May 2021

Hitting the EV Inflection Point

Electric vehicle price parity and phasing out combustion vehicle sales in Europe

TRANSPORT & ENVIRONMENT

BloombergNEF

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$58/kWh

Expected average battery pack price in 2030

2025-2027

Years at which BEV prices reach parity with internal combustion engine vehicles in all light vehicle segments in Europe

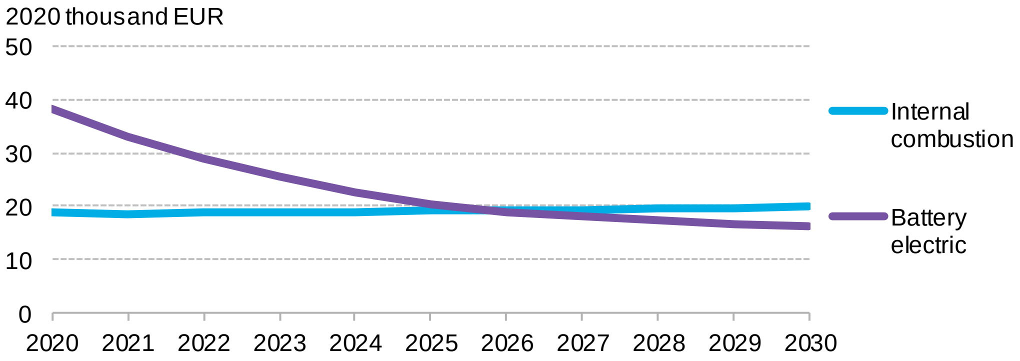
51%

Base case BEV share of light duty passenger vehicles sales in Europe in 2030

Electric vehicle sales are rising fast in Europe and a growing number of governments have set targets for phasing out new internal combustion vehicle sales. A fundamental input in deciding the feasibility of such policies is how quickly battery electric vehicles can reach price parity with their internal combustion counterparts. Further improvements in lithium-ion batteries will be critical and manufacturing strategy will also play a role. This report shows trajectories of cost developments for the production of battery electric vehicles and internal combustion engine vehicles, and the implications for the adoption of electric vehicles in Europe.

- Battery electric vehicles in all segments in Europe are expected to reach upfront cost price parity with equivalent internal combustion engine vehicles within the next product cycle. Falling battery prices and the development of optimized platforms lead the rapid decline in BEV costs. An optimal vehicle design, produced in high volumes, can be more than a third cheaper by 2025 compared to now. However, risks remain, primarily in achieving low enough battery prices and managing demand uncertainty.
- Battery technology continues to improve rapidly leading to lower prices and increased competition in Europe. New chemistries, better manufacturing methods, innovative cell and pack design concepts and other factors contribute to average prices per kilowatt hour declining by 58% from 2020 to 2030. There is visibility into how those declines can be achieved up to the late-2020s. Beyond that, the technology roadmap expands with some concepts, such as solid-state, still emerging. Uncertainties throughout the period to 2035 include raw materials prices that can become volatile and cancel some gains, and the speed at which the supply chain can scale up rapidly and sustainably in Europe.

Figure 1: Estimated pre-tax retail prices for C segment vehicles in Europe



Source: BloombergNEF Note: includes only passenger cars; ICE is internal combustion engine vehicle and BEV is battery electric vehicle

- Electric vehicle sales are set to rise strongly in the short term to meet the upcoming CO2 emissions target in Europe. By 2025, BNEF expects 4.3 million plug-in vehicles to be sold in Europe, representing around 28% of all sales in that year. BEVs capture over half of those plug-in vehicles sales, the remaining are plug-in hybrid vehicles, which are likely to become a significant compliance tool for several automakers. Across Europe, short-term adoption is highly uneven. Strong policy support and automakers' market strategies mean EV adoption in countries in the north and west of Europe far exceeds that of countries in the south or east.
- Battery electric vehicle adoption can be quick between 2025 and 2035. In an economics-driven scenario, Europe could reach just over 50% BEV share of sales by 2030 and 85% by 2035. Countries leading in EV adoption currently, such as those in the Nordics and the Netherlands, will remain in a leading position. Large automotive markets, such as Germany, the U.K. and France, will follow and will contribute the highest unit sales increase across Europe. In turn, countries starting from a low adoption position now are likely to end up further behind those other groups, but can experience rapid growth in the late-2020s. Still, achieving such high shares of BEV sales depends on vehicle prices coming down considerably in the next few years, consumers continuing to receive some purchasing support, and charging networks rolling out widely across Europe.

Figure 2: Base case and accelerated battery electric vehicle share of new passenger car sales in Nordics+

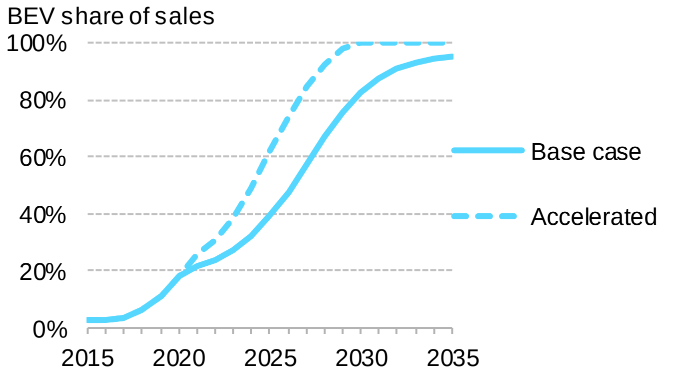


Figure 3: Base case and accelerated battery electric vehicle share of new passenger car sales in Western Europe

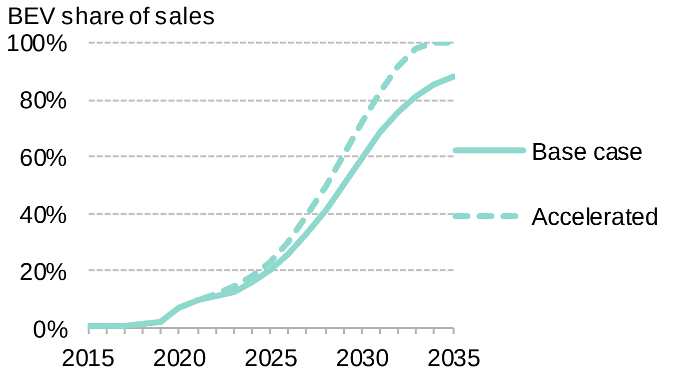


Figure 4: Base case and accelerated battery electric vehicle share of new passenger car sales in Southern Europe

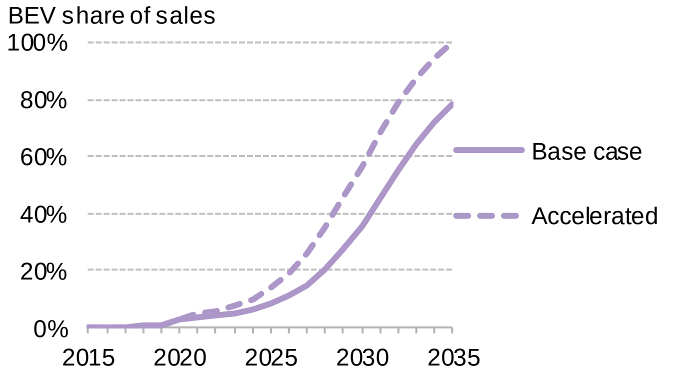
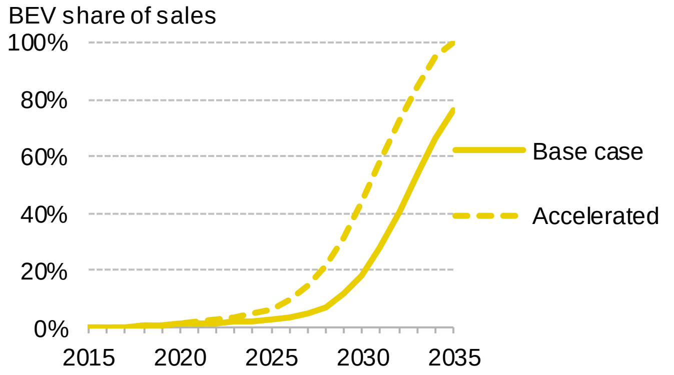


Figure 5: Base case and accelerated battery electric vehicle share of new passenger car sales in Eastern Europe



Source: BloombergNEF. Note: includes passenger cars only; includes adoption of battery electric vehicles (BEV) only; does not include plug-in hybrids (PHEV). Base case shows development trajectory under current technology outlook and policy measures. Accelerated shows potential scenario under additional stimulus.

- Even though organic BEV adoption is high by 2035, the EU and most countries would need to further expand their policy support frameworks to reach 100% adoption by 2035. A menu of options could include even tighter emissions rules, carbon taxes, subsidies for 'edge' use cases and extensive geographic coverage of charging networks. The accelerated scenario highlights the importance of the early buildup of BEV production and sales volume, as that drives cost reductions and also generates the necessary consumer buy-in for further adoption in the future.

This report was prepared by BloombergNEF for Transport & Environment.

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About BloombergNEF

BloombergNEF (BNEF) is a strategic research provider covering global commodity markets and the disruptive technologies driving the transition to a low-carbon economy. Our expert coverage assesses pathways for the power, transport, industry, buildings and agriculture sectors to adapt to the energy transition. We help commodity trading, corporate strategy, finance and policy professionals navigate change and generate opportunities.

TRANSPORT & ENVIRONMENT

About Transport & Environment

Transport & Environment (T&E) is Europe's leading clean transport campaign group. T&E's vision is a zero-emission mobility system that is affordable and has minimal impacts on our health, climate and environment.

Since T&E was created 30 years ago, it has shaped some of Europe's most important environmental laws. It got the EU to set the world's most ambitious CO2 standards for cars and trucks but also helped uncover the dieselgate scandal; campaigned successfully to end palm oil diesel; secured a global ban on dirty shipping fuels and the creation of the world's biggest carbon market for aviation.

Section 2. Introduction and background

The global EV market

Sales of electric vehicles are rising quickly, driven by supportive policy, technology improvements, urban air quality concerns, and rising consumer awareness. Over 3 million passenger electric vehicles were sold in 2020, up 47% from 2019, and the market is set to grow rapidly again in 2021. The Covid pandemic has roiled auto markets around the world, with total passenger vehicle sales dropping 16% in 2020. EVs have been mostly immune to this due to additional policy support, and a wide range of new models hitting the market.

Figure 6: Global passenger EV sales by region

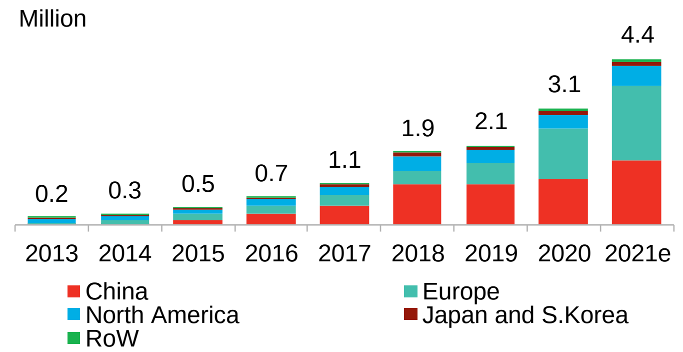
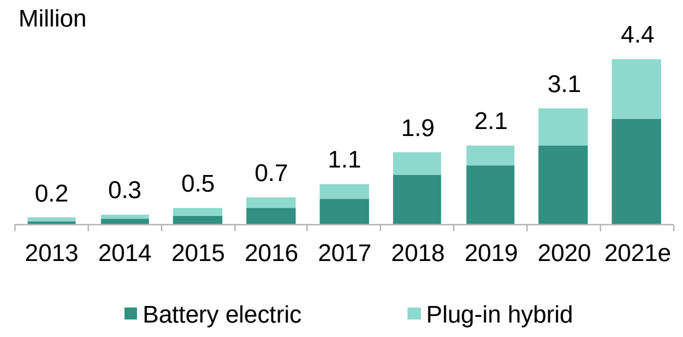
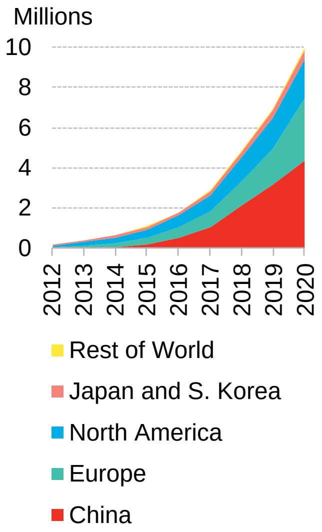


Figure 7: Global passenger EV sales by drivetrain



Source: BloombergNEF Note: EV are electric vehicles and include battery electrics and plug-in hybrids

Figure 8: Global passenger EV fleet



Source: BloombergNEF

China represented over 50% of global EV sales from 2017 to 2019, but that dynamic shifted in 2020 as EV sales in Europe more than doubled. Various policy mechanisms are being used to support this growth on both the demand side and the supply side. EV sales are slower in North America, but the Biden Administration is proposing $174 billion in investments to push the EV market forward, which, coupled with new fuel economy targets, could help close the gap with China and Europe. Battery electric vehicles (BEVs) form the majority of plug-in vehicles sold globally, though sales of plug-in hybrids (PHEVs) are rising quickly in Europe.

The total number of light-duty EVs on the road globally hit 10 million at the end of 2020, up from just 3 million in 2017. Electrification is also spreading into other segments of road transport and there are now over 500,000 e-buses in use. Commercial EV truck sales are still small, but there are nearly 350,000 on the road, mostly in China and Europe. Most of these are in the light commercial segment, though there is progress of electrifying larger vehicles. At the end of 2020, there were also around 190 million electric two-wheelers globally, including electric motorcycles, mopeds and scooters.

EV sales in Europe

The recent surge in EV sales in the EU is being supported by the new passenger car CO2 targets, which require automakers to reduce their overall fleet emissions to 95gCO2/km in 2020/21. As a result, automakers have launched many more EV models and increased production. More than 1 in 10 new vehicle sales in the region in 2020 had a plug. Only 95% of car sales were included in this target in 2020, but 100% will be included in 2021, leading to higher levels of EV adoption.

The CO2 targets are set to tighten again in 2025 and 2030. The current targets are set at a further 37.5% reduction from 2021-2030, but this is expected to be reduced further to keep the auto sector in line with the European Commission's Green Deal and its overall target of making Europe climate neutral by 2050. Many national governments also have demand-side incentives and fiscal policies in place to help stimulate EV adoption. EV sales have held up much better than combustion vehicle sales in Europe during the Covid-19 pandemic.

Passenger EV adoption varies widely between different European countries. In 2020, Germany was by far the largest EV market in Europe, with absolute EV sales in the country two times higher than in the next two largest markets, France and the U.K. The highest EV adoption shares are in the Nordics and the Netherlands, and EVs exceeded 10% of sales in a total of 12 countries in 2020. EV adoption has generally been slower in Southern and Eastern Europe.

Electric van sales were just under 2% of the total market in 2020. The sector has suffered from low model availability, with relatively expensive electric offerings, and a lack of widely accessible charging solutions for small and medium-size fleets. This situation is shifting, as both startups and established automakers are introducing new electric models with good enough range and cargo capacity to match different use cases.

Figure 9: Europe EV share of new passenger vehicle sales

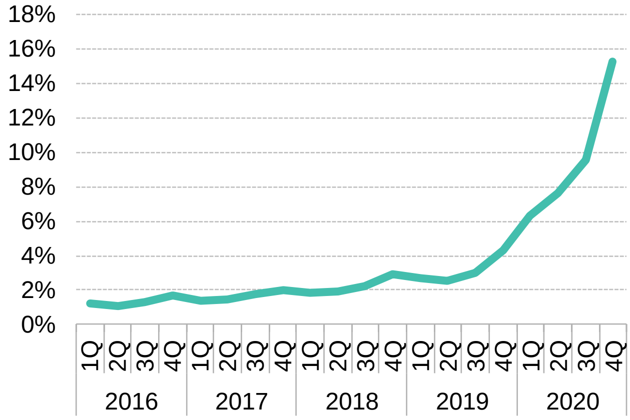
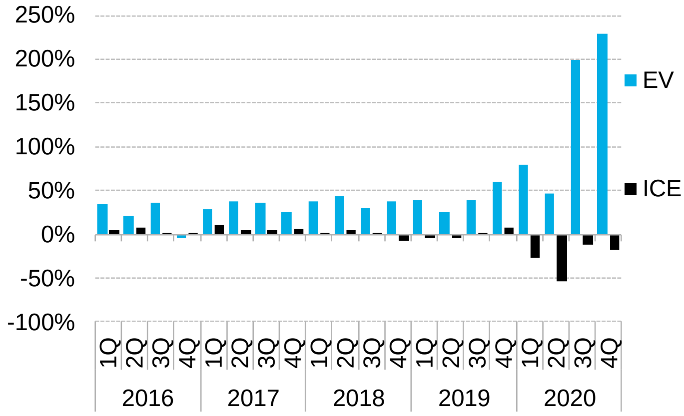


Figure 10: Europe passenger vehicles sales year-on-year change



Source: BloombergNEF, Marklines, Bloomberg Intelligence, vehicle registration agencies, EV Sales Blog, EAFO. Note: Europe data includes EU27 countries plus Norway, Switzerland, Iceland and the U.K. EV sales include BEV and PHEV sales. ICE = internal combustion engine.

Technology improvements

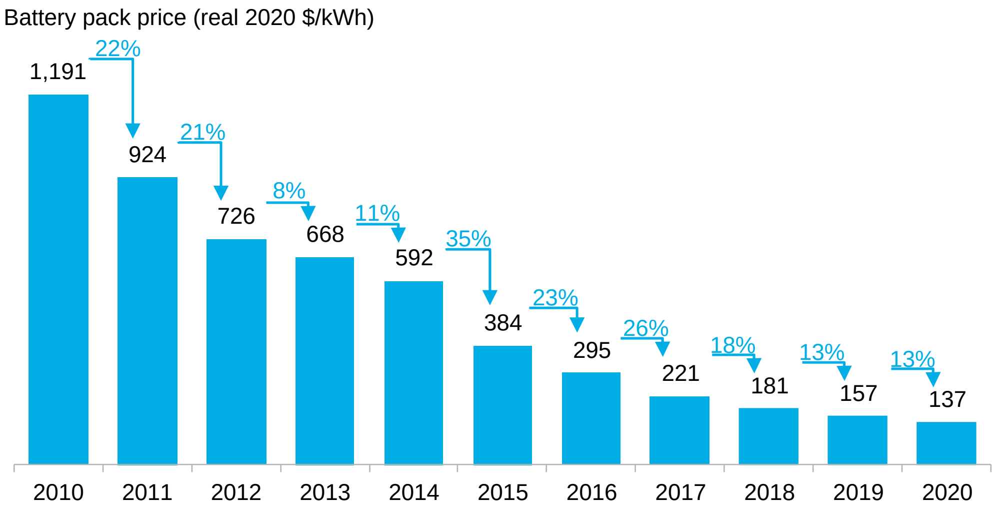
Falling prices for lithium-ion batteries are the biggest technology driver supporting the rapid rise in EV sales. Average lithium-ion battery pack prices fell 13% in 2020 and are now down 89% from 2010-20. While there is significant variation between applications, the average lithium-ion battery pack now costs $137/kWh and cells have already dropped to just over $100/kWh. Average lithium-ion battery pack energy density going into EVs has also been improving at 7% annually over the last 10 years.

Plug-in hybrid battery packs are more expensive on average, with prices of around $359/kWh 2020. In PHEVs, cells need to be balanced between power and energy. This is because packs need to be able to carry a vehicle a reasonable distance on battery power alone, while also providing the same peak power output as a BEV, and recovering energy under high-power situations, such as from regenerative breaking.

Battery material costs are currently rising, with prices of lithium carbonate, lithium hydroxide and cobalt rising 72%, 47% and 58%, respectively, in the first quarter of 2021. Despite this, BloombergNEF expects global volume-weighted average battery pack prices to cross $100/kWh by 2024.

Other EV technology improvements being implemented include using batteries as a structural element of the vehicle (sometimes referred to as 'cell-to-chassis'), higher efficiency electric motors, and better integration between EV components.

Figure 11: BloombergNEF lithium-ion battery price survey results



Source: BloombergNEF

Phasing out combustion vehicle sales

As EV sales rise and battery prices continue to fall further, a growing number of governments have set targets for phasing out new internal combustion vehicle sales – including the biggest car markets in Europe like France or the U.K. However, the feasibility and optimal timing of these is still debated. The most important factor is likely to be how quickly battery electric vehicles can reach price parity with their internal combustion counterparts. Further improvements in lithium-ion battery performance, energy density and cost will play a large role in determining this, but other components, vehicle manufacturing processes, and other factors will also play a role.

Automakers are also increasing their ambitions here. In 1Q 2021 alone, four automakers announced new plans to phase out sales of combustion vehicles. Three of them are global targets: the Jaguar brand is aiming to sell only EVs by 2025, Volvo is aiming for 2030, and GM is aiming for 2035. Ford's plan is regional: it will sell only EVs in Europe from 2030. VW also announced a new target for 70% of its sales in Europe to be fully electric by 2030. Other automakers have also committed to long-term 'net zero' targets including Daimler, VW, Renault, Honda and Toyota.

Most analysis on phasing out internal combustion vehicle sales to date has focused on either a single vehicle segment, or a single country, and has often used outdated battery price forecasts. There is now general agreement that price parity will be reached in the 2020s, but the actual point varies significantly by segment and geography, and most countries have very different starting positions on EV adoption. This has big implications for policy makers, who are trying to determine when and how ICE phase-outs might be achieved.

This report aims to address these shortcomings in the previous analysis the European context and answer the following questions:

- In what year will BEVs reach prices parity with comparable ICE vehicles in Europe and how does this vary by segment?
- What are the main drivers of these parity points and how sensitive are they to changes in input assumptions?
- What is the outlook for BEV adoption in Europe, and how does this vary between regions?
- What is a potentially feasible phase-out date for new ICE vehicle sales in Europe and what are some of the additional policy measures that would be needed to achieve this?

Methodology and approach

The analysis in this report is based on public and proprietary datasets, expert interviews, BNEF's in-house expertise and proprietary models. These models include BNEF's Bottom-up Battery Cost Model, Vehicle Economics Model and EV Adoption Model. For more details on methodology, please refer to sections 3.2, 4.2 and 4.3.

Section 3. Analysis of Vehicle Price Parity

3.1. Background and context

Declining battery prices and, in the European market, strict CO2 emissions targets for 2025 and 2030 mean that adoption of electric vehicles is set to continue increasing rapidly in the 2020s. However, electric cars (EVs) can currently cost about a third more than equivalent internal combustion engine (ICE) vehicles. As the exact timing of consumer demand is uncertain, automotive manufacturers are facing hard decisions regarding their product and manufacturing strategies for the current decade.

