38th International Electric Vehicle Symposium and Exhibition (EVS38) Göteborg, Sweden, June 15-18, 2025

Legacy vs. New OEMs: Divergent Innovation Strategies in Electrification and Autonomous Driving

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Executive Summary
This paper analyzes the innovation strategies adopted by legacy and new Original Equipment Manufacturers (OEMs) in the automotive industry. It examines various dimensions of innovation, including research and development (R&D) expenditures, patent activities, and strategic approaches toward electrification and autonomous driving. Employing a qualitative research methodology the study compares traditional and disruptive innovation models. The findings offer valuable insights into how established automotive giants and emerging players respond to technological disruptions and market transformations, and they discuss the potential for hybrid innovation models to drive sustainable growth. It is shown that legacy OEMs seem to be trapped in a classical "Innovator's Dilemma" and tend to adopt an innovation strategy based on closed innovation, whereas new OEMs prefer open and flexible innovation strategies. Furthermore, the results indicate that new OEMs tend to adopt faster innovation cycles.

Keywords: Electric Vehicles, Trends & Forecasting of e-mobility, Business models for vehicle sales, Autonomous xEV, Vehicle manufacturing

1 Motivation and Relevance

Since 1955, Fortune magazine has published an annual ranking of the 500 largest U.S. companies by revenue. A 2014 study by the American Enterprise Institute found that 88% of the original companies on this list no longer exist [1]. A company's ability to innovate is considered a key factor for profitable, sustainable growth and long-term business survival [2]. To remain competitive, companies must maximize their innovation output both quantitatively and qualitatively [3].

These challenges are reflected in areas such as electrification, autonomous driving, shared mobility, and connected cars, which are evolving rapidly [4]. Established manufacturers, or legacy OEMs, face significant pressure from new entrants bringing fresh technological approaches. New OEMs often benefit from starting without legacy constraints and with modern, flexible structures [5].

1.1 Research Questions

This paper focuses on OEMs in the automotive industry, specifically those selling finished vehicles under a brand name, classifying them as either "Legacy OEMs" (e.g., Volkswagen) or "New OEMs" (e.g., Xpeng, see Table 1). The paper aims to compare the innovation activities of legacy and new OEMs, with a focus on electrification and autonomous driving/ADAS. Key metrics like R&D spending, patents, and technical fleet developments (e.g., charging rates, electric range) are quantified and analyzed.

Table 1: Analyzed OEMs – Legacy vs. New

	1	2	3	4	5	6	7	8
Legacy OEM	BMW	Mercedes	Volkswagen	Porsche	Hyundai	Ford	Toyota	Kia
New OEM	BYD	Lucid	NIO	XPeng	Tesla	Polestar	Zeekr	

This paper addresses the following key questions:

- How do innovation strategies differ between legacy and new OEMs?
- What role do organizational structure, R&D investment patterns, and patenting behaviors play in driving innovation?
- How do external factors – such as regulatory policies, environmental mandates, and global supply chain issues – shape these innovation strategies?

2 Methodology

2.1 Research Design and Rationale

This study adopts a qualitative research design that emphasizes content analysis and case study methodology. The design allows for an in-depth exploration of both quantitative and qualitative dimensions of innovation across a diverse set of OEMs.

2.2 Data Collection Methods

Data were collected using a multi-method approach:

- Expert Interviews: Semi-structured interviews were conducted with innovation managers, R&D directors, and industry analysts from both legacy and new OEMs. These interviews provided insights into organizational strategies, challenges, and future plans.
- Secondary Data Sources: Industry reports, white papers, and databases such as SEC filings, the European Patent Office (EPO), and the United States Patent and Trademark Office (USPTO) were consulted to gather data on R&D expenditures and patent filings.
- Academic and Professional Literature: A comprehensive review of academic journals, books, and industry publications was undertaken to contextualize the findings within existing theories and frameworks.

The analysis was conducted using qualitative content analysis. Data were coded and categorized according to key themes such as R&D intensity, patent activity, strategic partnerships, and digital integration. Software was employed to manage and analyze the qualitative data, ensuring that themes were consistently identified across multiple data sources.

Triangulation of data sources (expert interviews, patent data, industry reports) was used to enhance the reliability and validity of the findings. Member-checking was also implemented by sharing preliminary results with several interviewees to verify the accuracy of the interpretations.

All participants were informed about the purpose of the study and provided their consent for participation. Confidentiality was strictly maintained, and data were anonymized to protect individual identities. The study adhered to ethical guidelines as outlined by the relevant research institutions.

3 Results: OEM analysis

3.1 R&D expenditures

The R&D expenditures of relevant OEMs from 2018 to 2023 have changed significantly. The data were derived from the annual reports of these companies – specifically, from the SEC's standardized Form 10-K and Form 20-F filings, which provide comprehensive financial information for investors [7] - [70]. To ensure comparability, all figures have been converted into Euros using the year-end exchange rates. For Zeekr and MG, no reliable data could be obtained.

The data illustrate the absolute R&D spending (in billion Euros) of the OEMs analyzed over the period. Throughout the entire paper, legacy OEMs are represented by solid lines, while new OEMs are shown with dashed lines (see Figure 1).

3.1.1 Total R&D expenditures

For the purpose of this paper, Volkswagen refers to the Volkswagen brand – not the group. VW exhibits significantly higher R&D expenditures compared to other OEMs, explaining the large gap observed (see Figure 1 (a)).

