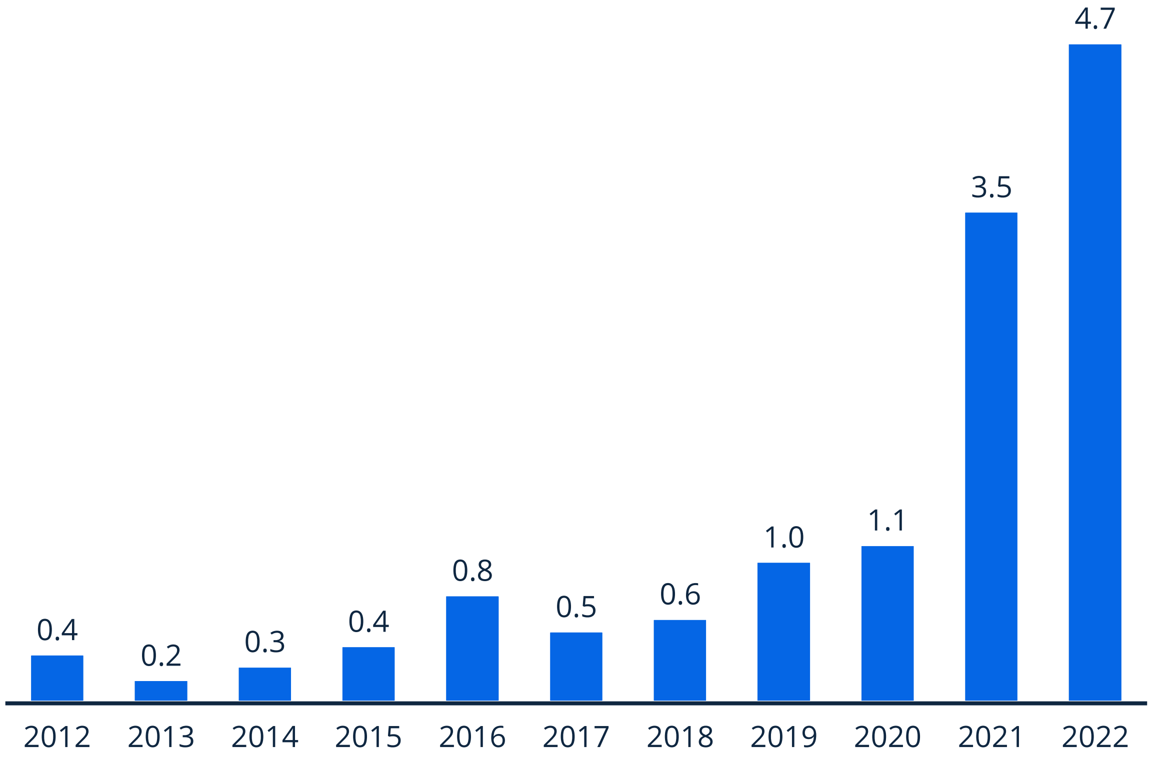


Notes: (1) Including BEV and PHEV vehicles

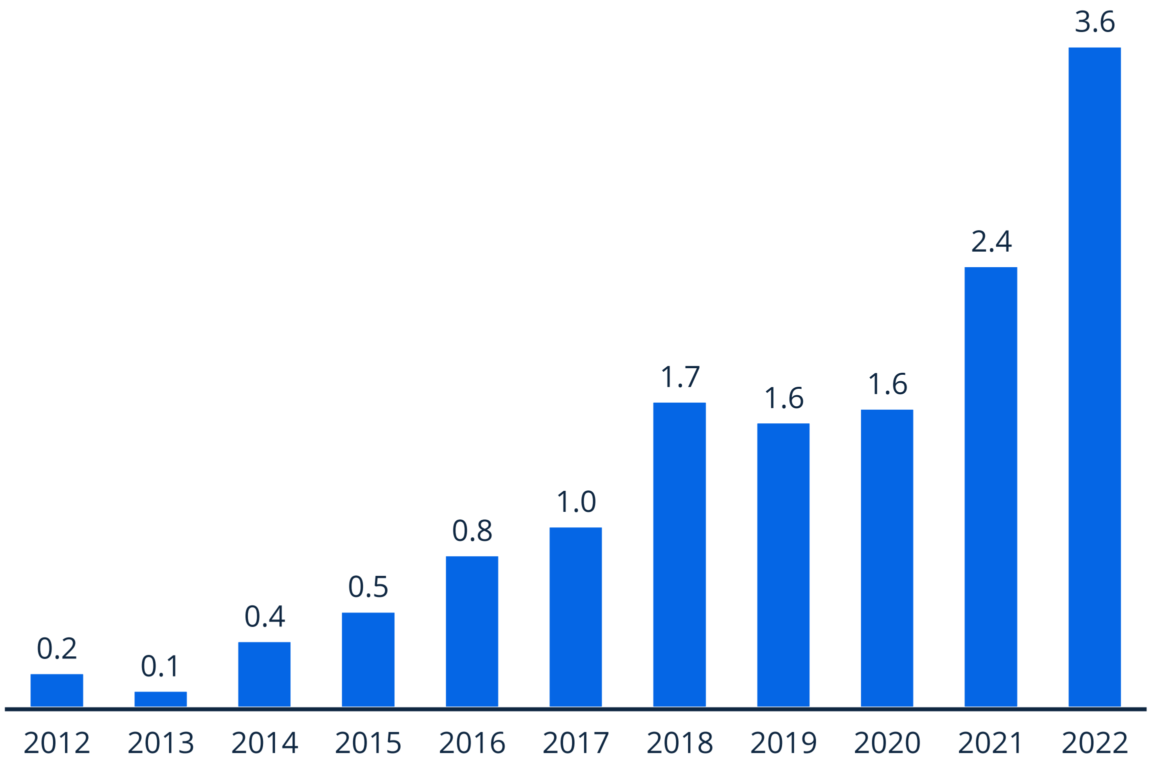
Sources: International Energy Agency (IEA)