One of the main decisions revolves around the speed at which automakers should switch their supply chains, industrial footprint, manufacturing base, and intellectual capital over to electric vehicles, and the magnitude of the required change. More specifically, one of the fundamental considerations involves the affordability of electric vehicles. In BloombergNEF's view, a mass market for unsubsidized EVs is only possible once they are cost competitive with equivalent ICEs.

This part of the report presents a price outlook for battery electric vehicles (BEVs) in Europe, as well as the different cost drivers and manufacturing approaches that are part of achieving those prices. The analysis includes ICEs and BEVs in different segments (Table 1 and Table 3) and presents trajectories of estimated pre-tax retail prices by 2035. One metric typically used for the economic competiveness of BEVs is the price-parity year – ie, the year at which BEVs cost the same to manufacture and sell as equivalent ICEs. Despite the popularity of this metric, which is also included in the results below, there are limits to the value that a single year can provide. For more details on that and, primarily, on the wider implications of these price trajectories to EV adoption in Europe by 2035, see Section 4.

Table 1: Vehicle segments considered in this report

Segment	Examples	Market share in EU27+U.K. in 2019	Average or typical retail price in 2019 (EUR)
B	Renault Clio	18%	15,900
C	VW Golf	23%	23,200
D	BMW 3 Series	6%	36,400
SUV-B	Honda HR-V	37%	28,800
SUV-C	Toyota RAV4		
SUV-D	Volvo XC60		
Light van	Renault Kangoo	25%*	19,200
Heavy van	Ford Transit	56%*	38,400

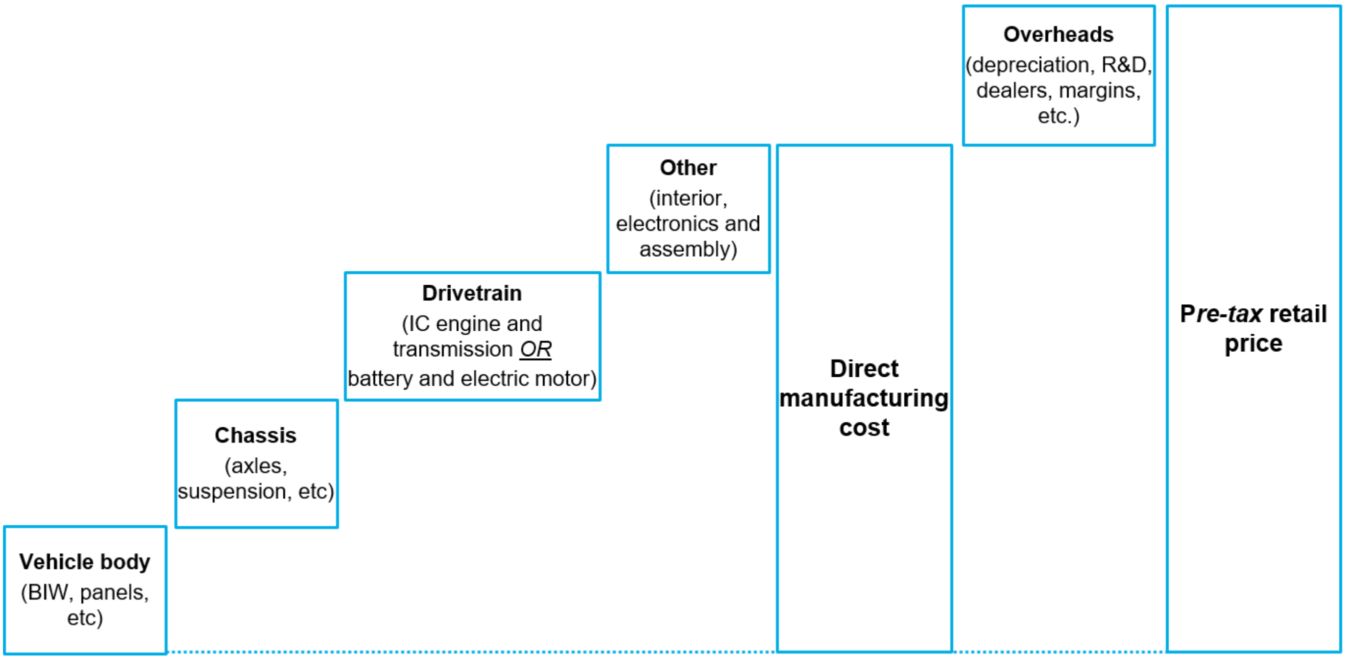
Source: BloombergNEF, ICCT, MarkLines, EU Commission, ACEA. Note: retail prices exclude tax, assumed at 20%. Van shares are share of light-duty commercial vehicle market.*

3.2. Methodology

The pricing methodology presented below is a cost-based approach and consists of deriving the direct manufacturing costs of various vehicle systems, and then adding the associated indirect costs (Figure 12). Direct manufacturing costs (DMC) include materials, labor, energy, building and machinery costs directly employed in the production of components. Costs such as depreciation or capital expenditure, research and development, marketing, transportation and distribution, warranties, profits and others are included in the production and corporate overhead costs.

Our modeling focuses on underlying production costs, while pricing can be a strategic choice made by automakers to manage supply and demand. Price parity will theoretically be achieved when an automaker can make and sell an EV with a comparable margin as a similar ICE model, without subsidies.

Figure 12: Vehicle cost methodology



Source: BloombergNEF

Baseline and optimized battery electric vehicles, and central scenario

We estimate two sets of production costs for BEVs. In the baseline case, we assume that vehicles are developed and manufactured using engineering platforms modified from existing ICE vehicles. In the optimized case, BEVs are designed and produced based on dedicated platforms (Table 2, and explanation box at the end of this subsection).

We combine those cost sets to derive our central pricing scenario, based on the manufacturing strategies of major automakers in Europe. We use this scenario in the price parity analysis and adoption forecasts. We estimate that in 2020, electric vehicle prices are heavily skewed toward the costlier baseline case, since many BEVs currently on sale are built on modified platforms. However, the weighting quickly shifts as several automakers develop dedicated platforms. We expect that by 2025 most BEVs available will be built on dedicated platforms.

Baseline electric vehicles may cost 10-30% more to manufacture and sell, depending on segment. The cost gap is primarily a result of different production volumes, mostly through lower battery costs. The distribution of the considerable development costs to more vehicles and more efficient inventory management are additional benefits. A second volume-related effect specific to BEVs is that dedicated all-electric platforms can in principle be used to build vehicles in several widely different segments. That is in contrast to existing ICE platforms, which can typically only accommodate vehicles on adjacent segments.

Dedicated platforms also offer possibilities for the engineering optimization of BEVs, such as better weight distribution and more opportunities for lightweighting, simpler assembly and specifically re-designed components, including axles and suspensions.

The main drawback of developing a new platform is demand uncertainty. The costs, the development timescales and the lifetime of automotive industrial assets make such decisions challenging. On the cost side, R&D expenses may well exceed 5 billion euros for a new platform, with additional capital expenditure needed to re-tool plants and other costs required to establish solid supply chains. The resulting manufacturing footprint needs to be fully utilized in order to recoup those investments, while timescales can be long. It can take three to five years to develop from scratch a new platform, which can be used for five to seven years. It can take an additional one to two years in strategy deliberations before taking a decision to even begin development. So, a manufacturer that may have started thinking of new EV platforms in 2020, should be relatively confident of sales volumes even into the early 2030s[1].

In the current European automotive market, regulation offers some counterbalance for those inherently risky decisions. Specifically, the tailpipe CO2 emissions targets for 2025 and 2030 provide demand anchors for electric vehicles, as automakers need to introduce BEVs and PHEVs in large numbers to meet those targets. We believe that the European Commission is likely to tighten them further in the future. Hence, we expect that in the second half of the 2020s most manufacturers in Europe will have developed dedicated EV platforms or lease/contract these from other suppliers. In our results, about three quarters of BEVs sold in Europe in 2025 are based on such architectures. Manufacturers will have ever stronger incentives to base more output on dedicated platforms, as BEV volumes rise over the next few years. By 2030, we assume that all BEVs will come out of dedicated platforms to take full advantage of the cost advantages of high volume manufacturing. Still, there are fundamental uncertainties in making such decisions and we treat those as part of the price sensitivity analysis.

Vehicle platforms and production volume

A platform is the set of component designs, manufacturing equipment, production processes and even supply-chain relationships that can be shared between different vehicles. Two of the main benefits of a platform are the opportunity for high-volume manufacturing of individual components and the ability to relatively quickly introduce new vehicle models and adapt to changing consumer demand. Typically, ICE platforms can be used for vehicles in two to three adjacent segments and they have a lifetime of about five to seven years. Initial BEV designs used modifications of such platforms.

Dedicated BEV platforms from incumbent manufacturers have only recently appeared and, in principle, can accommodate vehicles across more segments. As the development of a brand new platform may require more than 5 billion dollars, building vehicles from many segments on a single platform could provide scale benefits to manufacturers.

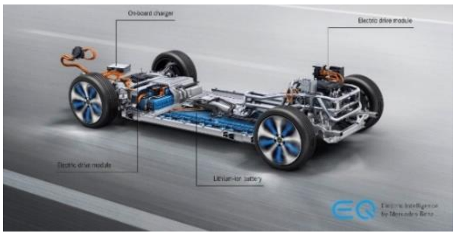
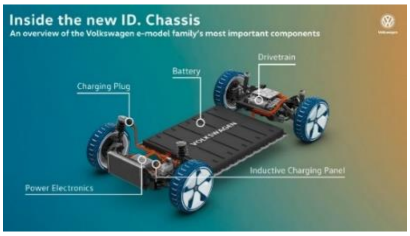
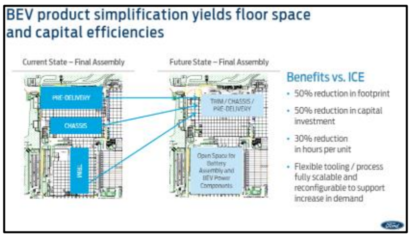
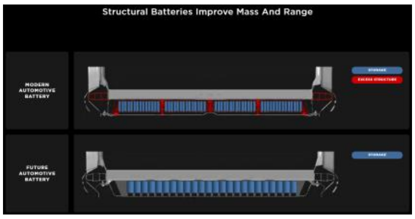
Some manufacturers are developing multi-energy platforms, which can support the development and production of vehicles with several powertrain technologies, including both

[1] There are indications that the development timescales of electric vehicles may be on the shorter end of that range, while the expected accommodation of more vehicle segments on a single platform may offer some flexibility to adapt to demand variations. However, the main thrust of the argument – that of high upfront investments and long timescales – remains.

combustion engines and batteries. These purpose-built platforms may not get the entirety of benefits of dedicated ones, but are a huge improvement over modified platforms.

The tradeoffs involved in a platform strategy are several, but the overarching consideration is the expectation of future demand. Those companies developing dedicated BEV platforms are more invested in an electric future, whereas those with multi-energy platforms value more the flexibility they offer in an uncertain future vehicle market.

Table 2: Battery electric vehicle development and manufacturing strategies

Approach	Examples
Current: BEV designed from the ground up, using modified ICE platforms (eg, Bolt, iPace, EQC, Ioniq, Peugeot 2008). This is our *baseline case*, representing the majority of BEV models in the market now and in the short term.	Daimler's EQ platform 
Dedicated platform: entirely new platform and manufacturing processes designed and developed for BEV (eg, ID.3, Model Y). Currently under development by Daimler, Hyundai, GM, Ford, and others. This is our *optimized case* and our expectation for the market norm around the mid-2020s.	VW's ID. platform  Ford's approach 
Next generation: tighter integration of the battery and the vehicles – eg, Tesla's most recent announcement. Still unproven.	Tesla's latest announcement on 'cell-to-chassis' design, whereby the battery pack becomes an integral, even structural, part of the vehicle. This has the potential to save costs on materials, but could potentially make repairs more expensive. The concept has not been yet tested in a production vehicle. 

Source: BloombergNEF

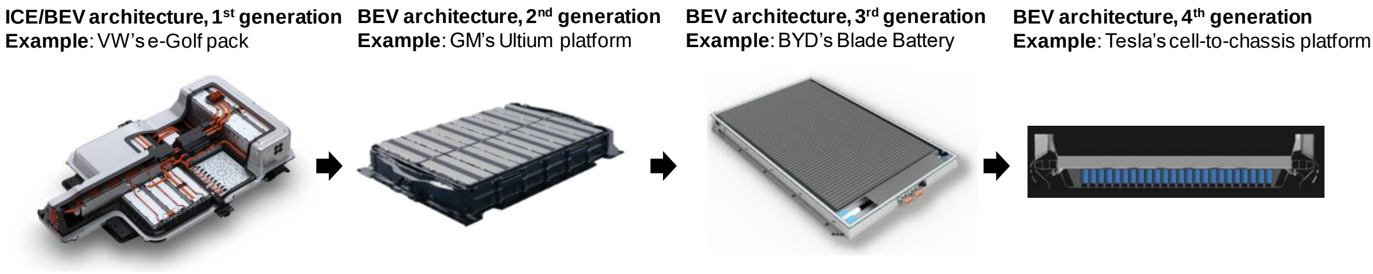
Battery pack improvements

Over the next decade, the introduction of more refined BEV pack architectures will continue to drive down prices (Figure 13). However, the rate of adoption of these new architectures will vary significantly across the industry.

Automotive companies like VW and GM are now adopting their second-generation pack designs. These are designed specifically for EVs, they can be adapted for multiple vehicles and are simpler to mass produce than first-generation packs. These designs are centered around standardized modules that can use a variety of different cell formats and chemistries.

In the long run the role of the cell will become more important in BEVs and the role of the pack will diminish. However, the timeline for this will vary by company and moving more slowly along this path does not necessarily mean that a company will be at a disadvantage. A more advanced architecture may be less reliable or harder to manufacture. There may also be limitations around the chemistry or cell format that can be used.

Figure 13: Evolution of battery pack design



Source: Volkswagen, General Motors, BYD, Tesla

Chinese automotive companies are already adopting third-generation pack designs. BYD's new Han EV uses the company's blade battery technology, which eliminates the need for modules and uses fewer cells. The company claims this approach reduces the pack price by as much as 30%. For the moment, this pack uses LFP batteries, which means that despite the lower cost the range of vehicles will still be lower than EVs using second-generation packs of an equivalent kWh size equipped with NMC (811) cells.

High-nickel chemistries are more likely to be used in these third-generation designs. BAIC already uses NMC (532) in CATL's cell-to-pack design, giving pack-level energy densities equal to a second-generation pack using NMC (811). Concerns around safety and cycle life (due to changes to the thermal management systems and BMS) explain automakers' reluctance to integrate higher-nickel chemistries immediately.

The fourth generation of pack design was highlighted at Tesla's so-called Battery Day event. The company announced it would eventually adopt a cell-to-chassis design, though the timeline for this is not clear. Tesla suggested that the design could be in use as early as 2023, but BloombergNEF believes 2025 is a more realistic timeline. This design would drastically alter the pack-level costs. If the pack housing is considered part of the vehicle, the pack costs may only include the cells, BMS, thermal management system and connections. Tesla claimed that this approach and the accompanying changes to the cell design could cut the pack price by 56%.

Reference vehicles in each segment

Current and future reference vehicles in each segment in this report are based on prevailing technical characteristics in the European market in 2020 and recent trends. We use the vehicle weight as the main parameter that determines the vehicle's physical size and segment, and the power-to-vehicle-weight ratio as that which affects its performance. We define equivalent ICEs and BEVs as those that have a similar 'starting' weight and the same power-to-vehicle-weight ratio. For BEVs, we also set the real-world electric range and keep that constant for all years between 2020 and 2035 (Table 3).

The starting weight of the BEV is that of an ICE in the same segment, excluding the latter's drivetrain – ie, consisting mostly of the weight of the body and chassis, without the engine, transmission, fuel tank and some other components. On top of that, we add the weight of the battery, electric motor, (potentially) e-axles and other components. We then estimate the energy required to propel that mass and calculate the necessary battery capacity. We iterate this process in order to take into account the improving battery energy density and electric motor power density.

When designing a new BEV, automakers make a choice on the level of lightweighting by considering the costs of introducing new materials to reduce weight versus those of adding additional battery capacity to counteract heavier vehicles. The rapidly declining battery prices tip the balance in favor of the latter approach. Some lightweighting will nevertheless continue to be applied, but is more likely to be restricted to components, such as body panels, that may not serve structural purposes and could be shared between several vehicles.

We find that battery electric vehicles can be between 20-40% heavier than equivalent ICEs now (Table 3). The weight penalty declines rapidly, as the battery energy density improves around 50% between 2020 and 2030. By that time, BEVs tend to be up to 10% heavier, depending on the segment. The weight reduction resulting from more energy dense batteries is the major contributor to the efficiency improvements of BEVs by about 30% to 2030 (for more on battery technology improvements, see section 3.3). By that time, battery packs can weigh about a third less for the same capacity. For the same BEV range, batteries could weigh about half as much or less depending on starting vehicle weight. In 2020, we estimate that the energy density of battery packs was about 170 Wh/kg, which we expect to increase to around 250 Wh/kg by 2030.

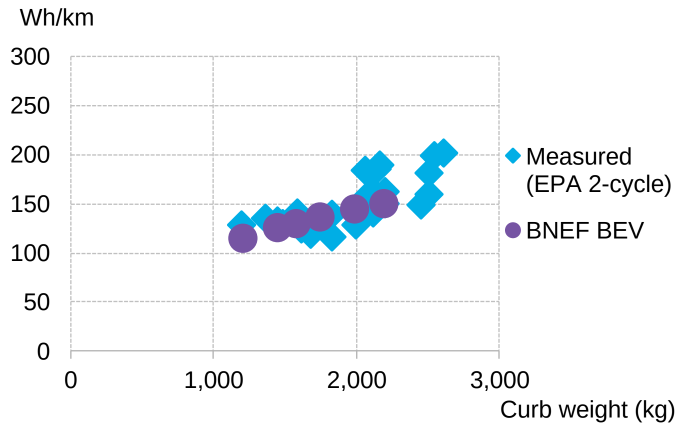
Table 3: Reference vehicle characteristics in 2020 and 2030

Segment	Type	Weight (kg)	Power (kW)	Electric real-world driving range (km)	Battery capacity in 2020 (kWh)	Efficiency (L/100km or Wh/km)	
						2020	2030
B	ICE	1,000	59	-	-	8.2	7.4
	BEV	1,200	70	300	57	171	121
C	ICE	1,200	84	-		9.9	8.4
	BEV	1,600	109	400	84	188	131
D	ICE	1,450	119	-	-	12.5	9.9
	BEV	2,000	164	500	113	203	142
SUV-B	ICE	1,250	67	-	-	9.2	8.1
	BEV	1,450	79	300	61	182	128
SUV-C	ICE	1,350	92	-	-	10.8	8.9
	BEV	1,750	118	400	87	195	135
SUV-D	ICE	1,650	128	-	-	14.0	10.6
	BEV	2,200	172	500	116	208	146
Light van	ICE	1,300	71	-	-	9.6	8.4
	BEV	1,500	84	300	62	185	131
Heavy van	ICE	1,900	100	-	-	15.1	12.7
	BEV	2,300	122	400	93	209	155

Source: BloombergNEF, MarkLines, EU Commission, ICCT, EPA. Note: the 2020 vehicle characteristics are the same for the baseline and optimized cases; figures are rounded. Efficiency is real world efficiency corresponding to the EPA cycle; BEV battery capacity declines 25-35% by 2030 under equal range.

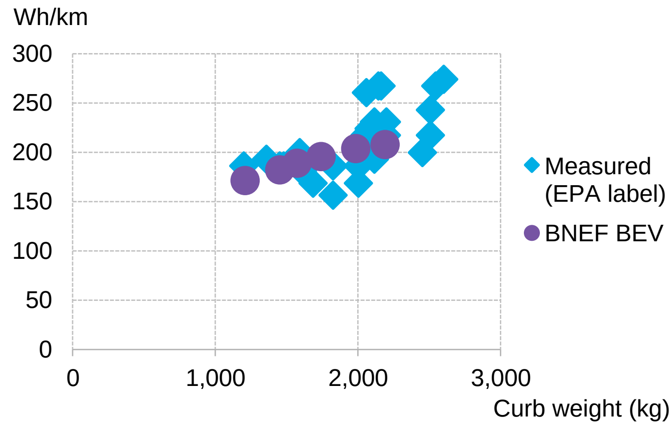
We compare the derived BEV efficiencies to those of the latest BEVs that have come into the market for both the testing cycle and real-world efficiencies (Figure 14 and Figure 15). Even though such comparisons depend on a number of factors, such as battery energy density, range, motor efficiencies, aerodynamics, and others, we find that our efficiency estimates fall within the range of real-world vehicles.

Figure 14: Cycle efficiency comparison between BEV available for sale and BNEF's reference vehicles



Source: EPA, BloombergNEF. Note: "measured" vehicles are those tested and certified for model year 2021 in the U.S.

Figure 15: Real-world efficiency comparison between BEV available for sale and BNEF's reference vehicles



Source: EPA, BloombergNEF. Note: "measured" vehicles are those tested and certified for model year 2021 in the U.S.

The driving range of electric vehicles

In this report, we assume that BEVs need between 300 and 500 km of real-world driving range. Such ranges are lower than the driving range of ICEs on a full tank. One of the main factors influencing the validity of this assumption is the expected deployment of public charging infrastructure. We explore that in the section on sensitivity.

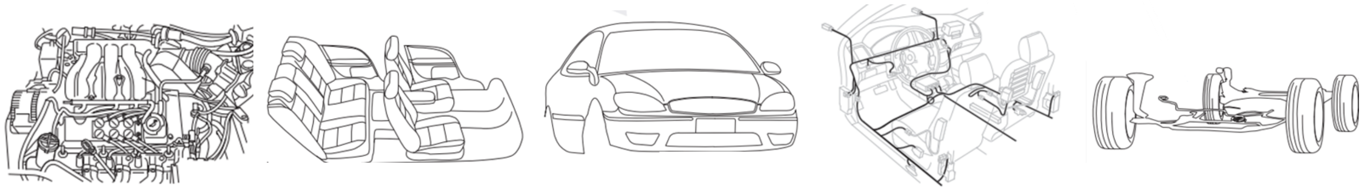
Between 2011 and 2019, the compound annual growth rate for the average range of BEV models launched globally was 13%, reaching just under 300 km (based on the EPA testing cycle; real-world driving range can be 20-30% less). New models in 2020 had an average range of 380 km, with some vehicles exceeding 600 km.

Despite that high growth, as well as promises of 1,000 km BEVs, we expect that range will not rise indefinitely. It is more likely that it will plateau later in the 2020s as charging networks improve. The market may eventually split, with lower-range smaller cars aimed at urban families with two vehicles, and larger, longer-range ones aimed more at single-car households.

