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# P3 Charging Index: Comparison of the fast-charging capability of various battery electric vehicles

Christian Daake M.Sc.[1], Dipl.-Ing. Markus Hackmann
[1] *P3 Automotive GmbH, Heilbronner Straße 86, 70191 Stuttgart, Germany,*
*Christian.Daake@p3-group.com*

**Executive Summary**

P3 developed the P3 Charging Index to compare the charging speed of several battery electric vehicles (BEVs), from a user perspective. Combining the charging curve and the energy consumption of each EV, the recharged range (in km) over a certain charging time can be determined. 1.0 or higher was defined as an adequate value of the P3CI, for long-distance mobility. This corresponds to charging 300km range in 20 minutes. Most of the EVs evaluated in this study exceed that value, showing big advances in charging speed and energy consumption, compared to the first P3CI study in 2019, where among ten European EVs studied, the best ranked had a P3CI of only 0.72 [1].

*Keywords: Electric Vehicles; Standardization; AC & DC Charging technology; Fast and Megawatt charging infrastructure; Battery Management System;*

## 1 Introduction

When it comes to the long-distance capability of electric vehicles, negative headlines often dominate, fueling personal discussions and debates on social media. This makes it challenging to engage in an objective and fact-based examination of the topic. Statements such as “It takes hours to charge an electric car” or “Electric mobility is only suitable for the city and short distances, long journeys are not possible as I like to drive 800 kilometers” have become common prejudices. Such statements create uncertainty among potential users and interested buyers, who often decide against purchasing an electric vehicle. This is largely because questions about charging behavior and long-distance suitability are not adequately explained or fully addressed.

As an independent party for electric mobility, P3 is dedicated to delivering clear and comprehensive insights on the subject. The P3 Charging Index 2024 investigates and analyses the long-distance suitability and charging behavior of modern electric vehicles in order to assess how good the charging performance of current electric vehicles really is. The aim is to answer the central question in a factual and data-driven manner:

*“How many kilometers of real range can an electric car charge in 20 minutes at a fast-charging station?”*

## 2 Approach

In competitive comparisons of different electric vehicles, the parameters of maximum charging power in kilowatts [kW] and time for fast charging from 10% to 80% SoC are often presented in a simplified form. However, from the user's point of view, these two parameters are only of limited importance for the everyday fast-charging capability of electric vehicles. The P3 Charging Index was developed by the P3 Group in 2019 to make the real charging speed of electric vehicles comparable and easy to understand.

Key parameter for the user is the time needed to recharge the real range in kilometers. The P3 Charging Index uses this to compare the long-range capability of different electric vehicles. Using the vehicles' consumption and charging curves, the number of kilometers recharged in 10 and 20 minutes of charging time can be displayed, allowing a concrete comparison of the vehicles' fast-charging performance.
At the end of 2019, P3 recognized that there was no concrete comparison of fast charging behavior and developed the P3 Charging Index (P3CI), an independent standardization that enables a usage-based and realistic comparison of the fast-charging performance of electric vehicles. It considers the charging window between 10% and 80% state of charge (SoC), as this is when vehicles charge the fastest. The ideal value of the P3 Charging Index is 1.0, which corresponds to an effective recharged range of 300km in 20 minutes:

$$\text{P3 Charging Index} = \frac{\text{Real recharged range [km] in 20 minutes}}{\text{300km}}$$

*Figure 1: Calculation of the P3 Charging Index*

As in previous editions of the P3CI, vehicles optimized for range (e.g. long range model rather than performance models) [2] are tested and compared to better assess their suitability for long-distance travel. Furthermore, only vehicles equipped with the European charging standard CCS (Combined Charging System - fast charging via Combo 2 plug) are considered. To ensure consistency, practicality and comparability of results, P3 refers to the ADAC Ecotest fuel consumption figures. The consumption data used are published on the ADAC website and are all based on the well-known Ecotest electric cycle. The vehicles tested are mainly press vehicles from the manufacturers and the selection aims to represent as broad a cross-section of the market as possible. However, not all vehicles were available, meaning some electric vehicles are not included in the comparison test. To ensure comparability of the data, all charging curves shown were recorded by P3 experts at charging points with a maximum charging capacity of 350kW or 400kW.
This P3 Charging Index 2024 study for the 38th International Electric Vehicle Symposium and Exhibition (EVS38) focuses on the luxury class comparing eleven all-electric vehicles, including, for the first time, vehicles from China, which are now also available in Europe. The vehicles compared are part of the luxury class, which was defined beforehand by dividing 22 vehicles into two categories of eleven vehicles each, based on the gross list price of each model for the luxury class (> 62.500€) in question (German market). All-electric vehicles ≤ 62.500€ as part of the premium class are not included in this P3 Charging Index 2024 study for the EVS38 as this would go beyond the scope of this study.

