Delft University of Technology

Master Thesis

The EV Shock Doctrine: China's Competitive Leap and the Future of German Automaking

First Supervisor & Chairman: Dr. Servaas Storm
Second Supervisor: Dr. ir. Udo Pesch

Nima Kazemi (5805147)

Delft University of Technology

Executive Summary

This thesis, "The EV Shock Doctrine: China's Competitive Leap and the Future of German Automaking," investigates the critical challenge facing Germany's automotive industry: the consistent undercutting of German-manufactured electric vehicles (EVs) by the Chinese counterparts in European and Chinese markets. This phenomenon is not merely a matter of competitive pricing, but it represent a profound structural shift with far-reaching implications for EV adoption, industry strategy, policy, and for the livelihoods of over 700,000 domestic workers in Germany automotive sector.

The core problem stems from China's rapid emergence as an EV superpower, which, combined with the disruptive shift from internal combustion engine (ICEs) to software-centric EV platforms and increasing geopolitical volatility, has created a "shock" to Germany's traditional industrial strengths. While German automakers have historically excelled in mechanical engineering and premium branding, the EV era demands a new paradigm centered on digital architecture, battery performance, and integrated software systems- areas where Chinese firms have taken a significant lead. The dominant design and future of the automotive industry is considered to be the Electric Battery Vehicles based on prevalent academic and industrial research concerning the climate and technological aspects.

This study aims to investigate the fundamental reasons behind China's competitive advantage by meticulously examining key supply-side factors:

- **Labor and Energy Costs**: Differences in labor and energy prices between Germany and China adequately explain the price disparity.
- **Learning By Doing**: The research explores how cumulative production experience, particularly in battery manufacturing, drives down unit costs over time, benefiting high-volume producers.
- **Vertical Integration**: The impact of integrated supply chains, where companies control multiple stages of production from raw materials to final assembly, on overall cost efficiency is analyzed.

A significant challenge in this research was to secure comparable and reliable data, as detailed, firm-level financial and logistical information often remains proprietary and varies widely across regions and markets. To overcome this challenge, the methodology used in this research involved a rigorous process of collecting inflation-adjusted, pre-tax/pre-subsidy retail price data for mid-size, non-luxury EVs in Germany and China. This was achieved through a combination of investigating various industry databases and targeted web scraping from validated sources.

For a robust comparison, data from the most well-known and productive companies in both regions, including Volkswagen, BMW, Mercedes-Benz, Xiaomi, Nio, BYD, etc., were analyzed. The focus of this study is on the mid-size, non-luxury segment centered on a direct comparison between BYD and Volkswagen, given their significant market presence and comparable vehicle offerings. By neglecting the luxury brands, the effects of strategic brand-pricing, skimming, etc.

The results of this research indicates that the observed price gap between Chinese and German EVs is not fully justifiable by the commonly cited reasons found in much of the existing literature. While factors like labor costs, learning-by-doing, and vertical integration contribute to a portion of the differential, a substantial "residual gap" remains unexplained by these production-side elements. This suggests that other strategic and non-cost dimensions, such as brand positioning, market adaptation strategies, and the pace of technological integration, play a critical role in sustaining the price disparity.

Ultimately, this thesis aims to provide a nuanced understanding of the forces shaping the global EV market, offering insights and recommendations for German automakers and policymakers to bridge this competitive gap and secure a resilient, decarbonized mobility future for Europe.

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1 Introduction

In 2024, Germany's most resourceful automaker, Volkswagen (VW), made a shocking announcement: it would close several of its domestic plants, a decision unprecedented in the company's history. Once considered the crown jewel of German industry, VW's struggles in its home base revealed more than a company in trouble, it marked a turning point for the entire European automotive sector. With shrinking profits, a rapid shift to electric vehicles, and fierce competition from Chinese manufacturers, German carmakers face their most serious challenge since the postwar era. This study investigates the deeper forces behind this transformation and the growing threat to the industrial core of Germany.

1.1 A Sector in Crisis

The German automotive industry, once a model of technological prowess and economic reliability, is now on the verge of a historic crisis after suffering a rough year in terms of profits and market share. For decades Germany's automakers dominated the global stage, producing premium vehicles that set the benchmark for quality, engineering, performance, and design. With globally recognized leading brands such as Volkswagen, Daimler, BMW, and Audi, the country exported millions of internal combustion engine (ICE) vehicles around the world, contributing approximately 5% of Germany's GDP and employing close to 800,000 people according to Germany's Statistisches Bundesamt (Destatis). However, in recent year, this era of dominance has been rapidly fading.

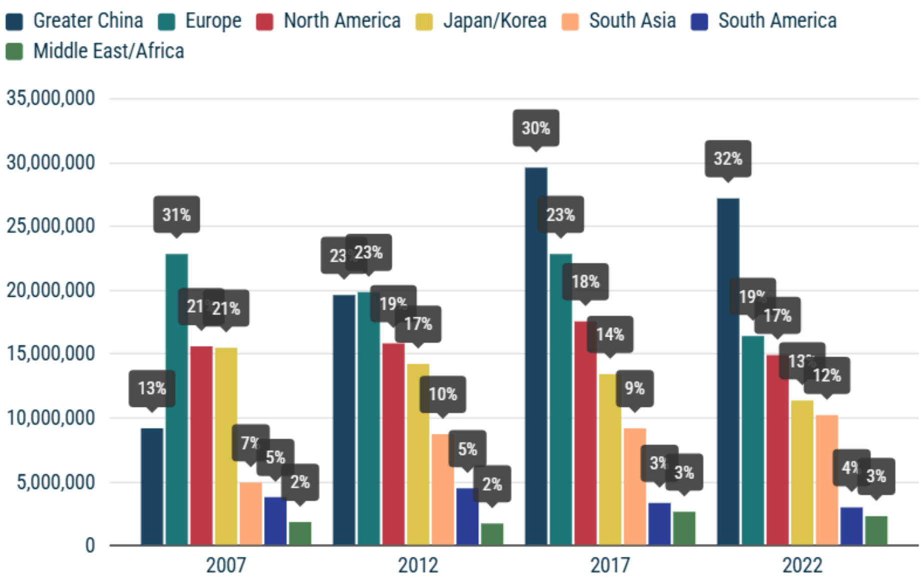

Figure 1: World Vehicle Production, *Source: ACEA*
In units, % share/2007-2022

As illustrated in Figure 1, China has taken the lead in terms of Vehicle production, which is partly dependent on their rapidly rising EV production. What was once difficult to imagine has now become more sensible. Collapsing profit margins, factory closures, falling demand, and the relentless rise of Chinese Electric Vehicle (EV) manufacturers. These pressures are not cyclical nor temporary, but a representation of structural issues. As industrial policy, global trade flows, and technologies shift, the foundations of Germany's auto-based industrial model are being shaken.

Volkswagen's announcement is one of the most visible symptoms of this transformation, where Germany's largest private employer and their reference point of the car economy decided to shut down plants in their home country. While the company has backed off from its first claims after coming alongside an agreement with trade unions to cut approximately 30,000 domestic jobs by 2030, this event alarmed that such changes might not be short-term adjustments but long-term strategic shifts (Reeves & Lacour, 2024). Volkswagen's financial data reveals that although revenue streams are stable and in line with previous years, operating profits and net profits have both declined by 15% and 30%, respectively, with particularly severe losses in China—its largest market—where vehicle deliveries dropped by 9.5% year-over-year.

Yet, VW's story is only one chapter in a broader narrative. In May 2025, Ford Germany became the latest manufacturer to face the social consequences of this industrial struggle. Facing a large number of layoffs, Ford's workers across its German operations began striking, demanding security and transparency as the company prepared to downsize in response to EV transition and global market volatility, according to Reuters (Link). Moreover, Bosch, Germany's largest automotive supplier, announced in 2025 that it would cut up to 5,500 jobs in its mobility division, due to "stagnant global demand," "unpredictable market developments," and a slower-than-expected ramp-up in EV technology adoption.

These dependent events are pointing to the same thing, the crisis is sectorial. This systematic situation is affecting manufacturers, suppliers, and users. It represents a structural shift in the paradigm model of the German automotive industry, in which its strengths, such as precision engineering, ICE expertise, and premium branding are not being challenged by an entirely different competitive paradigm.