Vehicle manufacturing cost breakdown

We estimate the costs of five vehicle systems (Figure 16) using a combination of methods, such as models for total costs, detailed manufacturing cost breakdowns, and individual component prices. With the addition of assembly costs, these comprise the total direct manufacturing cost of the vehicle (Figure 12).

Figure 16: Vehicle system costs by system and component



Most expensive car components

Drivetrain	Interior	Body	Electronics	Chassis
~ 33%	~ 19%	~ 18%	~ 13%	~ 13%
Engine ~ 20%	Seating ~ 8.5%	Body-in-white ~ 8.2%	HVAC ~ 2.9%	Suspension ~ 3.7%
Transmission ~ 8%	Dashboard ~ 5.7%	Paint ~ 2.9%	Interior ~ 2.5%	Steering system~3.2%
Fuel system ~ 2.3%	Trim ~ 2.5%	Body hardware ~ 2.0%	Drivetrain ~ 2.5%	Braking system~2.6%
Exhaust system~1.5%	Door modules ~ 1.9%	Closures ~ 1.5%	Chassis ~ 2.5%	Rims and tires ~2.0%
Cradle ~0.7%		Glazing ~ 1.6%	Exterior ~ 1.3%	Driveshaft/axle ~1.1%
Oil and grease ~0.5%		Exterior trim ~ 0.9%	Engine thermal ~ 1%	Differential ~ 0.8%
		Bumpers ~ 0.8%	Energy storage ~0.5%	
		Sealers ~ 0.2%	Emission control~0.3%	

Major cost High cost Some cost Minor cost

Source: BloombergNEF, ORNL, INL, ANL, McKinsey. Note: refers to C segment vehicle.

For internal combustion engines and transmissions (which can account for more than a quarter of the ICE direct manufacturing cost, Figure 16), and for electric motors we use cost models that mostly depend on the vehicle's power output. Such models naturally adapt to vehicle sizes, based on their different technical characteristics. For batteries, we use the same price for all segments and power outputs.

Beyond the drivetrain, the main differences between ICEs and BEVs are found on the chassis and electronics (Figure 17). Suspensions, steering and braking systems, and axles can be more complex and 5-15% more expensive for a BEV, especially one built on a non-dedicated platform. The additional weight of electric cars, as well as the potential integration of motors or other items on the axles, determine the cost of such components. However, the magnitude of some of those effects declines as electric vehicles become lighter.

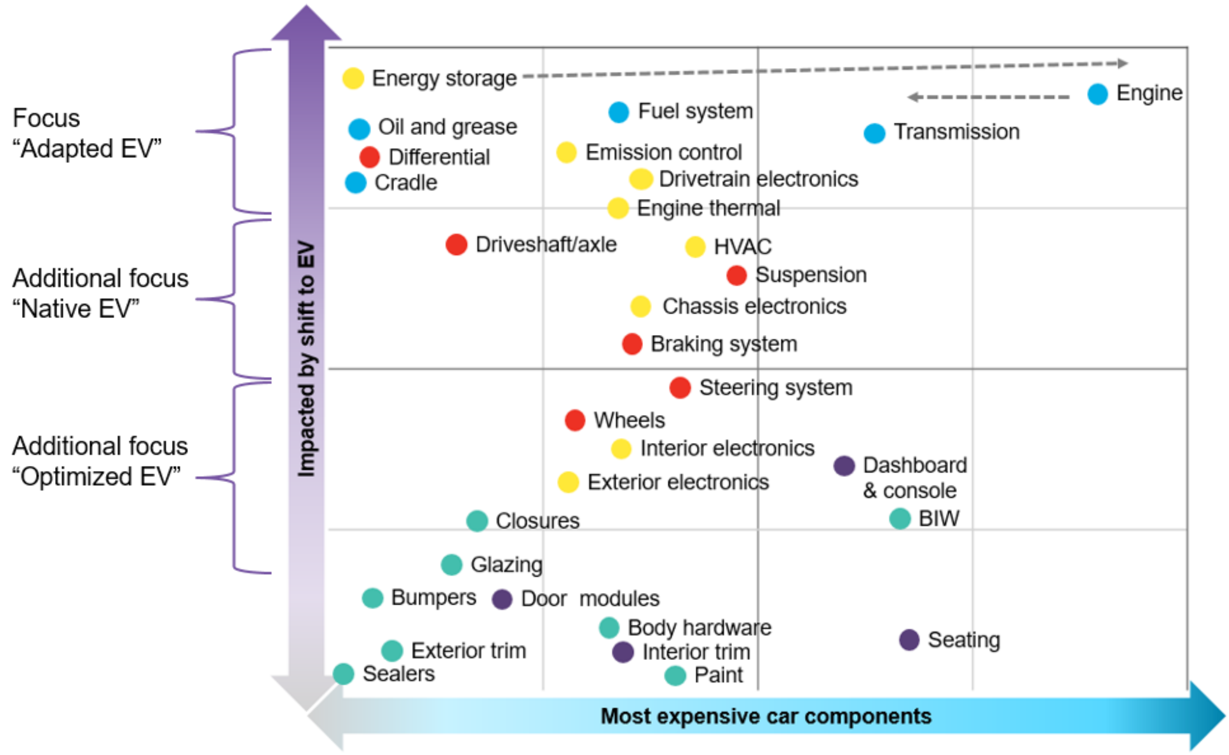
On the electronics side, the high electrical power of BEVs and the lack of the thermal output of the combustion engine affect the cost differential of control electronics, and heating and ventilation systems[2] (HVAC). The BEV-to-ICE cost difference can be between 50-100% for the whole electronics system, in particular with the currently low manufacturing volumes and still-emerging supply chain. However, scale effects could push lower the costs of many of those components by 2030, even though HVAC systems may still command a small premium.

[2] We take into account the additional battery capacity that may be required for heating and air-conditioning when estimating the total energy requirements of BEVs.

The manufacturing methods and cost structure of vehicle bodies are likely to remain similar between the ICEs and BEVs. We use the detailed direct manufacturing cost breakdown of the body of an average vehicle[3], which we then scale to other required sizes and materials choices. We adjust for some differences in complexity between the two powertrain technologies, such as the non-existent engine bay structure in BEVs, but these tend to have a low impact.

In the interiors, some components – such as seats – may be more complex for BEVs, but others, such as dashboards, may be simpler[4]. On balance, we expect that interior costs will be almost the same between ICEs and BEVs. We estimate those using individual component costs from a baseline vehicle, some of which may vary slightly between segments following differences in the vehicles' physical dimensions. We assume no change of those costs over time.

Figure 17: Focus areas for shift to EV



Source: BloombergNEF, expert interviews.

From manufacturing costs to the market prices of vehicles

The estimated direct manufacturing costs are between 50-70% of the total costs of developing, producing and selling a vehicle (Figure 18, corresponding to a medium size sedan). The additional costs comprise production and corporate overheads, such as R&D and management, selling, marketing and distribution costs, as well as the cost of managing and maintaining a dealer network. Lastly, a profit margin should be added to arrive at a vehicle's pre-tax retail price. For the

3 Into material, labor, directly attributable production overhead, maintenance and energy costs.

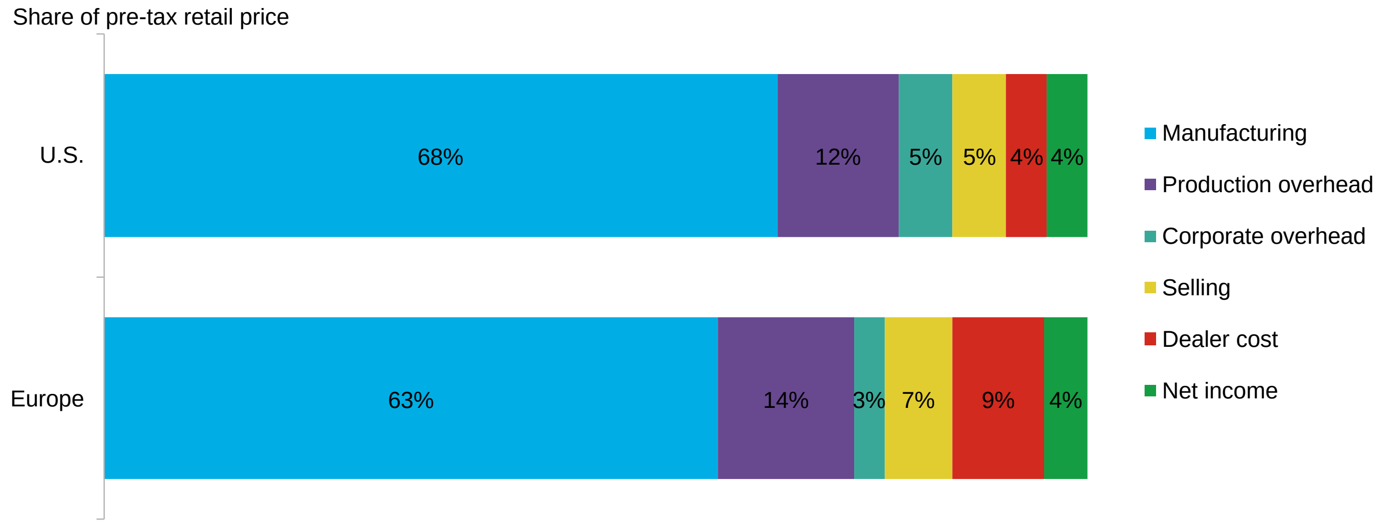
4 While there are no inherent reasons for that, some automakers have expressed the opinion that BEVs offer opportunities for simplification of some parts of the interior. That is due to the mere fact that BEVs can be marketed afresh and do away with components and design choices that are considered established in current vehicles.

analysis, we assume that the required profit margin for ICEs and BEVs is the same. We believe that this is a necessary condition for automakers, as they attempt to maintain the overall profitability of their businesses. Some manufacturers have stated that they expect to reach such 'profit parity' in the next few of years, whereas others may cross-subsidize their EVs using higher margins in ICE vehicles until battery prices fall further.

The allocation of these indirect costs to particular vehicle models is not straightforward and potentially is a strategic as well as an accounting choice for an automaker. For ICEs, we estimate these additional costs as a markup on the direct manufacturing costs; the markup factors range from 1.6 to 2.0, depending on vehicle segment. We estimate that based on different cost structures between automakers as evidenced in their annual accounts[5] and comparing with market prices.

Following the same approach for BEVs means that these costs are directly affected by battery manufacturing costs. However, we believe it is unlikely that many of those expenses, such as R&D or marketing, would either be as large now or drop as fast in the future as current and future battery costs may imply. So, we use the costs estimated for ICEs as a basis and we adjust them mostly for different expected production volumes. The resulting markup factors range from 1.6 to 2.1 for BEVs built on modified platforms, and between 1.5 and 2.0 for those built on dedicated platforms.

Figure 18: Vehicle retail price breakdown



Source: EPA, FEV, BloombergNEF Note: refers to a medium-size passenger car

3.3. Battery pricing and outlook

Prices today

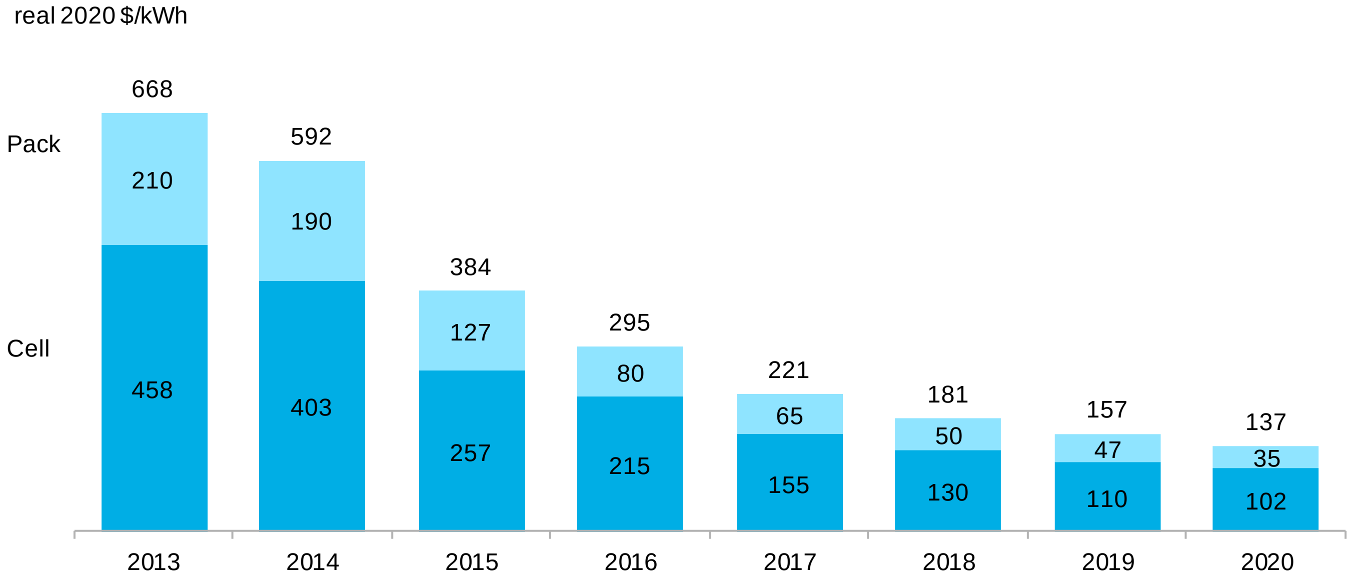
Falling prices for lithium-ion batteries are the biggest technology driver supporting the rapid rise in EV sales. BloombergNEF's 2020 volume-weighted average lithium-ion battery pack price was

[5] Using automakers' quarterly and annual accounts it may possible – in some cases – to also back-calculate aspects of the cost structure for groups of popular model lines. This is of course not entirely precise and we use it as a check of the direction and magnitude of differences in the markup factors.

$137/kWh, a fall of 13% in real terms since 2019. In EVs, the pack consists of cells, module housing, the battery management system (BMS), wiring, pack housing and thermal management system. Average lithium-ion battery pack prices are now down 89% from 2010.

Battery cell prices are already approaching $100/kWh. In 2020, the pack-to-cell split for across all battery segments was 74:26 (Figure 19). This marks a change from previous years when the split has been closer to 70:30. The split varies significantly between use cases. In e-buses and commercial EVs in China the split is closer to 85:15, whereas in plug-in hybrid electric vehicles (PHEVs) the split is closer to 45:55. The differences come from the variations in pack design and requirements.

Figure 19: Pack and cell split, all sectors



Source: BloombergNEF 2020 Lithium-ion Battery Price Survey

For the past decade, the battery pack has been the single most expensive part of an electric vehicle (EV). In 2016, the pack accounted for almost 50% of a medium-sized battery electric vehicle (BEV) in the U.S. It is now closer to 30% and will continue to fall. There is still a wide range of lithium-ion battery pack prices in the market. High-volume BEVs typically have lower average battery pack prices per kWh than plug-in hybrids or commercial vehicles.

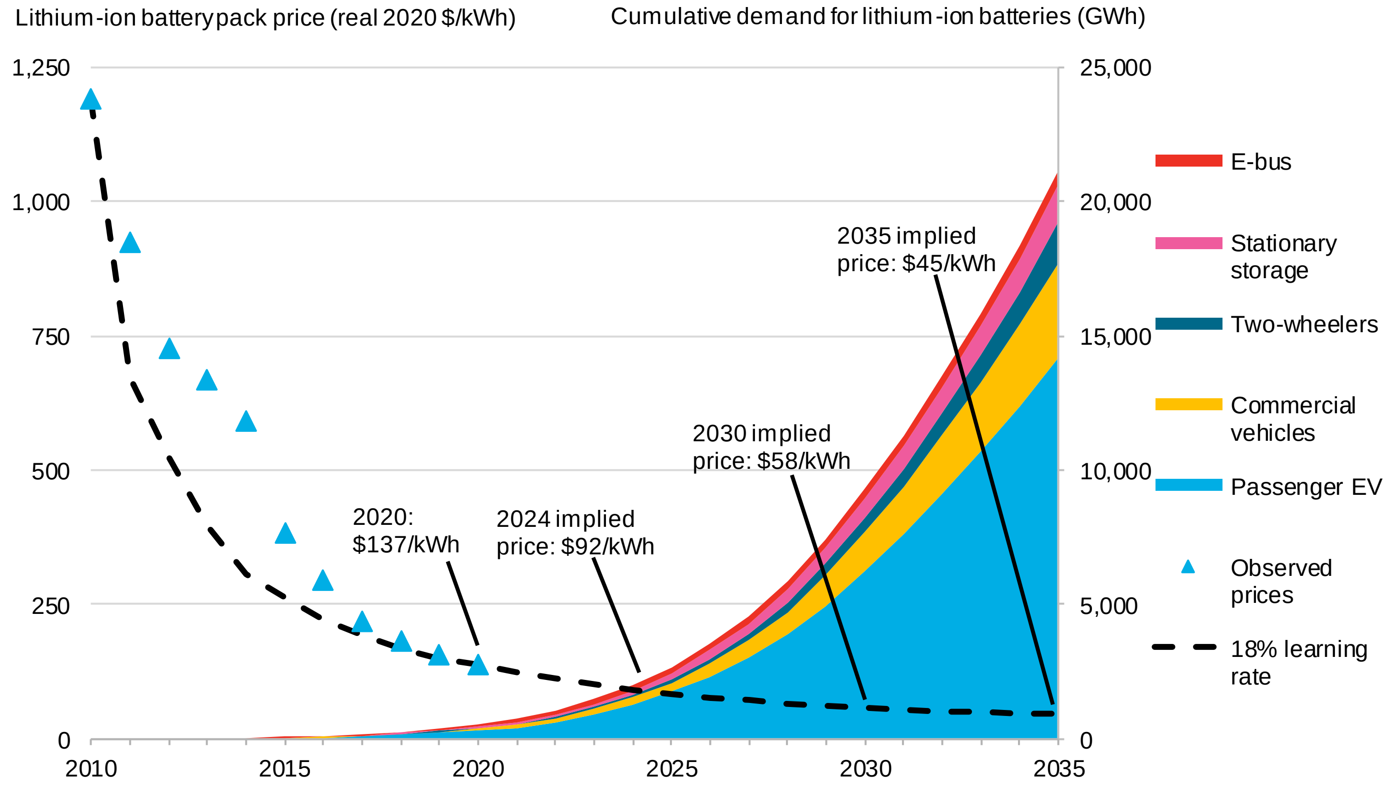
In 2020, the cheapest European batteries were competitive with some of the lowest prices globally, but prices in Europe were more widely spread. This means the average price for battery packs in Europe was higher than the global average, partially resulting from some lower volume orders. As sales expectations and manufacturing strategies differ between automakers, we expect such price differences to persist for a few more years. Our cost estimates take that difference into account, whereby modified BEVs incur higher battery costs compared to those built on dedicated platforms (for which we use the battery prices in Figure 20). We expect manufacturers to gradually adopt dedicated platforms, and our vehicle cost declines also reflect this switch to cheaper batteries by 2025.

Battery price outlook

Demand for lithium-ion batteries used in EVs and stationary storage has grown more than 264 times from 2010 to 2020. BloombergNEF has collected pricing and volume data for lithium-ion battery packs since 2010. Based on an 18% learning rate, BloombergNEF expects lithium-ion battery pack prices will fall below $100/kWh in 2024 and reach $58/kWh in 2030 (Figure 20).

By 2035, BloombergNEF projects that lithium-ion battery packs could achieve a volume-weighted average price of $45/kWh. For an EV with a 100kWh battery pack, the pack price would be $9,200 cheaper in 2035, a fall of 67% from 2020. It is not yet clear from a bottom-up perspective how the industry can achieve these prices. It may well require material substitution and will certainly require further technology advancements. It is equally hard to understand the full implications of this low pricing, which could unlock new demand sectors that are currently not addressable, and improve economics (and subsequent uptake) in sectors that have already started to electrify.

Figure 20: Lithium-ion battery pack price and demand outlook



Source: BloombergNEF 2020 Electric Vehicle Outlook and 2020 Lithium-ion Battery Price Survey.

Despite these implied low pack prices, the annual rate of price declines is slowing. This is consistent with the concept of a learning rate, which links the rate of price declines to the cumulative volume of battery packs deployed on the market. The observed 18% learning rate indicates that every time the cumulative volume of batteries deployed on the market doubles, pack prices fall by 18%. As the market expands, more time elapses between each doubling of cumulative battery capacity. In the five-year period between 2020 and 2025, cumulative volumes are expected to double twice (Figure 20). A decade later, in the five years between 2030 and 2035, volumes only double once.

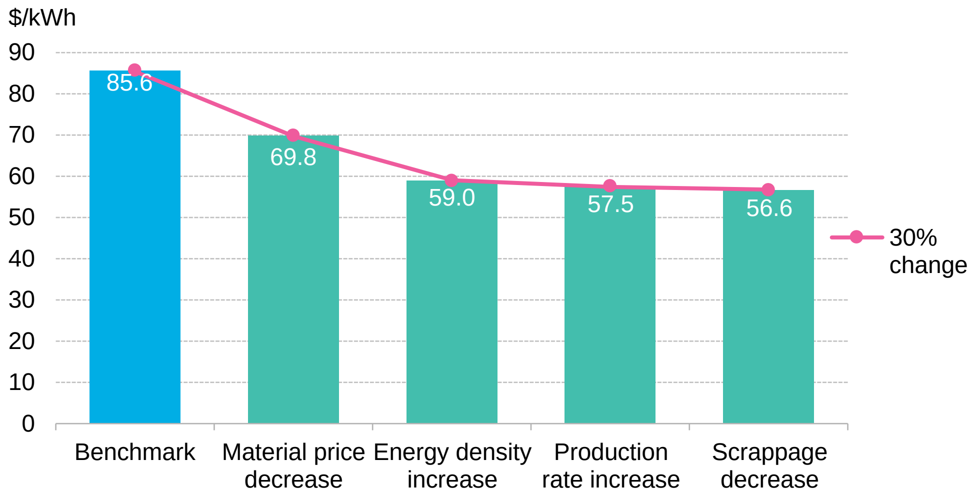
Price outlook: 2021-2025

The cost reductions that can be achieved over the next five years are already well understood. In the automotive industry, cells have already been procured, with prices set, for most vehicles being launched over this period. Outside of passenger EVs many companies still procure cells closer to when they are required.

The biggest uncertainty for most automakers will be the cost of raw materials (see the section on sensitivity below). Automakers may be forced to quickly pivot to different chemistries or suppliers if key raw materials like cobalt or nickel are in short supply. This would affect pack pricing as well.

