P3 Charging Index
UNITED STATES

Comparison of the fast-charging capability of electric vehicles

Report

06/23

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All-Electric Luxury Vehicles on top in the first US Edition of the P3 Charging Index

Simon Buderath / Christian Daake / Marian Cammerer

Since 2019, P3 has published three reports for the European market on the long-distance suitability of all-electric vehicles. In 2023, P3 is publishing its first P3 Charging Index in the United States to target the US audience.

Almost all long-distance, all-electric vehicles (EVs) coming onto the market can have a charging power of more than 100 kilowatts (kW). Some EVs can even have a maximum charging power of more than 150 kW with upper bounds of 300 kW. Maximum charging power in kilowatts is often used as a simplified way to compare electric vehicles. However, this parameter itself is neither reliable nor representative of the actual charging performance. The determining parameter for the user to evaluate the long-distance capability of an EV is the time required to recharge a specific range (in miles).

To compare the long-distance suitability of electric vehicles, P3 developed the P3 Charging Index.

At the end of 2019, P3 established an independent standardization by creating the P3 Charging Index (P3CI). This metric enables a user-oriented and realistic comparison of the long-distance suitability and fast-charging performance of different electric vehicles. The number of recharged miles over charging time can be derived by measuring charging time and recharged energy of the vehicles and applying these values to the vehicle's consumption. This enables a more accurate assessment of the long-distance capability of each car.

The target P3CI - US value of 1.0 corresponds to the ability of electric vehicles to recharge 200 mi of range within 20 minutes (starting from a low State of Charge of 10% SoC), enabling practical long-distance mobility from a consumer's perspective.[1]

$$\text{P3CI - US} = \frac{\text{Real recharged range within 20 minutes}}{\text{200 mi}}$$

Since its first edition, the P3 Charging Index has continuously evolved with the ever-changing EV industry and, in 2023, is now being published for the first time as an independent, standalone version for the US market. Therefore, the majority of electric vehicles in this publication are US-based models.

! Long-distance suitability and fast-charging

Driving long distances with an EV is only viable if the number of charging stops and the charging time is kept to a minimum. P3 defines the long-distance suitability of an EV as the ability to drive an extensive distance without charging and to then recharge within a short period of time before continuing (= fast-charging). This assumes that a low State of Charge is reached before recharging.

For the United States P3 deemed a recharged range of 200 miles within 20 minutes as reasonable.

[1] In the European edition of the report an index of 1.0 corresponds to 300 km of range recharged in 20 minutes


TESLA
2A

Car selection for the P3 Charging Index - US

Only all-electric vehicles with the charging standard "CCS" (Combined Charging System - fast-charging with Combo 1 plug) and Tesla with its proprietary plug were considered for testing. Vehicles were primarily selected based on recent sales numbers and availability to P3 for testing. The vehicles tested were press vehicles from the manufacturers and open market rentals with the latest software and hardware releases. The selection of cars represents a cross-section of the market as large as possible. However, only some of the requested vehicles were made available to P3, so some electric vehicles are not included in the P3 Charging Index - US.

The 2023 US edition of the P3 Charging Index encompasses a total of 13 electric vehicles. The models were divided into two categories to better

structure the analysis and visualization of the data. Considering that tax credits are available for specific models in the United States, the report classifies EVs based on their eligibility for those credits.

Certain electric vehicles purchased in 2023 are eligible for a federal tax credit of up to $7.500, depending on factors such as their MSRP (manufacturer's suggested retail price), location of final assembly as well as their purchase scenario (placed in service on/after vs. before April 18, 2023).[2]

Classification of vehicles in this publication was conducted under purchase scenario 1 (placed in service on or after April 18, 2023), as this aligns with the testing phase in April of 2023 and applies to cars purchased after the release of the publication.[3] Vehicles are categorized as either not eligible or eligible; credit amount is not factored in.

Not Tax Credit eligible (net battery capacity in kWh)	Tax Credit eligible (net battery capacity in kWh)
BMW i4 eDrive40 Gran Coupe (19 in. wheels, 80.7 kWh)	Ford F-150 Lightning 4WD Extended Range (131 kWh)
BMW iX xDrive50 (22 in. wheels, 105.2 kWh)	Ford Mustang Mach-E CAL RT 1 ER RWD (91 kWh)
KIA EV6 LR RWD (74 kWh)	Rivian R1T (125 kWh)
Lucid Air Grand Touring (112 kWh)	Tesla Model 3 Long Range AWD (75 kWh)
Polestar 2 LR Single Motor (75 kWh)	Tesla Model Y Long Range AWD (75 kWh)
Porsche Taycan GTS (83.7 kWh)	VW ID.4 Pro (77 kWh)
Tesla Model S Plaid (19 in. wheels, 95 kWh)	

[2] See https://fueleconomy.gov/feg/tax2023.shtml
[3] Classification of vehicles is solely based on the timing of this publication to organize and visualize the data. It does not reflect any judgment or view of P3