### 2.1 Impact of charging power

The maximum charging performance of electric vehicles is only achieved under ideal conditions, i.e. when the vehicle has a low state of charge (SoC) and the battery is at the optimum temperature for fast charging, which can be achieved, for example, by preconditioning. The aim is to ensure that the vehicle's high-voltage battery is tempered so that it is within the optimum temperature window at the start of charging. This prepares the battery for the maximum possible charge. In some vehicles, if available, this is done via the vehicle's navigation system when the charging stop is scheduled (e.g. Porsche Taycan); in others, battery preconditioning can also be started manually (e.g. BMW).

The Porsche Taycan, Xpeng G9 and Genesis GV70 vehicles have an 800V electrical system and, as can be seen in the Figure 2, achieve the highest charging performance compared to all other vehicles. The reason for this is that they are charged with a higher voltage. The vehicles with a 400V architecture, such as the NIO ET5 and the BMW and Mercedes-Benz vehicles, are limited by their lower battery voltage and a maximum possible charge current of 500A at around 200kW.

The comparison of different vehicles shows that the charging curves are very individual and that the maximum charging power is only reached for a certain period of time during the charging process, with the vehicle-specific performance varying greatly. This is particularly evident in the charging curve of the Xpeng G9, which quickly loses a lot of power and therefore also shows a large difference between maximum (319kW) and average charging power (233kW) between 10% and 80% SoC.

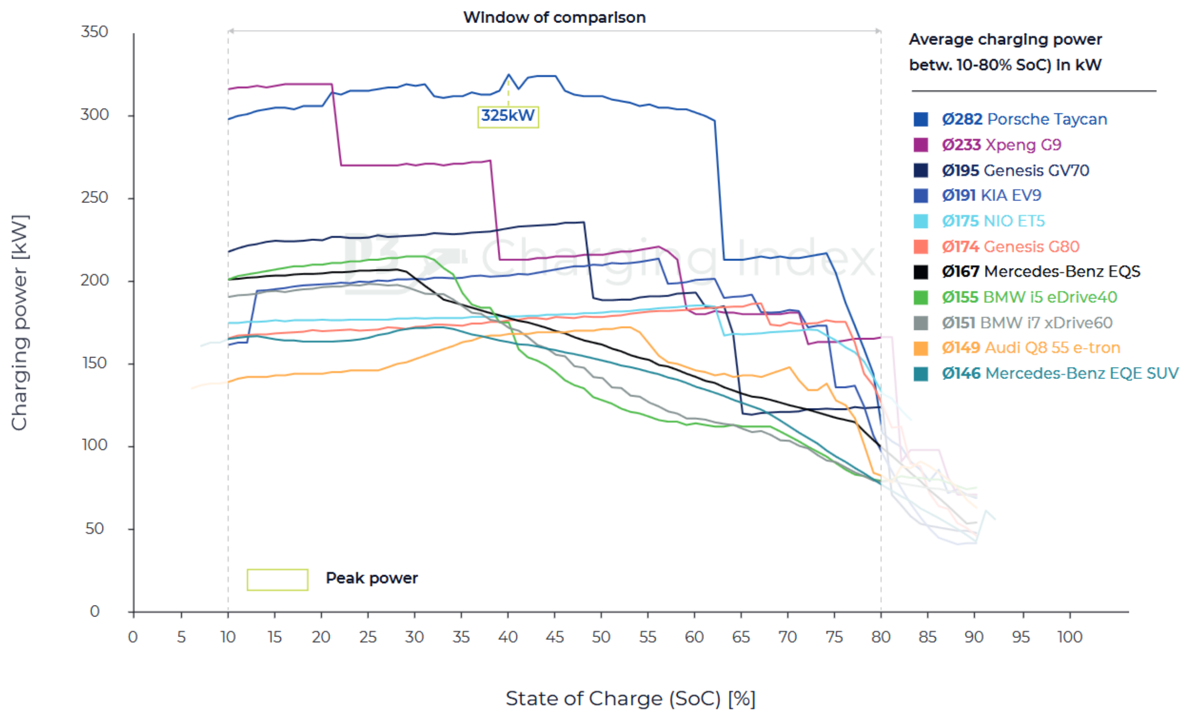


*Figure 2: Comparison of charging performance for the P3 Charging Index - luxury class category*