Using BNEF's Bottom-Up Battery Cost Model, we outline one route cell manufacturers can take to reduce manufactured cell costs to the point that they enable pack prices of less than $100/kWh (a benchmark we expect by 2024). A 30% improvement in four key areas would reduce the manufactured cost of a cell by 33%, to $61/kWh (Figure 21). The four areas are: decrease in material costs, increase in energy density, increase in output and decrease in scrappage rate. The cost trajectory in Figure 21 is a scenario, whose individual steps are already technically feasible in isolation albeit harder to achieve simultaneously. Still, the resulting price should not be viewed as a floor below which battery costs cannot pass. Material prices can also fall by changing things like the chemistry composition, for example substituting cobalt for nickel or nickel for manganese.

Figure 21: Potential battery-cell cost reductions



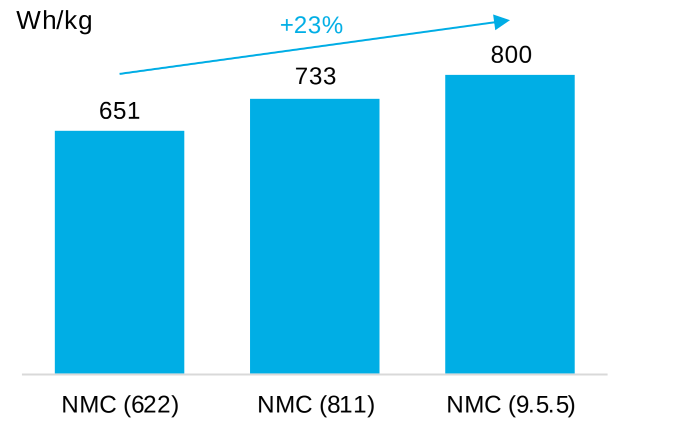
Source: BloombergNEF. Note: Using the manufacturing cost of NMC (622) prismatic cell in 2019 as benchmark. The material price decrease calculation only includes the prices of four major components - cathode active material, anode active material, electrolyte and separator. Energy density refers to cathode active material energy density, instead of battery energy density; the figure shows a scenario of possible cost reductions, assuming a 30% change for each of the four steps given as labels.

Additional costs such as SG&A (selling, general and administrative expense) and the manufacturer's margin would give a final cell price of around $70/kWh. Assuming the pack-to-cell price ratio of 74:26 in 2020 gives a final pack price of $94/kWh. This is in line with our expectation for average pack prices in 2024.

Cell chemistry improvements

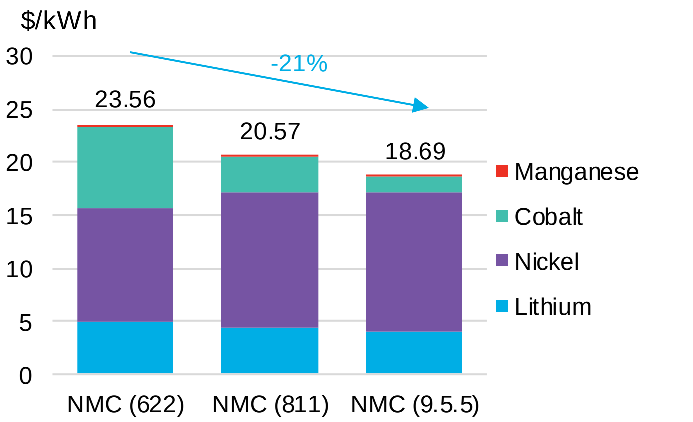
The adoption of new cathode materials alone can almost realize these savings. Moving from the commonly used NMC (622) cathode material to NMC (9.5.5), which SK Innovation will use in commercial cells from 2022, would result in a 23% increase in energy density and a 21% decrease in raw material costs (Figure 22 and Figure 23).

Figure 22: Energy density by chemistry



Source: BloombergNEF. Note: NMC (9.5.5)'s energy density is estimated.

Figure 23: Raw material costs by chemistry



Source: BloombergNEF. Note: Based on commodity prices as of November 30, 2020. Does not include processing costs or losses from production.

Cell manufacturing improvements

Improvements to production and scrap rates are likely to outstrip the 30% improvements shown in Figure 21. Over the past three years, average scrap rates have fallen from around 7.5% to 5%, a reduction of 33%, a trend that we expect will continue.

Production rates for cell lines are also increasing dramatically. The unit production rate of cylindrical lines increased 150% between 2010 and 2020. If improvements continue at this rate production speeds may be 75% higher by 2025. The output of cell lines in GWh can also increase through the adoption of new cell designs that pack in more kWh per cell. Cell formats have become increasingly standardized in recent years. This is increasingly important for large automakers, which may need to procure from different suppliers in different regions.

Battery manufacturing capex

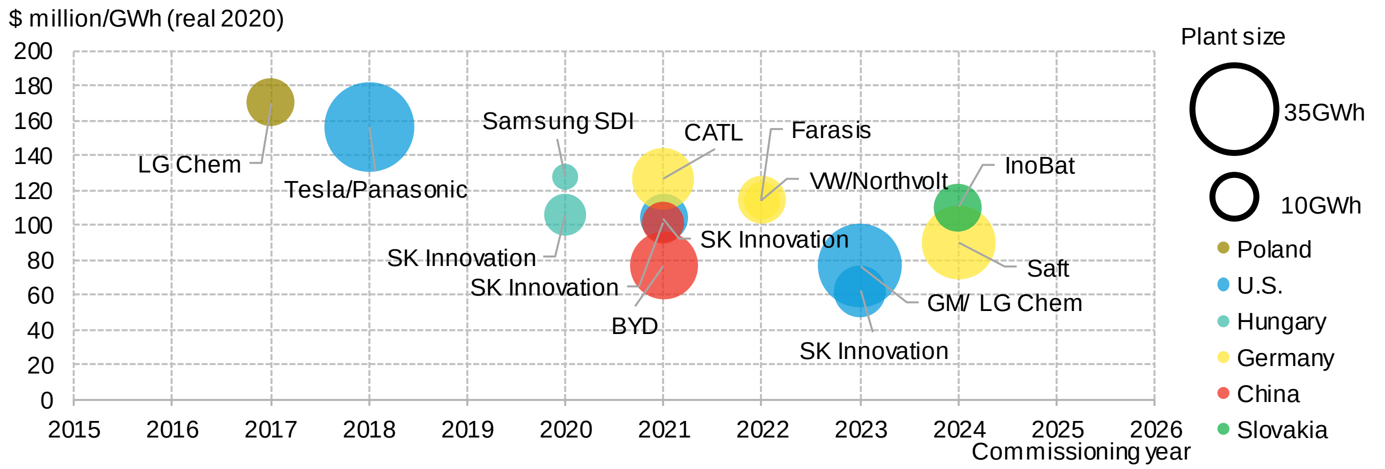
BloombergNEF's benchmark capex cost for a new-build battery manufacturing plant is around $110 million/GWh. Since 2017, capex costs have fallen 34% and are set to fall another 28% by 2023 (Figure 24).

Reducing capex is an important way to lower cell costs. Capex savings for new-build plants will come from a number of different areas:

- **Chemistry changes:** Plants can produce a set number of cells each year. Producing higher energy density cells increases the kWh contained in each cell, lowering the $/GWh capex.

- **Power versus energy:** PHEVs use cells that are geared toward power, while BEVs use energy cells. As the ratio of PHEVs to BEVs sold in the market shifts in favor of the latter, manufacturers will produce more energy cells. Energy cells have more kWh than power cells, which means this industry trend will increase the GWh produced at factories, thereby reducing the $/GWh capex.
- **Manufacturing equipment:** Companies continue to improve the factory efficiency and utilization. This results in capex and opex savings as well as higher output volumes. CATL and LG Chem both highlighted the role increased utilization played in increasing margins and reducing cell costs in their 1Q 2020 reports.
- **Subsidies:** These have played a key role in attracting battery manufacturing to certain regions.
- **Greenfield versus brownfield:** It can be cheaper to expand existing sites than open up new ones. This is because much of the infrastructure is already in place and the land already owned or leased. The scale of new manufacturing plants required by 2030 will limit how many brownfield sites can be expanded.
- **Location:** The location of a new plant impacts the capex required. Building a factory in Poland is less capital intensive than building in other parts of Europe (Figure 24). There are, of course, other considerations that should be taken into account, such as the grid emissions of the country and the availability of a skilled workforce.

Figure 24: Greenfield battery manufacturing capex



Source: BNEF, public reports. Note: it is not always clear if a facility will manufacture cells, or cells and packs.

Price Outlook 2025-2030

There are many possible pathways to realizing the price declines expected during the second half of this decade. This could be through the adoption of new system designs, such as solid-state cells, or improvements to existing liquid-based systems. There is tremendous overlap between these pathways. Improvements under development for liquid-based systems, such as dry electrode coating, could equally be adapted for solid-state cells.

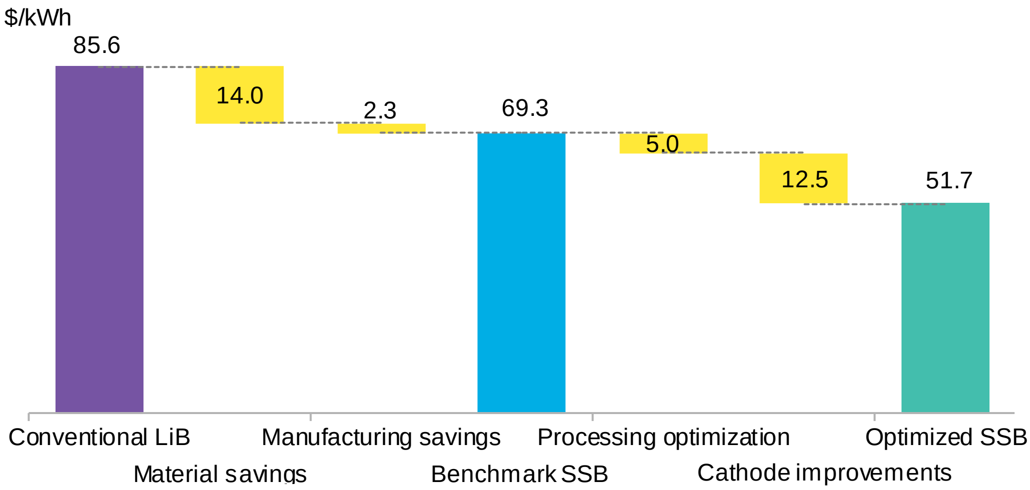
Solid-state

Solid-state cells could be manufactured for $52/kWh

Solid-state cells are likely to be more expensive than cells using liquid-based electrolytes when initially introduced. Nonetheless, their costs could fall quickly. Manufacturing costs could fall since the technology obviates the need for certain processes like formation or aging. The technology also enables the adoption of new cathode and anode materials that may not be compatible with the existing generation of liquid electrolytes.

BloombergNEF estimates that an optimized solid-state cell using next-generation cathode materials and 15µm thin lithium foil anode could be manufactured for a cost of $52/kWh (Figure 25). BloombergNEF currently expects that supply chains and technology could be sufficient to enable this by around 2030.

Figure 25: Solid-state battery (SSB) cell manufacturing cost reduction outlook, 2030



Source: BloombergNEF. Note: Conventional LiB is based on a 60Ah NMC (622) pouch cell. SSB refers to the solid-state battery with lithium metal anode. Material savings include reduced material costs for both active and inactive components as well as the increased cost for the electrolyte. Manufacturing savings include saved costs across labor, manufacturing as well as equipment and plant depreciations

This would still be around $5-10/kWh too high to realize our 2030 pack price of $58/kWh. Improvements to manufacturing, like cell line speed and dry electrode coating, could, however, further reduce the manufactured cost and make this target achievable.

Solid-state batteries are not the only route to further cost reductions. There are various innovative approaches that could help liquid electrolytes maintain their dominance of the lithium-ion battery market, including improved cell designs and new electrolytes.

Liquid electrolyte

Lithium-ion batteries have used liquid-based electrolytes for the past 30 years. Various innovative approaches could help this technology maintain its market dominance.

Improved cell design

Cylindrical cells are the cheapest to produce on a unit basis, but they have in the past faced limits on their maximum size. The larger they are, in diameter and height, the harder it is to control their internal thermal behavior, which hinders performance. This can give pouch and prismatic cells, that are produced at a slower unit rate but contain more kWh, an advantage over their cylindrical counterparts. At its 'Battery Day' event, Tesla unveiled a new tab-less cylindrical cell design, which enables it to overcome some of the size limitations of cylindrical cells. Using this approach, it expects that with the current generation of liquid electrolytes, it can further reduce cylindrical cell costs. BloombergNEF estimates that its manufactured cell cost would be close to $50/kWh. In contrast to Tesla, VW has chosen a prismatic cell format for use in 80% of its vehicles by 2030.

New electrolytes

Innolith, a startup headquartered in Switzerland, has developed a novel inorganic liquid electrolyte. Unlike the organic electrolytes used today, it can be used in combination with next generation high-energy density, high-voltage cathodes. These new materials promise to both increase energy density, which reduces manufacturing costs, and reduce material costs.

Cathode material production

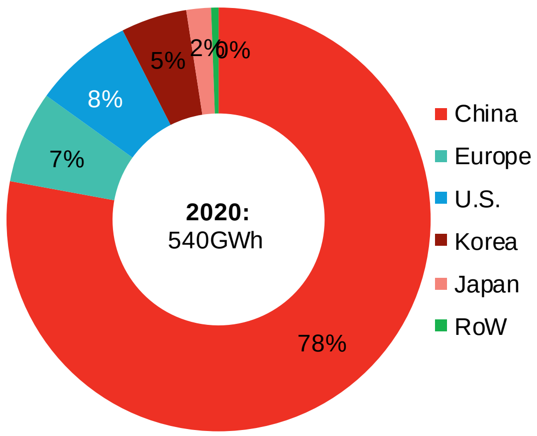
Cathode materials account for an increasing proportion of cell and pack costs. We expect the cathode will account for 43% of the pack price, an increase from 31% today, on a volume-weighted basis. Multiple companies are working on innovative approaches to reduce the cost of producing raw materials, precursors and cathodes.

Increased competition

Some 21% of commissioned manufacturing capacity will be in Europe by 2025

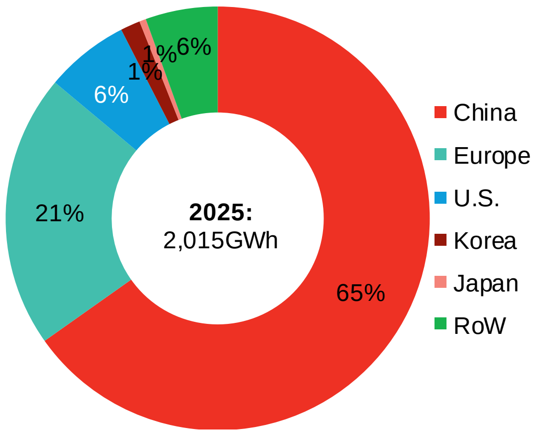
Various new cell manufacturers, such as Northvolt, Freyr and Automotive Cell Company (ACC), are all vying for a share of the growing market. These new manufacturers, alongside the expansion of existing companies, will help Europe grow its share of installed capacity from 7% to 21% (Figure 26 and Figure 27). As these new manufacturers start volume production, there could be increased pressure on companies' pricing strategies as they attempt to increase or maintain market share. Margins may well be sacrificed along the way.

Figure 26: Global manufacturing capacity, 2020



Source: BloombergNEF

Figure 27: Global manufacturing capacity, 2025



Source: BloombergNEF

Price Outlook: 2030-2035

How the industry achieves costs reductions beyond 2030 is unclear as we are only just beginning to quantify how manufacturing, materials, cell and pack designs will change over the next decade.

It is fair to say that continued improvements across all these areas will remain important in realizing these prices well into the next decade.

3.4. Vehicle cost results

Main outputs

The estimated pre-tax retail prices of battery electric vehicles are set to decline rapidly by 2030, as average battery prices fall by close to 60%. However, the vehicle price decline between 2020 and 2030 is steeper than this. BEVs in the early 2020s will mostly be built on non-dedicated platforms with relatively low production volumes. The switch to dedicated platforms by the mid-2020s implies that production volume-related BEV cost penalties are set to disappear (Figure 28 and Figure 29 show the price curves for all segments in Appendix A).

The cost difference between average BEVs and equivalent ICEs varies widely by segment. Light and heavy battery electric vans are for now about 50% more expensive, as they have modest performance requirements and medium ranges. In contrast, smaller battery vehicles in segments A and B can cost more than twice as much compared to ICEs. Powertrain costs in these segments tend to be low compared to total manufacturing costs at the moment, due to wide use of smaller and cheaper gasoline engines. Even low-capacity batteries – around 55 kWh for B-segment BEVs – may cost more than three times the total ICE drivetrain today.

Figure 28: Estimated pre-tax retail prices for C segment vehicles

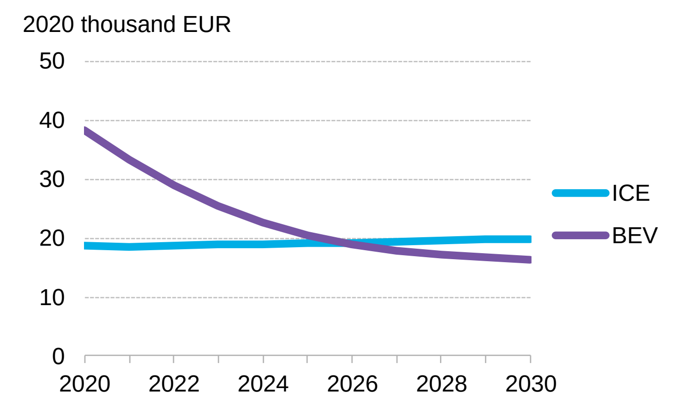
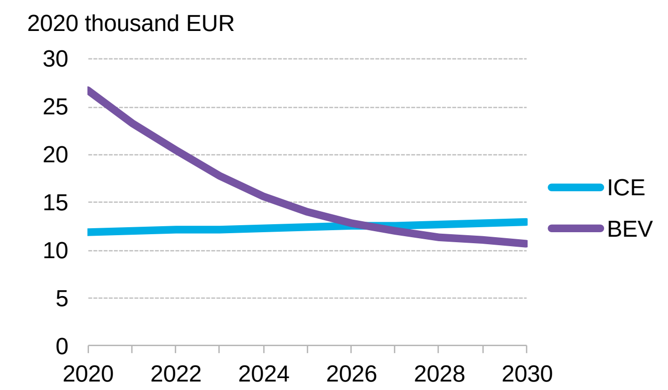


Figure 29: Estimated pre-tax retail prices for B segment vehicles



Source: BloombergNEF Note: ICE is internal combustion engine vehicle and BEV is battery electric vehicle

Figure 30: Estimated pre-tax retail prices for SUV-C segment vehicles

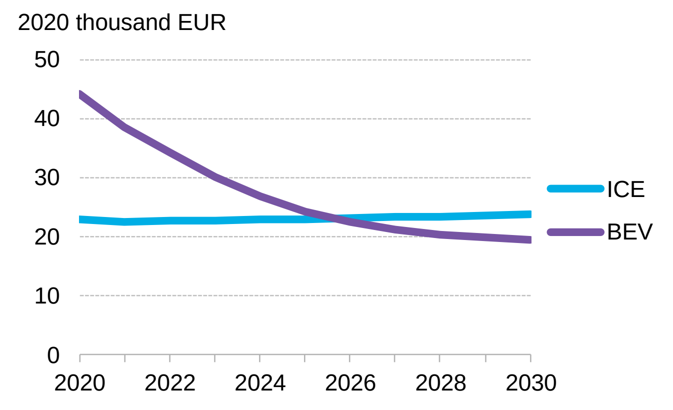
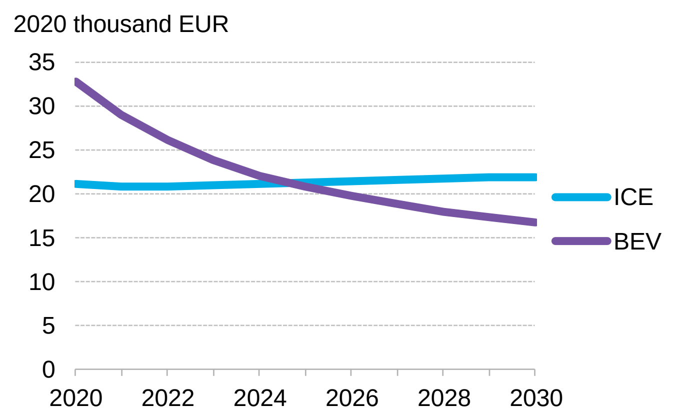


Figure 31: Estimated pre-tax retail prices for light vans



Source: BloombergNEF Note: ICE is internal combustion engine vehicle and BEV is battery electric vehicle

The BEV-to-ICE price difference gets increasingly small over the next five-to-six years in all segments. Battery electric vehicles reach the same price as equivalent ICEs within a tight window between 2025 and 2027 (Table 4). Vans reach price parity the earliest, B segment vehicles are the latest, while larger sedans and SUVs are in between. This ranking of price-parity years depends mostly on the vehicles' technical characteristics – primarily, their assumed range – and not directly on their average purchase price.

Table 4: Years at which BEVs reach upfront cost price parity with equivalent ICEs

Segment	Year	Segment	Year	Segment	Year
B	2027	SUV-B	2026	Light vans	2025
C	2026	SUV-C	2026	Heavy vans	2026
D	2026	SUV-D	2026		

Source: BloombergNEF. Note: we define price parity as the year at which a BEV becomes cheaper than the equivalent ICE.

Vehicle cost structure

In this section we show in more detail the direct manufacturing costs of ICEs and BEVs (Figure 32 and Figure 33).

Some modest cost declines for the body and chassis of ICE vehicles are quickly outweighed by the rising expense of improving the combustion engine. The 2025 and 2030 tailpipe CO_2 emissions regulations and the Euro 7 emissions standards – which are being planned and set to come into effect by 2025 – pose serious challenges for the cost-effective development of new combustion drivetrains. The need for elaborate injection equipment and turbochargers, as well as more complex exhaust systems mean that within the 2020s combustion engine costs will rise between 1% and 2.5% annually. Cost increases will be higher for smaller segments, as gasoline engines are also closing the efficiency gap with diesel powertrains.

The direct manufacturing costs of BEVs drop by at least 50% by 2030, depending on the segment, and more than three-quarters of that is due to the battery. Additional cost declines are a result of more power-dense electric motors and cheaper electronics.