1.1.1 From Strength to Stagnation

Germany's success story exists after World War II, where low labor and energy costs combined with a rapidly rebuilding industrial base to fuel the rise of IC vehicle production. German firms took the advantage to form themselves ahead of their global rivals, specifically in terms of mechanical innovation, production quality, and scale. By the 1990s and 2000s, brands like BMW and Audi were synonymous with luxury and reliability, while Volkswagen became a global mass-market giant. This position gave Germany's automakers significant geopolitical leverage as their exports drove trade surpluses, established relationships with the American, Chinese, and Asian markets and creating hundreds of thousands jobs.

All being said, and by early 2010, as climate awareness and electrification gained momentum, German automakers were still largely focused on squeezing more efficiency from combustion engines rather than pivoting indefinitely to battery-powered platforms. As shown in Figure 2, climate awareness had significant effects on the automotive industry, forcing new regulations and restrictions on traditional automakers. When Tesla first revealed over-the-air updates, software-centric vehicle designs, and integrated battery systems, German firms were caught flat-footed. The mixed responses by leading firms reflect the complex organization and uncertainty that evolved within this sector.

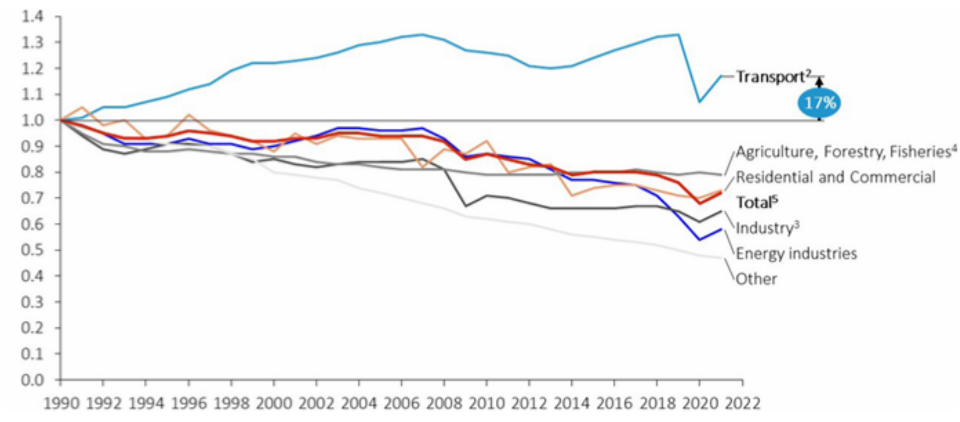

Figure 2:
Evolution of greenhouse gas emissions by sector in EU (Index 1990=1).
Source: European Commission, 2023

1.2 Three Shocks Reshaping the German Automotive Industry

Germany's automotive sector is currently grappling with difficulties arising from a combination of several interconnected factors, rather than any one issue alone. This research focuses on three powerful and overlapping forces that represent a structural break that together, challenges the very foundations of Germany's industrial competitiveness: the rise of the Chinese EV manufacturers, the disruptive nature of the electric vehicle transition, and the new geopolitical-economic landscape.

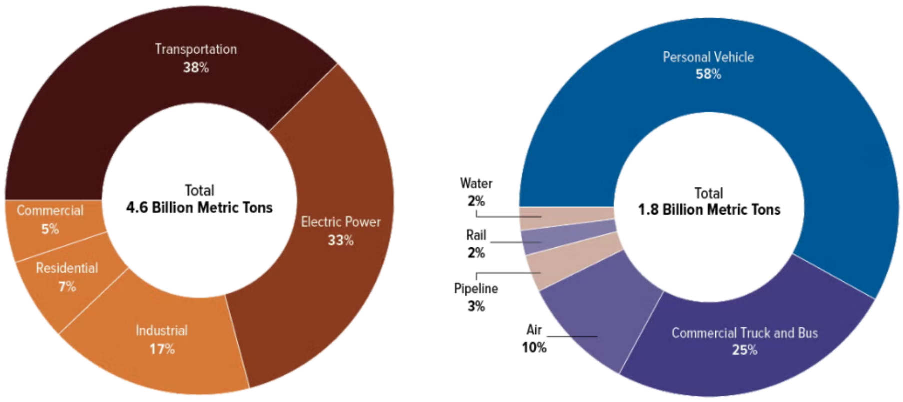

Figure 3: Breakdown of U.S. carbon dioxide emissions from energy use by economic sector (left, 2021) and transportation-related CO emissions by mode of transport (right, 2019). Source: Congressional Budget Office

1.2.1 The Second China Shock: Cheap, Smart, and Scalable

The first China shock is defined by offshoring and cheap labor, and the second one is unfolding currently, defined by China's emergence as a high-tech industrial superpower, particularly in the EV market. Nowadays, Chinese manufacturers are not only concerned with cheap products or low-cost assembly, but they are also becoming frontiers of technologies such as battery technology, software integration, autonomous driving features, and vertically integrated production. Companies like BYD, NIO, Speng, and SAIC are considered powerhouses of EV technology. Consequently, Chinese EV production has been rising sharply, and the surpassed Japan as the world's largest automotive exporter, shipping over 5 million vehicles (more than half of which were non-ICE). In this light, BYD exported more than 400,000 vehicles globally, which brought huge profits as BYD reported revenues exceeds \$100 billion. These firms are producing fully-featured EVs at price points European firms cannot match, leveraging in-house battery production (like BYD's Blade Battery), proprietary software ecosystems, and massive economies of scale. Moreover, Chinese EVs are not just cheaper, but increasingly more advanced. For instance, NIO and Xiaomi models feature integrated AI systems, over-the-air updates, high efficiencies, and competitive ranges at mid-market prices. This technological leap, paired with aggressive pricing and fast-paced innovation cycles, has given Chinese firms a head start that German automakers are struggling to close.

1.2.2 The EV Disruption: A Paradigm Shift in Vehicle Design

German carmakers have long excelled in combustion engine development, which makes their transition to EV as not just a powertrain upgrade, but a fundamental change in their approach. EVs are conceptually and foundational different from ICEs. Rather than relying on complex mechanical systems, these vehicles are built on digital architecture, battery performance, and software systems. Whereas ICE vehicles require complex systems like gearboxes, multi-part engines, and exhaust systems, EVs have simpler designs and fewer moving parts. More importantly, the EVs are digital products, and the transition to EVs undermines Germany's legacy advantages they possess in ICE. Considering an example of EV manufacturers, Tesla's success is recognized through remote diagnostics, software updates, and integrated user interfaces, areas in which Chinese and American companies have taken the lead (Draghi, 2024). On the other hand, German firms are often hampered by legacy systems and slower development cycles. VW's software arm, Cariad, has demonstrated cost overruns, delays, and internal dysfunctions (Inagaki & Keohane, 2024; Nilsson, 2024). Despite major investments, incumbents like Volkswagen and BMW are still struggling to develop cohesive, flexible EV platforms that match the pace of Chinese or U.S. rivals.

This is not just about software but about philosophy. The car is no longer primarily a mechanical product but a smart, data-driven device. Chinese automakers, originating from tech or battery sectors, have adapted more quickly to this new reality. German firms now face a painful learning curve, trying to retrofit an outdated business model into a rapidly changing competitive landscape. Predictions on the increasing maturity of the EV ecosystem—encompassing technological readiness, cost competitiveness, and widespread market adoption—are mostly unanimous, indicating that this design will take over shortly, with most projections by 2040 and 2050. Figure 4 shows estimations on how the EV design will gain market share and mature and its effects on the ICE design.