Top 8 countries in 2022: e-LCV sales in Europe (4/4)

Number of e-LCVs(1) sold in Italy in thousands



Number of e-LCVs(1) sold in Spain in thousands



Notes: (1) Including BEV and PHEV vehicles

Sources: International Energy Agency (IEA)

CHAPTER 14

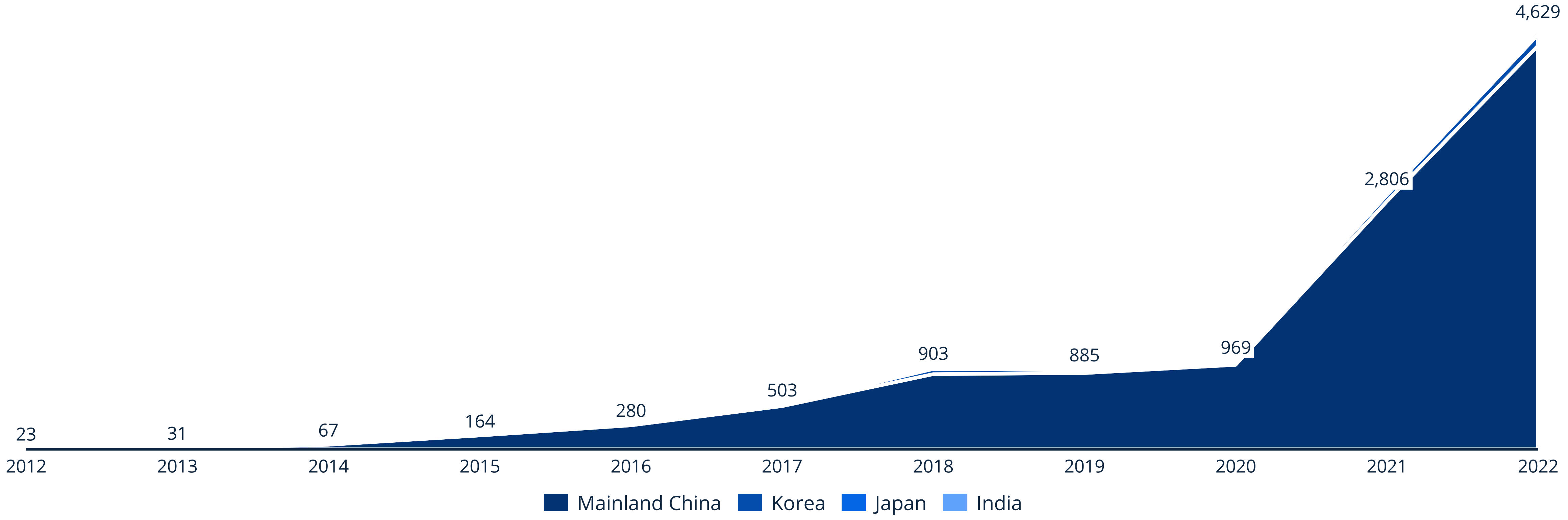
Special: EV sales in Asia

Mainland China is by far the market leader, not only in Asia but also worldwide. PEV sales amounted to over 4,400,000 units in 2022—nearly 175 percent more than the combined PEV sales in Europe. South Korea, Japan, and India are the other leading markets in Asia.

As for e-LCVs, Mainland China and South Korea account for an 86% share in the Asian market, with combined sales of over 167,500 units in 2022.

Development of PEV sales in Asia in number of cars

Development of PEV sales in Asia in thousands



Sources: International Energy Agency (IEA)

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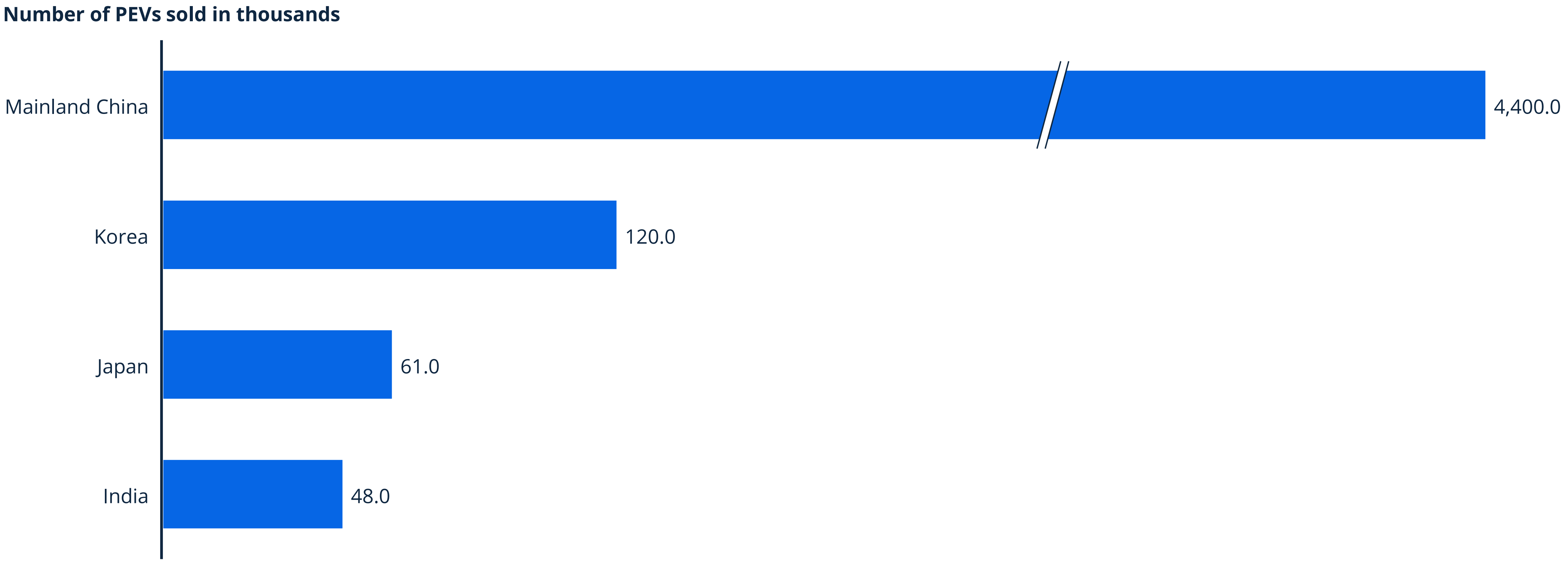
Number of PEVs sold in selected Asian countries in 2022