Figure 32: Direct manufacturing costs for ICEs and BEVs, C segment vehicle

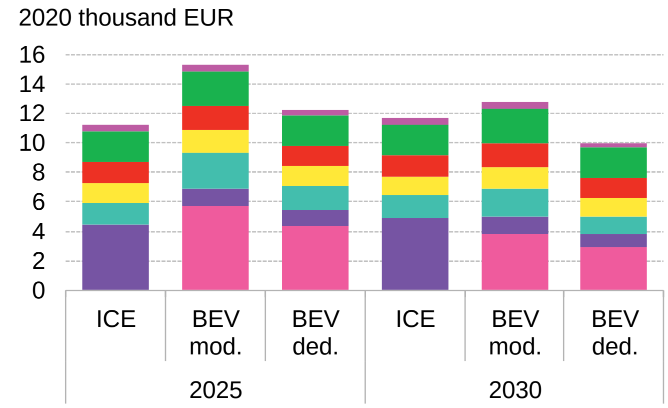
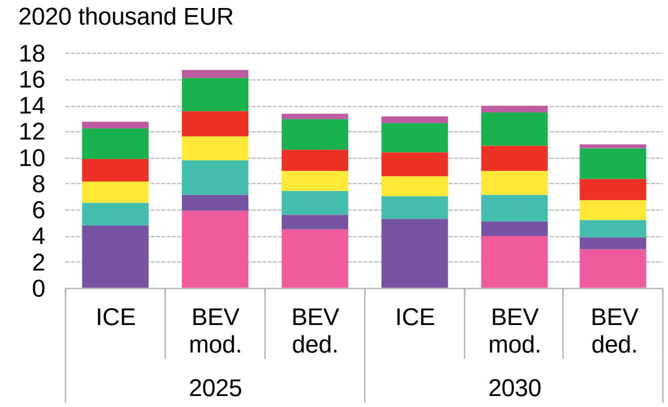


Figure 33: Direct manufacturing costs for ICEs and BEVs, SUV-C segment vehicle



Battery, Drivetrain, Electronics, Chassis, Body, Interior, Assembly

Source: BloombergNEF. Note: "BEV mod." refers to the conservative pricing scenario using a modified platform and "BEV ded." to a BEV built on a dedicated platform; the drivetrain of the ICE includes the engine, transmission, etc, whereas for the BEV it includes the electric motor, its transmission and electronics; ICE is internal combustion engine vehicle and BEV is battery electric vehicle

Sensitivity analysis

The pre-tax retail prices for battery electric vehicles derived above depend on four main parameters: platform choice, battery price, driving range and vehicle efficiency. Changing these inputs (as in Table 5) provides an estimate of vehicle-price sensitivity within a wide range of the assumptions that underlie vehicle prices.

Changes in the input parameters are not mutually exclusive, though not every combination is equally likely. For example, in a lower-than-expected battery price environment, automakers may well choose to increase, rather than decrease, the driving range of their vehicles. There are several reasons for potential variations in input assumptions including consumer behavior, local and national policies, as well as companies' and countries' industrial strategies.

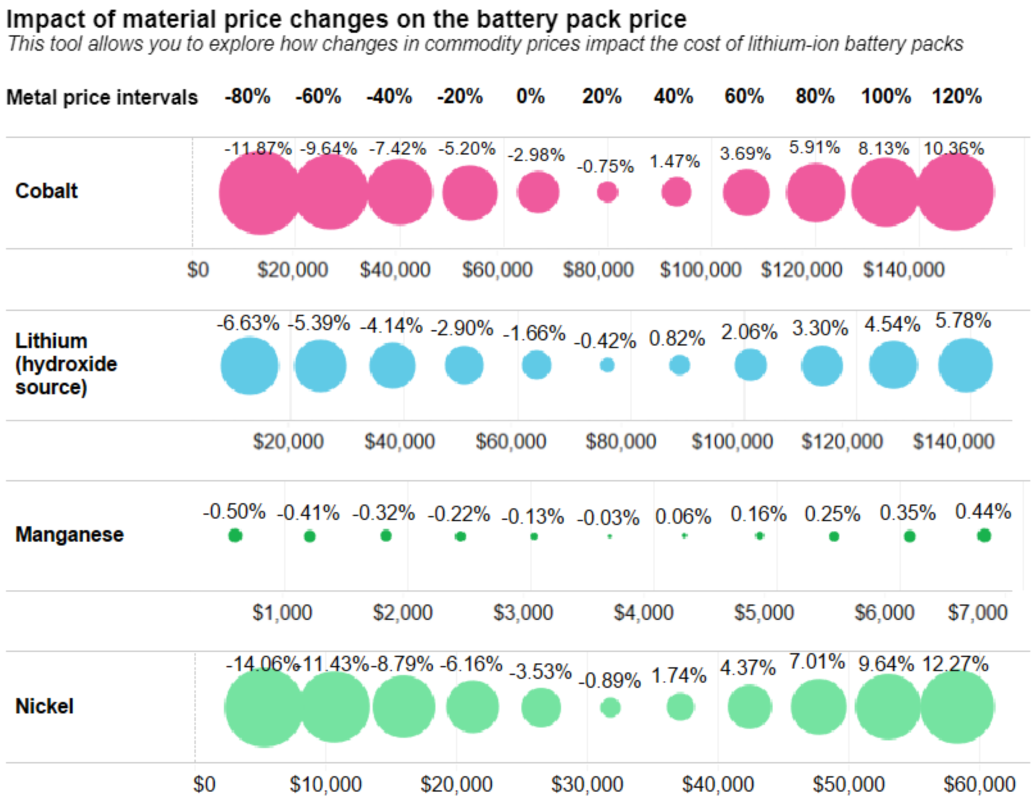
Table 5: Battery electric vehicle price sensitivity parameters

Parameter	Low value	High value
Platform	Dedicated	Modified
Battery price	-15% in 2030 vs BNEF central battery price forecast	+75% in 2030 vs BNEF central battery price forecast
Driving range	-50% vs central scenario	+50% vs central scenario
Vehicle efficiency	+12% vs central scenario	-12% vs central scenario

Source: BloombergNEF. Note: the "low" and "high" values for the platform are qualitative, rather than quantitative, labels; the driving range and efficiency depend on vehicle segment (Table 3).

For batteries, in particular, volatile input material costs pose a considerable uncertainty for their price outlook. In the last few years, the direction of raw material prices was supportive to battery cost declines. However, prices for some of those materials have been edging upward recently, while they have experienced sizeable price swings in the past. Nickel and cobalt prices have the largest effect on the cost of an NMC (622) pack. A doubling of prices of these (from around $26,000/metric ton and $65,000/metric ton, respectively, in February 2021) would increase battery costs by about 9.5% and 8.1%. If material prices reduce by 40%, then the battery pack cost would also drop by 8.8% and 7.4%. The change in the final price of a battery pack is a lot lower than that of input material costs. Even if cobalt, lithium and nickel prices double (compared to Feb 2021 prices), then battery pack prices would only increase by less than 25%. The high end of our battery prices in the sensitivity analysis here is likely to result not from higher material prices alone, but also from a combination of several factors, such as low production volumes, slow technology improvements and other factors.

Figure 34: Impact of material price changes on pack price of a NMC (622) battery



Source: BloombergNEF. Note: Bubble size represents the change in the price of a battery pack corresponding to the change in the price of one of the materials in the cathode; input material prices are from February 2021

With the changes in Table 5, the pre-tax retail prices of BEVs can range from 16% lower to about a third higher compared to our central scenario. The choice of platform strategy – which encompasses the combined effects of production volume, efficient vehicle design and optimized cost structure – is crucial, as by 2030 BEVs built on dedicated platforms may cost about a quarter less to produce versus those that may still use modified ones (Figure 35).

On the individual parameters, the choice of driving range can materially change a BEV's affordability. A 50% change in the driving range of a BEV in the C segment, results in about 25%

difference in the price of the car in 2025 compared to the central case[6]. The effect of the battery price change alone is lower, at around 17% by 2025. Finally, good old engineering design should not be underestimated. Increasing a BEV's efficiency by about 10% can result in a similar magnitude improvement in costs versus the central case, as a result of fewer losses and lower vehicle weight, hence smaller battery and electric motor requirements.

The price parity years could shift by up to two years as a result of the changes in Figure 35 and range between 2025 and 2028 for the C segment vehicle, compared to 2026 for the central scenario. The biggest effect is from the battery cost, either through the $/kWh pack price or the vehicle's driving range. In the unfavorable cases of Table 5, price parity is delayed by two years, whereas it can come one year earlier with low battery prices or shorter driving ranges. Due to the performance and price advantages, we expect manufacturers not to stay behind on dedicated platform development by the latter half of the 2020s, outside some niche applications. We acknowledge that the share of the market that could make use of dedicated platforms by 2025 could be lower than three quarters. In a less optimistic scenario where the market delays, and only about half of vehicles are built on dedicated platforms, this would move the average parity year from 2026 to 2027. Automakers who move earlier could have an advantage over those who chose to stay on older platforms.

Figure 35: BEV price sensitivity for a C segment vehicle

Source: BloombergNEF Note: the scenario inputs are in Table 5 and more details on the central scenario in Section 3.2

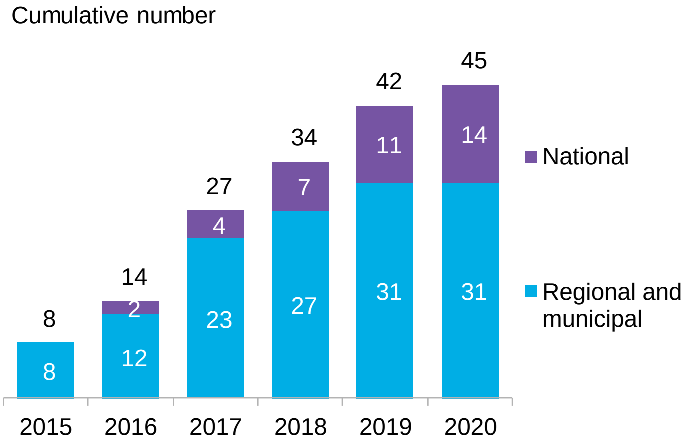
[6] For C segment vehicles, the central case is 400 km of real-world driving range, so this change results in BEVs with either 200 or 600 km of range.

Section 4. Phasing Out Internal Combustion Vehicle Sales in the European Union

4.1. Background and context

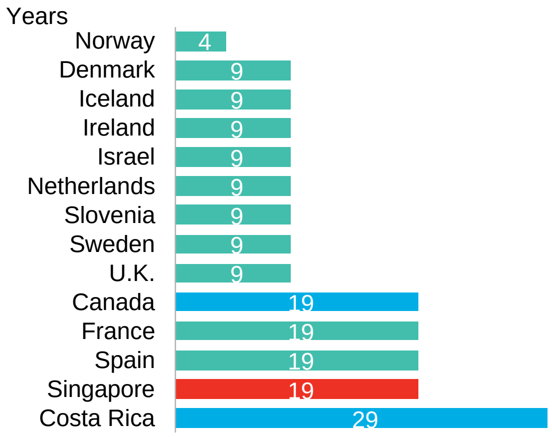
The number of countries planning to phase out sales of internal combustion engine vehicles (ICE) continues to increase. Fourteen countries have now expressed long-term policy goals of phasing out sales of ICE vehicles. Together, the national targets represented 11% of global new passenger car sales in 2019. Additionally, 31 regional and municipal governments around the world announced their intentions to phase out ICE vehicle sales (Figure 36).

Figure 36: Number of national, regional and municipal governments announcing plans to phase out sales of combustion vehicles



Source: BloombergNEF

Figure 37: Years remaining until ICE sales phase-out targets in select countries



Source: BloombergNEF. Note: U.K. target includes PHEV sales until 2035.

European countries represent ten out of the fourteen national ICE phase-out ambition announcements globally, and are among the countries with the most aggressive targeted dates (Figure 37). However, such targets globally remain vague on many aspects – around the inclusion of hybrid and plug-in hybrid vehicles and potential penalties for missing the target. There are also questions on the enforceability of national phase-outs within EU member states. Due to these uncertainties, the targets are not assumed to be hit in this outlook and are not included in our short-term and long-term EV-adoption forecast discussed below.

With only nine years left for reaching many of the targets (four in the case of Norway and 19 for France and Spain), most of the European countries with ICE phase-out plans are still some way from reaching them. At the end of 2020, Norway was on broadly on track for its 2025 target, while Iceland was half way toward the target set for 2030, with EV adoption in Sweden, the Netherlands and Denmark at 32%, 25% and 16%, respectively. The progress toward ICE phase-out targets in larger European car markets, like France or the U.K., is further behind, with the EV share of passenger car sales just exceeding 10% at the end of 2020 in both countries (Figure 38 and Figure 39).

Figure 38: 2020 Europe passenger BEV and PHEV sales, by country

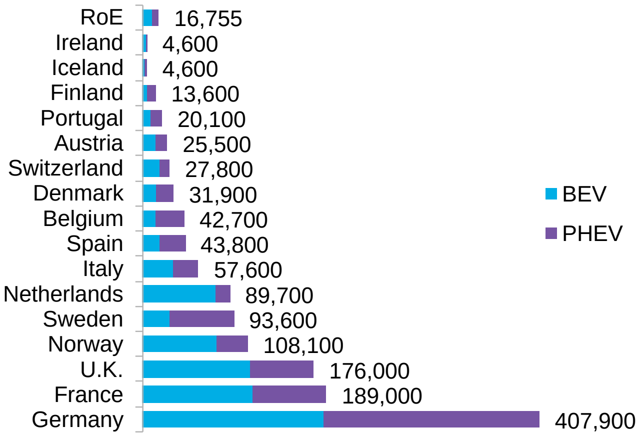
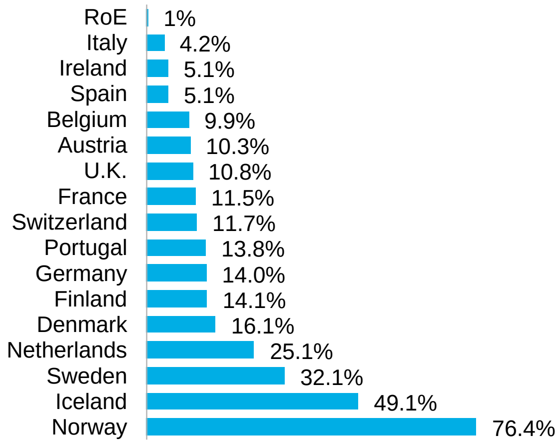


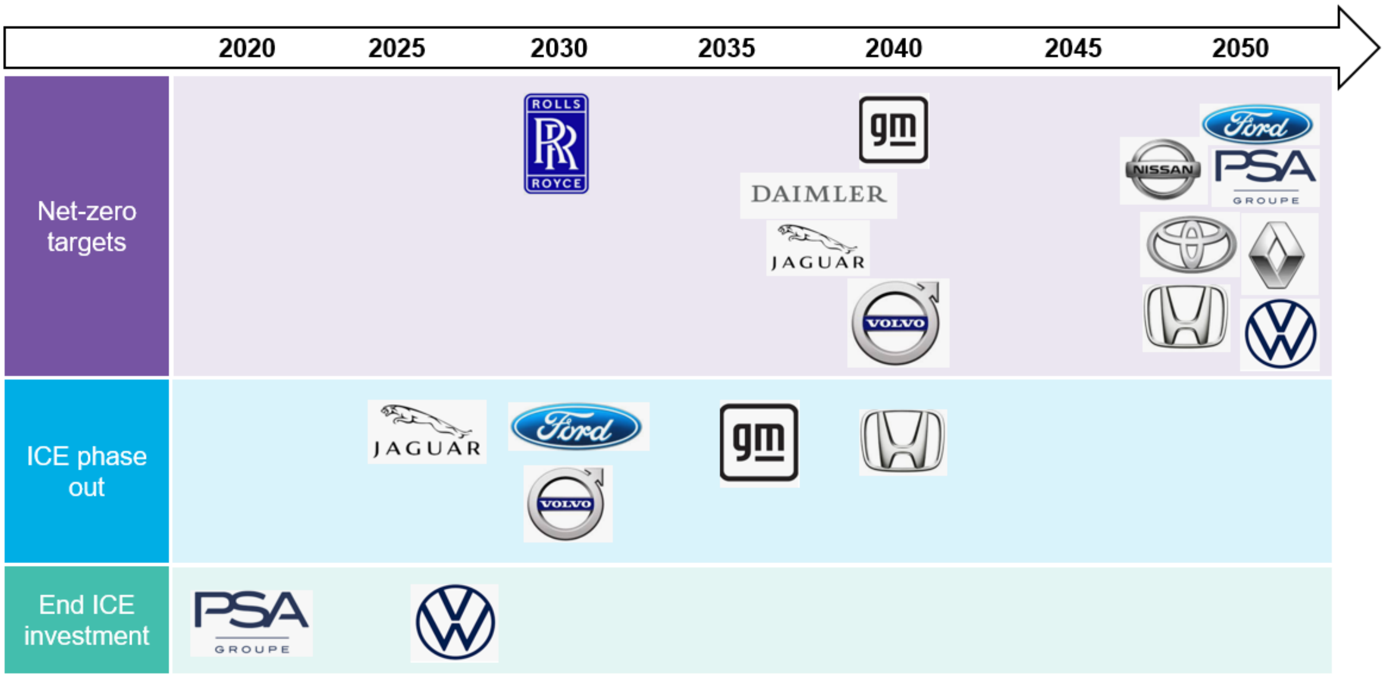
Figure 39: 2020 Europe EV share of total passenger vehicle sales



Source: BloombergNEF, Marklines, Bloomberg Intelligence, vehicle registration agencies, EV Sales Blog, EAFO. Note: Europe data includes EU27 countries plus Norway, Switzerland, Iceland and the U.K. EV sales include BEV and PHEV sales.

While France's target is still 19 years away, the U.K. will have considerably less time to scale up to 100% adoption by 2030 – which also indicates that EV sales in the country will have to grow very rapidly in the next five to six years in order to get there. Such targets in the larger auto markets can also be challenging from the supply-side perspective. However, some of the major global automakers are also increasing their ambitions in this area (Figure 40). In 1Q 2021 alone, four automakers announced new plans to phase out sales of combustion vehicles.

Figure 40: Automakers' drivetrain development targets

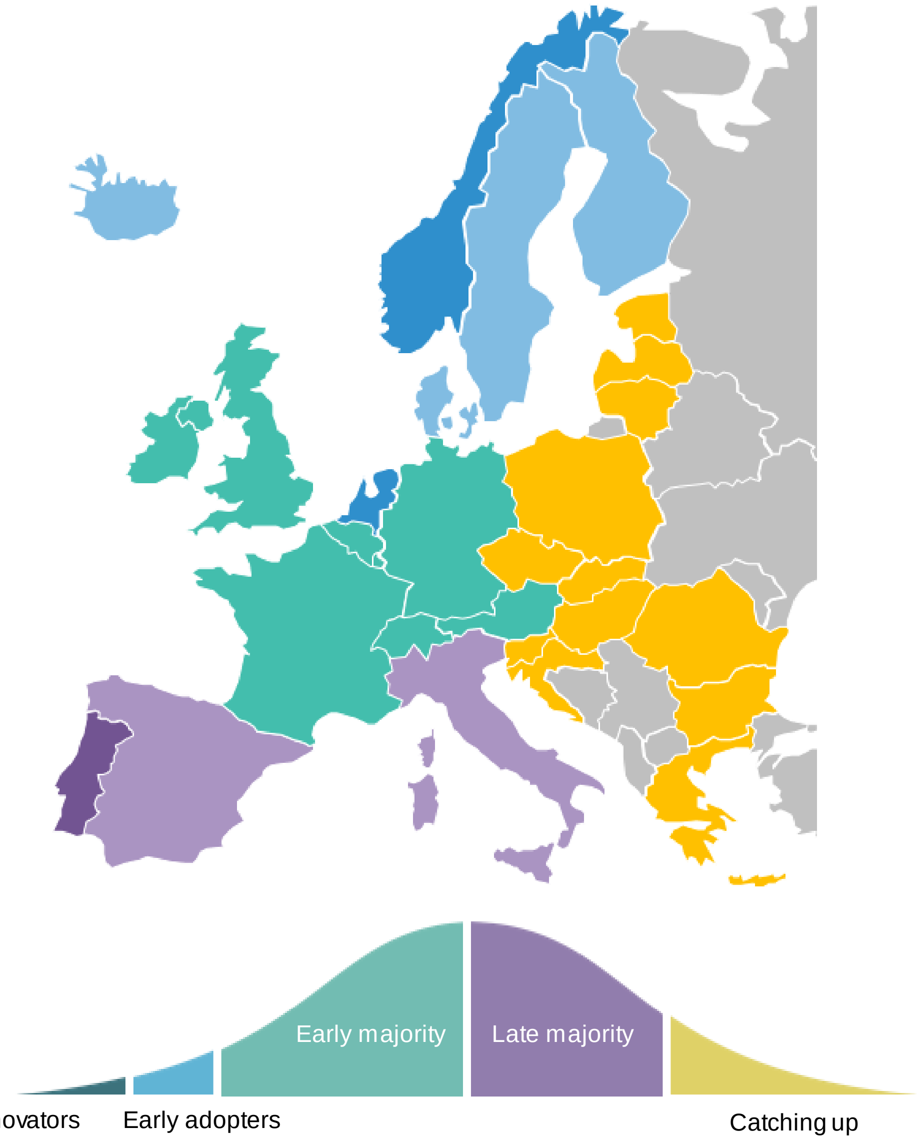


Source: BloombergNEF. Note: Ford ICE phase-out target is for Europe only.

Country groupings

To compare EV adoption trajectories across Europe, we grouped the countries in the EU, plus the UK and EFTA countries into four distinct regions: the initial innovators and early adopters, the early majority, the late majority and those catching up on EV adoption (Figure 41). The main metric for consideration is the current BEV share of vehicle sales. A number of additional metrics include total sales, fleet size, population size and GDP per capita, as well as supporting policies, phase-out targets and charging-infrastructure development.

Figure 41: Distribution of adoption groups and country grouping



Source: BloombergNEF. Note: Several countries might be slightly ahead of the region within which they are grouped. Notable are Norway, the Netherlands and Portugal, which are colored darker for this reason.

Our country groupings are as follows:

Nordics+ includes Scandinavian countries like Norway (BEV and PHEV share of 76% of sales in 2020) and Sweden (32% share), which are leading with strong support mechanisms and high adoption shares. The Netherlands (25% share) can be counted as one of these pioneering countries in terms of EV adoption, policy measures and charging infrastructure development in Europe and hence is grouped together with the Nordics. Despite boasting an average EV sales share of 17% BEV and 12% PHEV in 2020, these are relatively small markets and only accounted for 8% of all vehicle sales in Europe in 2019.