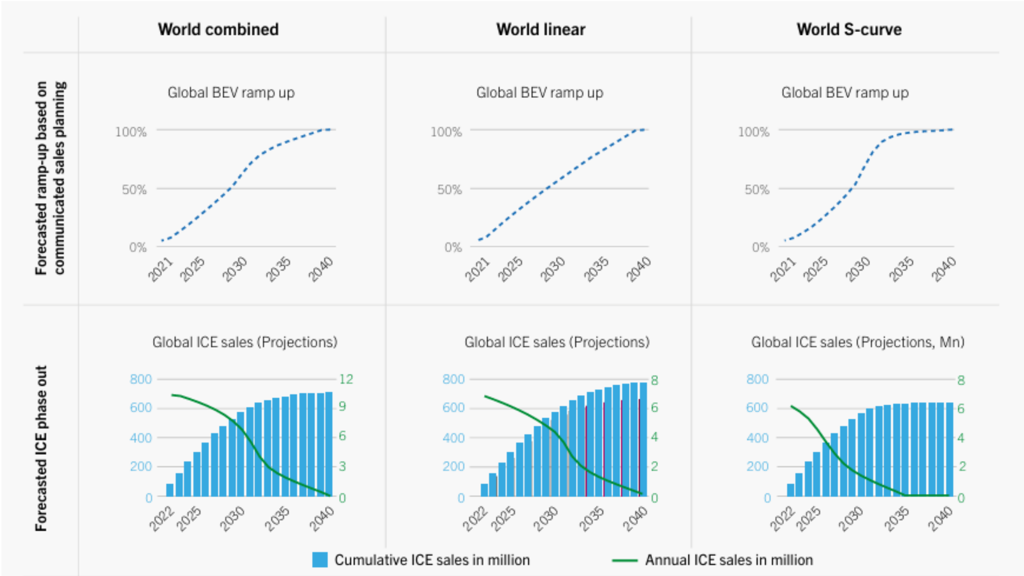

Figure 4: Projected total ICE sales up to 2040 (Teske et al., 2022)

1.2.3 Geopolitical and Economic Volatility: A New Playing Field

Rapidly changing geopolitical and economic environments further exacerbate the current position of German manufacturers. Agreements and accepted frameworks of free trade, cheap energy, and global stability are crumbling. The war in Ukraine, the decoupling between the U.S. and China, and the emergence of protectionist industrial policies have radically reshaped the rules of global competition. Germany, a major beneficiary of such frameworks, is now finding itself on the back foot. Rising energy prices, particularly after Europe's reduced access to Russian gas, has increased costs in Germany, making local manufacturing less competitive. Meanwhile, trade tensions are intensifying. In response to China's growing automotive exports, the United States has imposed tariffs of up to 100% on Chinese EVs, and the European Commission is considering similar measures of up to 38%. While these policies aim to protect domestic manufacturers, they also introduce uncertainty and disrupt global supply chains, many of which German automakers rely on—particularly for batteries, semiconductors, and raw materials.

These three shocks, Chinese competitive acceleration, the disruptive nature of EVs, and geopolitical volatility, have collectively destabilized the industrial foundations that once secured Germany's global automotive dominance. This research aims to examine how these forces have impacted the cost structures and EV adoption rate in Germany, and Europe as the bigger picture compared to their Chinese counterparts. The following section explores how innovation in the automotive sector has evolved, and why it now defines the competitive edge in a rapidly transforming global market.

1.3 Innovation in Automotive Sector

Since the third industrial revolution and the introduction of complex computational devices, the automotive industry has also undergone a transition from traditional mechanical engineering to incorporating advanced software systems. This evolution has fundamentally reshaped vehicle design, moving beyond purely mechanical complexity to prioritize digital architecture. Consequently, vehicles are now conceived as sophisticated digital devices, with their performance, safety, user experience, and energy efficiency increasingly managed and enhanced by integrated software, artificial intelligence, and data-driven functionalities. Hence, vehicles changed from not only mechanically complex and robust products to sophisticated digital devices. AI and digital technologies are inseparable concepts of vehicles where they enhance the vehicle in various aspects such as user experience, navigation, safety, and energy efficiency.

Tesla's disruptive innovation in different forms, including the agile process, technology-focused, and vertically integrated approach has changed the automotive industry for good. The direct-to-consumer sales strategy and emphasizing on over-the-air software updates have set the company apart from traditional automakers. Allowing continuous improvement of vehicle performance and customer experience, the need for service visits also dropped significantly. Moreover, the company's focus on developing high-efficiency battery systems has been critical in increasing the range and performance of electric vehicles.

Dynamic innovations have been increasing product quality and accelerating development cycles. For instance, the adoption of modular platforms, such as Volkswagen's Scalable Systems Platform (SSP), allows producers to enhance the manufacturing process by using standardized components across different models. Furthermore, and notably, the concept of vehicles being defined by their software capabilities has gained attention, which automotive manufacturers use in enhancing driving experience and vehicle performance. These innovation have all accelerated development cycles, where automotive incumbents are now developing new vehicle models in months instead of years. This makes the market more agile and adoptable to customer's demands according to Electric & Hybrid Vehicle Technology .

1.4 Electric Vehicles: Structure, Core Technologies, and Value Chain Disruption

The radical shifts incorporated in EV production make these products structurally, digitally, and economically distinct from the ICE vehicles. While there are other types of non-conventional vehicles, as shown in the figure, electric vehicles are considered to be the next dominant design in the industry. This transformation has allowed new market entrants, particularly in China, where the Chinese industry's gamble on EVs investments has reshaped the competitive nature of the automotive EV industry. Some of the most notable differences between ICEs and electric vehicles are discussed in the following.

1.4.1 Technical Anatomy of EVs vs ICEs

Conventional ICE vehicles are mechanically complex products containing more than 2000 moving parts, such as engines, turbochargers, fuel systems, multi-gear transmissions, exhaust systems, etc. In contrast, EVs contain significantly fewer parts, which can positively affect the maintenance requirements for parts, points of failure in the vehicle, and production labor intensity of the product. More precisely, this simplified structure allows new entrants to enter the market and compete without the necessity of having a manufacturing legacy or supplier complexity.

1.4.2 Battery as the Core Element

At the heart of the EV is the **Battery Pack**, which plays the same role as the combustion engine for the ICE vehicles. Battery costs are a significant factor in EV production, consisting of 30-40 percent of the total cost. Depending on the chemistry and pack size, the ratio can vary. Battery prices have significantly dropped, which makes the EV prices compatible with conventional cars. Consequently, in economic analysis, understanding the battery cost structure is essential as it directly impacts the initial purchase price of the potential for cost parity with traditional vehicles. In 2023, the average price for battery electric vehicle (BEV) packs was approximately $128 per kilowatt-hour (kWh), with cell costs averaging $89/kWh, which accounts for almost 80% of the total pack price, according to Bloomgberg (Link).

Ongoing research targets price parity with ICE cars in 2026-2030 based on studies from different research where average battery prices could fall toward $80/kWh. The supply chain in EV production, and especially battery packs, including the extraction and processing of critical materials such as lithium, cobalt, and nickel is crucial in pricing and subsequently the competitive advantage. Localizing this supply chain presents opportunities for upstream investment and can mitigate geopolitical risks associated with material sourcing (Carreon, 2023).

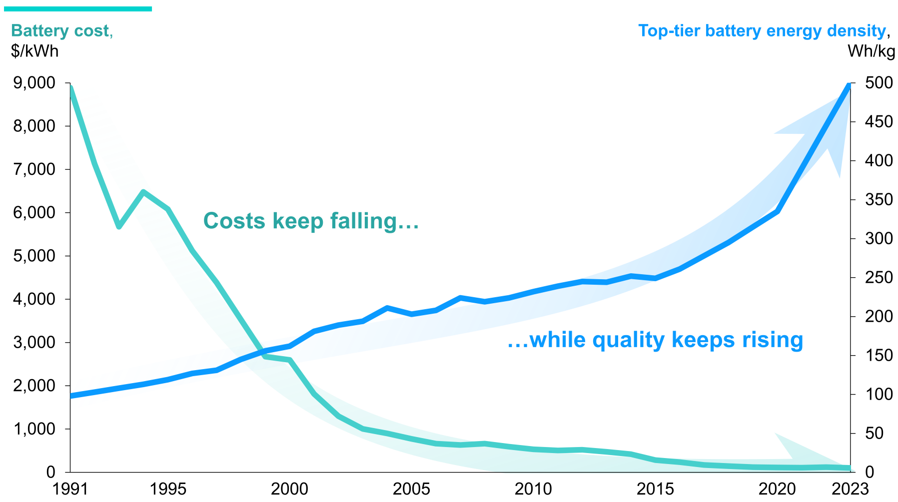

Figure 5: Trends in battery cost and energy density from 1990 to 2023. Battery prices have significantly declined while top-tier energy density (Wh/kg) has steadily improved. - Source: Ziegler and Trancik (2021)

1.4.3 Software as a Competitive Layer

Modern vehicles and, at the forefront, electric vehicles are increasingly defined by their elegant design and software capabilities, where areas such as battery management, safety in driving, autonomous driving features, and infotainment systems are continuously improved. This shift requires software development and integration, positioning software proficiency as a key competitive differentiator among manufacturers. The concept of electric vehicle software has attracted the most famous digital and electronic incumbents, such as Xiaomi, Apple, etc., to become major players in the EV market. In addition, the ability to deliver over-the-air software updates (OTA) allows manufacturers to enhance vehicle performance, introduce new features, prolong product life cycles through updates and upgrades, and address issues without the need for physical intervention. Last but no least, the amount of data integrated and possessed by the automotive industry, such as Tesla, can significantly increase their efficiency and decision-making (O'Kane, 2018).