Data collection for the P3 Charging Index - US

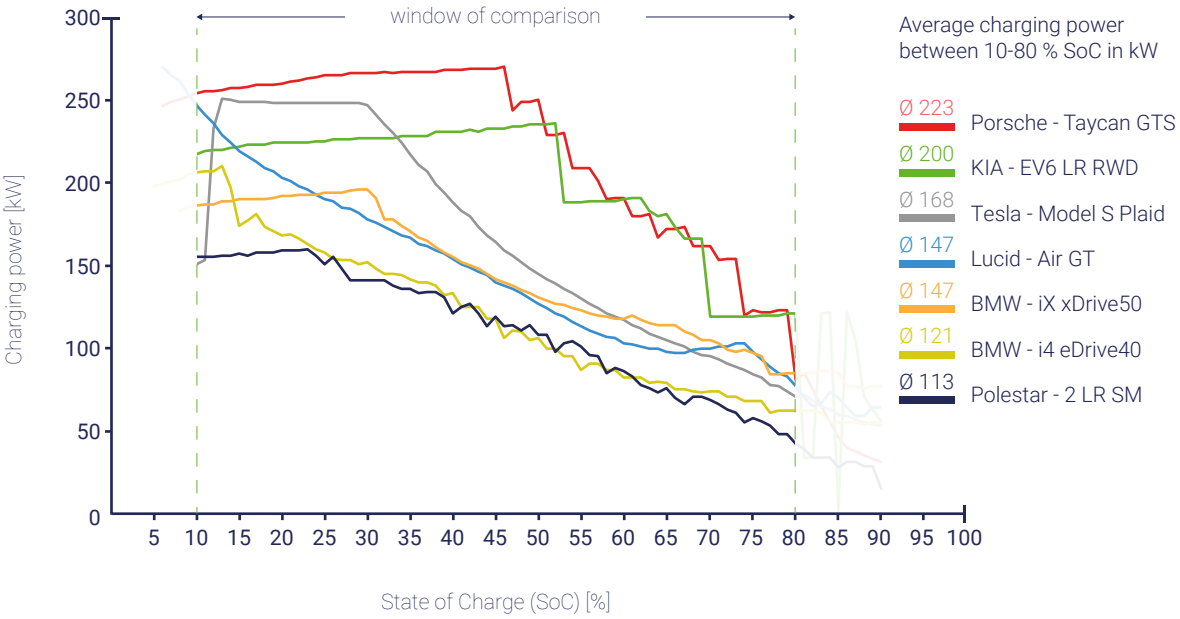
To better assess the long-distance suitability of the vehicles, the comparison is based on the recharged range of the cars rather than their charging behavior. To determine that range the vehicles were charged and charging power, total recharged energy and time were recorded for each SoC increment. All charging curves shown were measured by P3 experts at charging stations of the same network provider in California, with a maximum charging power of 350 kW. Only the Tesla Model 3, Model Y and Model S Plaid were measured at Tesla Supercharger V3's since Tesla models in the United States are not equipped with a built-in CCS 1 connector.

Charging power itself is not a reliable indicator of the long-distance suitability of electric vehicles

The charging behavior is considerably impacted by ambient conditions such as temperature and available power at the charging station. To ensure consistency of the data, the publication compares the charging speeds of the vehicles under ideal conditions, allowing each car to reach maximum charging power. This requires the battery to have a relatively low SoC and be preconditioned for fast-charging. The tests were therefore designed to replicate those ideal testing conditions.

The P3 Charging Index considers a charging window between 10%-80% SoC, representing the best possible charging session based on the experience of P3 experts and users. Manufacturers charging durations are usually indicated for this range as well. Multiple charging cycles were measured per vehicle to guarantee that conditions were met. Tests were performed in April, and California was selected as the testing location, as it provides extensive fast-charging infrastructure and moderate ambient temperatures at that time of the year.

P3 charging curves for different battery electric vehicle (BEV) models



Source: P3 Test Drive

Comparison of maximum and average charging power of electric vehicles [kW]

The comparison of different electric vehicles shows that the maximum charging power indicated by the manufacturers is only achieved for a few minutes during the charging session and that the vehicle-specific performance varies significantly. Looking at the average charging power, a "charging window" between 10%-80% SoC is representative of the charging behavior between vehicles, which is also underlined by the comparison of selected cars:

Porsche
Taycan GTS

The Porsche Taycan GTS achieves the highest peak power in the P3 Charging Index - US test, reaching 270 kW (together with the Lucid Air GT), as well as the highest average charging power between 10%-80% SoC of 223 kW. These values can be attributed to the 800 V architecture. The Taycan GTS can charge >200 kW from 10% to >55% SoC and >120 kW up to 80% SoC.

Highest peak power

270 kW

Lucid
Air Grand Touring

In the 2023 P3 Charging Index - US, the Lucid Air Grand Touring reached 270 kW[4] instead of the advertised 300 kW peak power. This is still the highest value in this publication, together with Porsche's Taycan GTS. As with the Porsche Taycan GTS, the high peak power can be attributed to an 800 V architecture. Featuring a regressive charging curve, an average charge power between 10%-80% SoC of 147 kW was achieved.

Tesla
Model S Plaid

The Tesla Model S Plaid shows a peak power of 251 kW and an average charging power of 168 kW[5] between 10%-80% SoC, although based only on a 400 V architecture. Notably, the Model S Plaid can sustain a charging power of over 200 kW up to 35% SoC, enabling faster charging and enhanced convenience for Tesla Model S Plaid owners.