In general, legacy OEMs display relatively stable R&D spending with slight increases from 2018 to 2023. Notable exceptions include Volkswagen's steep rise from about 14 billion Euros in 2020 to nearly 22 billion Euros in 2023, Toyota's reduction of roughly 7.5% over the period, and BMW's increase of approximately 42%.

In contrast, new OEMs (with the exception of Polestar) show much higher percentage increases – often exceeding 100% – with BYD's growth reaching about 700% from 2018 to 2023. Despite this, legacy OEMs still maintain substantially higher absolute R&D investments. Only Porsche, Hyundai, and KIA exhibit values that are comparable to those of leading new OEMs.

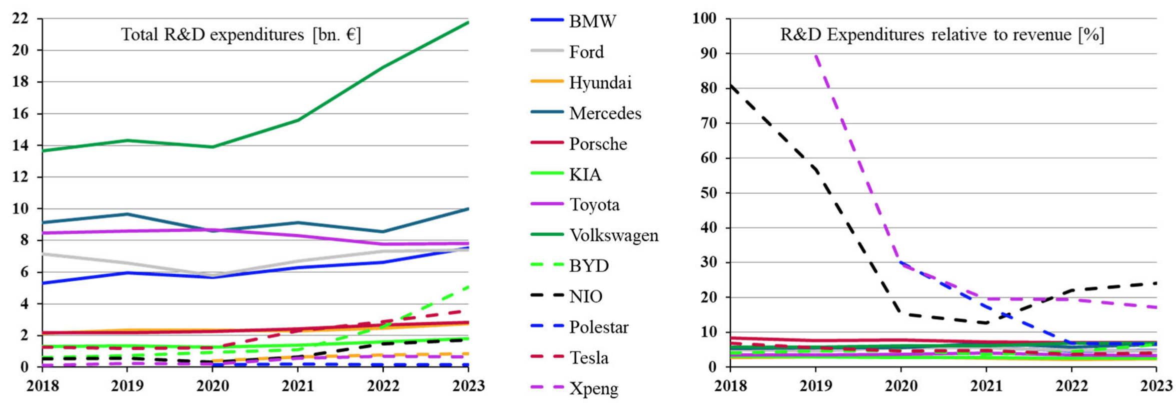

Figure 1: (a) Total R&D expenditures of OEMs in billion euros (annualized) and (b) relative R&D expenditures based on revenue of OEMs in billion euros (annualized) [7] - [71].

3.1.2 R&D Intensity Relative to Revenue

Figure 1 (b) presents R&D expenditures as a percentage of annual revenue. Only values within the 100% range are included; outliers such as Lucid and, for 2018, Xpeng are excluded.

Most OEMs, both legacy and new (e.g., Tesla and BYD), concentrate within a range of approximately 2% to 8% of revenue.

However, some new OEMs like Xpeng, Tesla, and Polestar initially show much higher percentage values, which tend to decrease over time. For instance, Xpeng and NIO stabilize between just under 20% and around 24%, with NIO even demonstrating a slight upward trend.

After initially high percentages in 2020 and 2021, Polestar's values also settle in the 2% to 8% range.

In summary, while new OEMs exhibit dynamic growth in R&D intensity relative to revenue, legacy OEMs still lead in terms of absolute R&D spending.

3.2 Trend 1: Electrification

At the 2015 Paris Climate Conference, international commitments were made to limit global warming to well below 2°C – ideally to 1.5°C – compared to pre-industrial levels [72]. Achieving this target requires a rapid transition to zero-emission mobility [4].

3.2.1 Country Comparison on Electrification

Differences in electrification across global markets are evident in national policies and charging infrastructure. The analysis focuses on China, the USA, and Germany.

China

The Chinese government actively supports the development of the electric vehicle (EV) industry through various incentives. These include subsidies for both manufacturers and consumers, direct payments to OEMs, and tax exemptions for new energy vehicles (NEVs) until 2025, with phased reductions thereafter [73]. China's charging infrastructure is robust, featuring high densities of HPC, DC, and AC charging stations. In January 2022, the country set a target to support 20 million battery electric vehicles (BEVs) by 2025, underscored by significant increases in public and private charging facilities. However, regional imbalances exist, with over 70% of public fast chargers concentrated in just ten provinces [74].

USA

In the United States, EV promotion is largely decentralized, with state-level programs and incentives such as a previously available federal tax credit of $7,500. Non-monetary incentives, like the use of dedicated lanes in California, also play a role. The U.S. charging infrastructure remains sparse – approximately two charging points per 1,000 km on highways – with plans to install 500,000 new charging stations by 2030 and a focus on fast charging expansion [75] [76].

Germany

Germany introduced an "environmental bonus" in 2016 in collaboration with OEMs, combining manufacturer and federal incentives, though it was discontinued in December 2023 (BAFA, 2023). Additional incentives include tax benefits and non-monetary measures such as free access to environmental zones. The country's charging infrastructure is characterized by 1.23 HPC locations per highway kilometer and higher densities for DC and AC chargers, supported by federal investments of around €1.9 billion to establish a nationwide fast-charging network [76] [77] [78].

3.2.2 Patent Analysis

Patent filings in alternative drive technologies were analyzed using the WIPO PATENSCOPE database and specific IPC codes [79]. Although classification challenges exist due to overlaps among BEVs, FCEVs, HEVs, and PHEVs, the analysis groups OEMs into three categories:

- High Patent Filings: Legacy OEMs such as Toyota, as well as Hyundai and KIA in combination, exhibit significantly higher patent counts.
- Moderate Patent Filings: Legacy OEMs like Ford, BMW, Mercedes, and Volkswagen fall into a mid-range group.
- Lower Patent Filings: New OEMs, including BYD, NIO, Xpeng, and Tesla, generally record fewer than 200 patents annually.