Country ranking (1/2)

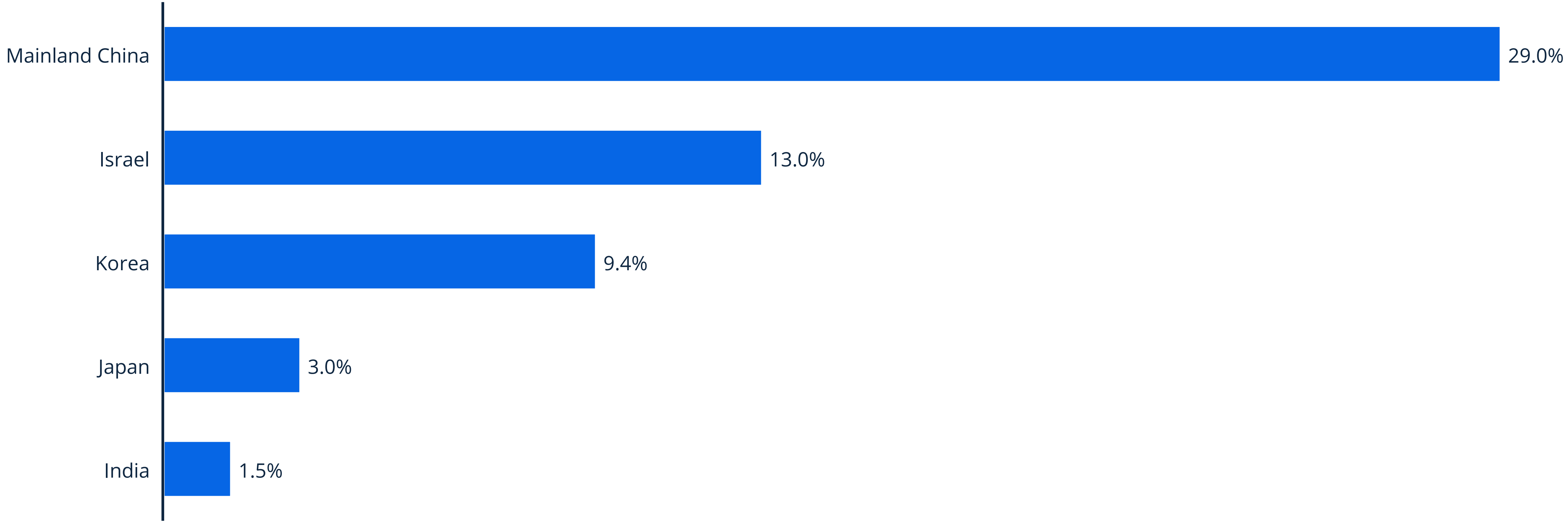


Sources: International Energy Agency (IEA)

EVs market share in selected Asian countries in 2022

Country ranking (2/2)