[4] Note that the maximum charging power of 270 kW is reached below 10% SoC and therefore not factored into the average calculated between 10%-80% SoC.
[5] The Tesla S Plaid ramps-up charging power at 12% SoC; however, the average charging power is calculated between 10%-80% SoC.

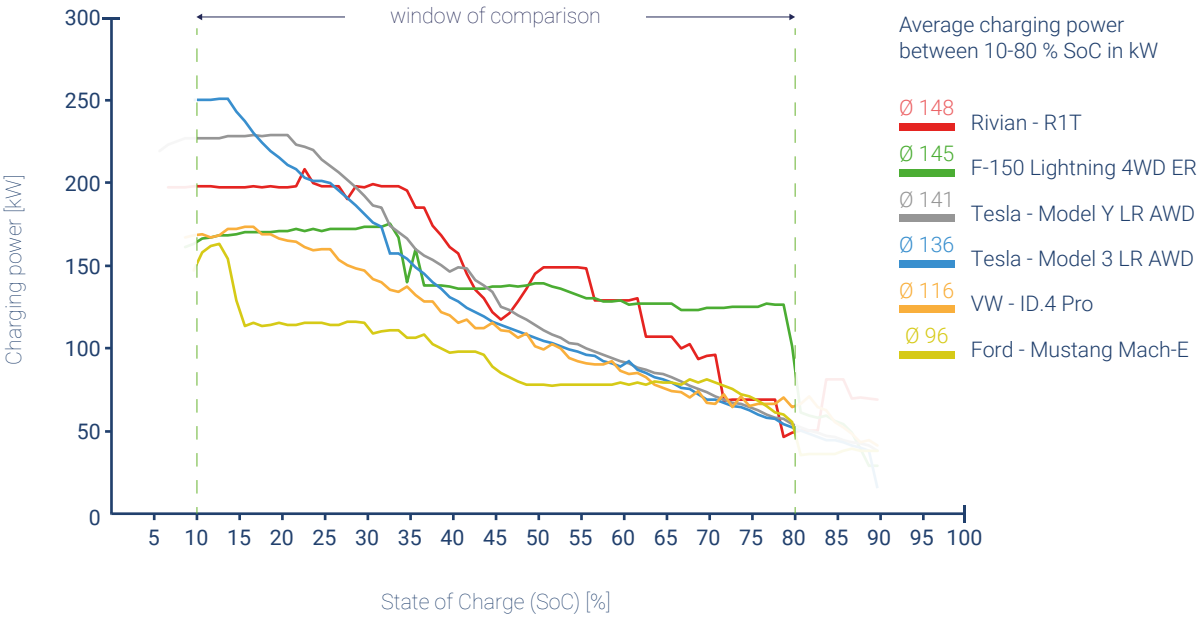
KIA
EV6

The KIA EV6 can charge with a maximum charging power of 236 kW. Its 74 kWh usable battery capacity is based on Hyundai Group's proprietary E-GMP platform and can be charged with an average charging power of 200 kW between 10%-80% SoC also based on an 800 V architecture.

BMW
iX xDrive50

Despite its charging power peak at 200 kW, the BMW iX xDrive50 exhibits a charging curve like that of the Lucid above 30% SoC. Both vehicles achieve the same average charging power of 147 kW between 10%-80% SoC.

P3 charging curves for different battery electric vehicle (BEV) models



Source: P3 Test Drive

Rivian R1T

The Rivian R1T charges at a peak power of 208 kW and an average charging power of 148 kW between 10%-80% SoC. Notably, the R1T maintains a charging capacity of about 200 kW up to 35% SoC, allowing faster charging.

Ford
F-150 Lightning

Despite that its average charging power between 10%-80% SoC of 145 kW is very similar to that of its pickup competitor Rivian and that their battery capacities are comparable, Ford F-150 Lightning's fast-charging capability is lower, especially until about 35% SoC. While the R1T maintains its charging power around 200 kW up to 35% SoC, the F-150 only charges up to 175 kW in that range.