- **Porsche Taycan:** With the model launched in 2024, the charging power is increased by 50kW compared to the first generation from 2020 and the fast-charging window is now significantly extended. With a peak of 325kW, the Porsche Taycan achieves the highest charging power of all vehicles and maintains its peak plateau with more than 300kW up to over 60% SoC. This is reflected in the average charge between 10% and 80% at 282kW, which is also a good ratio of peak to average charge. The average charge power is the highest average of all the vehicles, meaning that the Porsche is the clear leader in charge performance and the new "Performance Battery Plus" can be charged from 10% to 80% in 18 minutes.

- **NIO ET5:** The electric estate car from China has a 400V architecture and charges almost constantly at around 180kW. This results in an average of 175kW over the entire SoC range, which is significantly higher than other 400V vehicles. The NIO ET5 is also unique in that it is the only vehicle in the comparison to have a battery swapping system. This allows the empty high-voltage battery to be swapped automatically for a 90% charged high-voltage battery in about five minutes at battery swapping stations, giving a real range of 362 kilometers (Assuming a battery of the same size with 10% SoC is replaced by one with 90% SoC).

- **Mercedes-Benz EQS:** The Mercedes-Benz EQS is based on a 400V architecture, but with its large 107.8kWh battery it can deliver a peak power of around 210kW and an average power of 167kW in the measured SoC window (10-80%).

- **BMW i5:** The all-electric BMW i5 eDrive40 has an 81kWh battery and, like the Mercedes, is based on a 400V architecture. At its peak, the i5 achieves a max. charging power of 215kW and is charged on average with 155kW from 10% to 80% SoC; the BMW i7 & i4, which are equipped with different battery sizes, can also achieve similar values. The BMW iX xDrive50, which has been available on the market since 2021 (see P3 Charging Index 2022), is also at a similar level to the i5 & i7.

Futurewise, the charging performance of electric vehicles will once again increase significantly in the coming years. In Germany, manufacturers such as BMW, Mercedes-Benz and Volkswagen will rely on innovative and new platforms in the future to make charging faster and more efficient. According to initial announcements, these efforts are expected to be accompanied by the following key metrics:

- **BMW** will increase charging speed by up to 30% compared to the current generation with the switch to an 800V architecture, with the New Class available from 2026. According to initial information from the Munich based company, it should be possible to recharge 300km within ten minutes. [3]

- **Mercedes-Benz** is pursuing a similar approach with the MMA platform. The all-electric CLA is to be equipped with an 800V architecture and achieve a max. charging capacity of over 320kW. [4]

- With the new **Porsche Macan** and the **Audi Q6 e-tron**, the Volkswagen Group has for the first-time launched vehicles based on the newly developed PPE (Premium Platform Electric) platform. This flexible platform will continue to evolve over the coming years, enabling the brands to integrate the latest technologies in high-voltage systems, powertrain, and chassis. Porsche also recently announced the launch of an all-electric Porsche Cayenne, which is expected to significantly exceed the current 270kW charging performance of the Porsche Macan.

- The electric car manufacturers from China are already setting new standards in terms of charging speed, as some announcements show. Vehicles such as the **Zeekr 007** with the Golden Brick Gen2 battery are expected to achieve C-rates of up to 5.5C with a charging power of more than 400kW, which corresponds to a charging time of 10.5 minutes for 10-80%. A C-rate of 1C means that a battery can be fully charged/discharged within one hour. [5] With its Qilin battery, CATL has developed a technology that can recharge almost 300 kilometers in ten minutes, according to a statement from CATL. [6]

- The **Lotus Emeya**, equipped with the CATL Qilin battery, already highlighted China's progress in the P3 Charging Index Asia in May 2024: the sedan was charged by P3 experts at a public CCS charging station in Germany with a maximum of 402kW. The average value between 10% and 80% was 331kW, outperforming the Porsche Taycan by almost 50kW. This charging performance was achieved by charging the vehicle at up to 600A using the 800V architecture. [7]