EVs[1] market share in 2022



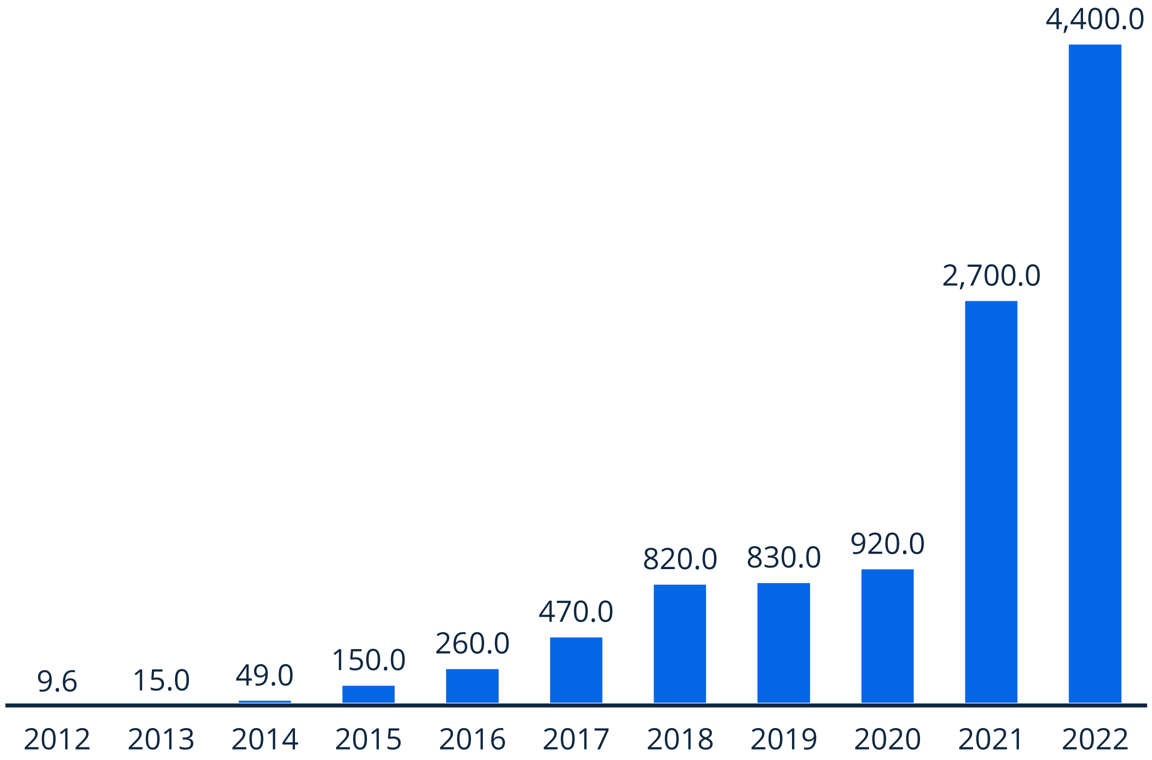
Notes: (1) EVs include BEVs and PHEVs

Sources: International Energy Agency (IEA)

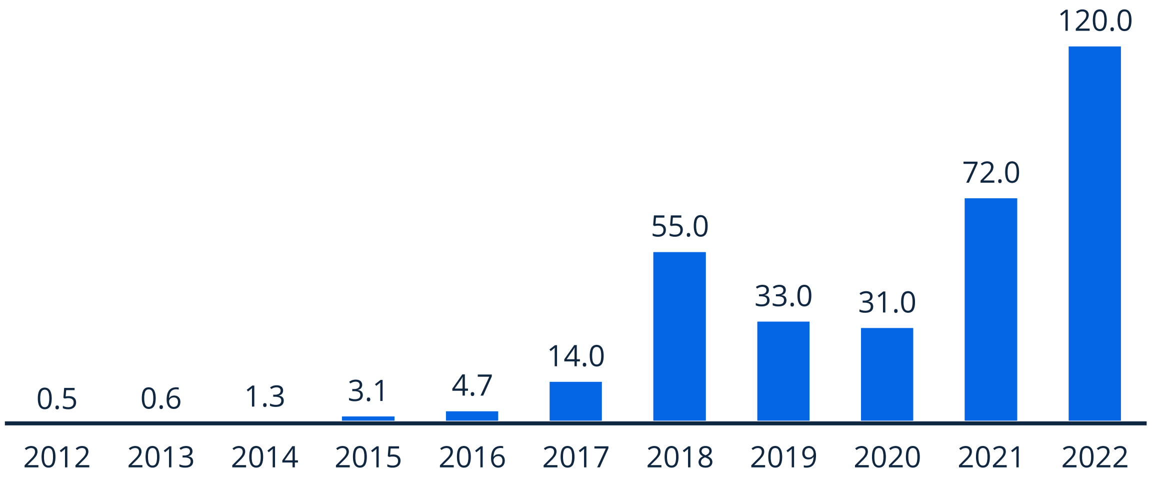
Top 4 countries in 2022: PEV sales in Asia (1/2)

Electric vehicles sales (1/2)