1.4.4 Modular Platforms and Agile Manufacturing

Platform flexibility and the adoption of modular platforms like Skateboard chassis enable manufacturers to develop multiple vehicles using a common underlying architecture. This approach reduces the time-to-market for new models significantly (predictions of more than 70% until 2050). Novel techniques such as "giga-casting", which uses large-scale casting machines to produce substantial sections of a vehicle's structure, improve the simplicity in assembly and cost efficiency in production (Lambert, 2021).

1.4.5 Value Chain Disruption

The transition to EVs has significantly impacted the relationship among suppliers and incumbents. Manufacturers are constantly seeking partnerships with battery producers, software developers and electronic giants, and semiconductor companies. These changes in the priorities within the automotive industry can create conflicts and tensions among different actors, especially in those countries with higher protection for conventional suppliers. In this light, some companies, especially Chinese automakers, are pursuing vertical integration by bringing critical components of the EV supply chain in-house, which can reduce dependence on external suppliers and improve control over production processes, according to Reuters' report (Link).

1.5 The EV Market Landscape

The global car industry is experiencing a major shift, with electric vehicles playing a central role in shaping both its present dynamics and future trajectory. The recent change was was led by notable changes in market dynamics, characterized by China's rapid rise as a dominant EV producer, exporter, and market.

In 2024, the EV market experienced a 25% growth compared to 2023, with more than 17 million vehicles sold globally according to Reuters, accounting for approximately 20% of all cars sold, a substantial increase from just 2% in 2018. The Chinese market has been the main driver behind this growth, with more than 60% of EVs sold in China, followed by 25% in Europe and below 10% in the United States, indicating a high concentration for these regions. Although sales of electric vehicles in emerging markets, led by Brazil and Southeast Asia, are increasing, the low base makes the adoption in these regions more complex. Numerous reasons could explain this centrality of EV adoption, such as infrastructure, economic incentives, environmental awareness, etc. However, the increase of trust in the EV market and especially the battery technology can significantly increase the adoption in these regions, according to IEA (Link). It is worth mentioning that the European adoption rate of EVs is substantially different. Numerous studies have investigated the different rates of adoption, especially within the European Union, which will be analyzed later on in this study.

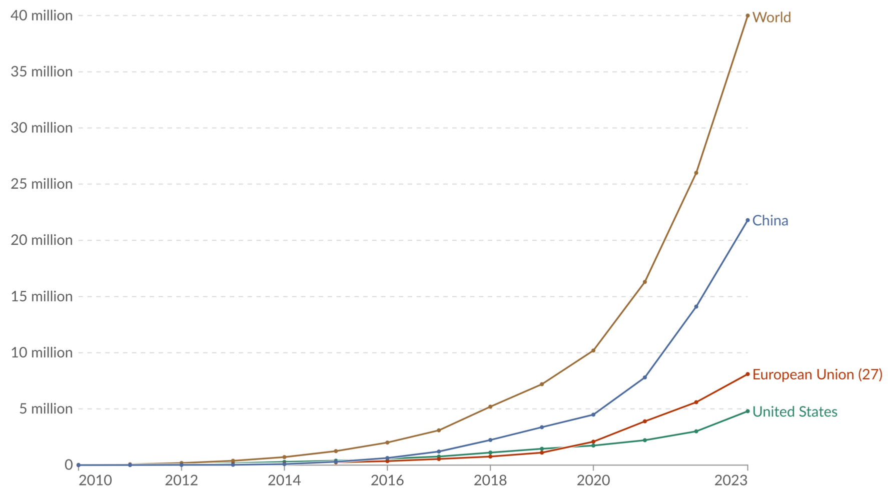

Figure 6: Electric car stocks (including battery electric vehicles and plug-in hybrids), 2010 to 2023 according to Our World in Data

Chinese manufacturers have enjoyed a booming market and an increasing market share, as BYD reported revenues exceeding $100 billion, surpassing archrival Tesla sales. The company sold approximately 4.3 million vehicles globally, with more than 400,000 cars exported, where BYD exports increased by more than 70% from the previous year. The pressure on European and American automakers in terms of competition is increasing, with Chinese manufacturers taking more shares from their European and American counterparts. This has forced even governments to react by introducing subsidies such as 100% tariff on Chinese automotive products under President Biden. Moreover, the European governments have also introduced tariffs on Chinese vehicles up to 38%.

1.6 Deglomeration and Offshoring in the Automotive Industry

Since the early 1990s, with the collapse of the former Soviet Union (USSR), the introduction and adoption of personal computers, the progress of Information and Communication Technology (ICT), and globalization, the deglomeration and offshoring of manufacturing began from developed countries to emerging economies with lower wages. The de-industrialization stabilized the prices of commodities by bringing down the labor cost, energy cost in some cases, and access to materials, along with penetration into new emerging markets. Offshoring also enabled firms to develop a more resilient and efficient supply chain by situating production closer to suppliers and raw materials, resulting in cost and process efficiency. While these strategies draw attention to quality control, intellectual property, and geopolitical risks, it resulted in the de-industrialization of the Western and developed economies. The automotive industry has also been transformed in such a manner, with China, Mexico, and Eastern European countries seeing increasing investments and production plants by the automotive industry.

1.7 Financialization and Ownership Structures of Leading EV Manufacturers

The structural changes in the industry and economy in the developed countries have significantly impacted the automotive industry as well. As debt and loans have become a pillar in not only the United States economy, but in most developed countries, financialization has become a norm in every sector. While automotive firms are subjected to different structures and ownerships, based on the specific regulatory and policy restrictions, firms have generally become more financially active, where firms such as General Motors (GM) or General Electric (GE) have enjoyed periods where their financial activities outperform their manufacturing activities in terms of profit. Speculations on technology and innovation are an inseparable part of the automotive industry, evident by the staggering gap between the market cap of automotive firms. Tesla's market cap has reached around half of the entire sector, while its revenues are not among the top 5 companies. This form of valuation could certainly alter the firm's behavior into more profit-making short-term activities.

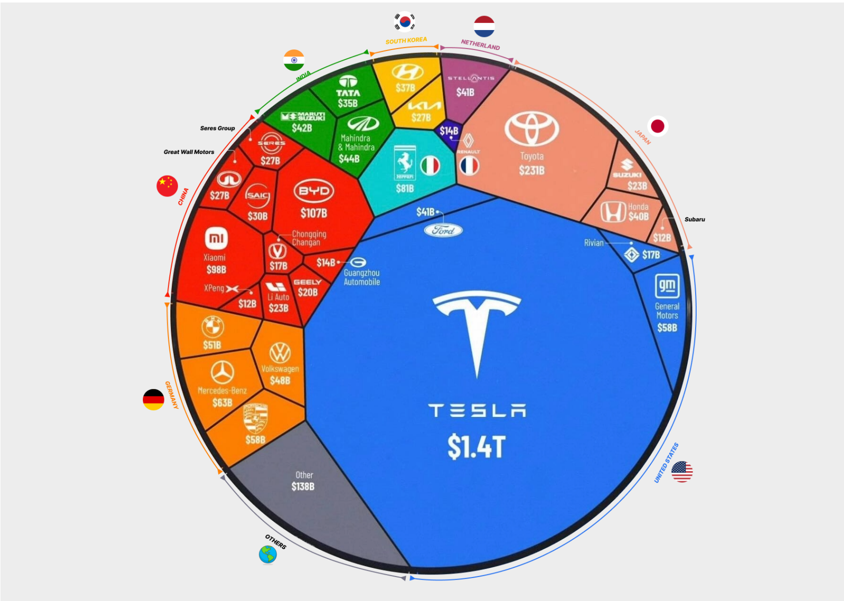

Figure 7: Global Automotive Industry by Market Cap as of December 13, 2024
Source: CompaniesMarketCap.com

Figure 7 shows the market capitalization of Auto Manufacturers, and while a company like Tesla has had almost equal value as all other companies combined, it is important to consider the effect of financialization and financial markets in this valuation. Higher market capitalization does not necessarily correspond to higher production output or current profitability. For instance, Tesla's valuation significantly exceeds that of traditional automakers despite lower sales volume. This reflects a growing emphasis on innovation potential, technological disruption, and speculative confidence in future growth, especially around software, autonomy, and battery ecosystems.