Data for some OEMs (e.g., Zeekr, MG, Polestar, Lucid) could not be validated, and Volkswagen's figures represent only its core group. Overall, while legacy OEMs maintain higher absolute patent counts, notable variations exist across different groups.

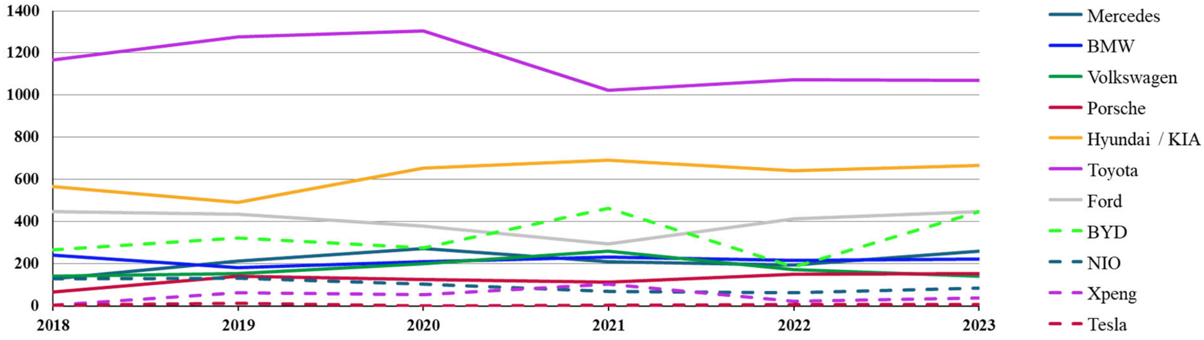

Figure 2: Total Patent Applications – Alternative Drivetrain Technologies

Table 2: Used IPC Codes – Alternative Drivetrain Technologies

Topic	IPC-Codes
Assembly/Assembly Components – General	B60K1/, B60K16/, B60K6/, B60K7/00, B60K17/356
Electrically powered vehicles – General	B60L3/, B60L8/, B60L11/18, B60L15/, B60L50/50 - B60L50/53, B60L50/60 - B60L50/62, B60L50/64, B60L50/70 - B60L50/72, B60L50/75, B60L50/90, B60L53/, B60L55/, B60L58/
Assistance systems – drive control	B60W10/04, B60W10/06, B60W10/08, B60W10/26, B60W10/28
Generation/conversion/distribution of electrical energy	H02J7/14, H02J7/16, H02J7/18, H02J7/20, H02J7/22, H02J7/24, H02J7/26, H02J7/28, H02J7/30

3.2.3 Electric Ranges

Electric range for the purpose of this paper is measured in kilometers under the WLTP cycle (“Worldwide Harmonised Light-Duty Vehicles Test Procedure”), a globally accepted method to determine consumption, emissions, and range. In some cases, original range data were collected using the NEDC (“New European Driving Cycle”) and subsequently converted to WLTP values using a factor of 1.2 [80]. This conversion ensures comparability across models and markets.

Legacy OEMs

BMW’s smaller BEV models (iX1, iX3, iX2) achieve ranges between 436 km and 471 km, with the iX1 showing a 6.2% increase from 2022 to 2023. Their larger models (including iX, i4, i5, and i7) consistently surpass 500 km, with the i7 reaching up to 623 km. These figures suggest that BMW’s range updates are more pronounced in its compact segment, while the premium segment has already achieved high performance. However, BMW has followed a strategy of not updating / increasing its electric ranges during the product life cycles (see Figure 1 (a)).

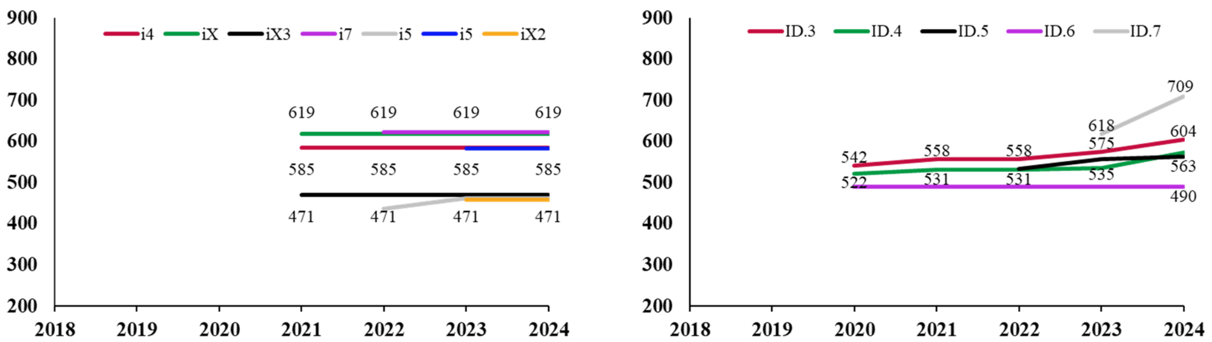

Figure 3: WLTP Electric Ranges [km]– (a) BMW [38] - [43], (b) Volkswagen, [65] - [70]

Mercedes' portfolio exhibits a wide variety of battery electric vehicle (BEV) models. With the exception of the EQA and EQB introduced in 2021, nearly all models achieve WLTP ranges exceeding 500 km. For instance, the EQS initially reached a maximum range of 769 km, which increased to 816 km by 2024. Annual range updates are regular; the EQA, for example, demonstrated a 23.5% increase from 2021 to 2022, while high-range models such as the EQS SUV show more modest gains around 6.8% over similar periods. This consistency in range performance reflects both technological stability and continuous incremental improvements.