Tesla
Model Y

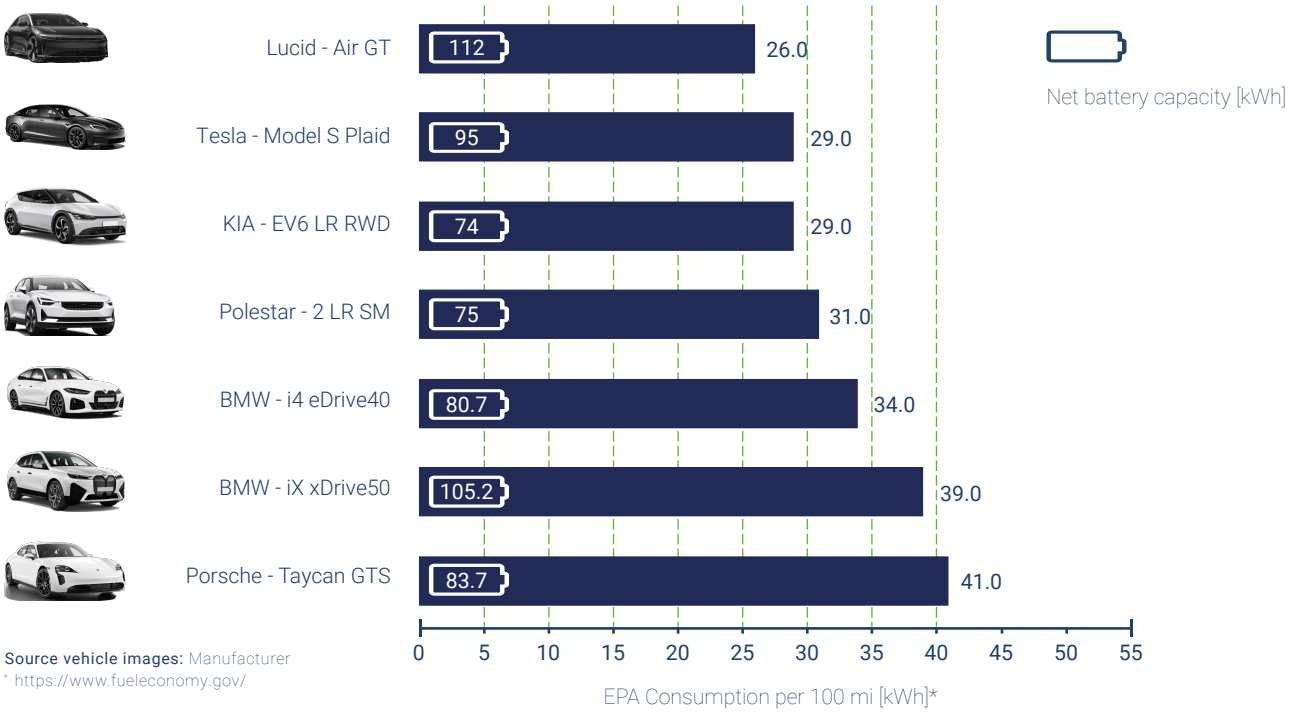
The tested Tesla Model Y is built with BYD battery cells, which can maintain the charging power longer, resulting in an increase of the average charging power from 109 kW in P3CI - EU 2022 to 141 kW in the P3 Charging Index - US.

Vehicle consumption used in the P3 Charging Index - US

In the United States data on fuel economy and fuel consumption can be obtained from the Environmental Protection Agency (EPA). Car manufacturers test their vehicles in a laboratory following specific test procedures and are required to submit their data annually to the EPA. During this test, the EV is tested on a dynamometer through a combination of city and highway driving cycles. Adjustment factors are applied to reflect real-world conditions more accurately. EPA confirms the accuracy of the data through reviewing and testing.[6]

The energy consumption of EV's is listed in kWh / 100 mi on fuel economy labels[7]. Since the EPA values are used for the official fuel economy labels of new cars in the United States, the 2023 P3 Charging Index - US uses

Comparison of the BEV consumption (EPA)



Source vehicle images: Manufacturer

* https://www.fueleconomy.gov/

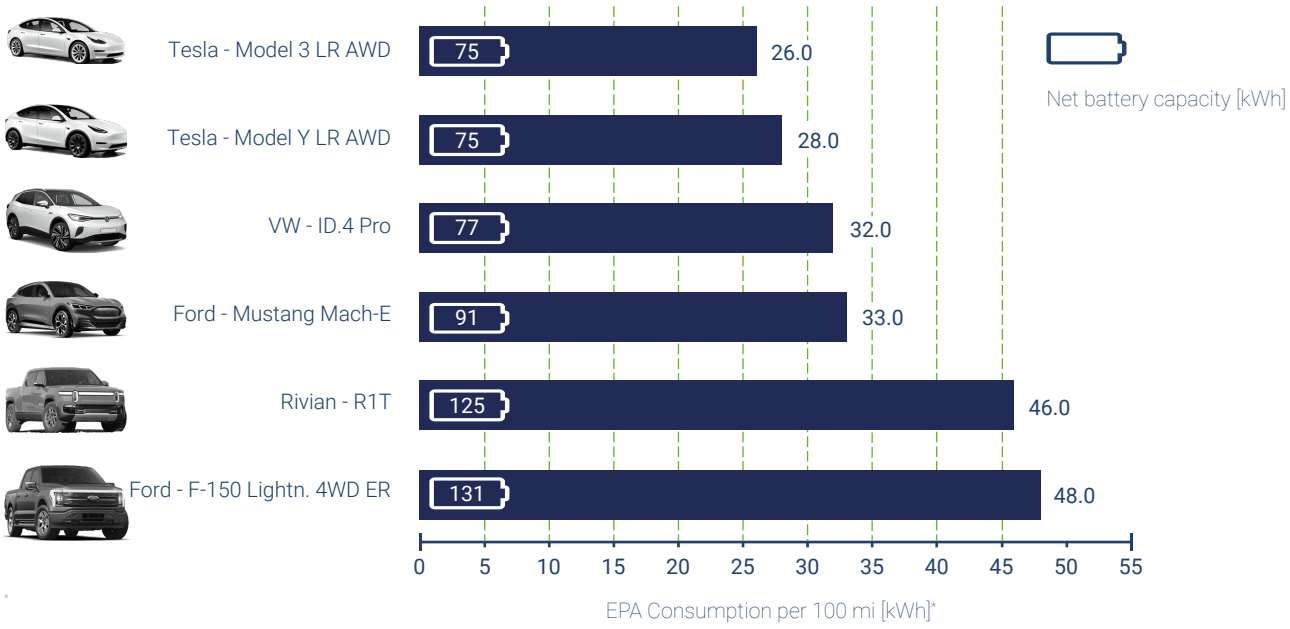
[6] https://www.epa.gov/greenvehicles/testing-national-vehicle-and-fuel-emissions-laboratory
https://fueleconomy.gov/feg/pdfs/EPA%20test%20procedure%20for%20EVs-PHEVs-11-14-2017.pdf
https://fueleconomy.gov/feg/how_tested.shtml