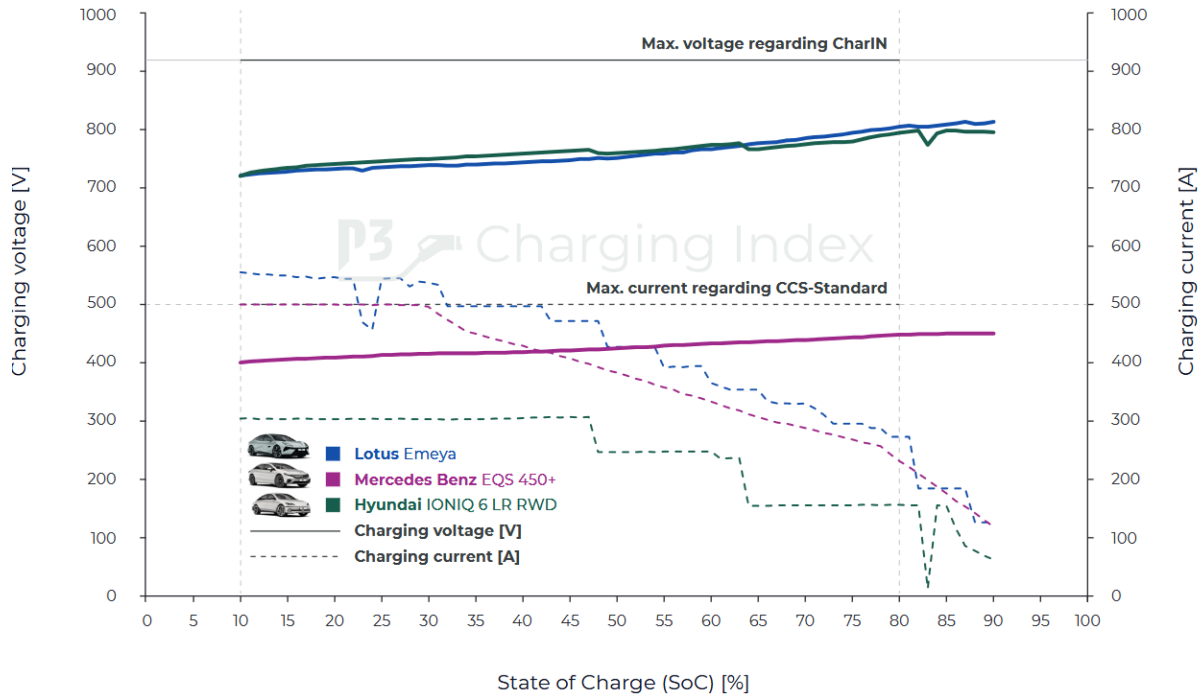


*Figure 3: P3 current/voltage curves for various battery electric vehicle models (BEV)*

The current limits for CCS charging are defined by CharIN with a maximum voltage of 920V as the upper limit for HPC charging stations and the CCS standard with a maximum current of 500A. In order to achieve the maximum theoretical charging capacity of 460kW, both values must be fully utilized. However, this is hardly possible as the charging voltage starts well below 920V (720V to 730V for the Emeya) and rises as the SoC increases. This leads to differences of 48V (EQS) to 84V (Emeya) in the measurements taken from 10% SoC to 80% SoC.
The charging currents, on the other hand, decrease significantly during the charging process. This is due to the increase in SoC and temperature, so although the charge voltage increases, the charge current decreases in the same way. In order to achieve even higher charging capacities at the beginning, charging currents up to the 600A mark are increasingly being targeted, which the Lotus Emeya also uses to achieve >400kW peak charging capacity.

## 2.2 Impact of vehicle consumption

In order to include the most realistic consumption figures possible for the individual electric vehicles in the calculation of the P3 Charging Index, the consumption values determined by the ADAC Ecotest were used. In the graph shown, these are compared with the WLTP consumption data and are shown together with the relative differences. [8] The ADAC electric cycle (part of the ADAC Ecotest) is run through in one go and repeated until an SoC <50% is reached or the cycle has been run six times. The vehicle is then fully charged using a type II charging plug (22kW or maximum possible AC charging power) and the required electrical energy is determined. The energy measurement also takes into account the charging losses that occur during normal charging (AC charging). [9]

Compared to premium class vehicles, luxury class vehicles generally have larger batteries, which range from 77.4kWh (Genesis GV70) to almost 108kWh in the Mercedes-Benz EQS in the vehicles analyzed. In addition to the weight of the battery, another factor for the energy consumption of an electric vehicle is the aerodynamics, which is described by the drag coefficient (cW value). Saloons in particular are characterized by very low drag coefficients, which has a positive effect on overall consumption. In comparison, most larger SUVs perform less well in terms of consumption, as they tend to consume more energy due to their higher wind resistance and often higher weight. One notable exception, however, is the Mercedes-Benz EQE SUV, whose consumption of 19.2kWh is only just behind that of the BMW i5 in the ADAC Ecotest.