The major **Western European** markets of France and the U.K., where BEVs and PHEVs had an 11% share in 2020, and particularly Germany (14% share in 2020) show rising EV adoption, strong policy support, and large-scale infrastructure roll-out. Smaller surrounding countries like Austria, Switzerland and Belgium are on similar trajectories. Car sales in the region account for 61% of all units sold in Europe. The average BEV sales here jumped from 1.7% in 2019 to 5.7% in 2020**.**

Southern European countries have been slightly more limited in their support for EVs, but Italy has shown a rapid increase in EV sales in 2020 (from 0.7 to 4%) and regional infrastructure build-out is under way. Spain is catching up to its neighbors (5% EV sales in 2020), whereas Portugal has higher EV sales (12% BEV and PHEV share in 2020). The Southern European countries represent 21% of all vehicle sales in Europe, yet less than 8% of EV sales in 2020.

Electric vehicle adoption is just getting started in most **Eastern European** countries. EVs are picking up and have surpassed 1% of sales in many countries in this group in 2020 for the first time. Poland is the major market in this region, responsible for half of overall sales. Most of these markets are characterized by relatively low sales of new vehicles (10% of all new vehicles sold in Europe) in comparison to the share of the overall European fleet of vehicles on the road (21%) and share of the population (22%). This is due to a large second-hand market through imports from other parts of Europe. The motorization rates are similar to most other regions in Europe, but the average vehicle age is higher. Greece has been categorized in this group as well, mainly due to low turnover in recent years. Several of these countries, including Estonia and Slovenia, show slightly higher EV sales.

Table 6: Overview of country comparison metrics by region

	Nordics+	Western	Southern	Eastern
EV share of total sales 2020	17.3% BEV, 12.3% PHEV	5.7% BEV, 5.1% PHEV	2.2% BEV, 2.5% PHEV	1.4% BEV, 1.1% PHEV
EV share of total sales 2019	10.4% BEV, 3.7% PHEV	1.7% BEV, 1.1% PHEV	0.7% BEV, 0.5% PHEV	0.5% BEV, 0.3% PHEV
Total sales	1.4M (8%)	10.5M (61%)	3.6M (21%)	1.7M (10%)
Fleet size	22M (8%)	133M (47%)	70M (25%)	59M (21%)
Population	45M (8%)	251M (48%)	118M (22%)	115M (22%)
GDP/Capita	46k EUR/year	38k EUR/year	26k EUR/year	14k EUR/year
EV policy	Multi-layered support, phase-out targets	Strong support, some phase-out targets	Moderate support, some phase-out targets	Largely limited support, some phase-out targets
Charging infrastructure	Large-scale roll-out underway	Large-scale roll-out underway	Low-density network	Low-density network

Source: BloombergNEF, Bloomberg Economics, Marklines, OECD, IMF, World Bank. Note: Except for 2020 EV sales, other values based on 2019 values to exclude effect of Covid-19.

The BEV adoption outlook in the following sections is done in two parts: a bottom-up short term forecast covering 2021-2025, and a top-down, techno-economic consumer-adoption approach from 2026-2035, for each of the four country groups.

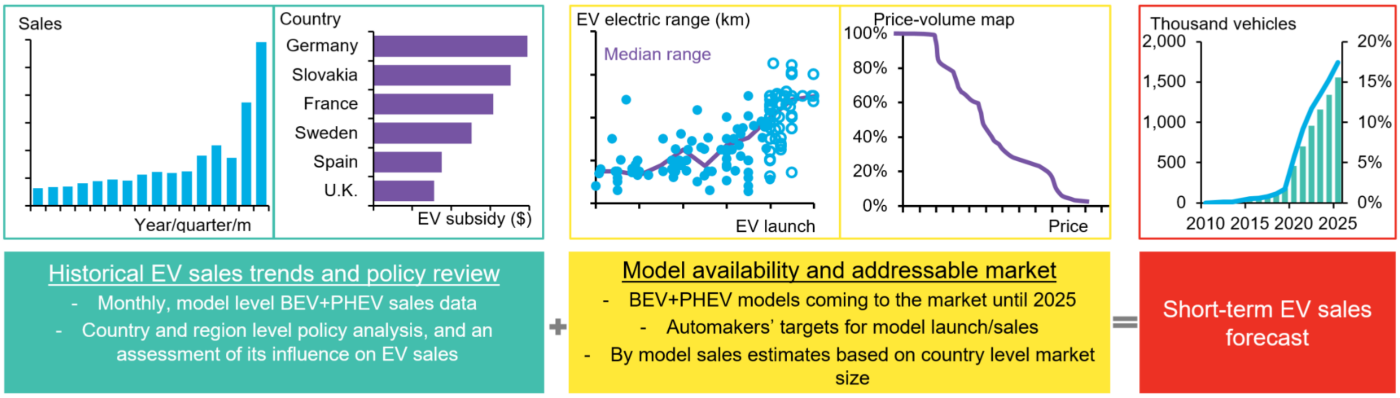
4.2. Short-term methodology and forecast, 2021-2025

Short-term methodology 2021-2025

In our short-term EV sales forecast methodology we take a bottom-up approach. We begin by updating our database of upcoming EV model releases in Europe. To compile this database we rely on company announcements, filings and third-party data.

We then project EV sales for each market in Europe by taking into account historical EV sales trends, model availability as well as any active relevant policies in place, including purchase subsidies and regulatory mandates (Figure 42).

Figure 42: Short-term EV adoption forecast methodology



Source: BloombergNEF

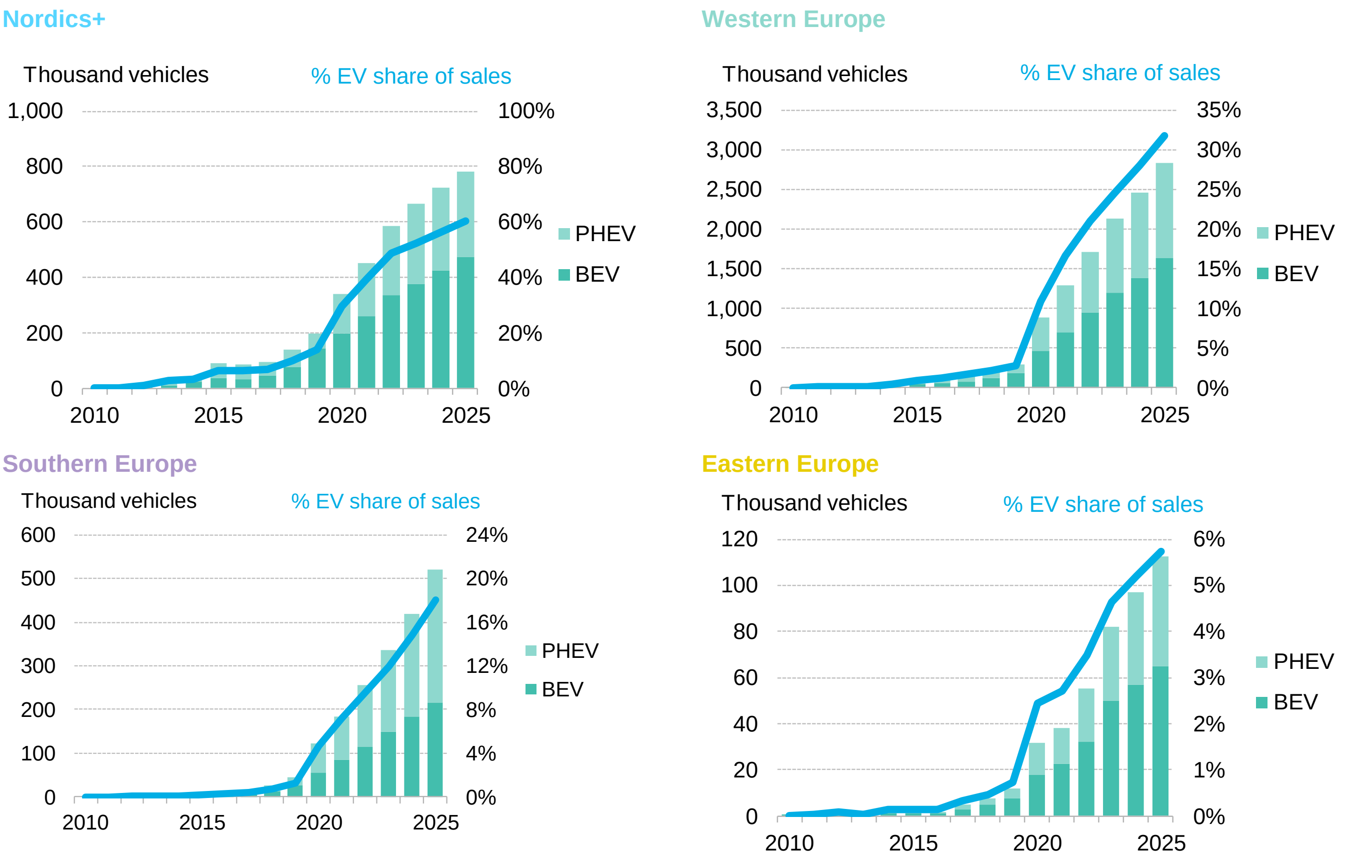
In the model review we take into account announced upcoming EV models that are to be introduced to the market until 2025. Considering their characteristics – drivetrain type, segment, range and price[7] – we use regression analysis to estimate their addressable market in any given country, and their potential sales in their specific segment up to 2025. Although we do not take concept models into consideration, we do account for various automakers' announcements as to their targeted sales or planned model introductions. For example, Hyundai Motor Group announced its plans to introduce 23 battery electric vehicles globally by 2025 – in our short-term forecast we have estimated their sales in each country, based on an assumed segment those vehicles will address. In the policy review, we look at the availability of purchase subsidies in the analyzed countries to understand the eligibility criteria – for example price caps, EV range etc. – and their influence on the upfront price of an EV model. We use that knowledge to buffer model-level sales – where we believe that generous subsidies can potentially boost a specific model's sales beyond what historical sales trends would indicate.

[7] We use various inputs to estimate the prices of upcoming BEVs: manufacturers' suggested prices, where available; prices for comparable vehicles in the same segment; or manufacturers' expectations as to the competitive vehicles with a given BEV. For upcoming models, where less information was provided by the manufacturer (usually models expected to come to the market towards the end of the short-term forecast period) we incorporate our expectations of lower cost BEVs hitting the market, as more models become available and battery prices fall further.

Short-term forecast 2021-2025

European EV sales continue to grow at a fast pace. Several European countries have already left the early-adopter phase of the market. Norway finished 2020 with BEVs and PHEVs at 76% of sales, Iceland at 49%, Sweden at 32% and the Netherlands at 25%. These are small auto markets, but they highlight how quickly things are changing. Last year, 2020, was a breakthrough for EV sales in some of the major markets in Europe as well, and those are now quickly catching up.

Figure 43: Short-term EV adoption forecast for Europe



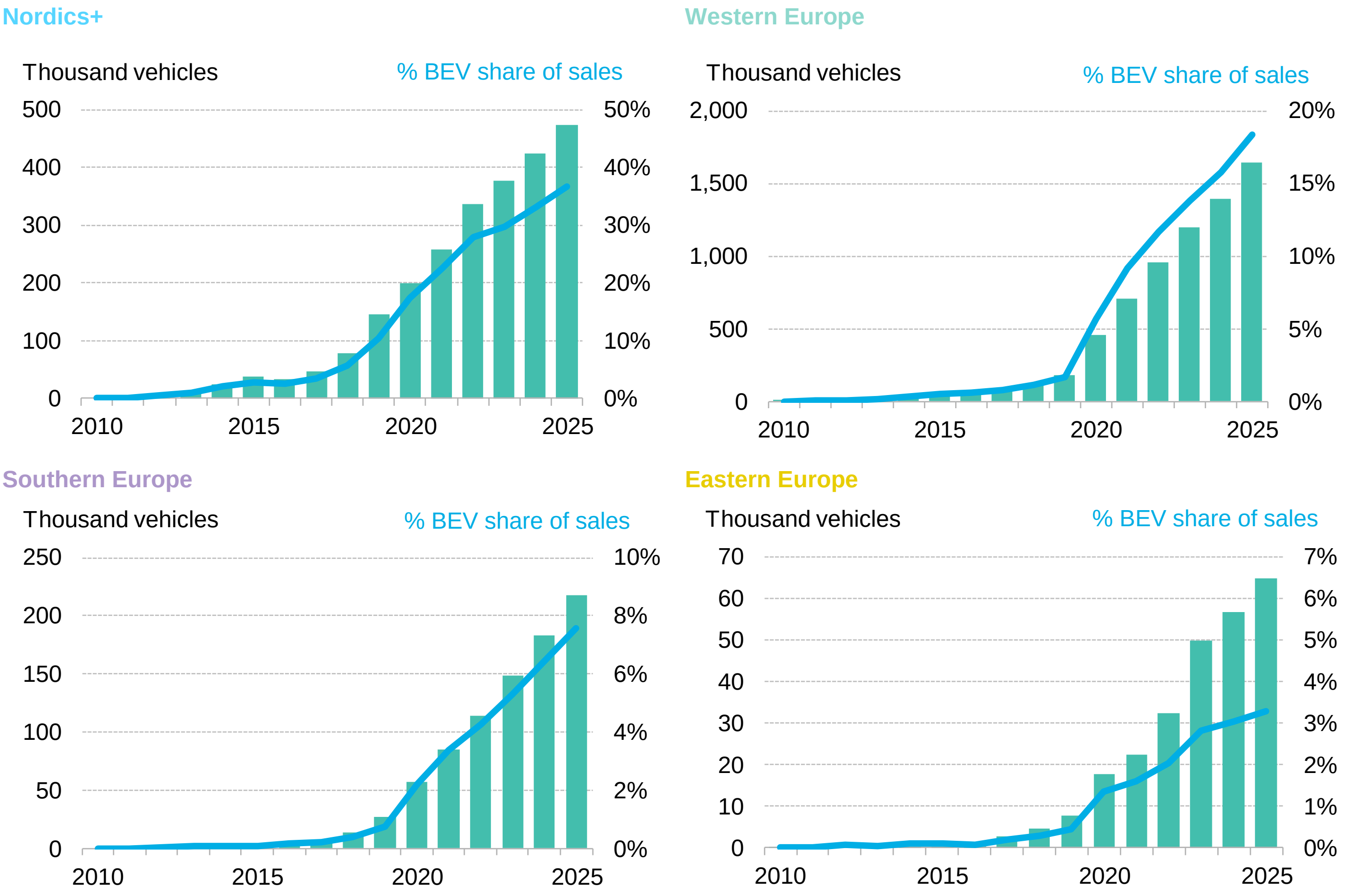
Source: BloombergNEF. Note: Each region on a different scale.

We expect electric vehicle sales in Europe to continue to grow in 2021 to just over 1.9 million units. This is up 43% from the previous year. The growth in sales will continue to be driven mainly by the CO_2 regulations. More importantly, from 2021 the average emissions of all newly registered cars from a manufacturer will have to be below the target, including the worst performing 5%, which were exempt in 2020. This means that some of the more popular automakers in Europe that rely on sales of SUVs – including Daimler or Audi – will need to double down on EV sales. The addition of the 5% least efficient vehicles to the compliance pool will also likely push PHEV sales up in the region in 2021. Automakers are responding by increasing their sales targets – Volkswagen aims to double its electric car sales in 2021, while BMW plans to increase EV sales by more than half, at the same time doubling its sales of pure electric vehicles – and by adding new electric models to their offering.

Our short-term EV sales forecast brings EV sales in Europe to a little under 4.3 million units by 2025, or around 28% of all passenger vehicles sales in the region. Adoption in the four specified groups will vary widely and not all markets will move at the same pace. While EVs reach 60% market share in 2025 in the Nordics+ and 32% in Western Europe, the adoption still hovers under 20% in Southern European countries and barely reaches 6% in Eastern Europe (Figure 43).

Battery electric vehicles will continue to contribute over half of the expected EV sales in the region. BEVs will be responsible for around 37% of all passenger car sales in the Nordics+, 18% in Western Europe, just under 8% in Southern Europe and little over 3% in Eastern Europe by 2025 (Figure 44).

Figure 44: Short-term BEV adoption forecast for Europe



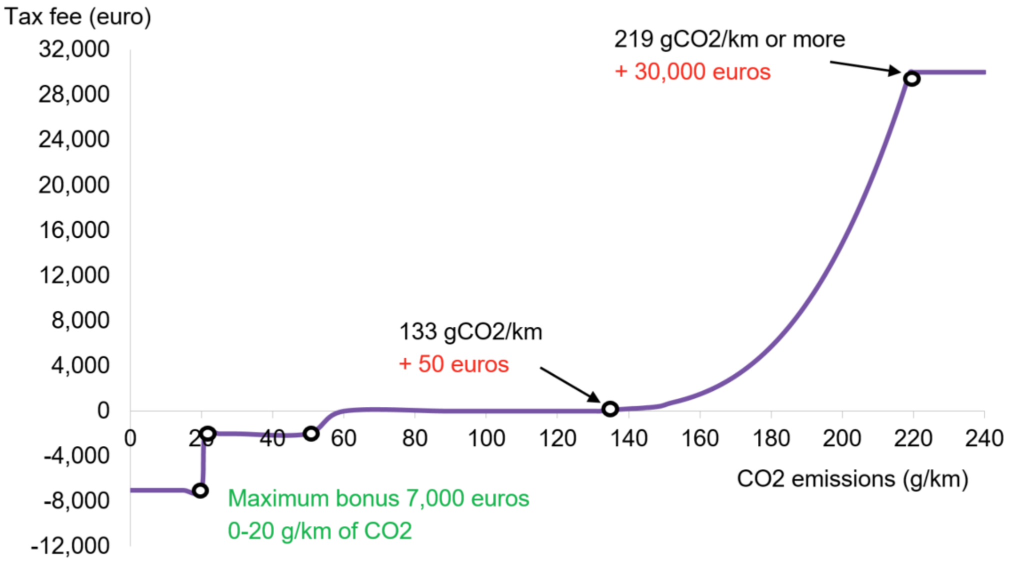
Source: BloombergNEF. Note: Each region on a different scale.

There are several reasons for the observed regional differences. First, countries in Western Europe and the Nordics have some of the most comprehensive support for EVs in Europe, and globally. Favorable tax discounts in Norway mean that EVs have been cheaper to buy there than ICE vehicles for several years now. This has led to the accelerated EV adoption in the country.

The *bonus-malus* systems in place in Sweden or France allow for the continued offering of hefty BEV and PHEV purchase subsidies (*bonus*), which are paid for by the penalizing CO2 tax levied on the purchase of most polluting vehicles (*malus*). For example, in France, buyers of new BEVs are eligible for a purchase incentive of 7,000 euros, while buyers of vehicles emitting 219g CO2 per kilometer or more have to be prepared to pay a 30,000 euros CO2 tax on top of their purchase price (Figure 45). Such a system effectively moves buyers of heavier vehicles toward plug-ins.

Similarly in Germany, EV purchase subsidies – raised in 2020 to 9,000 euros as part of the Covid-19 stimulus package – contribute more than 20% to the price of an average BEV in the country[8]. And the level to which EV purchase subsidies can lower the upfront price of an EV in any given country matters. EV purchase subsidies on offer in Spain or Italy effectively contribute only around 10% to 12% of the average BEV price in the two countries.

Figure 45: France bonus-malus system



Source: BloombergNEF, French government.

However, purchase subsidies alone are not enough to significantly boost EV adoption. In countries like Poland or Hungary, EV subsidies can also contribute more than 15% to the average price of a BEV. Despite this, even in 2020, EVs made up just a fraction of total passenger car sales in the two countries.

Countries in the Eastern Europe group (Figure 41) are predominantly second-hand car markets and are not the focus for automakers to direct their newly released EV models. For compliance with the CO2 targets, countries with high share of new car sales attract the majority of EV supply. Additionally, automakers are likely not yet considering the Eastern and Southern European consumers' "desirability" criteria, when deciding which EVs should be released next. Therefore, the "desirable" EV – meeting the price, segment, range criteria of an average buyer from the groups of Southern and Eastern European countries – may not exist yet. This is changing slowly, as brands more popular in the region, like Skoda or Dacia, begin to release new EV models – but

8 We use the Tesla Model 3 (Standard Range Plus version) as a reference vehicle. Prices of the model are country-specific: Germany at 39,990 euros, Spain at 45,090 euros and Italy at 48,990 euros. Subsidy value used (excluding any available scrappage bonus additions): Germany at 9,000 euro, Spain at 4,500 euro and Italy at 6,000 euro.

it does show that model availability and locally preferred brands should not be underestimated when discussing the drivers for EV adoption.

Why model availability matters

1. EV models addressing popular segments can make or break a local market: A good example of this is the Mitsubishi Outlander PHEV – the first PHEV SUV globally. It was first introduced in Europe in late 2013. In 2014, EV sales in Europe jumped 85% compared to 2013, with the Outlander quickly becoming the leading EV model in the region, contributing 21% of total EV sales that year.
2. Affordable, high spec, mass market EVs can make the segments lines blurry: and therefore significantly boost their addressable market. Tesla Model 3 is an excellent example. Introduced in late 2017 in the U.S., its production was slowly ramping up, until sales went up rapidly in 2018. The Tesla Model 3 contributed 39% to the total EV sales in the U.S. that year. This is also when EV sales in the U.S. increased 80% compared to 2017. They have been relatively flat since then.