[7] https://www.fueleconomy.gov/feg/label/learn-more-electric-label.shtml

those same consumption values to calculate the recharged range.
Although the Lucid Air GT has the largest battery in the "Not Tax Credit eligible" vehicle class with a net capacity of 112 kWh and the third largest battery in the entire P3 Charging Index - US, it has a low EPA consumption of only 26 kWh / 100 mi. This is the lowest consumption among all 13 vehicles and can only be matched by the Tesla Model 3 LR AWD. Based on EPA consumption values, the Lucid Air GT consumes 15 kWh / 100 mi less than the Porsche Taycan GTS, as the Porsche has an EPA value of 41 kWh / 100 mi.

The Tesla Model S Plaid consumes more than the Lucid, with 29 kWh / 100 mi. On the other side, the battery capacity is lower at 95 kWh but still higher compared to Tesla Model 3 and Model Y of the “Tax Credit eligible” category with 75 kWh each. The KIA EV6 LR RWD shares the consumption value of Tesla’s Model S Plaid with 29 kWh / 100 mi, but its battery is smaller, with 74 kWh net battery capacity.

Comparison of the BEV consumption (EPA)



Source vehicle images: Manufacturer
https://www.fueleconomy.gov/

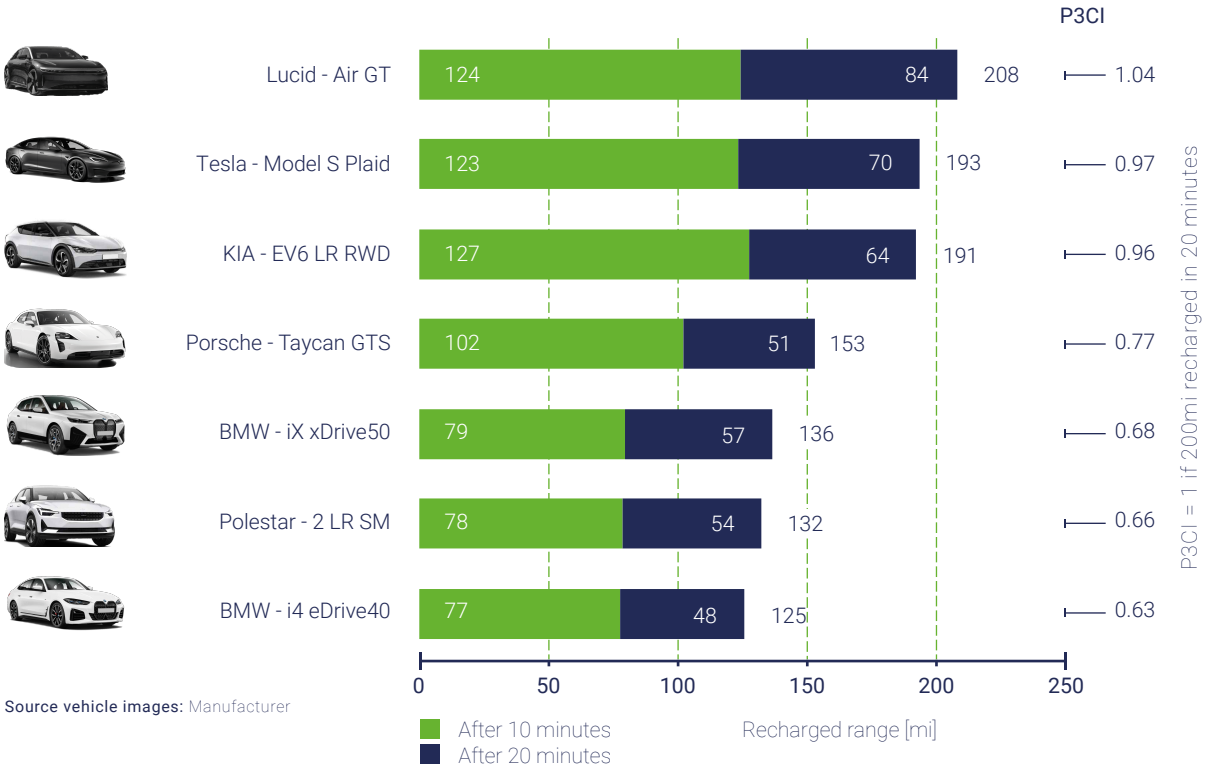
From a consumer's perspective, the evaluation must also consider consumption and charging duration

Neither the maximum charging power nor the consumption are individually determining the long-distance suitability because a typical, real-world charging session needs to answer one crucial question for the electric vehicle driver:

→ What range is required to reach the next destination, and how long does it take to recharge that range?