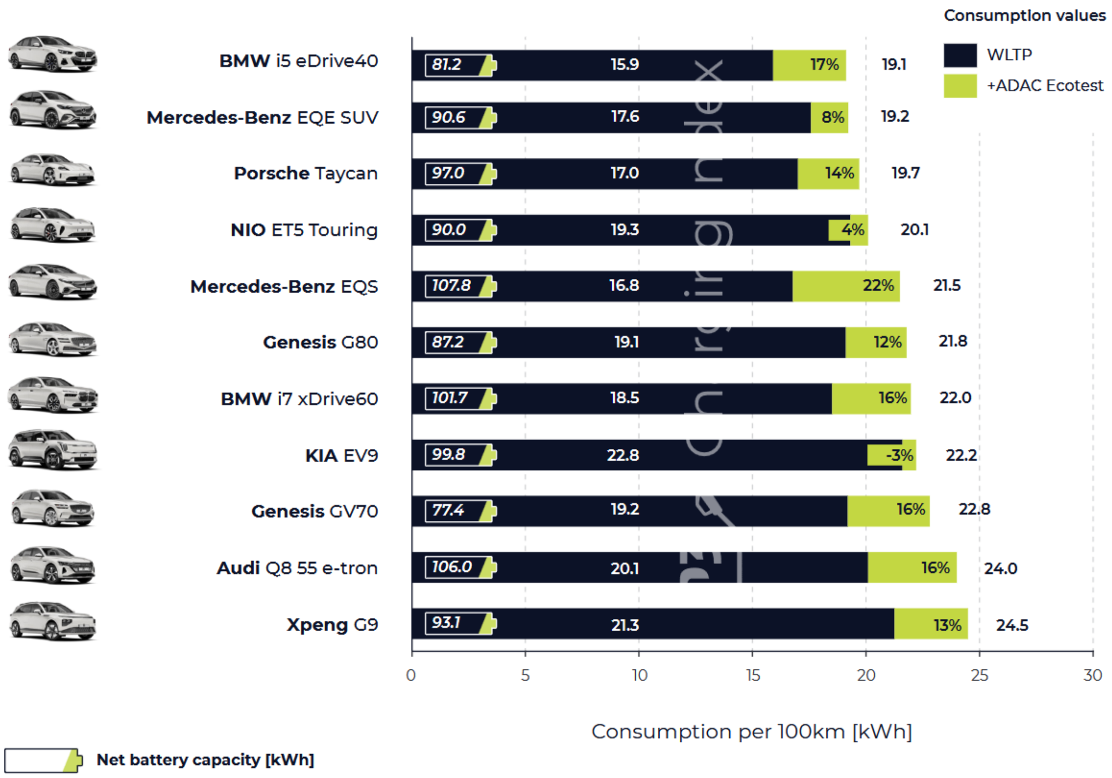


*Figure 4: Comparison of fuel consumption and battery size of vehicles in the P3 Charging Index - luxury class category*

Overall, the vehicles' fuel consumption varies widely, ranging from 19.1kWh per 100km in the BMW i5 eDrive40 to 24.5kWh per 100km in the Xpeng G9. In the i5 eDrive40, BMW has installed a particularly efficient powertrain. The business sedan has the lowest fuel consumption in the luxury class in both the WLTP and the ADAC Ecotest, with a difference of almost 20%. This is at the top end of the range and is only surpassed by the Mercedes-Benz EQS at 22%, while the majority of vehicles are below this with an average deviation of 12%.

The consumption of electric vehicles will be significantly reduced again in the next generation of vehicles. Trends are already emerging for the next generation of electric vehicles: BMW is emphasizing high efficiency when it comes to the “New Class”, which is set to be launched on the market in 2026 based on 800V architecture: the Generation 6 battery cell is expected to offer up to 30% more range, up to 30% faster charging and more than 20% higher energy density compared to the previous generation currently available on the market. This should increase efficiency by up to 25% through the sum of all measures. [10] With the PPE platform (first used in the Porsche Macan and Audi Q6), Volkswagen plans to further reduce fuel consumption and increase the range beyond the 600km mark. [11] The Chinese car manufacturer Xpeng, founded in 2014, published the data of the new P7+ in October 2024, which is based on an 800V architecture on the one hand, but is also supposed to achieve a very low consumption of just 11.6kWh thanks to a silicon carbide inverter, which in all likelihood does not represent WLTP consumption but the Chinese CLTC standard. [12]