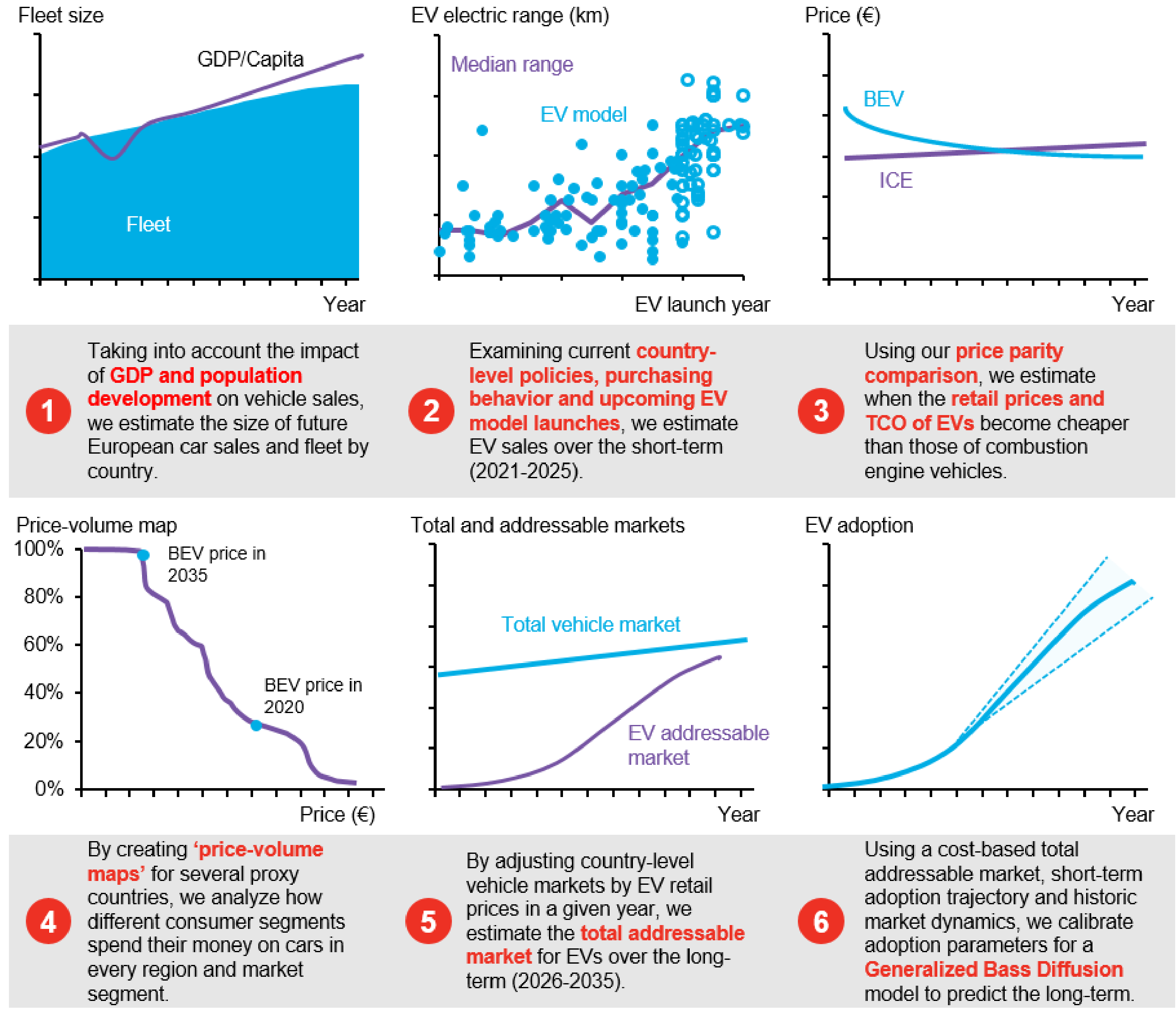
   In July 2018, Tesla sold around 14,000 units of the Model 3 in the U.S. This was remarkable since it was the highest monthly sales on record for a single EV model sold outside of China. Moreover, it was the best-selling premium mid-sized sedan in the U.S. that July and it outsold other leading vehicles in that segment – the BMW 3 Series, Infinity Q50, Mercedes C-class and Audi A4, for example. A year prior, none of the ICE models in the premium mid-sized segment in the U.S. achieved monthly sales of 14,000 or more. Most importantly though, Tesla revealed that the top five cars that the Model 3 buyers traded in (if they were not trading in an older Tesla model) included the Toyota Prius, the BMW 3 Series, the Honda Accord, the Honda Civic and the Nissan Leaf – all with a lower price tags than the Model 3. This indicates that many Tesla Model 3 buyers were trading up, which could indicate that the Model 3 is re-defining, or at least bending, current car segment categories.

4.3. Long-term methodology and forecast, 2026-2035

Long-term methodology 2026-2035

Our long-term forecast approach has six main steps (Figure 46 on the following page):

Figure 46: Simplified battery electric vehicle adoption forecast methodology



Source: BNEF. Note: Charts illustrative only.

1. **Sales and Fleet:** To build our adoption forecast, we develop an outlook for total vehicle sales over time. We start with a regression of historical sales and GDP-per-capita for each individual country in Europe. Based on country specific economic development trajectories from the OECD and IMF, we forecast future total sales and adjust this for population development using data from the World Bank. In the short-term we assume a gradual post-Covid recovery. At the same time, we also calculate the development of the fleet size, as this helps determine how quickly rising EV sales affect the electrification of the vehicle fleet. This has knock-on effects on the speed of consumer adoption, which to some measure impacted by what people see driving around.
2. **Short-term dynamics:** The short-term EV sales forecast, described in the previous section, in combination with expected total sales provides us with a view on EV adoption

share in the next five years. Combined with a timeline of historic EV sales dating back to 2015, this gives us a timeline of 10 years on which we can calibrate adoption for the 10 years ahead. For some countries, like Norway, Sweden and the Netherlands, where there is more data available dating further back, we use these to additionally inform our adoption parameters.

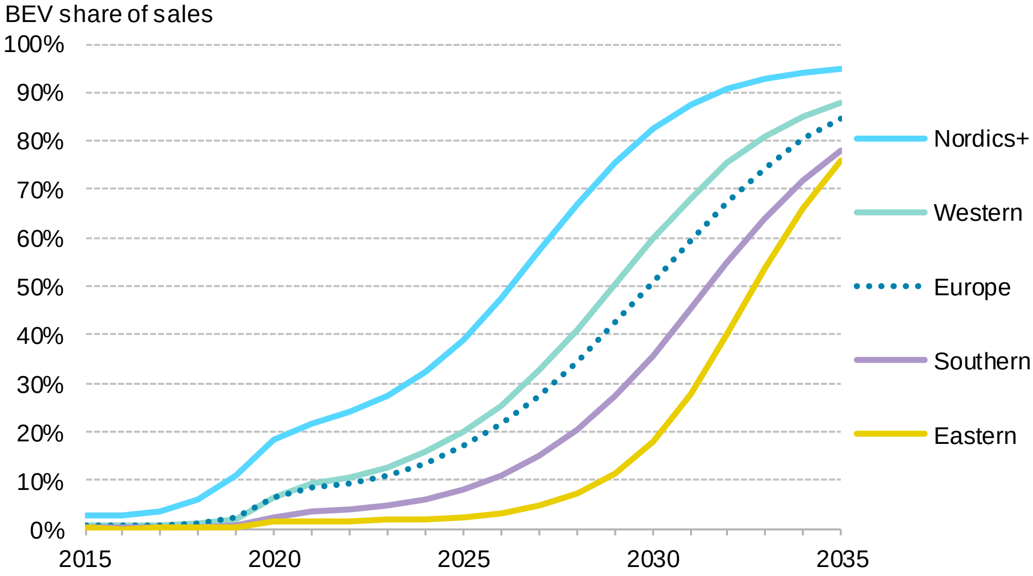
3. **Price parity comparison:** We use our price parity work as described in Section 3 to calculate upfront prices for ICEs and BEVs. However, while consumers might mainly focus on the sticker price of a car, companies particularly also focus on total cost of ownership (TCO). Taking into account factors such as fuel prices, annual kilometers travelled, residual value and maintenance cost, we calculate TCO values for both BEV and ICEs. As EVs reach TCO parity earlier than upfront price parity, this functions as an additional driver.
4. **Consumer price segments**: We analyze the car market by looking at relationships between prices and sales volumes in different countries and segments. Such 'price-volume maps' give an indication of consumers' spending patterns and provide the economically potentially addressable market for a BEV at a particular price point.
5. **Total addressable market:** As the average price of BEVs drop, the share of consumers for whom an EV would be a cheaper option rises. The speed at which this happens depends on factors such as distribution of the price-volume maps by segment and region, with larger pockets of consumers in certain price segments. Other potential factors affecting the market dynamics that could slow down or accelerate a shift to EVs, such as charging infrastructure availability and the role of shared mobility are discussed in Section 4.4.
6. **Adoption curve:** In the long term, we think the adoption of privately owned EVs is fundamentally a question of consumer technology diffusion and we use an adapted Generalized Bass model to capture such effects. This is done through BloombergNEF's proprietary EV Adoption Model, which is calibrated on historical adoption data and observed market dynamics. It includes consumer 'innovation' and 'imitation' factors, and integrates price elasticity of demand effects that reflect our forecasts for both vehicle up-front prices and total cost of ownership.

The long-term adoption forecast is demand-driven and does not assume that the currently legislated 2030 CO_2 emissions targets are met. As such, the forecast does not assume any other regulatory support for BEVs in the time period to 2035.

Long-term forecast 2026-2035

European BEV sales reach 85% of total by 2035 under the current base case trajectory, having already crossed 50% by 2030 (Figure 47). BEV sales growth slows slightly between 2020 and 2025, even though sales continue to increase steadily, because of the jump in 2020 to meet the 95g CO_2 target. Adoption accelerates quickly from 2025 as different segments hit price parity in quick succession and more EV models are launched.

Figure 47: Battery electric vehicle share of total annual passenger vehicle sales by region in Europe: base case scenario



Source: BloombergNEF. Note: The Europe adoption curve shows the adoption for all four regions combined according to their sales. Includes adoption of battery electric vehicles (BEV) only; does not include plug-in hybrids (PHEV). Base case shows trajectory under current economic development and policy measures, but does not take into account any constraints due to charging infrastructure, raw material availability or other factors.

The Nordics+ are expected to charge ahead on BEV adoption, with Norway largely on track to meet its 2025 ICE phase-out target. The saturation of the Norwegian market causes some deceleration on the average adoption growth across this region. Adoption in Denmark, Sweden and Finland rises quickly in the years ahead. Changing stimulus measures in the Netherlands have caused the market go forward and backward several times, but overall this region reaches very high BEV shares, hitting 39% in 2025, 82% in 2030 and 95% in 2035 (Figure 47).

Norway's trajectory provides a playbook to understand aspects of adoption in other countries as well. Battery electric vehicles there have been at similar prices with ICEs for a number of years. Still, it takes time after that parity year for adoption to exceed 50% and grow further. Some of the restrictions, such as limited model availability and patchy charging infrastructure networks, are gradually being lifted for other countries in early stages of adoption. However, other hurdles may remain, such as the need for additional BEV price declines to reach wide parts of the auto market in less wealthy places, as well as an increased consumer acceptance of the new technology.

The adoption trajectory **in Western Europe** is also rising and is a case in point. In Germany and France, generous subsidies and increased model offerings from domestic manufacturers provide support and choice to consumers, and help the region gain momentum. The U.K. is also developing well in terms of roll-out of charging infrastructure and more BEV models on sale – now and in the near future – in the popular SUV segment. The region becomes the second highest for BEV adoption and the biggest market for BEVs, which reach 20% of sales in 2025, 60% in 2030 and 88% in 2035 (Figure 47). The rate of growth in Western Europe after 2025 is stronger than in the Nordics+, but not the highest in Europe after 2025.

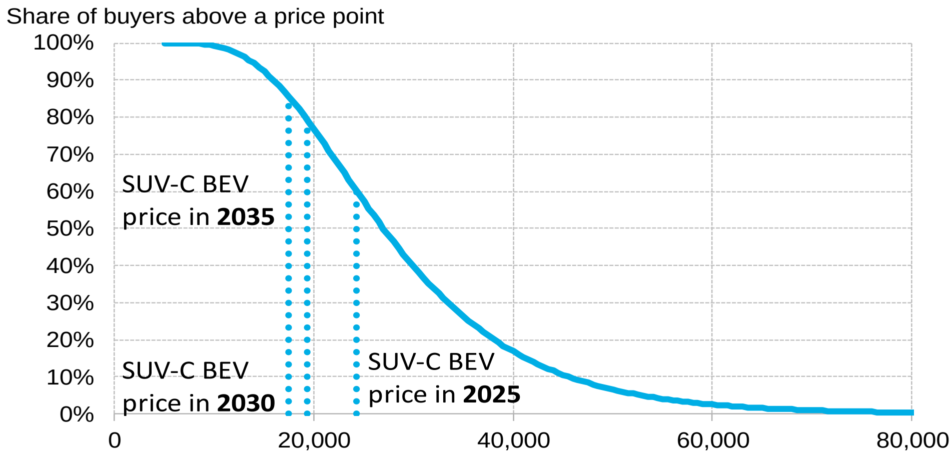
In particular, **Southern Europe** and **Eastern Europe** grow the fastest in the 2020s, as they start from a low base (Figure 47). In Southern Europe, signs are there to demonstrate a change in consumer demand for EVs in general, as Portugal (in the last couple of years), and Italy and Spain more recently experienced strong demand for electric cars. Growth rates are set to accelerate in the region and will be even higher in the second half of the current decade than between 2020 and 2025. During that period, all vehicle segments reach price parity, making purchasing BEVs a simpler choice than in earlier years. BEV adoption in Southern Europe reaches 8% in 2025, 36% in 2030 and 78% in 2035.

Despite cost competitiveness, it takes until 2030 for the Eastern Europe region to hit 18% BEV adoption based on the current trajectory. Consumer buying patterns will not flip overnight and the second-hand market remains larger than elsewhere in countries within that group. That limits BEV growth for several more years, and automakers may choose to sell lower-priced mass market ICE vehicles in these countries. However, this strategy will not hold for long. As EVs become more ubiquitous in other parts of Europe, there is a delayed, but very rapid increase in adoption rates closer to 2030 and beyond. In fact, between 2025 and 2030, BEV sales in Eastern Europe will grow twice as fast as in Southern Europe and more than five times over the rate of growth of the Nordics+ region. BEV adoption in Eastern Europe hits 76% by 2035.

Getting to 100%

BEV adoption in our base case slows down slightly in the early 2030s as some segments saturate. In the smaller vehicle segments, stripped down, low performance, low cost internal combustion vehicles will be hard to beat on price for some time, particularly given the assumed BEV ranges used in this analysis. This highlights an important difference between price parity in relation to average prices in a vehicle segment and price parity with all vehicles in that segment. Figure 48 shows that even with a BEV SUV well below the average ICE price in that segment in 2030, there are still corners of the market that remain unaddressed from a purely economic perspective. Vehicles in adjacent segments, such as SUV-B, could fill the remaining gap in that part of the market, as such vehicles could be cheap enough in the 2030s to do so. Market dynamics and potential segment shifts – eg, whether consumers are willing to buy those smaller SUVs – are likely to affect the speed and difficulty of reaching full BEV adoption in all segments.

Figure 48: Price-volume map for SUV buyers in Germany



Source: BloombergNEF. Note: the price-volume map shows the share of buyers that purchase vehicles above a given price; for example, 40% of buyers purchase SUVs costing 30,000 euros or more and the other 60% purchase SUVs that cost less than 30,000 euros; here we have combined all SUV sub-segments together.

In order to test what reaching 100% BEV adoption would look like, we built an accelerated scenario for each region, shown in Figure 49 to Figure 52. This scenario assumes that governments introduce more supportive policies that push the market toward much faster BEV adoption and, hence, does not consider additional potential constraints, such as charging infrastructure, raw material availability for batteries and other factors. In particular, short-term BEV volumes are higher by 2025, and the earlier sales momentum forms the basis for higher consumer adoption in the second half of the 2020s. At the tail-end, we assume additional support ensures a reduction in the natural slow-down that would be caused by hard-to-reach pockets and more difficult use cases. Such a trajectory relies on more expanded policy support for consumers and businesses, as well as on charging infrastructure. A non-exhaustive list of the potential tools is outlined in page 45 below.

In the accelerated scenario, the Nordics+ maintain an almost linear growth trajectory in the coming decade to hit 100% BEV sales by 2030. If Norway were to keep its current growth it could hit 100% by late 2023. However, the last 10% of any market is challenging and likely to be hard to fill. In addition, countries such as Sweden and the Netherlands have relied to PHEVs in the past, but this scenario assumes that they shift exclusively to BEVs.

In Western Europe, the U.K. already has announced updated phase-out targets (100% BEV + PHEV by 2030, 100% BEV by 2035) and is rolling out a large amount of charging network, while Germany is also investing heavily in charging infrastructure. For this group of countries, adoption has to come forward by only a couple of years to place them in the trajectory needed to hit 100% of sales just after 2030. Risks in these countries include any delay in the rollout of BEVs in the SUV segment, with buyers turning to PHEVs to meet their needs.

The accelerated adoption in Southern Europe could be similar to the 100%-trajectory of the Western countries, but delayed by a few years. The car markets in these groups have some similarities and as adoption increases in the region, BEVs start to become cost competitive. Still, overall BEV sales will have to increase by more than 40x to reach a complete ICE phase-out by 2035.

Hitting 100% BEV adoption in the countries of the Eastern Europe group will the most challenging. Due to very low adoption currently, and a limited outlook for BEV sales growth in the short-term, the region has to experience an unprecedented sales acceleration to reach the 2035 target. BEVs at the lowest end of our estimated pre-tax retail prices will be needed to spearhead adoption around 2025 in the region. That may require lower driving ranges or different, and cheaper, battery technologies.

Figure 49: Base case and accelerated passenger battery electric vehicle share of sales in Nordics+

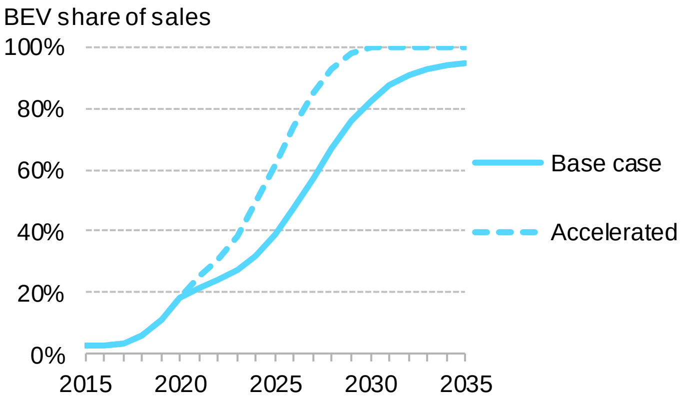


Figure 50: Base case and accelerated passenger battery electric vehicle share of sales in Western Europe

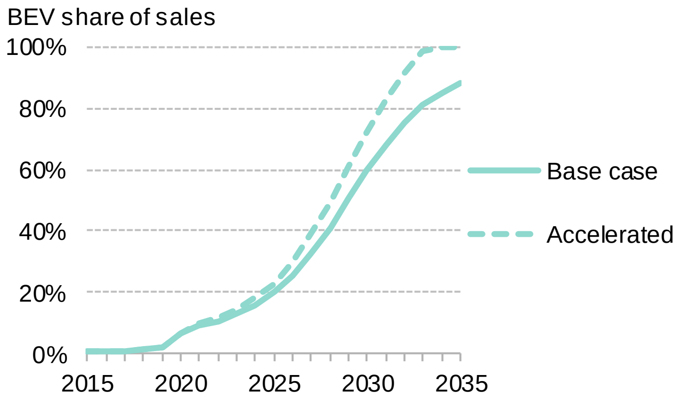


Figure 51: Base case and accelerated passenger battery electric vehicle share of sales in Southern Europe

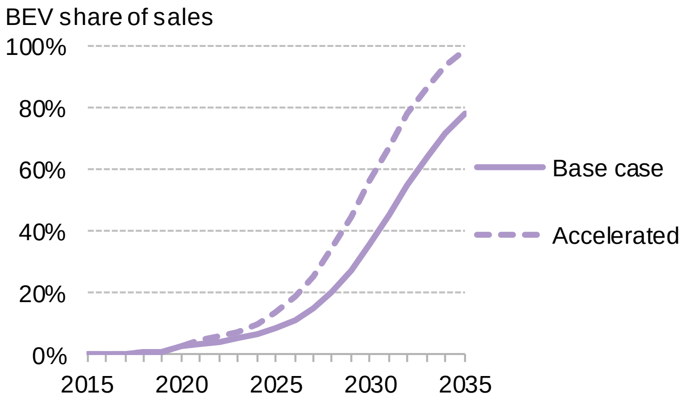
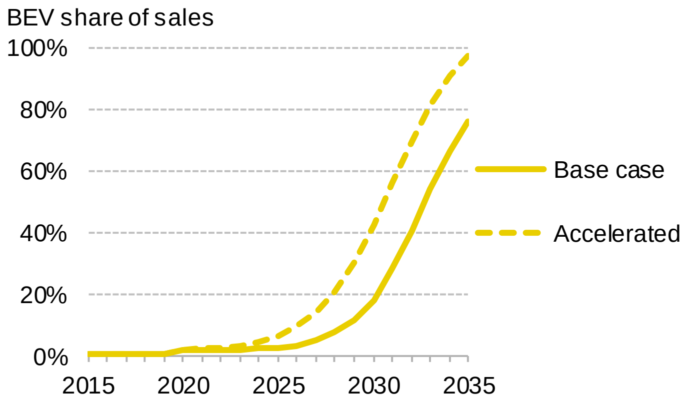
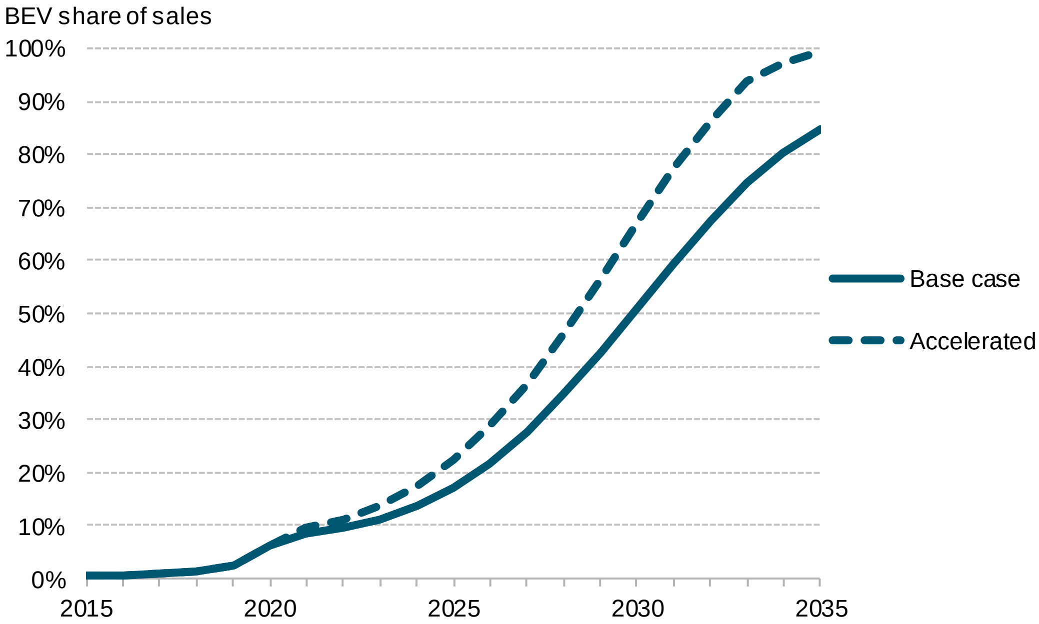


Figure 52: Base case and accelerated passenger battery electric vehicle share of sales in Eastern Europe



Source: BloombergNEF. Note: Includes adoption of battery electric vehicles (BEV) only; does not include plug-in hybrids (PHEV). Base case shows development trajectory under current technology outlook and policy measures. Accelerated shows potential scenario under additional stimulus

Figure 53: Base case and accelerated passenger battery electric vehicle share of sales in Europe



Source: BloombergNEF. Note: The Europe adoption curve shows the volume weighted average adoption for all four regions combined. Includes adoption of battery electric vehicles (BEV) only; does not include plug-in hybrids (PHEV). Base case shows development trajectory under current technology outlook and policy measures. Accelerated shows potential scenario under additional stimulus

Overall, BEV adoption in Europe follows a trajectory similar to the curve for Western Europe, which represents the majority of the market (Figure 53). Adoption reaches 22%, 67% and 100% of total sales by 2025, 2030 and 2035, respectively, in the accelerated case.