Volkswagen's models generally offer high ranges that, while slightly below those of Mercedes, remain competitive. A particularly notable update is the ID.7, which increased from 618 km in 2023 to 709 km in 2024 – a 14.7% jump – indicating a significant recalibration or technological enhancement in that model series.

Within the legacy group, Porsche's BEV offerings also show distinctive dynamics. The Taycan, in particular, records the highest percentage increase – 32.5% – with its range growing from 513 km to 680 km. Meanwhile, the Macan, a newer model, is limited to a range of 644 km in 2024, illustrating how product positioning and model maturity influence range improvements.

Additional legacy brands like Hyundai, KIA, Ford, and Toyota generally present stable BEV ranges with only minor updates over time. For example, Hyundai's IONIQ5, IONIQ6, and Kona EV range from 481 km to 614 km, and similar stability is seen in KIA's offerings. These manufacturers maintain consistent performance, indicating that their focus may lie more on reliability and incremental refinement rather than radical range enhancements.

New OEMs

BYD offers an extensive BEV portfolio covering a broad range of electric ranges. High-range models such as the Seal and Song L deliver 570 km and 551 km respectively. Conversely, models starting at lower range levels, like the Tang, have experienced dramatic improvements; the Tang's range increased from 400 km to 528 km (a 32% rise), demonstrating rapid technology maturation in these vehicles.

Xpeng's model G3 experienced a significant range leap – from 290 km to 433 km, marking a 49.3% increase – while other models in its lineup (G6, G9, P5, and P7) typically maintain ranges between 500 km and 576 km. This indicates that while early models underwent substantial improvements, the later models have reached a performance plateau.

The evolution in MG's older BEV series shows notable range updates. The model ZS, for example, improved its range from 263 km to 440 km, corresponding to a 67.3% increase. This suggests that legacy brands transitioning into the new OEM category can achieve rapid enhancements, particularly in previously underperforming segments.

Among the new OEMs, NIO displays considerable variability in its BEV ranges. Early models such as the ES8 increased from 295 km to 483 km (a 63.7% increase), and the ES6 saw a 21.4% gain between 2020 and 2021. Later models are positioned between 500 km and 590 km, with certain high-end models (ET5, ET7) reaching an impressive 833 km during the 2023–2024 period. The substantial improvements, especially in recent updates, underscore NIO's commitment to advancing its technology.

Zeekr, although offering a smaller model lineup, shows significant progress. The Zeekr 001, for example, increased its range from 583 km to 860 km (a 47.5% gain between 2022 and 2023), highlighting aggressive improvements in newer product introductions.

Tesla's range values vary between 533 km and 652 km, with the Model S at the upper end of the spectrum. Updates across Tesla's lineup are relatively modest, with the Model Y showing the largest percentage increase of 12.6% from 2023 to 2024. Overall, Tesla's early high range values have largely stabilized over time.

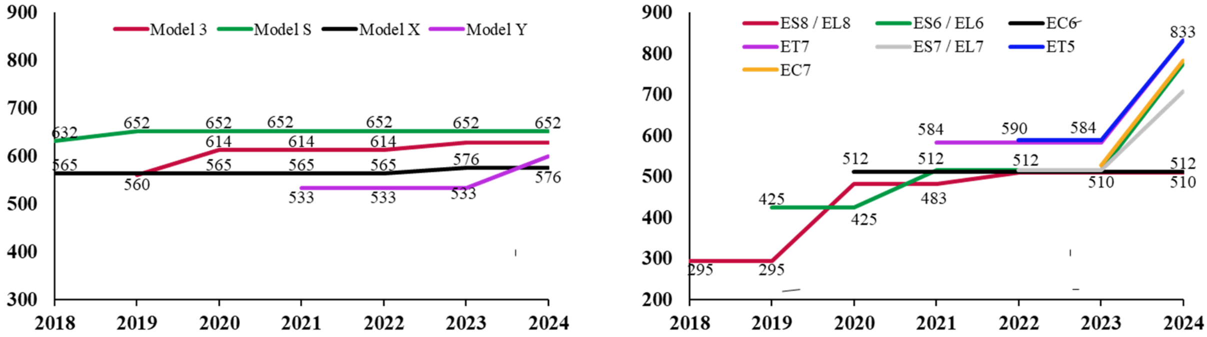

Figure 4: WLTP Electric Ranges [km] – (a) Tesla [14] - [19], (b) NIO [20] - [25]

Lucid's flagship, the Lucid Air, boasts an impressive initial range of 833 km, which remains relatively unchanged, indicating that it achieved a high level of performance at launch that competitors are still striving to match.

In the case of Polestar, only the Polestar 2 has a documented range evolution – rising from 487 km to 551 km between 2020 and 2021, and from 551 km to 655 km between 2022 and 2023, reaching 659 km in 2024. The newer Polestar 3 and Polestar 4 models offer ranges in the vicinity of 650 km and 620 km, respectively, suggesting consistency across the brand's recent launches.