The financial stature and ownership dynamics of automotive companies have profound implications for their strategic decisions and market behavior:

- **Strategic Agility:** Companies with more concentrated ownership can make swift and strategic decisions where they can acquire a competitive advantage on novel and uncertain aspects. This can also lead to increased volatility and risk associated with over-reliance of individuals and put employees and stakeholders at risk.
- **Governance Challenges:** In firms with significant government or institutional ownership, strategic decisions may be influenced by political considerations or the need to balance diverse interests. This can impact the company's responsiveness to market dynamics and its ability to innovate.
- **Market Perception:** High ownership concentration can affect investor confidence and stock performance. While some investors may view concentrated ownership as a sign of strong leadership,

others may be concerned about potential governance issues and the lack of checks and balances.

The concentration of authority in the automotive industry can ease swift strategic changes aligned with the CEO's vision, impacting the company's direction and market perception. On the other hand, BYD's ownership is more diversified, with notable stakes held by institutional investors and government authorities. This structure reflects a balance between private enterprise and state influence, which is characteristic of many large Chinese corporations. In the case of Volkswagen, one of the largest automotive manufacturers globally, the company's governance is influenced by the Volkswagen Law, granting the German state of Lower Saxony a 20% voting stake and remarkable sway over corporate decisions. Moreover, Porsche SE holds around 31% equity stake and controls 53.3% voting rights, allowing it to dominate despite lacking an overall share majority. This unique structure can lead to a complex decision-making process, potential conflict among stakeholders, and slow transition toward EVs (Steitz & Waldersee, 2024). This could be one of the many reasons why German incumbents have lagged behind in terms of transition, where revenues earned by the ICE sector still outweigh the desire to enter into the competition with EV giants.

1.8 Germany's Economic Slowdown and Its Industrial Challenges

Germany, long regarded as the industrial backbone of Europe and a country where manufacturing and exports are still the main drivers of its economy, is now experiencing periods of prolonged economic struggles. Germany's GDP growth rate from 2022 is depicted in Figure 8 The decline in productivity growth, industrial contraction, rising energy prices, and the loss of competitive advantage in the market, especially in high-tech industries, have put the country in a stagnating stage. According to IMF reports from early 2024, Germany has been facing a technical recession as GDP contracted in multiple quarters and GDP growth in 2024 was below zero, with the manufacturing sector, especially automotive, chemicals and machinery, underperforming compared to their historical data, important aspects of the recent political turmoil in the country, according to IMF (Link). This situation is worsened by high labor costs, a shrinking working-age population, and a reliance on exports, where geopolitical shocks, particularly the Ukraine war and the uncertain situation in global trading conditions, are severely affecting the effects. Energy costs and mineral costs had soared in early 2023 is an indication of such effects. Emerging economies like China, India, and Mexico have become increasingly attractive manufacturing hubs due to lower costs and rapidly advancing industrial capabilities.

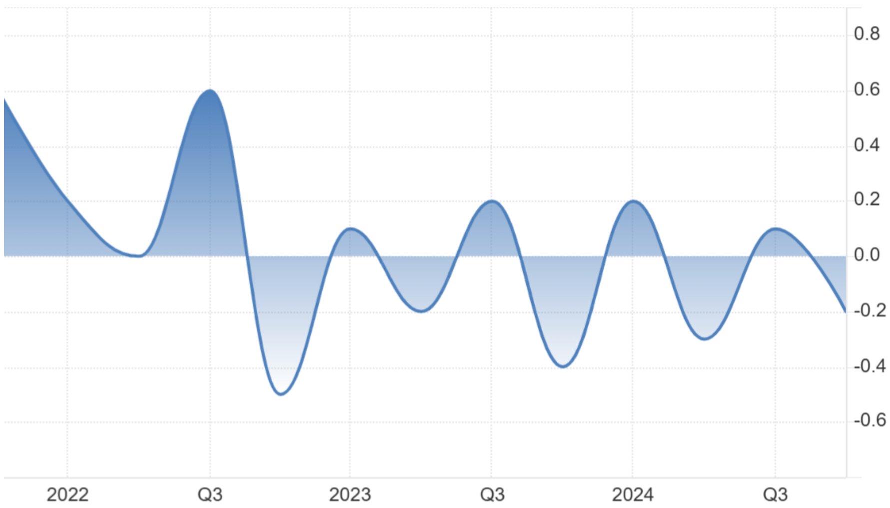

Figure 8: Germany's GDP growth - percent, Source: trading.com

In this regard, the German automotive industry, a benchmark traditionally for engineering, innovation, and reliability, is facing unprecedented competition. Sluggish domestic demand, environmental restrictions, and increased pressure from other countries in price competitiveness have forced German automakers to accelerate their offshoring and reconstruct their supply chains. Companies like Volkswagen, BMW, and Mercedes-Benz have increasingly relocated their production plants to Eastern Europe, such as Hungary, Slovakia, and Poland, and have been involved in joint ventures in China. Reducing costs, maintaining proximity to expanding markets, and a more efficient supply chain are some of the reasons in doing so. However, despite these efforts, German automakers are suffering from a strategic disadvantage, ironically due to their historical success with ICE vehicles. As well as what Schumpeter states, incumbent firms stuck in their previous achievements and profit traps would be blind to innovations, in this case, the EV and battery production. High margins from ICE technologies allowed German automakers to dominate global premium vehicles for decades, but also disincentivized early transition to electric vehicles. Investment in radical innovation—especially in software, battery design, and digital architecture—was often delayed or deprioritized. Additionally, the corporate governance models of German automakers, characterized by a complex balance of labor councils, public stakeholders (such as the state of Lower Saxony in VW), and family-owned holding companies (like Porsche SE), further slowed internal transformation efforts (Sebastian, 2022a).

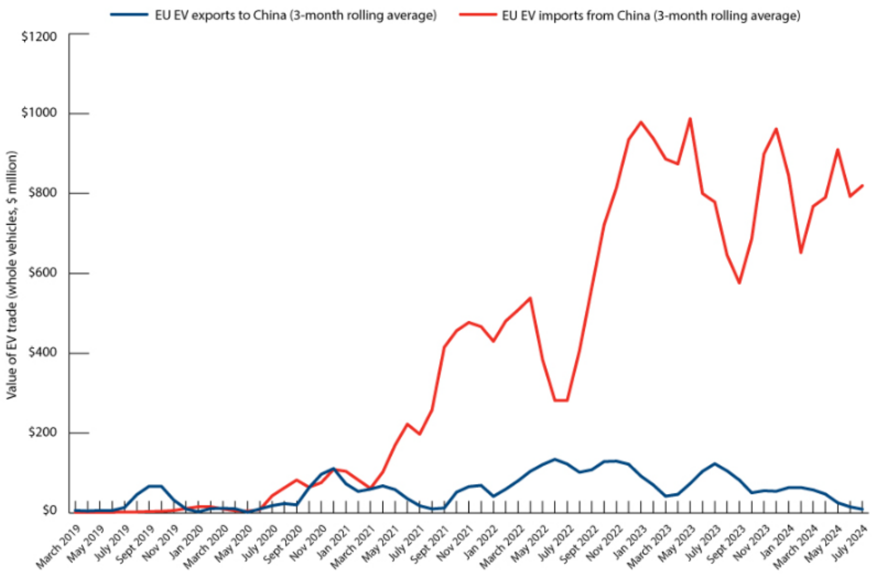

Figure 9: China's EV Export to Europe have rapidly grown, but European exports to China are roughly the same, Source: Eurostat

The Dieselgate scandal in 2015 exposed the German automotive industry's position and proved to be a turning point in the trajectory of this sector. Volkswagen's systematic manipulation of emissions data for its diesel vehicles not only resulted in staggering financial losses, recalls, and legal settlements but also deeply damaged the public perception of diesel technology. Estimates suggest Volkswagen lost over €30 billion in financial penalties and settlements, not including the opportunity costs in R&D and the delayed pivot to electrification, according to Reuters (Link). This crisis exposed the vulnerabilities of relying on ICE technology and delayed regulatory adaptation, especially as other countries began prioritizing zero-emission vehicle policies.

Meanwhile, firms like Tesla and BYD were rapidly gaining technological ground, offering software-defined vehicles, centralized electronic architectures, and in-house battery solutions—technologies that many German firms were not yet equipped to develop or scale internally. Efforts to catch up—such as the creation of Volkswagen's software arm Cariad, or partnerships with Chinese battery suppliers like CATL—have often been marked by delays, budget overruns, or poor integration outcomes (Nilsson et al., 2024).