Number of PEV cars sold in Mainland China in thousands



Number of PEV cars sold in South Korea in thousands

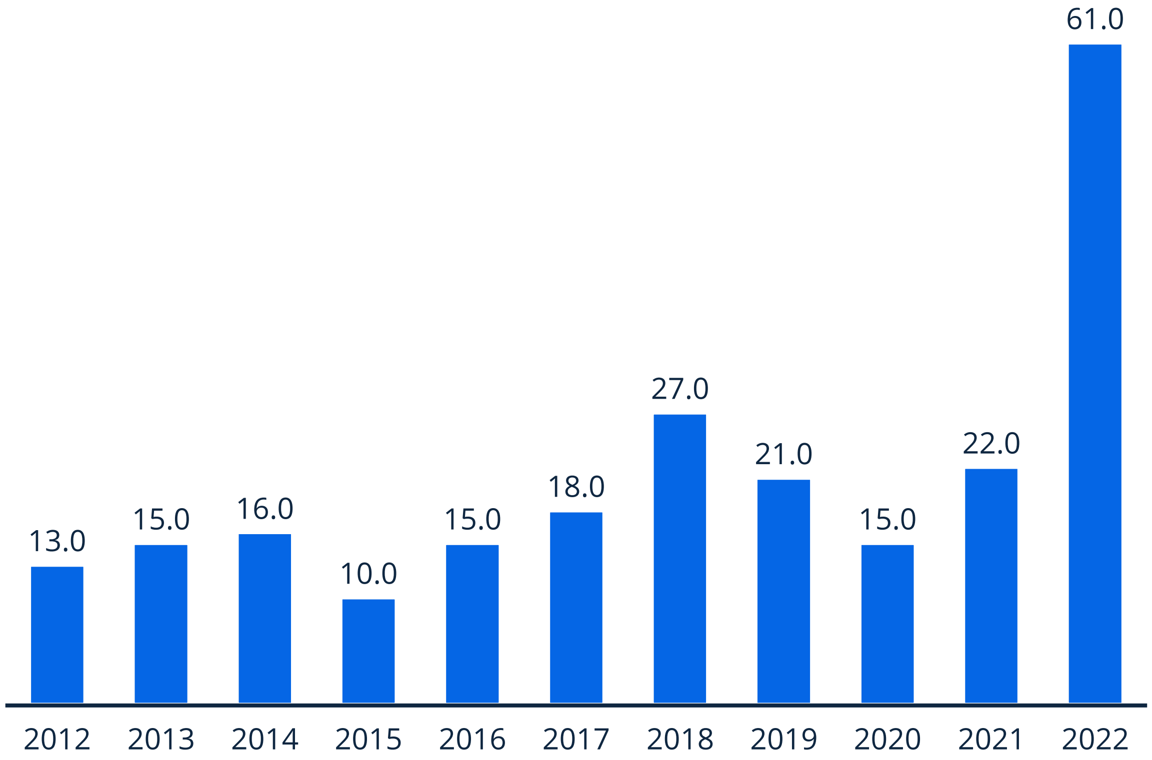


Sources: International Energy Agency (IEA)

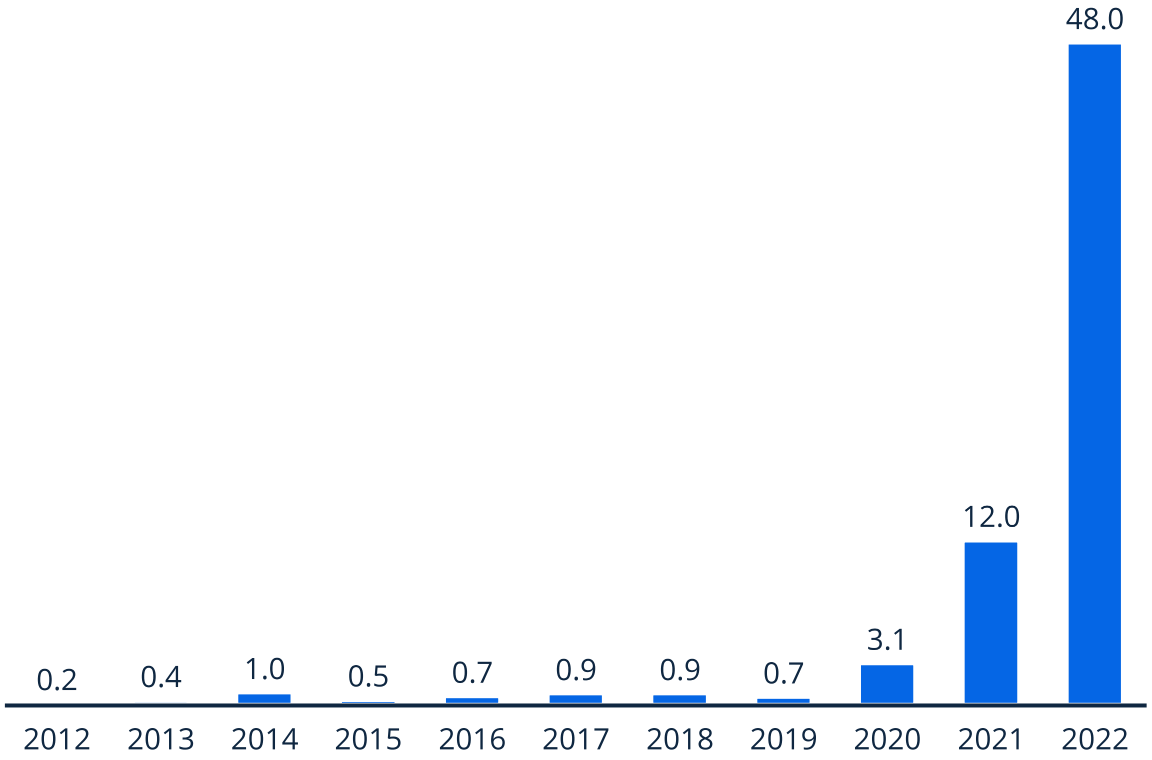
Top 4 countries in 2022: PEV sales in Asia (2/2)

Electric vehicles sales (2/2)

Number of PEV cars sold in Japan in thousands



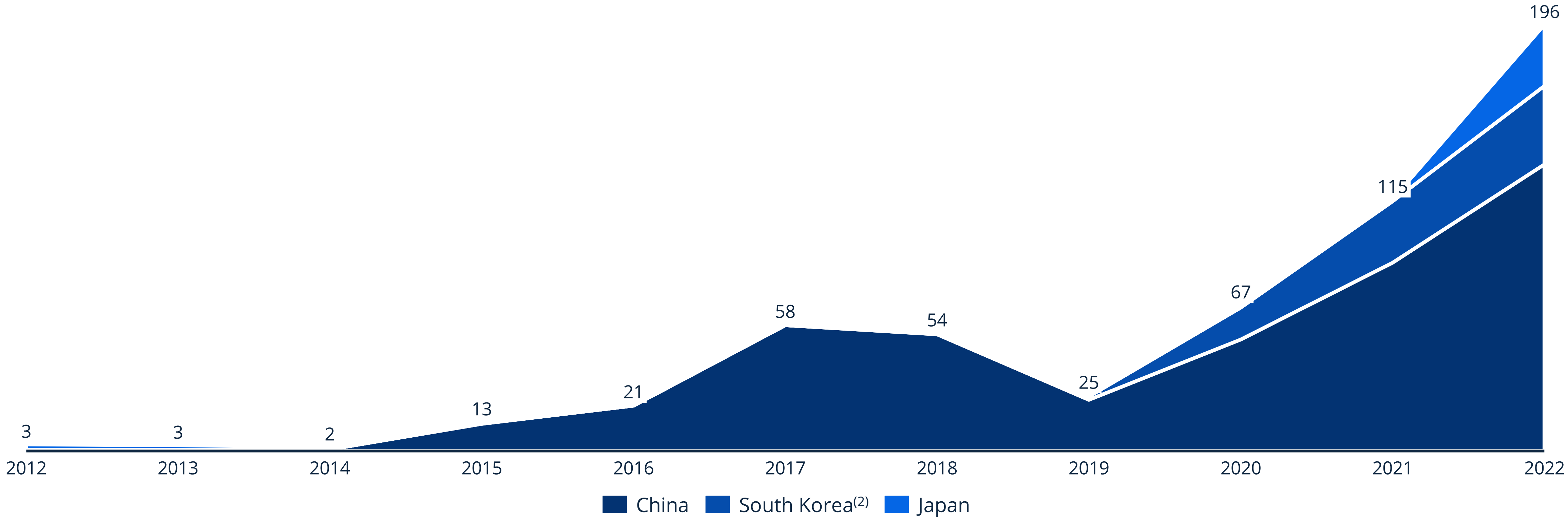
Number of PEV cars sold in India in thousands