Overall, while legacy OEMs still aim for higher absolute ranges due to their mature technology platforms and larger fleets, new OEMs exhibit remarkable percentage gains and rapid technological improvements. Based on the quantitative analysis, the model ranges of legacy and new OEMs differ significantly. Some new OEMs achieved high benchmark values for range and charging performance in their early years but showed little to no recorded improvements over time, eventually being surpassed by other OEMs – Tesla and Lucid being prime examples. In contrast, legacy OEMs generally display solid to high values in both range and charging performance, yet without significant jumps in the values achieved, while newer OEMs like Zeekr and Xpeng show significant increases in both aspects, reaching new highs in the comparison analyzed. These trends underscore the dynamic nature of BEV range development across different market segments and highlight the competitive evolution within the automotive industry.

3.2.4 Charging Performance

The analysis of charging performance within the examined vehicle fleets is based on the maximum DC charging power values (in kW) as communicated by manufacturers. It is noted that neither the duration for which these peak values can be maintained nor the overall charging time are considered in this analysis.

Legacy OEMs

Among legacy OEMs, the range of maximum charging power varies considerably across different brands and models. For instance, Mercedes-Benz offers a broad spectrum in its BEV portfolio. Models such as the EQS and EQS SUV can achieve maximum charging powers of up to 200 kW, whereas the entry-level models EQA and EQB are limited to around 100 kW. Over the period examined, Mercedes-Benz shows no increases in maximum charging power across its fleet at all (see Figure 5 (a)).

A similar pattern is evident among other legacy OEMs including BMW, KIA, Hyundai, Toyota, Ford, and MG. Although these manufacturers differ in absolute charging power levels, their fleets generally exhibit only minimal changes over time. For example, BMW's lineup spans a range similar to that of Mercedes, with models like the i4 and i5 reaching up to 205 kW, while the smaller iX1 and iX2 are around 130 kW. Meanwhile, KIA and Hyundai position their models (such as the EV6, EV9, IONIQ5, and IONIQ6) at a higher level, typically between 210 kW and 240 kW. In contrast, Toyota, Ford, and MG achieve maximum values between 92 kW and 185 kW, with Ford's Explorer EV reaching 185 kW in 2024. Across these brands, significant or regular increases in charging power are generally absent.

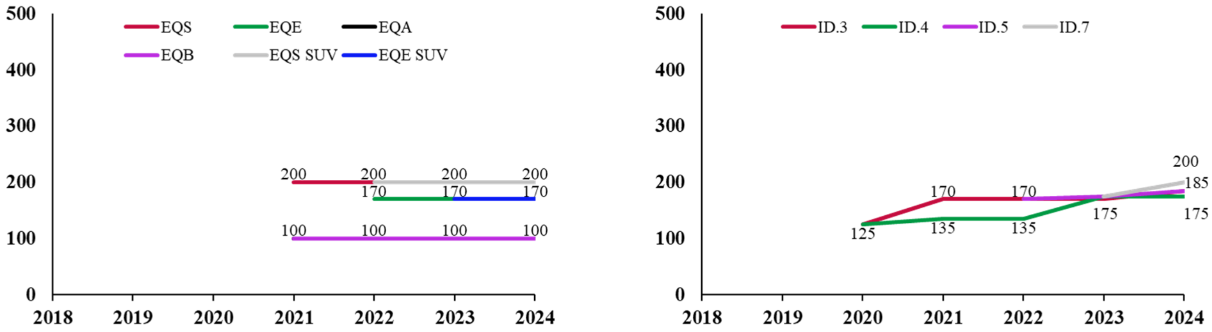

Figure 5: Charging Power DC [kW] – (a) Mercedes Benz [56] - [60], (b) Volkswagen [65] - [70]

Volkswagen presents a somewhat different scenario. Its fleet, illustrated in Figure 4.17, shows maximum charging powers ranging from 125 kW to 200 kW. The ID.7, for instance, reaches the highest value in 2024. Notably, Volkswagen demonstrates a higher frequency of charging power jumps compared to other legacy OEMs. The ID.4, for example, increased from 125 kW in 2020 to 135 kW in 2021, and then surged by approximately 29.6% to reach 175 kW between 2022 and 2023 (see Figure 5 (b)). No other legacy OEM exhibits a similar frequency of power increases.

Porsche's BEVs further illustrate variation within legacy fleets. Figure 4.18 shows that while the Macan – due to its relative novelty – has a maximum charging power of only 270 kW in 2024, the Taycan exhibits a significant improvement. The Taycan's charging power increased from 270 kW to 320 kW (an 18.5% increase, or 50 kW absolute) between 2023 and 2024. This makes the Taycan the legacy model with both the highest absolute and percentage increase in charging power within its group. No other legacy OEM demonstrates a comparable leap in this performance metric.

New OEMs

Among new OEMs, the range of maximum charging power is generally lower than that of legacy brands, yet several manufacturers display notable improvements over time. BYD's fleet, as depicted in Figure 4.19, covers charging powers from 60 kW to 170 kW. Although these values fall within a moderate range, there are discernible jumps in certain series. For instance, the Yuan series and the Dolphin model both experience a 46.7% increase – albeit with relatively modest absolute gains of around 28 kW. The Tang model, however, stands out by increasing from 120 kW to 170 kW between 2023 and 2024, representing the highest charging power in the BYD lineup (see Figure 6 (a)).