1.8.1 Volkswagen's Restructuring: An Indication of Germany's Automotive Struggles

Volkswagen (VW), long considered as the backbone of Germany's automotive sector, employs over 120,000 people in Germany alone, and 200,000 worldwide. It is Germany's largest private-sector employer, particularly significant in Lower Saxony, where its headquarters are based. German automotive industry accounts for roughly 5% of Germany's GDP, and VW's revenue in 2024 exceeded €320 billion, more than 10% of Germany's industrial turnover. This company's recent crisis is a projection of broader challenges facing Germany's industrial base. In late 2024, the company announced to shut down at least three plant in Germany for the first time in its history, which later been settled by a mutual agreement with the working union in cutting down almost 30,000 jobs by 2030. This unprecedented move reflects deep concerns about declining competitiveness, rising costs, and the difficulty in transition to EV production.

Volkswagen's financial reports further confirm the company's tough situation. Although total revenues remains almost the same for 2024 and 2023, operating profits fell by 15%, and net profit declined over 30%. The losses are more evident in China, where the delivery vehicle dropped by 9.5%, significantly affecting regional earnings. While Europe remained relatively stable (–0.1%), Germany itself saw a 2.2% drop in deliveries. North America grew slightly, but not enough to offset the decline in the Chinese market (Volkswagen Group Annual Report, 2024).

Several interlinked factors could bring about such a situation. First, according to the analysis, VW suffers from overcapacity in Europe. With the regional market shrinking by more than 2 million vehicles since 2020, VW's market share translates into excess capacity equivalent to two full production facilities. Moreover, operational costs in Germany have surged, driven by high energy prices, especially influenced by the Russian invasion of Ukraine, expensive labor, and relatively high inflation. VW's management has repeatedly emphasized that its costs are excessive and profit margins are low. Reports suggest that VW should address this inefficiency by becoming "much leaner" as it has "too many employees who don't work hard enough and too many committees". These suggestions become more sensible when compared to other world-leading automakers, such as Toyota. While Volkswagen data demonstrate a sale of 2.52 million vehicles last year with 200,000 employees, Toyota produced a quadruple amount with barely twice the number of employees (Reeves & Lacour, 2024).

To continue, China is Volkswagen's largest market, accounting to about a third of its total sales. VW is also a significant investor in China, with three joint ventures, 90,000 employees, and 30 plants. VW is considered to be the biggest European investor in China in 2021. However, VW has been losing market share in China due to the economic slowdown in the country and increased competition from local rivals, especially in EV sector. Companies like BYD have successfully captured market share with technologically advanced models appealing to customers, while VW has faced difficulties with its own transition to EVs. Declining sales of combustion-powered cars have prompted VW and a joint venture partner to consider shutting down a factory in China, with additional closures under review, reports indicate. VW's CEO acknowledged the difficult situation, stating: "The cake has become smaller, and we have more guests at the table." (Reeves & Lacour, 2024).

The difficulties Volkswagen facing is not unique to this company as other German automakers are dealing with a similar situation. For instance, according to Reuters (Link), Porsche company, a brand epitomizing elegant design and performance, is waning among Chinese consumers, who are increasingly drawn to local EV producers and their alluring advanced technology and competitive pricing. Porsche's data reveals a significant 42% decline in sales within the Chinese market, highlighting the broader challenges faced by foreign automakers in China. At the 2025 Shanghai Auto Show, although most brands such as VW and Audi showcased new electric models, Porsche focused on its combustion-engine heritage, showcasing various new versions of 911. This strategy is in dire contrast with the preference of Chinese buyers, especially the younger generation, for affordable EVs. Companies like BYD's Yangwang and Xiaomi have introduced models with impressive specifications at lower price points, such as Xiaomi's SU7 Ultra, which boasts 1,548 horsepower and a price of approximately $72,591, compared to Porsche's 911 starting at over $200,000. Industry experts suggest that foreign automakers are not adapting fast enough, which can be the reason for the falling market share in China. Porsche's CEO, Oliver Blume, acknowledged these issues but emphasized maintaining brand exclusivity over sales volume, even hinting at the possibility of withdrawing from China's EV segment if current trends remains in the future.

The case of Volkswagen highlights the systemic vulnerabilities of German incumbents in the face of global industrial transformation. It underscores how delayed adaptation to EVs, entrenched governance structures, and high-cost environments can limit strategic flexibility. In this light, VW's restructuring

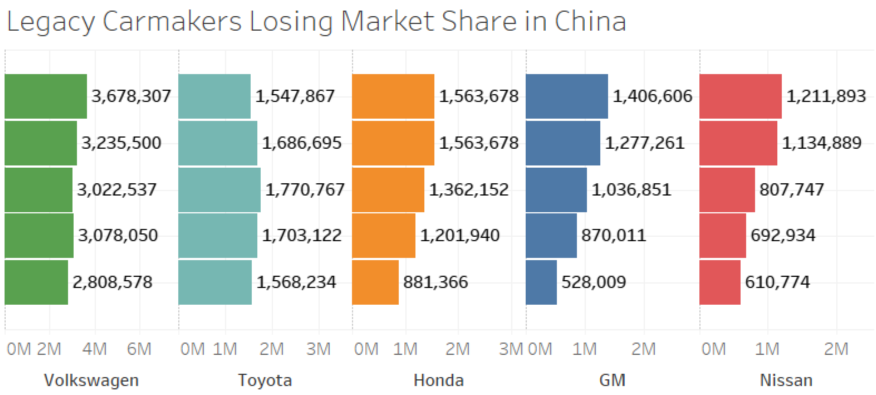

Figure 10: yearly data on total passenger car sales.
Based on data by Nick Carey and Alessandro Parodi - Source: Automobility

serves not only as a business strategy but as a symbolic marker of Germany's broader industrial crossroads.

1.9 The Rise of China as the Global EV Superpower

While conventional automakers and incumbents, especially in the case of German manufacturers, have struggled to adapt to the radical transformation in vehicle design and production, China has emerged as the dominating force in the global EV landscape. This domination is not the result of a single innovation or specific firm, but rather the result of a strategically orchestrated ecosystem. This strategy aggressive approach toward large-scale government support, vertically integrated firms, cutting-edge battery and software technologies, along with a massive domestic market that brings incredible benefits in learning-by-doing and economies of scale.

1.9.1 Strategic Leapfrogging: From ICE to EV Leadership

Recognizing relatively early on the fact that competing directly in the market for the ICE market, dominated mostly by German and Japanese firms, would be a losing game, the Chinese decided to heavenly invest in the new and disruptive technology in EVs, essentially betting that the next technological standard and dominated design would define the future of the automotive industry. Hence, the automakers and policymakers focused their efforts on battery tech, smart mobility, AI, digital architectures, and integrating infrastructures, which later on became central to their competitiveness and advantage in the EV market, according to Council on Foreign Relations (Link). This bold move has certainly been essential in China's current dominance in the EV market. China now not only produces the largest volume of EVs globally but also sets the cost and tech standards for the industry. Figure 11 shows that with the increasing dominance of EVs in Western and Asian markets, China's trade balance in the vehicle industry has changed significantly.