# 3 Assessment of the long-distance suitability of electric vehicles

From the customer's perspective, neither the maximum charging capacity nor the consumption are individually decisive for long-distance suitability, because a typical, real charging process is essentially orientated towards one important question for the electric vehicle driver: *"How many kilometers of real range can an electric car charge in 20 minutes at a fast-charging station?"*.
P3 compares the charging power, consumption, and time to be able to compare the cars under real conditions:

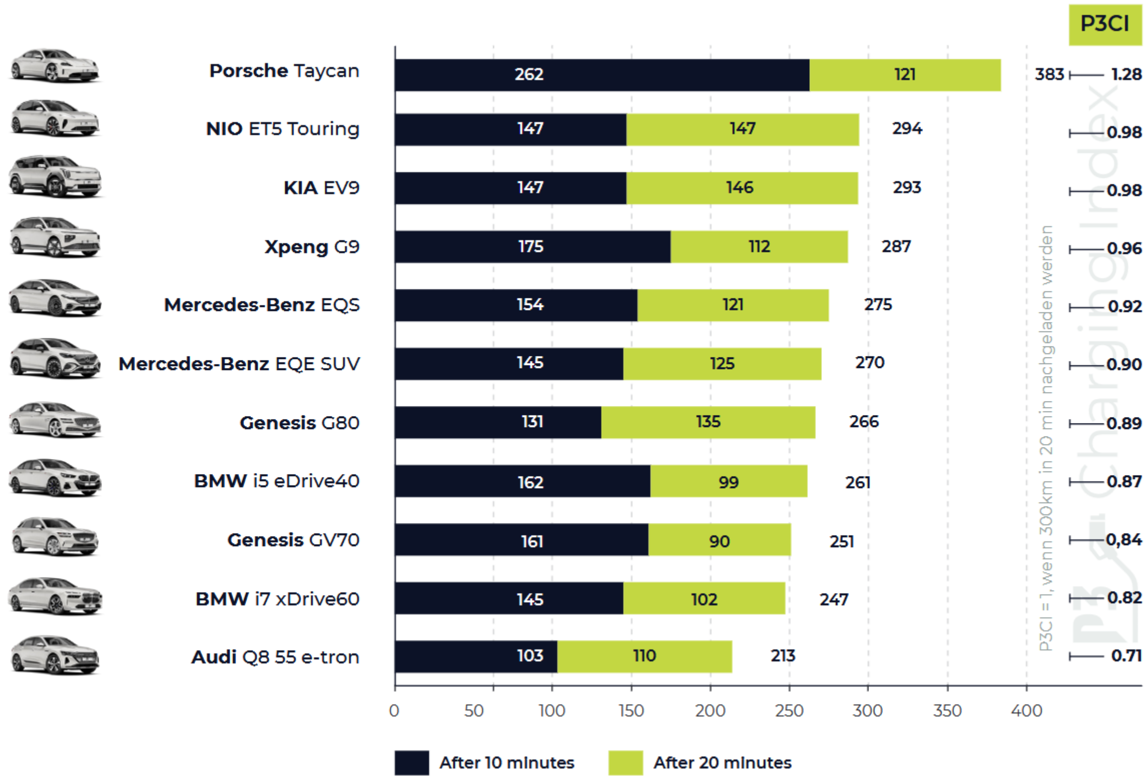


*Figure 5: Consideration of the real recharged range [km] in the P3 Charging Index - luxury class category*

- The **Porsche Taycan** is in first place in the luxury class of the P3 Charging Index and can recharge 262km of range in 10 minutes. In total, the saloon recharges 383km in 20 minutes. The Taycan thus impressively demonstrates the advantages that high charging performance in combination with low consumption can bring.

- A Chinese car manufacturer secures 2nd place in the luxury class at the first attempt, despite the 400V architecture, which underlines the rapid development of the Chinese car manufacturer and shows how quickly it can catch up. The **NIO ET5 Touring Long Range** recharges 294 kilometers of range in 20 minutes and is also the only vehicle that can also be recharged using a battery swapping system. This allows the empty high-voltage battery to be swapped for a 90% charged battery fully automatically in around 5 minutes at battery swapping stations.

- The **KIA EV9** follows just behind the NIO ET5 and recharges 293 kilometers of range in 20 minutes, which is a remarkable result considering the dimensions (size and weight) of the vehicle. The German vehicles with the 400V architecture come in behind the 800V vehicles. While they are still on a similar level to the 800V vehicles after ten minutes due to lower consumption and high charging performance, the comparatively weak charging performance becomes noticeable after approx. 40% SoC, which ultimately impacting the final result after 20 minutes.