Sources: International Energy Agency (IEA)

Development of e-LCV sales in Asia

Development of e-LCV[1] sales in thousands



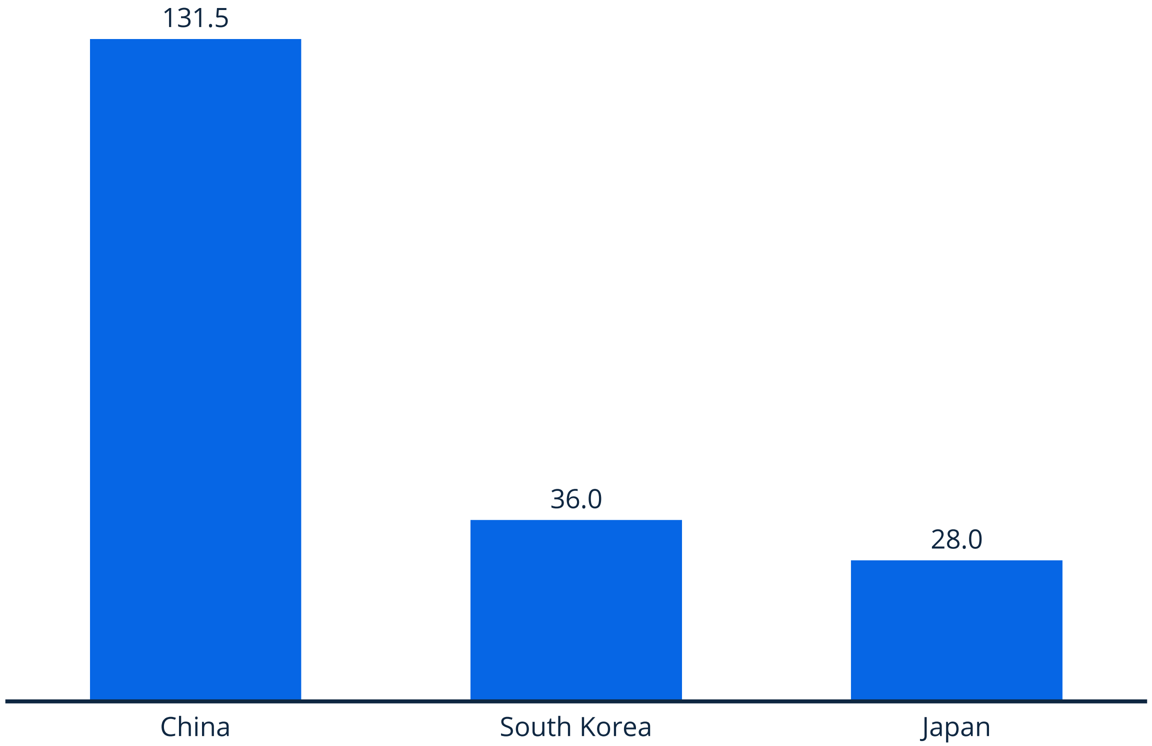
Notes: (1) Including BEV and PHEV vehicles (2) Data available only for 2015, 2016, 2018, 2019, 2020, 2021 and 2022

Sources: International Energy Agency (IEA)