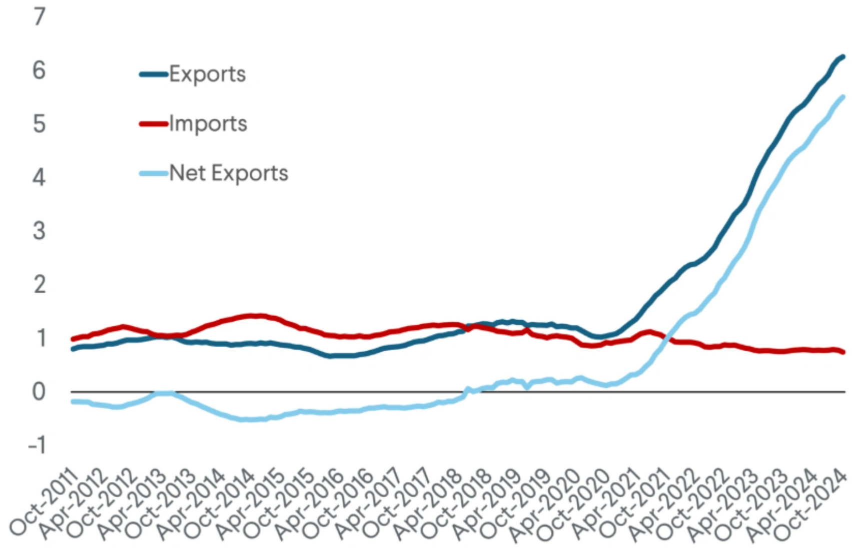

Figure 11: China's vehicle exports in millions, Source: (Council on Foreign Relations, 2024)

1.9.2 Export Boom and Market Penetration

China became the world's largest automobile exporter, overtaking Japan in 2023. In the first half of 2024, Chinese automakers exported over 2.1 million vehicles, nearly half of these electric and hybrid models (on Foreign Relations, 2024). This surge is not merely quantitative, and it represents a strategic transformation in the structure and direction of global auto trade. Firms such as BYD, SAIC, Geely, and Chery are increasing their localization strategies alongside their massive scale up production, setting up assembly plants and R%D centers in target markets to avoid trade barriers and tariffs. For instance, BYD owns production plants in Thailand and Brazil, and SAIC has expanded production and logistics hubs across Europe, offering EVs that are not only cheaper but increasingly feature-rich and technologically competitive.

Strong evidence of this export boom can be seen in global shipping capacity, where multiple logistics reports state that automakers are now reserving roll-on/roll-off (RoRo) vessels months in advance. This surge has led to capacity shortages and higher shipping rates, affecting even non-automotive sectors. Analysts argue that China's dominance in EV exports is now influencing global freight pricing, logistics flows, and trade routes — a level of influence previously associated with energy or tech sectors (He, 2025; on Foreign Relations, 2024).

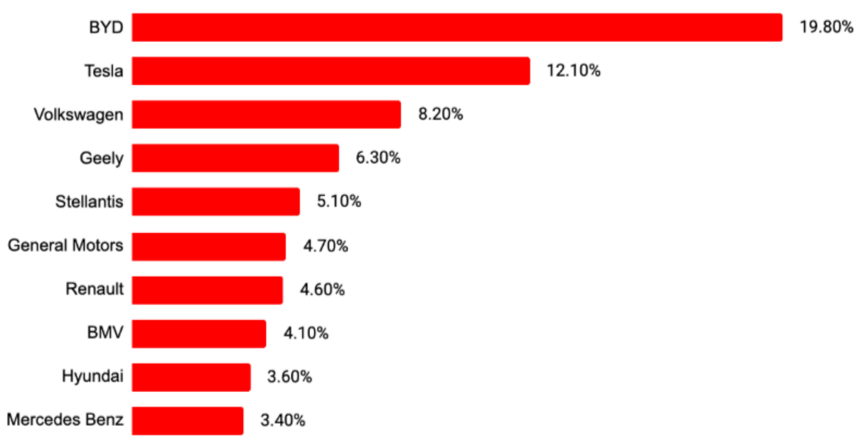

Figure 12: Global top EV automotive sales share (Q4 2022), According to Techloy.

As shown in Figure 12, BYD has surpassed its competitors both in domestic and worldwide sales. However, Chinese automakers, despite their technological advancements like proprietary battery technology and design, still find it difficult to establish a strong presence in Western automotive markets.

In the BYD case, according to (Hossain, 2024), one of the primary obstacles is the mismatch between BYD's ambitious sales target and the relatively weak demand for its vehicles in Western countries. The issue is compounded by a flawed pricing strategy, where BYD's vehicles are priced higher (due to different factors such as tariffs, distribution,n and shipping cost, and ambitious pricing strategy), deterring cost-sensitive customers. Additionally, the company faces regulatory hurdles, including investigations by Western authorities into subsidies provided by the Chinese government, which are perceived to distort market competition.

Quality concerns also hinder BYD's expansion efforts. Western customers often view Chinese-made vehicles with lower quality standards and the Chinese automotive industry must overcome these perceptions. Furthermore, the company must navigate complex safety and regulatory standards across different international markets, which would require resource and time allocation. Geopolitical factors further complicate BYD's international ambitions. For instance, the European Commission has launched an investigation into Chinese EV subsidies, which could lead to the imposition of tariffs on Chinese imports. Similarly, countries like India and Australia have rejected BYD's proposals to establish local operations, citing concerns over foreign influence and market distortion. These factors can benefit western automakers, and especially German ones as their reputation and branding still holds ground compared to their Chinese counterparts.

1.9.3 Technology, Supply Chain Dominance and Vertical Integration

Chinese firms are now considered as the leaders in battery cell technology, software integration, and platform design. Firms like BYD and CATL, backed by state-facilitated investments in African mining projects and Belt and Road logistic channels, have not only become top global battery suppliers, but also set pricing benchmarks and control a large portion of upstream materials like lithium and cobalt (Group, 2025). Furthermore, and in the software segment, EV upstarts such as Xpeng, NIO, and Li Auto have pioneered autonomous driving systems, OTA architecture, and AI-powered UI/UX interfaces, often at lower cost and faster iteration cycles than their Western rivals (Gunter & Sebastian, 2023).

Chinese EV firms have been enjoying production cost advantages compared to their rivals thanks to vertical integrations. Firms such as BYD have in-house production of batteries, semiconductors, and power electronics, which significantly affects their production cost. BYD manufactures nearly 75% of its components internally, including its signature Blade Battery, giving it tight control over cost, quality, and innovation cycles (Spotlight, 2024).

1.9.4 Government Subsidies and Industrial Strategy

Chinese firms, as mentioned before, have enjoyed a coordinated and harmonic approach to the new EV technology also from the Chinese government and regulators. Chinese government, through a combination of direct EV subsidies, R%D grants, tax incentives, and massive infrastructure investment in charging networks and smart grids, has created an enabling environment for EV manufacturers. Additionally, Beijing has imposed domestic production quotas for fleet electrification, incentivizing both state-owned and private automakers to shift to EVs rapidly. Unlike the fragmented or hesitant policy approaches in the West, China's industrial strategy is unified, long-term, and high-capacity.

1.9.5 Booming Domestic Demand as a Launchpad

With over 30 million annual car sales, China's domestic market offers unmatched scale for product testing, cost amortization, and network effects. EVs made up over 35% of new car sales in China in 2024, and that figure is expected to exceed 50% by 2026, driven by government mandates and consumer incentives (Daily, 2024). This strong internal demand allows firms to optimize operations, drive down unit costs, and experiment with product lines—something German manufacturers can no longer rely on due to weak EU demand and EV hesitancy.

1.10 The Problems & Objectives of this Study

The German automotive industry is not just an essential economic sector, but it is a strategic pillar of the country's manufacturing and export model. Accounting for approximately 18% of Germany's employment in manufacturing with around 800,000 workers, the sector has long symbolized German industrial strength, technological excellence, and trade dominance. The uncertainty regarding this sector could bring drastic side effects for both the German automotive industry and its economy overall. The German automotive huge investments in China can be a double-edged sword and makes this too big to fail sector more fragile. Moreover, and at the European level, these pressure are amplified. Energy insecurity, supply chain fragility, and technological dependencies has underscored the urgency for industrial resilience and autonomy. The automotive sector sits a the center of these challenges, and its failure or success in translating into EVs could be importantly representative of the continent's capacity to lead in strategic technologies such as artificial intelligence, semiconductors, robotics, and battery systems.