Analysis of recharged range (mi) Not Tax Credit eligible vehicles

Comparison of recharged miles after 10 and 20 min of charging (start @10% SoC)



Source vehicle images: Manufacturer

With a P3CI - US of 1.04, the Lucid Air GT places first in the class of vehicles not eligible for tax credits. Being the only vehicle of all 13 with a P3CI - US above 1.0 also makes the Lucid the overall winner of the 2023 P3 Charging Index - US. Its average charging power of 147 kW between 10%-80% SoC is outweighed by its low consumption, resulting in 208 recharged miles after 20 minutes.

Tesla's Model S Plaid comes in 2nd (193 recharged miles after 20 minutes) with a P3CI - US of 0.97.

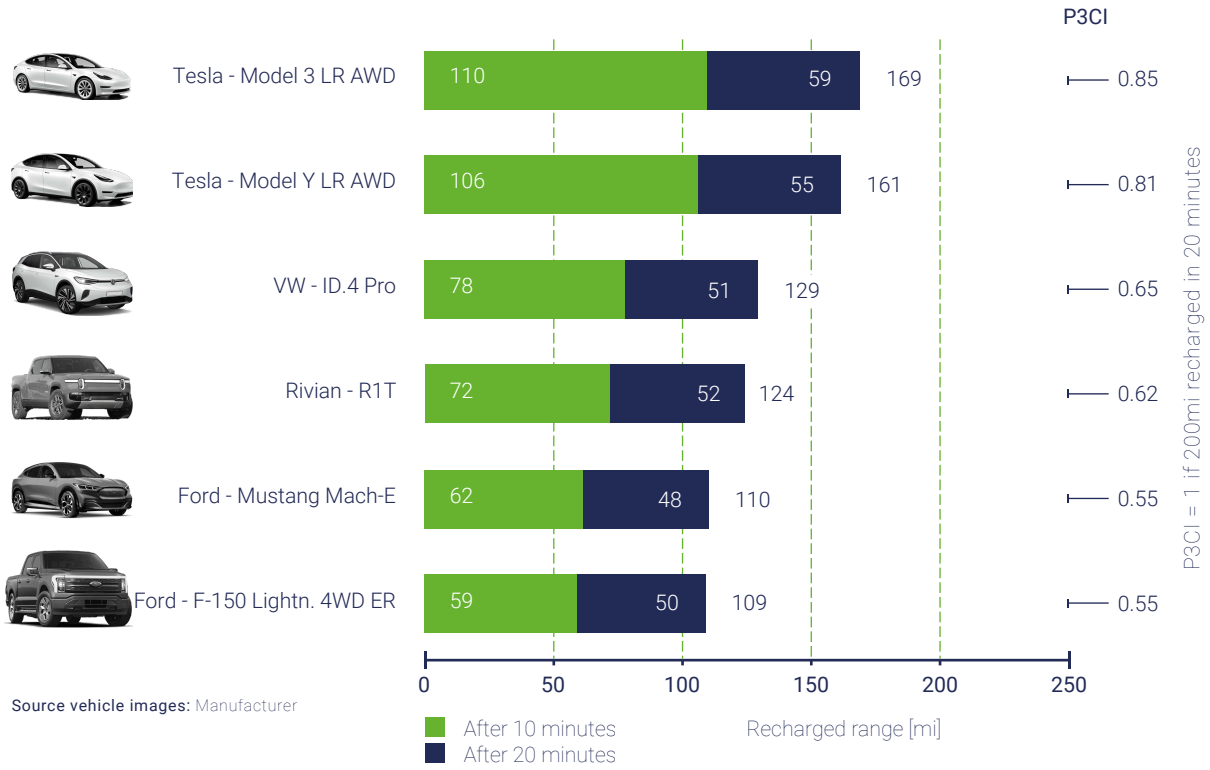
The KIA EV6, the winner of the 2022 P3 Charging Index - EU, ranks third with 191 miles recharged after 20 minutes and achieves a P3CI - US of 0.96.[8] The KIA benefits from its high charging power above 200 kW until 52% SoC, whereas the Tesla Model S Plaid charges below 200 kW already at 38% SoC. Since the P3 Charging Index - US considers a higher range of 200 mi (~321 km) than the P3 Charging Index - EU (300 km) and uses different consumption parameters (EPA instead of ADAC Ecotest), the values differ from last year's publication in Europe.

The Porsche Taycan GTS finishes 4th in this category with a P3CI - US significantly lower than the first three (0.77, based on 153 recharged miles in 20 minutes). Despite achieving the highest peak and average charging power, its high EPA consumption of 41 kWh / 100 mi leads to a lower P3CI - US of the German sportscar. Recharging 136 miles in 20 minutes, the BMW iX xDrive50 reaches 5th place and a value of 0.68. In 6th and 7th place in this category are the Polestar 2 (0.66, 132 miles) and the BMW i4 eDrive 40 (0.63, 125 miles).