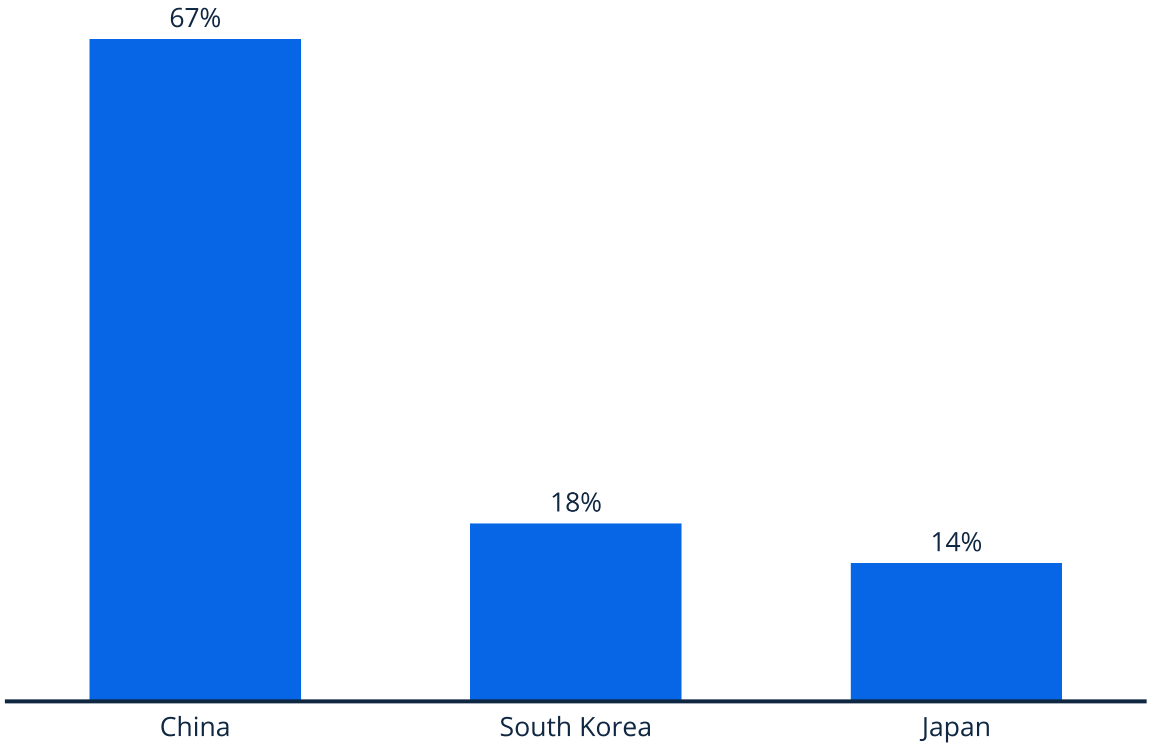
China dominates the Asian e-LCV market

Country ranking

Number of e-LCVs[1] sold in thousands in 2022



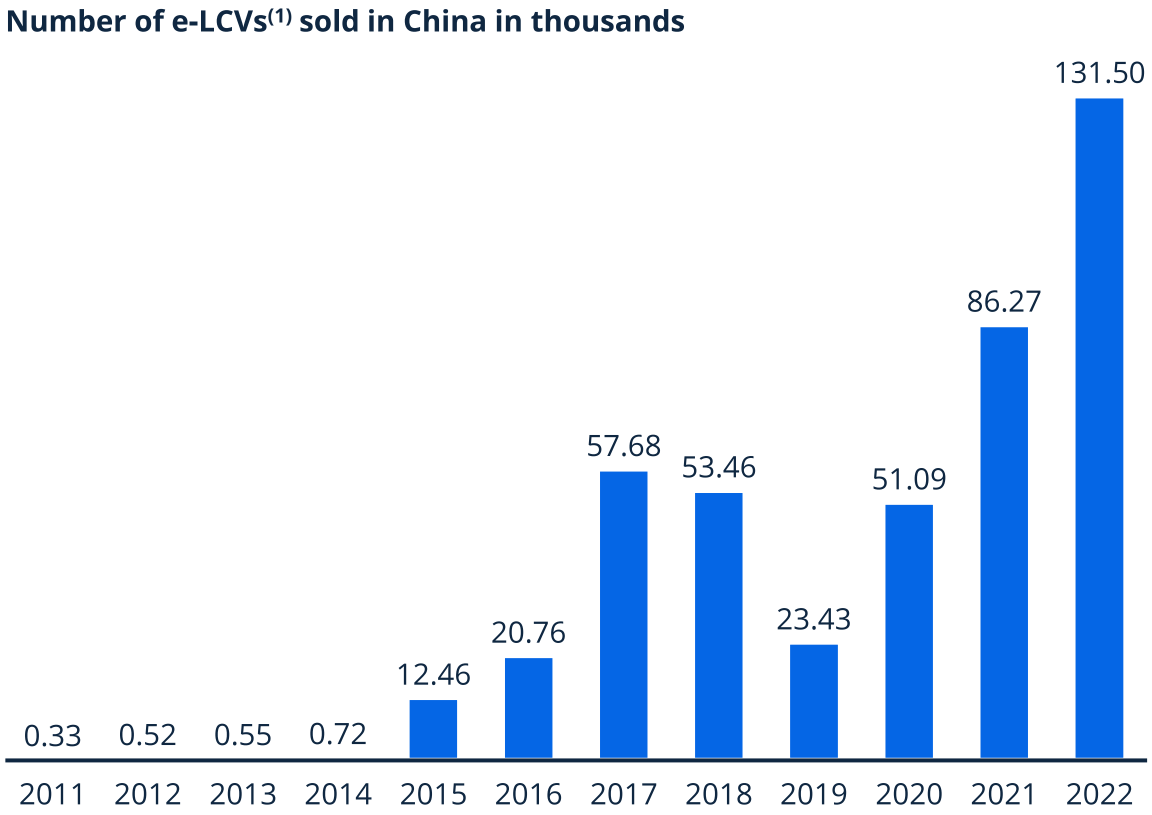
e-LCVs[1] market share as % of total sales in Asia in 2022