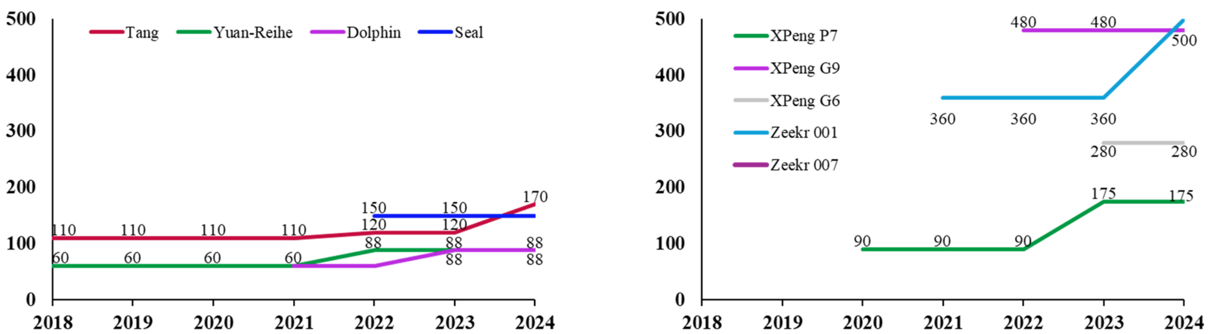

Figure 6: Charging Power DC [kW] – (a) BYD [32] - [37], (b) XPeng and Zeekr [28] - [31]

NIO follows a similar trend. Its ES8/EL8 series shows charging power jumps from 90 kW to 125 kW between 2019 and 2020, with a further increase to a maximum of 240 kW from 2021 to 2022 – exceeding the charging power levels seen in BYD models. Additionally, NIO's ET5 and ET7 models reach around 140 kW, aligning their performance with that of BYD's top models.

Polestar's data are more limited, with only the Polestar 2 showing a tracked increase from 155 kW in 2022 to 205 kW in 2023 (a 32.3% increase). In 2024, Polestar 3 and Polestar 4 report maximum charging powers of 200 kW and 250 kW, respectively, positioning them on par with the highest values recorded by NIO.

Tesla's model range is characterized by relatively high charging powers from the outset. As seen in Figure 4.20, its vehicles range between 120 kW and 250 kW. The lowest value is noted in 2018, while the largest increase occurs from 2018 to 2019 – a 66.7% jump corresponding to an 80 kW absolute increase. Subsequent improvements are limited to the Model S and Model X, which see increases from 200 kW to 250 kW between 2021–2022 and 2022–2023. Overall, Tesla's early high performance remains stable, with few further enhancements over time.

Lucid follows a similar pattern: the Lucid Air, which starts with a high charging power of 300 kW, shows no significant additional improvements over its operational lifetime.

Finally, Zeekr and Xpeng stand out for achieving exceptionally high charging power levels among new OEMs. The Zeekr 001 begins with a robust 360 kW and then climbs to 500 kW – a 38.9% increase – from 2023 to 2024. The Zeekr 007 also reaches 500 kW, marking the highest charging power in the overall analysis. Xpeng exhibits similar trends; while its G9 model reaches a maximum of 480 kW, other models like the G6 (280 kW) and the P7 (175 kW) record lower values. Overall, both Zeekr and Xpeng demonstrate very high charging performance relative to their competitors (see Figure 6 (b)).

Conclusion

In summary, the analysis reveals distinct differences between legacy and new OEMs in terms of maximum DC charging power. Legacy OEMs, such as Mercedes, BMW, and Volkswagen, generally offer higher absolute charging powers and exhibit a stable performance profile with few and in some cases significant improvements over time. In contrast, new OEMs – although starting with moderate charging capabilities – tend to display remarkable percentage increases and rapid technological advancements, particularly in models from BYD, NIO, Polestar, Zeekr, and Xpeng. Tesla and Lucid, meanwhile, maintain high charging performance from early on with only minimal subsequent enhancements. These trends highlight the diverse strategies and technological evolutions across the automotive industry, reflecting both established performance benchmarks and dynamic growth among newer entrants.

3.3 Trend 2: Autonomous Driving / ADAS

Autonomous driving is generally classified into five levels, although different sources may use varied names for each category. The essential insight is that these levels build upon one another in a stepwise fashion [81].

3.3.1 International Comparison of Autonomous Driving

An overview of the status quo in China, the USA, and Germany illustrates significant regional differences in the development and implementation of autonomous driving technologies.

China

Autonomous driving holds high strategic importance in China, where the government actively supports its development through comprehensive regulations and pilot programs. In 2023, new guidelines and pilot programs were introduced to facilitate the public road testing of Level 3 and Level 4 systems. Additionally, China emphasizes vehicle connectivity, as evidenced by the first 5G test site for intelligent vehicles in Shangrao Province. The country has established 17 test demonstration zones covering more than 3,200 km of dedicated test roads, which are instrumental in accelerating technology validation and deployment [82].

USA

In the United States, it is anticipated that by 2025 around 3.5 million vehicles operating at higher SAE levels will be on public roads [82]. Unlike China, the US lacks a uniform national regulatory framework for autonomous vehicles; instead, state-level policies vary widely. States such as California, Florida, Nevada, and the District of Columbia are at the forefront of testing autonomous systems. The US has been a pioneer in the testing of automated vehicles, partly due to the diverse regulatory environments across its states [83] [84].