[8] An increased target range of 200 miles and EPA consumption values caused a different P3CI - US of the KIA EV6 in 2023 as compared to the P3CI - EU 2022

Analysis of recharged range (mi) Tax Credit eligible vehicles

Comparison of recharged miles after 10 and 20 min of charging (start @10% SoC)



Source vehicle images: Manufacturer

None of the EVs eligible for tax savings come close to the P3CI - US target value of 1.0. Tesla is ahead with the Model 3 Long Range AWD at 0.85 and the Model Y Long Range AWD at 0.81. Model 3 achieves the highest peak charging power (251 kW) in the comparison in this category but only an average charging power of 136 kW between 10%-80% SoC. The Model Y maintains its peak power of 229 kW longer than the Model 3, resulting in a higher average charging power (141 kW) in this SoC window between 10%-80% SoC.

Within 20 minutes (starting at 10% SoC), the vehicles recharge a range of 169 miles (Model 3 with 26 kWh / 100 mi consumption) and 161 miles (Model Y with 28 kWh / 100 mi consumption). The VW ID.4 Pro, built on Volkswagen's MEB platform, charges a range of 129 miles in 20 minutes with its 400 V architecture, leading to a P3CI - US of 0.65. This shows that despite a lower average charging power of 116 kW, low consumption of 32 kWh / 100 mi can result in satisfactory charging.

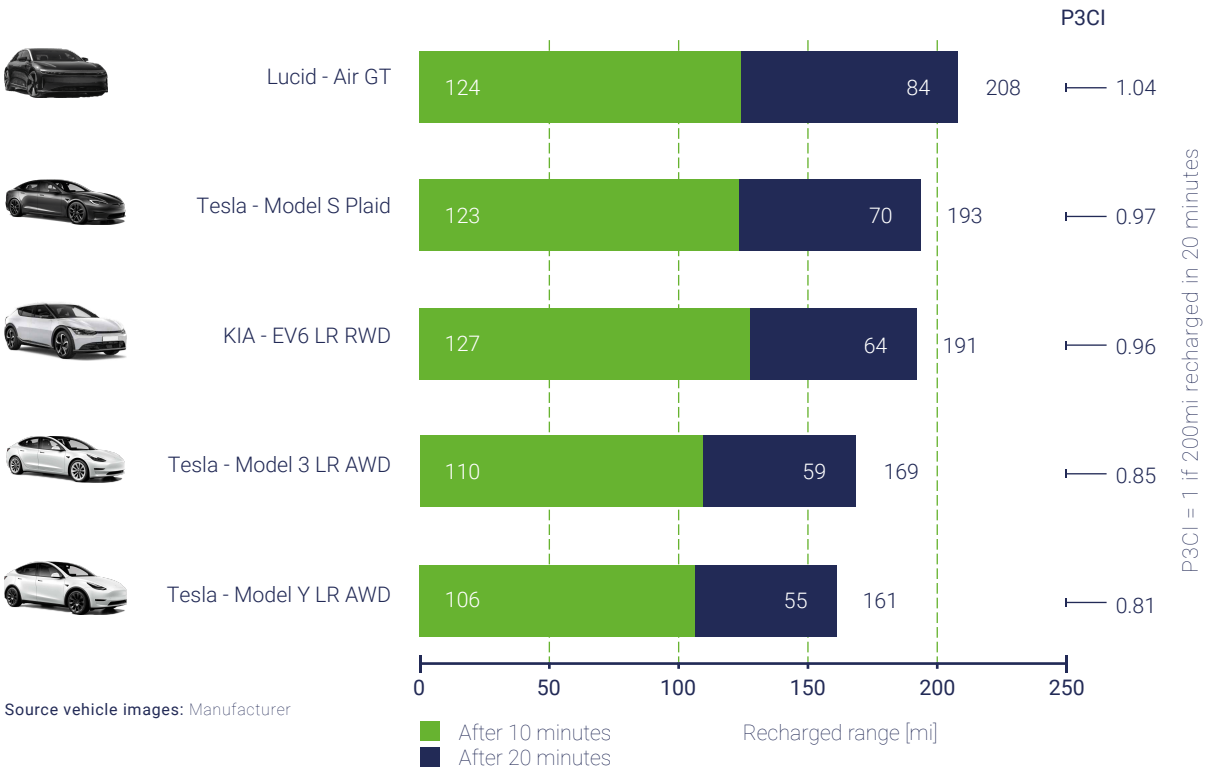
Analysis of the recharged ranges (mi) – Top 5

The Lucid Air GT emerges as the winner across both segments of the P3 Charging Index - US 2023 with a score of 1.04 (208 miles recharged in 20 minutes) due to a good charging performance but even more so because of a low consumption of 26 kWh / 100 mi. Tesla's Model S Plaid finishes second with a P3CI - US of 0.97 (193 miles), which is still quite noticeable but a little below the target P3CI - US of 1.0 based on a recharged range of 200 miles in 20 minutes of charging. The KIA EV6 LR RWD, as the P3 Charging Index - EU 2022 winner, secures third place with a score of 0.96 (191 miles). In contrast, the score is lower than in the EU publication due to a different underlying distance (miles instead of km) and a different consumption reference (EPA instead of ADAC Ecotest). The Top 5 is completed by Tesla's Model 3 (0.85, 169 miles) and Model Y (0.81, 161 miles), so Tesla secures three of the top five places in this year's P3 Charging Index - US.