# 4 Excursus: Development of electric mobility

More than five years after the publication of the first P3 Charging Index, the development of electric vehicles has come a long way:

**P3 Charging Index 2019: The beginning of long-distance electric mobility:**
In 2019, electric mobility was still at an early stage of technological development, particularly in terms of charging speed, range, and energy consumption. Nevertheless, the first vehicles with larger batteries and charging capacities of more than 100kW were launched. The Porsche Taycan set new standards with a peak charging power of up to 270kW and was able to maintain an average of 224kW in the charging range from 20 to 80% SoC. With this charging power, the Taycan was able to recharge approximately 216 kilometers of range in just 20 minutes. In comparison, the Tesla Model 3 achieved a maximum charge power of 250kW, with an average of only 128kW due to a constant reduction in charging power as the SoC increased. The energy consumption of the vehicles was typically between 22 and 28kWh/100km, which was considered efficient at the time. However, the target range of 300 kilometers after 20 minutes of charging remained an unattainable ideal. To make matters worse, a nationwide fast-charging infrastructure was still barely available, which severely limited the suitability of electric vehicles for everyday use on long journeys. The options in the event of an occupied or defective charging station in the vicinity were also very limited, so a charging station was often approached with a higher remaining SoC in order to have enough remaining range for an alternative charging station, just in case.

**P3 Charging Index 2021: Significant progress in charging speed and efficiency:**
In 2021, significant progress was already being made in the charging speed and efficiency of electric vehicles. The Mercedes EQS, equipped with a 400V system, achieved an average charging power of 164kW and was able to recharge up to 266km of range in just 20 minutes - a remarkable increase of 50km compared to the top models of 2019. Tesla was able to maintain its peak charging power of 250kW with the Model 3, while improving its average charging power and optimizing charging times in the 10-80% SoC range. Audi achieved a constant average charging power of 146kW with the e-tron 55 quattro, making it particularly suitable for long-distance driving, although consumption was expected to be in the higher range. Energy consumption has fallen to around 20-25kWh/100km for all vehicles, thanks to aerodynamic improvements and more advanced battery architectures.

**P3 Charging Index 2022: Breakthrough in the premium class category:**
Outstanding charging performance in the mid-size class was demonstrated in 2022. The KIA EV6, based on Hyundai's 800V E-GMP platform and equipped set new standards. With an average charging power of 203kW, the EV6 surpassed the ideal 300km range in just 20 minutes for the first time, achieving an impressive 309km (P3CI of 1.03). This was a significant improvement on the previous year's top models. The Hyundai IONIQ 5 and Audi e-tron GT also proved to be powerful vehicles with average charging capacities of 200kW and more, making long-distance journeys much easier. Energy consumption continued to fall, reaching 18 to 20kWh/100km in the premium class and 20 to 24kWh/100km in the luxury class, taking efficiency to a new level. These developments made electric vehicles increasingly attractive not only for premium customers but also for the volume market and have made a significant contribution to the market penetration of electric mobility in the past and today.

**P3 Charging Index 2024: Top level charging speed and efficiency:**
In 2024, electric mobility has advanced significantly in terms of technology, reaching new levels of charging speed and efficiency. The Porsche Taycan achieved a peak charging power of 325kW and was able to maintain an average charging power of 282kW in the charging range from 10 to 80% SoC. This allowed the vehicle to recharge up to 383km of range in just 20 minutes, a significant improvement over 2022. The Hyundai IONIQ 6 also made a strong statement in the premium class with an average charging performance of 193kW and a range of 346 kilometers in just 20 minutes. Consumption has been further reduced, with peak values of around 16-20kWh/100km for vehicles such as the VW ID.7. These advances not only make electric vehicles more suitable for everyday use, but also increasingly position them as an alternative for long-distance travel. The first vehicles from China are demonstrating their capabilities.

# 5 Conclusion and outlook

In this edition, the P3 Charging Index once again makes the real and practical charging performance of electric vehicles comparable, considering both the maximum and average charging performance of the vehicles, combining this with the overall efficiency and standardizing these key figures to a practical and realistic use case.