Germany

Germany was the first country to establish a regulatory framework covering Levels 3 and 4 of autonomous driving. Based on the 2021 Autonomous Driving Law and the Autonomous Vehicles Approval and Operation Regulation (AFGBV) effective from July 2022, Germany provides one of the most comprehensive legal bases for autonomous vehicles. However, practical implementation remains challenging due to unresolved issues regarding technology, legal certainty, and driver responsibilities. While the regulatory framework is generally well-regarded, difficulties persist in transitioning from test environments to everyday operations [85].

3.3.2 Patent Analysis for Autonomous Driving

The patent analysis in this study focuses on autonomous driving-related filings. For this purpose, a set of IPC (International Patent Classification) main classes was defined based on an analysis by the German Patent and Trademark Office [86]. It is important to note that there is no single IPC class exclusively for autonomous driving; therefore, the evaluation represents an approximation of the overall innovation activity in this field. Data were collected using the WIPO PATENTSCOPE database.

Figure 7 presents the annual patent filings by OEMs from 2018 to 2024, using the defined IPC codes. For some OEMs, such as Zeekr, MG, Polestar, and Lucid, valid data could not be collected – often due to their corporate affiliations – resulting in these figures being excluded from final comparisons. In addition, many of Volkswagen's group brands are not included, and Hyundai and KIA are analyzed together. The analysis reveals that among legacy OEMs, Toyota consistently exhibits the highest patent filing counts, while other legacy manufacturers such as Ford, Mercedes, BMW, and Porsche display similar ranges. Overall, new OEMs consistently have lower patent counts compared to legacy OEMs across the examined years.

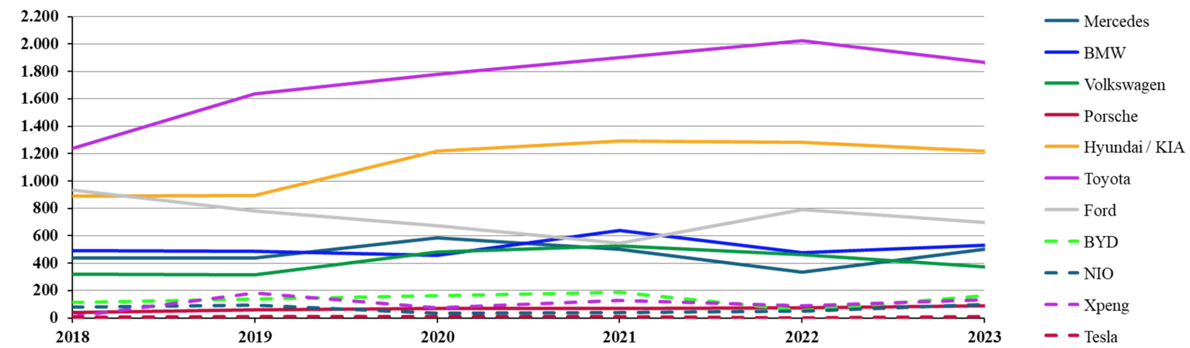

Figure 7: Total Patent Applications – Autonomous Driving

Table 3: Used IPC Codes – Autonomous Driving

Topic	IPC-Codes
General	G05D1
Assistance systems – drive control	B60W30/00 - B60W30/17, B60W40/00 - B60W40/10, B60W40/12, B60W50/00, B60W50/04, B60W50/08 - B60W50/14
Assistance systems – traffic control	G08G1/00, G08G1/07, G08G1/087, G08G1/09, G08G1/096 - G08G1/0967, G08G1/097 - G08G1/16
Electronics in Vehicles – General	B60R16/02
Navigation	G01C21/04, G01C21/26 - G01C21/36, B62D6/00 - B62D6/04, B62D1/24 - B62D1/28, G08G1/0968, G08G1/0969
Sensor Technology Environment Sensors	G06K9/62, G01S13/93, G01S15/93, G01S17/93
Communications	H04W 4/40 - H04W 4/48

Conclusion

This analysis synthesizes a multifaceted examination of autonomous driving technology, covering its classification into five levels which provides a structured understanding of technological progression. Internationally, regions such as China, the USA, and Germany exhibit unique regulatory and developmental environments that reflect differing strategic priorities and testing infrastructures. Patent analysis further underscores the technological leadership of legacy OEMs, particularly Toyota, while new OEMs generally lag behind in filing volumes. Notably, legacy manufacturers like Mercedes and BMW are leading efforts to advance existing Level 2 systems to Level 3, while new entrants from other sectors, such as tech companies, are entering the market with strategies that bypass intermediate levels to achieve higher levels of autonomy. Together, these insights highlight the complex, evolving nature of autonomous driving technology and the diverse approaches taken by different regions and manufacturers.

4 Divergent Innovation Strategies

Effective innovation management is crucial for both new and established OEMs to remain competitive, adapt to market changes, and secure long-term success [87]. Innovations can be categorized by their degree of novelty into incremental, radical, and disruptive types. Incremental innovations involve step-by-step improvements of existing products, radical innovations introduce fundamental changes and technological breakthroughs, while disruptive innovations transform or even replace existing markets [88] [89].

For successful innovation management, several key factors are critical. These include:

- Corporate Strategy: A clear vision and long-term goals that align with innovation priorities.
- Organizational Structure and Culture: Flexible structures and a participative, open culture promote the free exchange of ideas, while rigid, top-down approaches can impede innovation [90] [91].
- Management and Resources: Leadership, along with adequate investments in human capital, knowledge, financial resources, and assets, is essential [92].