P3 Charging Index - US

1st Place

Comparison of recharged miles after 10 and 20 min of charging (start @10% SoC)



Source vehicle images: Manufacturer

Summary

In its first edition for the United States, the P3 Charging Index - US analyzes the fast-charging behavior and long-range suitability of 13 electric vehicles. The P3CI - US translates charging performance and average consumption into a single value, thus enabling an user-friendly comparison of electric vehicles. In the 2023 Report, a P3CI - US value 1.0 is equivalent to a recharged range of 200 miles within 20 minutes.

The Lucid Air GT ranks highest with a P3CI - US of 1.04 and is the only vehicle with an index greater than 1.0. Its top rank can be attributed to high charging power and low consumption. The Tesla

Model S Plaid achieves an index of 0.97 and the KIA - EV6 LR RWD of 0.96 in the first P3 Charging Index - US, placing them 2nd and 3rd. Although two of the leading three cars are luxury cars, the KIA proves that non-luxury cars are capable of long ranges. Four of the top five cars are US models.

Comparing the P3CI - US rating to the vehicle data of the electric vehicles demonstrates that the long-distance suitability of electric vehicles depends on multiple factors. One of those is the 800 V architecture which enables higher charging power, although this only positively impacts long-distance suitability in combination with low consumption. The Porsche Taycan GTS featured an 800 V architecture and was able to maintain outstanding charging power until close to 46% SoC; however, because of its high consumption, only ranks 6th overall. Despite their lower 400 V architecture and average charging power, all three Tesla models rank higher due to their low consumption. The determining factors for the low ranking of the bottom five cars are attributed to low average charging power (VW ID.4 Pro, Ford Mustang Mach-E, and Polestar 2 LR Single Motor) or high consumption (Rivian R1T and Ford F-150 Lightning).

The 2023 P3 Charging Index - US demonstrates that more and more EVs can feasibly travel long distances. Long ranges are especially important in rural areas where charging stations are currently not as widely available. Programs such as the Michigan to Montana I-94 Corridor (M2M) or the Lake Michigan Electric Vehicle Circuit Tour will expand the charging infrastructure across the US. However, technological improvements across a broader range of vehicles are still needed to increase EV acceptance further. Vehicles popular in the US, such as pickup trucks (in this publication represented by the Rivian R1T and the Ford F-150 Lightning), could benefit from improved charging behavior. Future trucks such as the Chevrolet Silverado EV, GMC Sierra EV, and the Ram 1500 REV promise longer ranges on a single charge, but their charging speed remains to be assessed.[9]

[9] https://www.caranddriver.com/ram/1500-rev (June 5, 2023)
https://www.caranddriver.com/news/g29994375/future-electric-cars-trucks/ (June 5, 2023)

Regarding vehicle improvements, P3 does not consider further increases in battery capacities to be the primary way forward (except for larger and therefore heavier utility vehicles). The focus should instead be on possibilities for car and battery conditioning, increased efficiency, and optimized charging power, e.g., by adopting 800 V architectures. Those improvements, in combination with expanded charging infrastructure, will help to alleviate range anxiety and thus increase EV adaptation in the United States.

P3 has also entered into a partnership with car shopping resource Edmunds to develop consumer-focused charging insights. The initiative will combine P3 charging data with Edmunds' real-world range and efficiency testing.

Edmunds' Vice President of Editorial, Alistair Weaver said: "As more Americans consider an EV for their next vehicle purchase, range and charging efficiency will remain key concerns. The Edmunds EV Range and Efficiency Test has attracted global attention as an effective measure of real-world performance and P3 is renowned for its expertise in electric mobility. Through this partnership, Edmunds continues to empower and guide car shoppers with valuable insights. We look forward to sharing more in the months ahead."

P3 USA Partner for Strategy and Technology, Simon Buderath comment: "After the publication of our first P3 Charging Index Edition for the US, we look forward to stepping into a partnership with Edmunds, combining their range and efficiency data with our insights and knowledge about charging performance. Leveraging the knowledge of both companies will help in convincing customers to switch to an electric vehicle and to transform the industry."

About P3

P3 is an independent and international consulting company that offers consulting and engineering services, as well as software development for numerous customers.

Since its founding in 1996 in Aachen, Germany, P3 continues to grow with over 1.800 employees in 30 locations.

P3 has been working intensively on electromobility in all these facets and many more since 2008. This has given us a deep understanding of the technologies, production and players, which we continue to develop on a daily basis. This enables us to provide you with comprehensive strategic advice – and thanks to our proven practical relevance, we can also support you in the implementation.

More than 200 of our consultants, engineers and software specialists are now working on e-mobility. Whether it's about the technical transformation of powertrain systems, battery cells, the charging infrastructure or specific application scenarios, we are there as a leading technology consultant. In addition, we dedicate ourselves to the market, analyse, prepare studies and participate in research projects.

At the same time, P3 has long been active itself: we invest in battery cell manufacturers, develop module and drive strategies, 48V on-board network architectures and numerous software solutions around e-mobility. Our customer network includes not only the major car manufacturers and their OEMs and suppliers, but also energy providers, the public sector and the government. Accordingly, we are strong in benchmarking and in looking at complex challenges from the outside to develop solutions.

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