Additional policy options that can be considered to support the accelerated scenario

A full assessment of policy tools to achieve the accelerated scenario is beyond the scope of this analysis. Here we highlight several approaches that could be used to support this:

- Tailpipe CO2 emissions targets that are stricter and stretch further in time than current rules.
- Support for charging infrastructure expansion to remote and otherwise under-served locations.
- Consumer subsidies targeted to low-priced EVs to help access the full range of buyers and to the purchase of second-hand electric vehicles.
- Mandates for the electrification of fleets, including of those of governments and transport operators, such as mobility service providers.
- Tighter municipal regulations for vehicles entering urban areas.

Adoption of electric vans

Methodology

Total cost of ownership (TCO) is the main factor for forecasting the share of different powertrain technologies in commercial vehicles. TCO quantifies the present value of all relevant costs in owning and running a vehicle. It includes capital, fuel, maintenance and tires, and is normalized over the total distance traveled throughout the vehicle's usage period. The calculations here exclude driver wages. We adjust the calculations to penalize electric drivetrains for low model availability and undeveloped fueling infrastructure. However, we expect that by the mid- to late-2020s electric vans will be easily accessible to buyers.

We then stack the TCOs of the electric, diesel and gasoline vans (for both light and heavy) and estimate the market shares of the different technologies based on the ranked relative costs. In this process, the sales share of a particular fuel declines rapidly the further away it is from the cheapest option.

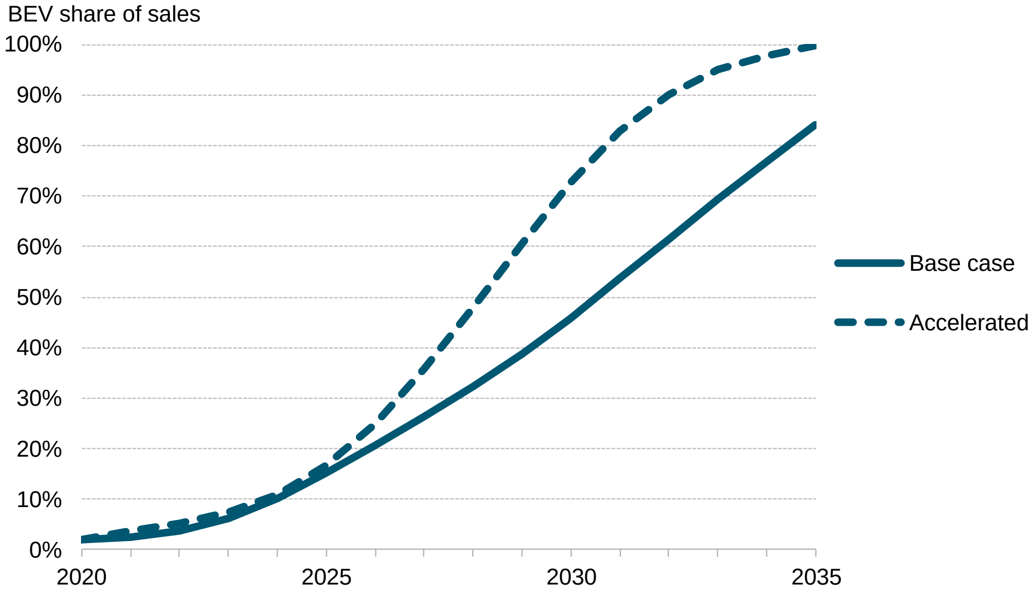
Forecast, 2021-2035

The total cost of ownership of light vans can already be lower than that of diesel equivalents for some duty cycles, especially in countries with the highest diesel- or gasoline-fuel costs. The TCO of both light and heavy vans becomes on average the lowest within the next few years. Such economic advantage drives the adoption of these vehicles in Europe to about 84% by 2035 (Figure 54), while all four country groups reach adoption shares between 70% and 86%.

The group of Western European countries starts from a higher base and grows the quickest. Still, the adoption of electric vans over time takes hold similarly in all country groups, more so than that of passenger cars. Another difference is a steadier adoption trajectory. That is due to the more economics-driven decision to purchase such vehicles. As the TCO advantage of those light-duty commercial vehicles steadily increases, wider parts of the market choose to own and operate electric vans.

Some hurdles that we expect to be gradually resolved are: the initially low model availability of suitable vehicles and the currently few charging infrastructure solutions for fleets. In addition, the predominance of smaller fleet – or even single vehicle – owners means that, until upfront cost price parity is reached, new financing tools would be required to allow capital constrained buyers' early access to such vehicles. In the next few years, large fleet owners and users will be the main buyers of electric vans, as many of them also put forward decarbonization and sustainability plans.

Figure 54: Base case and accelerated battery electric van share of sales in Europe



Source: BloombergNEF. Note: two vans classes are used, light and heavy vans, whose specifications are shown in Table 1 and Table 3.

4.4. Other considerations affecting BEV adoption

The BEV outlook in the previous sections is based on our assessment of the techno-economic factors driving adoption. There are several areas that are not considered in this analysis that could still impact adoption. These include, but are not limited to:

- **Company cars:** No differentiation was made in the analysis between private and company car sales. Company cars are a large share (more than 55% of sales in Europe in 2019[9]) of sales in the European market and a major driver of EV sales due to various tax incentives in place in different countries. Additionally, total cost of ownership (TCO) and residual values are often important factors for company car purchases. The higher focus on TCO price parity, which generally comes 1-2 years before up-front price parity, and potential further regulation could speed up adoption of electric vehicles in the corporate fleet. Sustainability considerations and corporate image concerns could provide a further push for electric company cars.
- **Shared mobility:** Shared cars including those deployed in car-sharing schemes, taxis and ride-hailing services. These have not been treated separately in the analysis. The high annual distance travelled of these vehicles – like other company cars – makes this part of the market more sensitive to TCO. Additionally, these vehicles are mainly deployed in urban environments, where air-quality concerns are rising and regulations are getting tighter. This will likely push these services to electrify faster than privately owned passenger cars. These services can also reduce private car usage, though the data here is mixed and many of the

9 Company cars include vehicles owned by corporations rather than individuals and can include cars provided to employees, rental cars, but also cars owned through a corporate structure.

trips they displace are from other modes like public transport. We have not included the impact of shared vehicles and the rise of potential robotaxis in this report.

- **Other drivetrains: PHEVs, fuel cell vehicles**: The analysis in this report has focused on the cost trajectory and potential adoption of BEVs. There are several reasons for this. We do not see PHEVs as an attractive drivetrain technology in the long term, since there is no route for them to become cheaper on an up-front price basis than BEVs. The current data on the amount they are charged is also mixed, with newer studies showing lower rates of charging. We expect automakers to continue to use PHEVs primarily as a compliance tool to reach CO2 targets but it is not clear if governments and regulators will continue to treat them favorably unless the data on charging becomes clearer.

  Fuel cell vehicles (FCVs) could also play a role in the future, but with only 30,000 on the road globally today, we do not expect any large-scale adoption in the 2020s. Even if the fuel-cell vehicle fleet were to grow very rapidly and double every two years all the way out to 2040, it would still only represent around 1-2% of the global vehicle fleet. Hydrogen production and distribution costs and a lack of infrastructure are further constraints for adoption in the passenger vehicle segment. We expect green hydrogen to be a scarce resource for the foreseeable future, and for governments to prioritize using it in hard-to-abate sectors like heavy industry, marine applications, and some power generation as seasonal storage in grids with high shares of renewable generation.

- **Raw material constraints.** We have not factored in any raw material constraints for the adoption analysis in this report. In practice, interest in battery materials is rising quickly, with prices of lithium carbonate, lithium hydroxide and cobalt rising 72%, 47% and 58%, respectively, in the first quarter of 2021. For lithium, the recent rise in prices is welcome as prices in the last two years were not high enough to support new capacity investment. Nickel bucked the trend and prices fell after China's Tsingshan announced in March that it will seek to produce nickel matte from its nickel pig iron smelters in Indonesia. Matte is suitable for refining to battery-grade nickel, and this provides another pathway to battery grade nickel besides high-pressure acid leaching. BloombergNEF estimates that nickel needs to be around $18,000/ton to incentive new development of battery grade capacity.

  As demand for battery materials increases and prices rise, both supply and demand patterns will change. On the supply side, more investment will flow into extraction and refining. Despite this, bottlenecks are likely to emerge in some areas. Cobalt and Class I nickel look the most likely to hit deficits in the near term. On the demand side, automakers and battery manufacturers will continue to adjust battery chemistries to reflect changes in underlying prices.

- **Plant conversions and EV manufacturing capacity:** The analysis in this report does not consider any of the logistical or political challenges of switching over large amounts of manufacturing capacity to produce EVs in a relatively short period of time. Parts of the ICE supply chain in particular are concentrated in some regions where there may be pushback if local jobs and economic activity are not created in newer parts of the supply chain. Governments will need to ensure that the switch to electric drivetrains is an equitable transition.

- **Changing segment trajectories:** Different sub-segments of the auto market may develop at different speeds. Large vehicles and sports cars often are produced at lower volumes, but with higher margins for automakers. This makes these an ideal case for automakers to push electrification in these segments first, while building up their electric supply chain. The high acceleration of electric vehicles can also add to the performance for this segment of vehicles.

On the other hand, buying certain high performance cars traditionally has been linked to the engine technology of these automakers and at least some part of the market might be reluctant to switch. Automakers will look for different ways to differentiate themselves in performance and additional luxury as BEV platforms make much of the vehicle technology more commoditized.

In the past 10 years there has been a rapid rise in sales of SUV and crossover body types in different segments. In this outlook we have kept segment trajectories fixed based on sales in 2020 because predicting how segments will change in the years ahead is very difficult. However, rapid development in certain popular segments could still accelerate EV adoption, while focus on other segments could result in the opposite.

- **Changing consumer demand:** Rising incomes and changing demographics including aging and urbanization can cause changes in consumer demand and spending habits. Other less tangible factors like cultural viewpoints might also change over time, potentially resulting in different use cases for vehicles and shifting of car trips into different modes of transport for certain trip lengths where trains or bikes might actually be more suitable. We have kept the shape of our consumer demand distribution similar across years in this analysis, but acknowledge these effects might change the segments of consumers buying a car at different price points.

Charging infrastructure

EV charging infrastructure constraints are specifically not addressed in the BEV adoption scenarios, but it is worth understanding the current state of the market, and how this could affect BEV adoption in the future.

The global public charging network grew 48% in 2020, compared to the previous year, to reach 1.36 million connectors. At the end of 2020 there were 810,000 connectors in China, 360,000 in Europe and 89,000 in the U.S. (Figure 55). Annual new installations soared across China, Europe and the U.S., despite the pandemic, as a combination of policy support and business interest brought new momentum to the market. Europe installed112,800 connectors in 2020 (Figure 56), over five times the 17,400 connectors installed in the U.S., but only about a third of the new installations in China.

Figure 55: Cumulative global public charging connectors installed

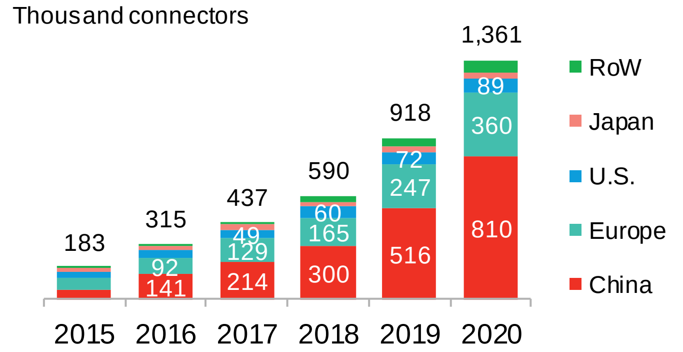
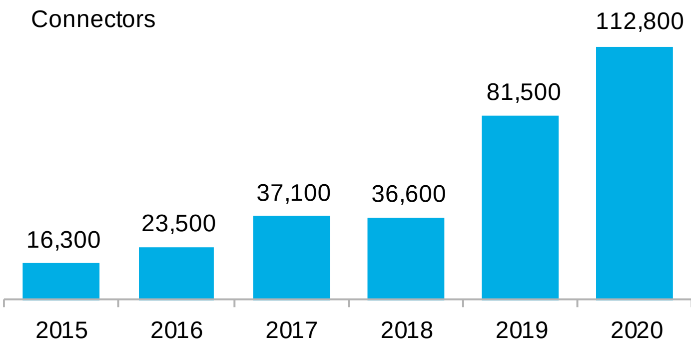


Figure 56: Annual public charging connector installations in Europe



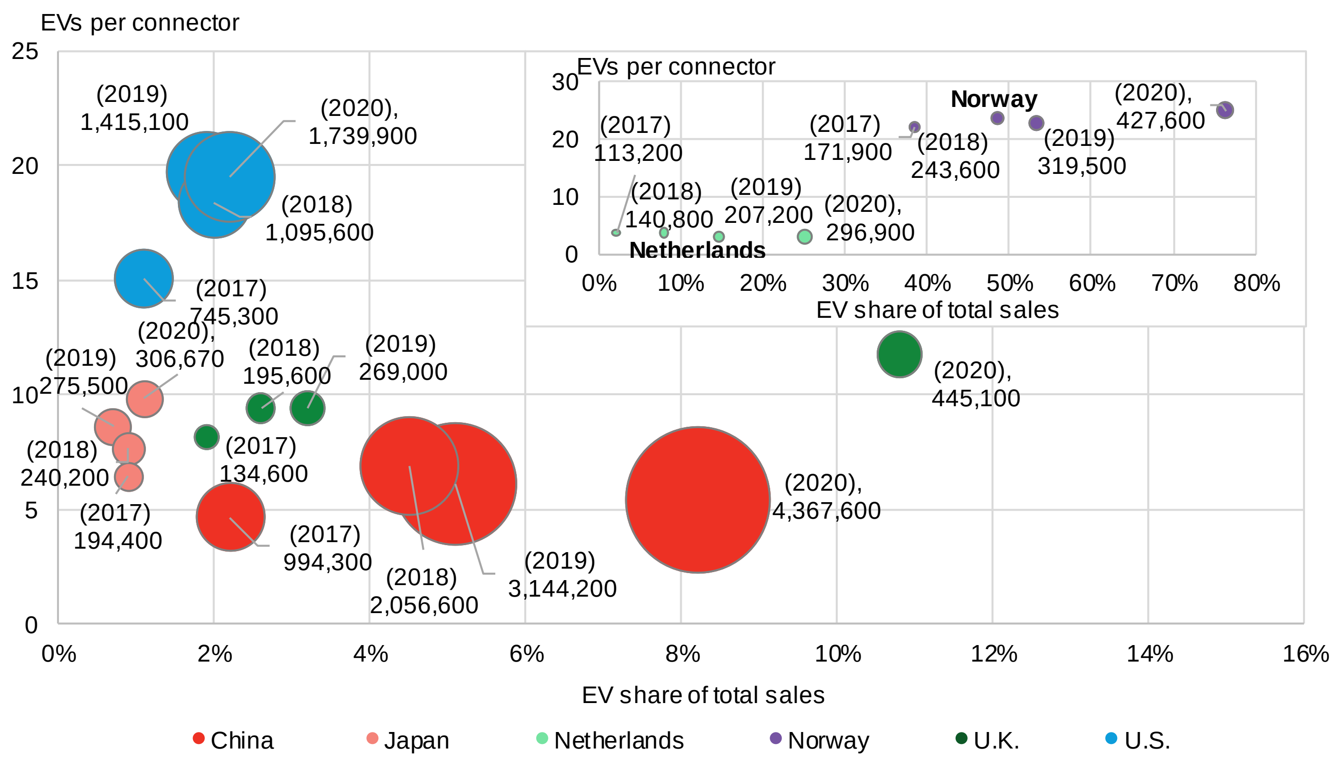
Source: BloombergNEF U.S. AFDC, Chargehub, China Electric Vehicle Charging Infrastructure Promotion Alliance, Various industry data sets. Note: Includes Tesla destination and supercharger networks even though this is semi-private.

Globally, the number of EVs per public connector stayed flat between 2019 and 2020, at 7.4 EVs per connector, showing that the growth in EV sales was matched by growth in public charging infrastructure. However, the ratio varies across countries, also in Europe. In Norway, the ratio of EVs per connector is much higher than the global average, at 25 EVs per connector. In contrast, the Netherlands has 3 EVs per connector. The differences between countries are due to a number of factors, including:

- Building stock: countries with a higher share of apartments will have a lower prevalence of home charging and are therefore more reliant on public charging.
- Public charging hardware power: countries with higher-power public infrastructure should need less connectors to charge the same number of vehicles.
- Electric vehicle stock: markets with a high number of plug-in hybrid sales will require a different blend of public charging infrastructure.

Further analysis shows that the ratio across leading EV markets has stayed consistent over the last four years (Figure 57), indicating that increasing sales of EVs act as a charging infrastructure investment signal. In the Netherlands, the ratio moved from 3.7 in 2017 to 3.0 in 2020, even though total EV sales increased 162% in that timeframe. In Norway, the ratio increased from 23 in 2019 to 25 in 2020, even as EV's share of total passenger car sales passed 70%. In the U.K., the ratio rose to 11.7 in 2020 from 9.4 in 2019. This shows slower public charging growth in the country compared to EV sales, which jumped to 11% of total sales in 2020 from 3.2% in 2019.

Figure 57: EVs per public charging connector across various regions over time



Source: BloombergNEF. Note: Bubbles indicate the size of the passenger EV fleet.

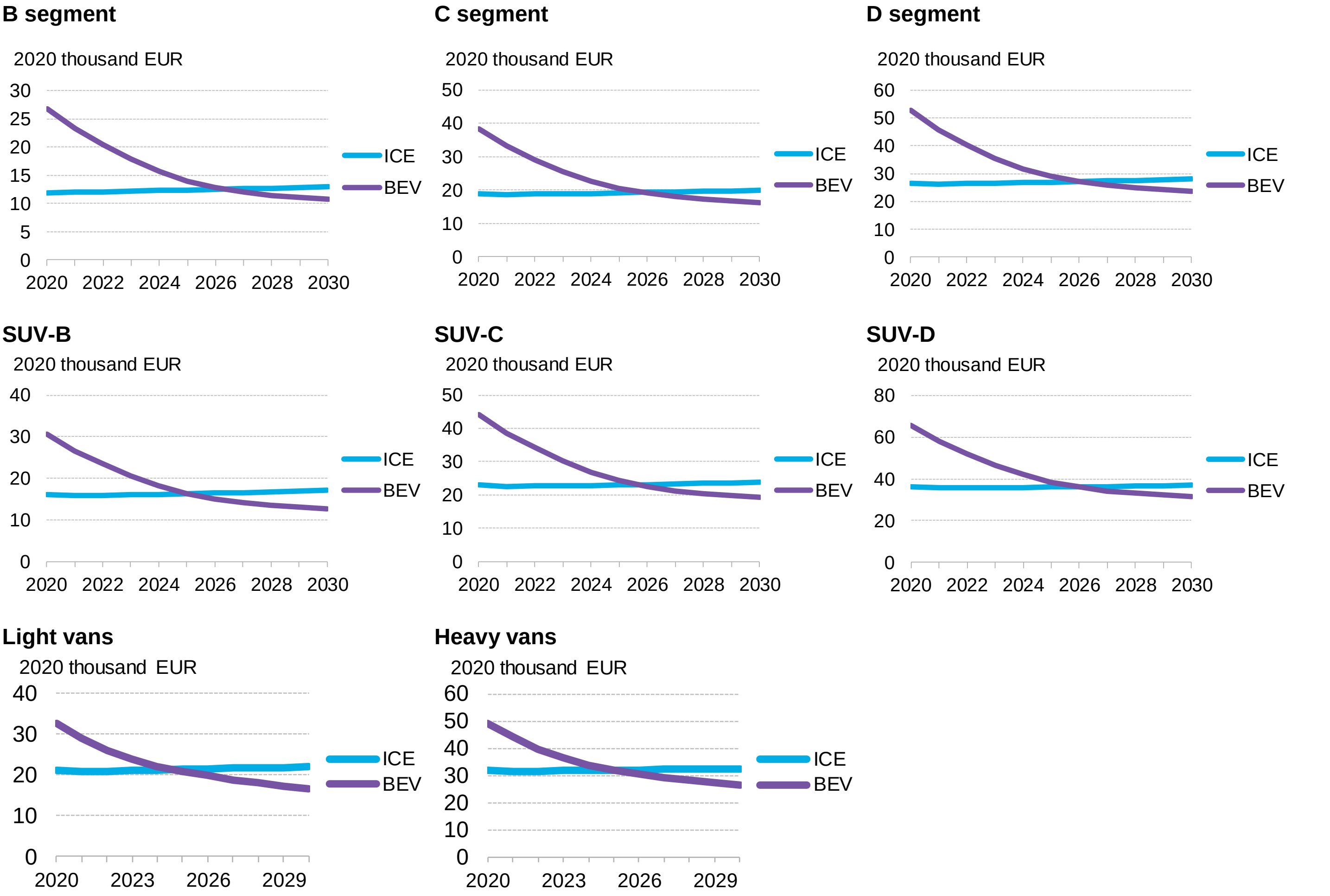
The need for charging infrastructure rollout will continue to grow. Today most EV charging takes place at home, but a robust public charging network will be needed to get to high levels of EV adoption across all buyer segments and housing types. Residents of high-rise multi-dwelling units in particular are more likely to rely on the public network than those who live in single detached homes.

We have not factored charging infrastructure spending into the BEV price parity analysis, or how a lack of public charging infrastructure could impact the adoption curves. However, BloombergNEF estimates that around 1.8 million public charging points will be needed across Europe by 2035 to support the private BEV fleet in this analysis in the base case and 2 million public charging points in the accelerated case. The total investment required for the base case public charging infrastructure requirements will be around $13.4 billion and for the accelerated case $14.6 billion. The European private EV fleet will be growing very rapidly by 2035, and the number of public charging points would need to increase further to around 2.5 million between 2035 and 2040 to continue to support this growth. This analysis does not include vans, shared vehicles or PHEVs, which may rely more heavily on public charging than private BEV vehicles.

Appendices

Appendix A. ICE and BEV pre-tax retail prices for all segments

Figure 58: Estimated pre-tax retail prices for passenger vehicles and vans



Source: BloombergNEF Note: ICE is internal combustion engine vehicle and BEV is battery electric vehicle

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