4.1 Comparative Analysis of Legacy and New OEMs

Based on the research questions, significant differences between legacy OEMs and new OEMs were identified through an analysis of influencing factors and market conditions:

4.1.1 R&D Spending

The hypothesis that legacy OEMs invest higher absolute amounts in research and development is confirmed by data from 2018 to 2023. Although legacy OEMs such as Mercedes, BMW, and others allocate considerably more resources in absolute terms, new OEMs sometimes show higher R&D intensity when measured as a percentage of revenue. This suggests that while legacy companies benefit from scale, new OEMs are more aggressive relative to their size.

4.1.2 Innovation Strategy and Patent Activity

Trends indicate that legacy OEMs tend to favor more closed innovation strategies. This is reflected in their significantly higher patent filings in areas such as alternative drive technologies and autonomous driving. By protecting their know-how, legacy OEMs – exemplified by Toyota – secure their competitive position by integrating innovation partners into their organizational processes to minimize risk and ensure profitability. In contrast, new OEMs like BYD, NIO, and Xpeng register far fewer patents. Tesla, for instance, has adopted an open-source patent strategy that encourages technology and information exchange [93]. Thus, while legacy OEMs exhibit higher overall patent activity, new OEMs may pursue more disruptive, open approaches which eventually lead to more frequent product / performance updates.

4.1.3 Degree of Innovation

The analysis reveals that companies must adopt different innovation strategies based on their starting positions. New OEMs are often compelled to introduce disruptive innovations to gain a foothold in the market. For example, early in its development, Tesla achieved high benchmark values for charging performance and range, which suggests a disruptive approach. Over time, however, improvements became incremental. Similarly, companies like Zeekr and Xpeng continue to push new performance benchmarks in charging and range, while NIO introduces alternative concepts such as "Power Swap Stations" as an innovative alternative to conventional charging infrastructure. In contrast, legacy OEMs tend to pursue incremental improvements that, while competitive in absolute terms, show less dramatic progress over time. This pattern is also evident in the evolution of autonomous driving systems, where legacy OEMs like Mercedes and BMW predominantly upgrade Level 2 systems to Level 3, whereas newer entrants – often originating from the tech industry – pursue more radical, disruptive approaches such as Tesla's "FSD" approach or BYD's "God's Eye" system.

4.1.4 Organizational Structure and Culture

Further differences are observed in corporate structures and cultural orientations. Legacy OEMs frequently display rigid structures and silos that can hinder knowledge sharing, and their top-down cultural approaches may stifle creativity. Although change processes are underway, it remains uncertain how deeply these transformations will take root. In contrast, new OEMs typically implement agile work methods and flat hierarchies that foster idea exchange and innovation. While this approach may sometimes lead to operational chaos, it is generally more conducive to rapid innovation.

The findings additionally support the hypothesis that legacy OEMs, with their established and often rigid structures, leave less room for radical and disruptive innovations – a phenomenon that aligns with the Innovator's Dilemma [94]. In contrast, new OEMs are seen to pursue more disruptive strategies, although the evidence regarding their overall innovative activity remains mixed. On one hand, legacy OEMs file more patents related to current trends in electrification and autonomous driving; on the other hand, the disruptive approaches of new OEMs are more immediately noticeable.

4.2 Conclusion

In the early market phase, the technical features of new OEMs indicate a disruptive approach to innovation; however, as the vehicle product lifecycle progresses, only small advances in range and charging performance are observed. Some new manufacturers, such as Zeekr and Xpeng, aim to set new benchmarks in these areas. Established manufacturers, on the other hand, generally follow incremental approaches, achieving competitive product performance but with less significant increases. Incremental progress also dominates in autonomous driving, with companies like Mercedes and BMW advancing existing Level 2 systems. New companies, particularly from the tech industry, adopt more disruptive approaches and sometimes skip development stages, eventually leading to faster innovation cycles. Country-specific differences, such as regulatory testing opportunities in the U.S. compared to Germany, also play a role and enhance or hinder individual efforts.

In summary, the analysis shows that while legacy OEMs leverage substantial resources and a stable operational base to maintain high levels of innovation in absolute terms, new OEMs tend to focus on agility, disruptive innovation, and open collaboration. This duality presents both challenges and opportunities for the automotive industry as it navigates rapid technological changes and evolving market dynamics.

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Presenter Biography

Bernd Propfe holds a full professorship for business adminstration and engineering at the University of Applied Sciences Suedwestfalen. He specializes in the field of electric mobility and product management.
Previous to his professorship, he held various positions at Porsche AG in Germany, including the position of Director Platform at the Product Line Taycan. Before that he was Manager Complete Vehicle at the Product Line Taycan and Manager Product Strategy Electricity Mobility. Bernd has researched and operated in the electric and hybrid vehicles space for 15+ years and wrote his PhD thesis on the topic of market prospects of EVs incl. in depth analysis of automotive engineering and electric mobility.

Justin Wenzel holds a Bachelor of Engineering in Industrial Engineering from the South Westphalia University of Applied Sciences in Soest. During his studies, he was able to gain experience at Porsche AG in Germany, working as an intern and student employee in various departments, such as project management at the Product Line Taycan and the procurement strategy. Currently, he is pursuing a Master of Engineering in Automotive Engineering at Wilhelm Büchner University of Applied Sciences while working as a student employee in the Driver Information Systems department at Porsche AG.