Electric mobility is suitable for long distances. The current generation of electric cars, such as the winning Hyundai and the almost twice as expensive Porsche, are proof of this. But the current success could be short-lived. Electric mobility has developed rapidly in recent years. Tesla has long been considered the unchallenged market leader, but the charging performance of the Tesla Model 3 has barely improved from 2019 (1st generation) to 2024 (Highland). The charging curve has been maintained since launch without any significant further development. Instead, European OEMs have continued to improve and will overtake Tesla in terms of charging performance by 2022. However, the focus should now be on keeping an eye on the Chinese OEMs and catching up. They are already setting the standard, and we can expect the bar to be raised even higher in the future with rapid development steps. European carmakers must act quickly and vigilantly, keeping an eye on the new manufacturers and, where necessary, forging strategic alliances to keep pace.

Despite all the new records, it is also important to develop electric mobility in a sustainable way, which was the subject of P3's recently published paper on the “State of Health” of batteries: the study shows that electric vehicle batteries have a long service life, even when used intensively. Even after driving more than 200,000 kilometers, most batteries retain more than 80% of their original capacity and can therefore be used well beyond the standard warranty period. Technological advances in cell chemistry and battery management systems continue to improve battery performance and durability. However, it is important to note that higher C-rates and faster charging lead to faster aging. The consequences of this for the batteries shown in the outlook, which are charged at extremely high charge capacities or C-rates, will become clearer in the future. Finally, the critical question is whether the battery system is designed for max. performance or max. life.

From P3's point of view, it is not technically or economically expedient to keep increasing battery sizes. Rather, optimizing the factors of charging power, efficiency and options for vehicle and battery conditioning are the most important levers for the future optimal and user-friendly design of electric vehicles. The aim is to find the sweet spot between maximum and average charging power, battery capacity and consumption in order to provide end customers with a good mix of parameters with the vehicle. If a single parameter is prioritized over others, the others often fall significantly, which ultimately diminishes the customer experience. This can be illustrated using the example of a significantly oversized battery. This is heavier and has a negative impact on consumption. On the other hand, it also requires a higher charging capacity to fully charge in a short time, which must be made possible by both the vehicle and the charging infrastructure.

In the long term, the success of electric mobility will largely depend on the combination of ultra-fast charging, high range, and reduced consumption. The technologies being developed by both European and Chinese manufacturers have the potential to complement each other and take electric mobility to a new level worldwide. While European manufacturers are aiming for ambitious targets in the coming years, China has already achieved them. This is both a challenge and an inspiration.

- Charging with 800V will become the standard. In the short to medium term, 800V technology is expected to become the standard for medium and luxury electric vehicles and charging times will be significantly reduced across all manufacturers. It is likely that other manufacturers will require charging currents more than 500A in order to achieve further increases in charging performance. Whether 800V technology will also find its way into the cost-sensitive compact class across the board cannot yet be predicted.

- Moderate battery sizes save weight and costs. In the near future, most electric vehicles will be launched with batteries between 80 and 100kWh net, according to current manufacturer announcements. This range represents a trade-off, as larger batteries offer greater range but also increase the weight and cost of the vehicle. The choice of battery capacity therefore remains a critical factor affecting both the efficiency and cost of vehicles.

- Energy consumption has a major influence on range and operating costs. The overall energy efficiency of the vehicle can be significantly improved by continuously reducing energy consumption. On the one hand, this can lower the running costs of the vehicle, and on the other hand, energy consumption has a significant impact on the range of the vehicle. This means that it is possible to achieve a high range with a moderate battery size, by balancing the parameters and identifying the sweet spot.

- The fast-charging infrastructure is being expanded across the board. On one hand, customer expectations are rising in terms of both the charging capacity of the vehicles and the charging infrastructure. On the other hand, charging point operators recognize an attractive business case and are increasingly focusing on HPC charging. In addition to the growing number of fast charging points in Europe, the average installed charging capacity is also steadily increasing.
  While the first generation of DC charging points could provide a maximum power of 50kW, charging parks with charging points in the 300-400kW range are increasingly being installed to meet the requirements of the current generation of vehicles. In addition to the expansion of the charging infrastructure for cars, an increasing number of CPOs are also announcing the construction of charging parks for electric trucks, which means that a P3 charging index for light and heavy commercial vehicles will become more realistic in the future.

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# Presenter Biography

Christian Daake is Senior Consultant E-Mobility at P3. He has been working at P3 since 2020 and is Team Lead for the topic area of DC Hardware & Interoperability Testing, which also includes responsibility for the P3 Charging Index. His academic background is based on a Master of Science in Industrial Engineering and Energy Management at University of Wuppertal and a Bachelor of Science in Electrical Engineering and Management at Bochum University of Applied Sciences.