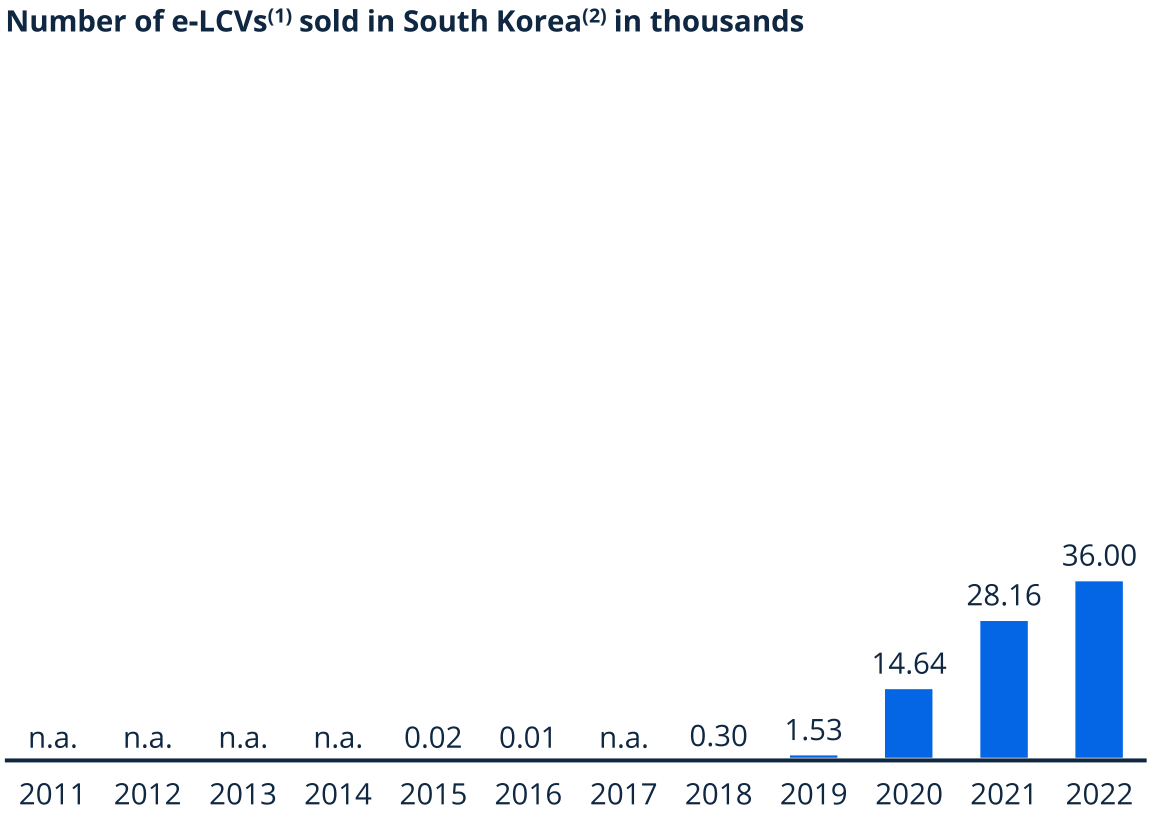


Notes: (1) Including BEV and PHEV vehicles

Sources: International Energy Agency (IEA)

Top 2 countries in 2022: e-LCV sales in Asia





Notes: (1) Including BEV and PHEV vehicles (2) Data for 2011-2014, 2017 not available

Sources: International Energy Agency (IEA)

CHAPTER 15

Appendix

Glossary (1/2)

Term	Abbreviation	Explanation
Autonomous, connected, electric, shared	ACES	The four key technological trends for future mobility.
Battery-as-a-Service	BaaS	A business model in which the battery of an EV can be rented from a service provider or swapped with another battery when it runs out of charge.
Battery EV	BEV	An all-electric vehicle that has an electric motor and a battery but no internal-combustion engine.
Dockless e-scooters	-	Electric scooters that have self-locking mechanisms and a GPS tracking facility with an average top speed of around 15mph. These are mainly used by bike-sharing companies such as Bird, Lime, and Spin.
Domain control units	DCU	A system that provides the key software functionality for a vehicle domain.
Electronic control units	ECU	An automotive embedded system that controls one or more of the vehicle's electrical systems or subsystems.
Electric vehicle	EV	A vehicle which uses one or more electric motors for propulsion. Includes cars, scooters, buses, trucks, motorcycles, and boats. This term includes all-electric vehicles and hybrid electric vehicles.
Hybrid EV	HEV	A vehicle powered by an ICE in combination with one or more electric motors that use energy stored in batteries. These are continually recharged with power from the ICE and regenerative braking.
Internal combustion engine	ICE	An engine in which the burning of fuels occurs in a confined space called a combustion chamber. Usually run with gasoline/petrol or diesel.
Light commercial vehicles	LCV	A commercial carrier vehicle with a gross vehicle weight of no more than 3.5 metric tons.

Glossary (2/2)

Term	Abbreviation	Explanation
Lithium-air battery	Li-air battery	A rechargeable battery which powers itself through the oxidation of lithium at the anode, and reduction of oxygen at the cathode.
Lithium-ion battery	Li-ion battery	A rechargeable battery made of lightweight lithium and carbon, commonly used in consumer electronics and electric vehicles.
Lithium-sulphur battery	Li-S battery	A rechargeable battery that replaces the liquid or polymer electrolyte found in current lithium-ion batteries with sulphur. They have more capacity than li-ion batteries.
Plug-in EV	PEV	An electric vehicle that can be externally charged and generally includes all-electric vehicles as well as plug-in hybrids. In this report we use the term for all-electric vehicles to differentiate them from plug-in hybrid electric vehicles.
Plug-in Hybrid EV	PHEV	A vehicle that can be powered either by an ICE or an electric motor. In contrast to normal hybrid EVs, they can It can be charged externally.
Solid-state batteries	-	A rechargeable battery that replaces the liquid or polymer electrolyte found in current lithium-ion batteries with a solid.
Vespa-like e-scooters	-	Vespa-like e-scooters look like traditional scooters but are run on batteries and generally have a higher range than the dockless ones. They are currently used mostly in Asia.

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