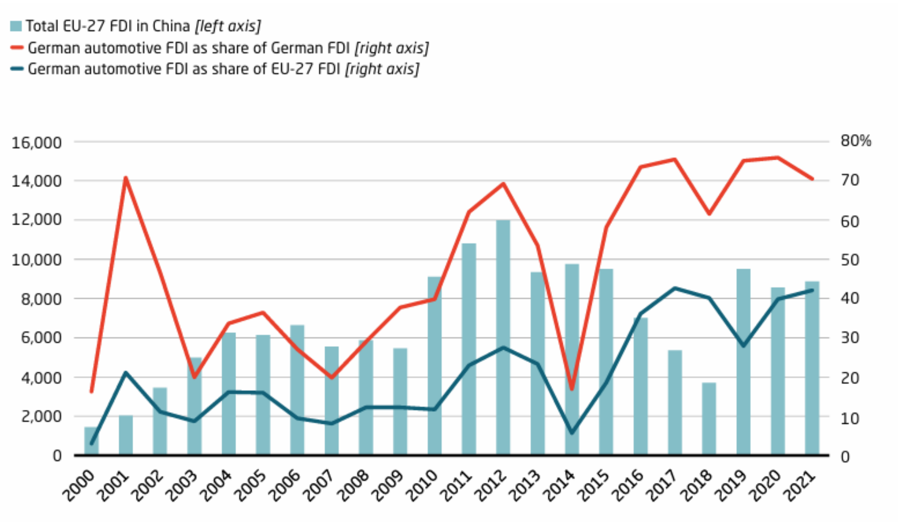

Figure 13: German automotive industry leads European foreign direct investment (FDI) flows into China. The chart illustrates FDI volumes in EUR million and their corresponding percentage shares.(Sebastian, 2022b)
FDI flow in EUR million and percent share

Volkswagen's announcement on shutting down production plants in Germany, an unprecedented decision, highlighted the urgency of the automotive sector. The company's withdrawal from these plans comes with agreements with the unions to cut down around 30,000 jobs by 2030 indicates that the company sees labor costs, declining margins, and inefficiencies in the shift to EV production in Germany as core justifications. While these challenges are not insignificant, attributing the structural problems in Germany's automotive sector solely to labor costs oversimplifies a far more complex and systemic issue. The aim of this study is to investigate factors and their magnitude contributing to this problem.

Recent evidence, including UBS's estimation of Chinese competitiveness and cost advantage, even in Europe itself, indicates the significant difference in other aspects besides wages and energy. This gap is driven less by labor or energy costs and more by vertical integration, economies of scale, and technological self-sufficiency. Beyond cost, China's EV firms lead in design modularity, software integration, and rapid development cycles. Yet, cost competitiveness remains the most decisive factor. To adapt, German manufacturers like Volkswagen have offshored production to regions like Eastern Europe, Mexico, and China, and expanded joint ventures with Chinese firms. However, this growing reliance on China raises concerns about long-term strategic autonomy. German firms have continued to lose market share in both Europe and China, facing increasing pressure from short-term volatility and declining profits. Figure 13 illustrates that German automakers account for the majority of EU foreign direct investment (FDI) into China's automotive sector. Over 70% of all German foreign direct investment (FDI) in China is concentrated in the automotive sector. As the red line indicates, Germany alone has invested as much in China's auto industry as the entire rest of the EU combined (blue line). This underscores the scale of the German industry's reliance on Chinese production, partnerships, and market access—exposing it to both economic and geopolitical risks.

The literature attributes this competitive disadvantage to various factors, including lower wages in China, reduced energy costs, economies of scale, and vertical integration (Jagani et al., 2024; Mazzocco & Sebastian, 2023). However, there remains a significant gap in the literature: no integrated, comprehensive analysis quantifies the relative impact of these cost drivers. Existing studies acknowledge that lower wages and reduced energy prices in China contribute to cost advantages (Sinn, 2006), but we argue that these factors alone cannot fully explain the cost differential between Chinese and German EV producers.

Instead, economies of scale and vertical integration are likely the dominant forces behind China's cost advantage, yet quantitative estimations of their impact remain scarce.

This study aims to bridge this gap by providing an empirical analysis of the cost structures in the Chinese and German EV industries, focusing on the role of scale economies and vertical integration. By identifying the key cost drivers, this research will contribute to a more nuanced understanding of competitive dynamics in the EV market and inform strategic decision-making for policymakers and industry leaders.

Problem statement: Chinese EV producers have overtaken European (German) EV producers in terms of (lower) cost, faster introduction of new cars, battery technology, software, and the overall philosophy of the car (i.e. the EV is an AI-driven computer on wheels). Because car buyers (esp. in China) are shifting to EVs, and the market for ICEVs is stagnating, German automotive firms are losing market share in China and Europe. The German car industry faces an existential crisis - it is make or break.

Research Question: To what extent do the identified structural drivers of cost competitiveness explain the persistent retail-price gap between Chinese-manufactured and German-manufactured electric vehicles in European markets, and what are the implications for EV adoption and the German automotive industry?

Sub-questions:

What are the primary supply-side factors contributing to the retail-price differential between Chinese-manufactured and German-manufactured electric vehicles?

Explanation: This question directly investigates and quantifies the contribution of key supply-side cost drivers. This includes an analysis of labor costs (both direct and indirect, derived through the Leontief framework), the impact of learning-by-doing effects on unit costs, and the cost advantages gained through vertical integration. These factors are central to decomposing the observed retail-price differential and understanding the structural advantages in China's production within the broader industrial and value chain framework.

How does the identified retail-price gap, particularly its unexplained residual, influence EV adoption rates in Germany and comparable European markets?

Explanation: This question specifically examines the demand-side implications of the observed retail-price gap. Leveraging established price elasticity frameworks, it quantifies how the overall price differential, and especially the portion not explained by production-related costs (the residual gap), impacts the rate of EV uptake in Germany and other European markets.

1.11 Outline of the Thesis

The remainder of this research is structured into the following five sections, each building upon the preceding one to comprehensively address the persistent retail-price gap between Chinese-manufactured and German-manufactured electric vehicles.

Chapter two provides a comprehensive review of the existing literature, establishing the theoretical foundations that underpin this study's analysis of cost structure, technological transitions, and industrial organization in the EV sector. It begins by presenting a conceptual model Figure 14, which serves as a framework for understanding the complex, self-reinforcing dynamics of EV competitiveness, guiding the subsequent empirical analysis. Following this, the chapter is structured to systematically explore the key supply-side factors identified as drivers of competitive advantage: battery cost dynamics and trends, the role of learning-by-doing in driving price reductions, and how vertical integration reshapes value chains and cost competitiveness. Furthermore, it delves into the demand-side factors influencing EV adoption, such as price elasticity and government incentives.

Chapter three outlines the methodological approach, detailing the comparative framework and the diverse data sources employed to analyze the EV price gap between Chinese and German producers. It explains how this study applies established analytical techniques—such as the Leontief input-output model for labor costs, Wright's Law for learning-by-doing effects, and comparative market analysis for vertical integration—to quantify the contributions of various factors. It is crucial to note that this research does not aim to build a new predictive or simulation model, but rather to leverage existing theoretical and empirical frameworks to systematically decompose and explain the observed price differences. Additionally, the chapter discusses how EV adoption trends, especially in key markets like Germany and Europe, are examined through the lens of price elasticity, providing insights into how affordability influences demand patterns.

Chapter four presents the empirical analysis, comparing the structural and technological factors underlying production costs and market performance. This includes a detailed breakdown of cost components, an analysis of learning curves, and an examination of supply chain configurations, with a special focus on firms such as BYD and Tesla on one side, and Volkswagen, BMW, and Mercedes-Benz on the other

Chapter five offers the conclusions and implications of the study. It summarizes the key findings regarding the explained and residual price gaps, integrates these results with the conceptual model, and provides interpretations of the findings.

Chapter six addresses the limitations of the study, including methodological constraints, scope, generalizability, and practical challenges.

Finally, **chapter seven** provides final reflections on the research journey and acknowledges contributors.

2 Drivers of Cost and Technological Competitiveness in the Automotive Sector: Literature Review

This chapter provides a comprehensive review of the existing academic literature, establishing the theoretical foundations that underpin this study's analysis of cost structure, technological transitions, and industrial organization in the electric vehicle (EV) sector. The primary purpose is to synthesize established academic outputs to construct a robust framework for understanding the complex dynamics of EV competitiveness, particularly the persistent price differential between Chinese-manufactured and German-manufactured EVs.

To guide this exploration, this chapter begins by presenting a conceptual model (Figure 14). This model, derived from a synthesis of interdisciplinary academic insights, serves as a comprehensive framework for understanding the self-reinforcing dynamics of EV competitiveness. It highlights the intricate interplay between supply-side factors (which are the primary focus of this study's empirical evaluation) and crucial demand-side factors, both of which collectively influence EV cost competitiveness, pricing, and ultimately, adoption rates.

2.1 Conceptual Model: The Self-Reinforcing Dynamics of EV Competitiveness

While there are abundant studies regarding different factors in EV market adoption, pricing, and competitive advantage, comparative analyses across global markets remain limited. China's current EV dominance is unlikely to shift unless major changes occur across suppliers, buyers, and regulators. This study seeks to quantify the economic inefficiencies arising from these disparities, providing an estimation of EU market losses.

The conceptual model presented here explains the structural factors that shape cost and technological competitiveness in the EV sector, with a focus on the diverging trajectories of China and Germany. The model distinguishes between supply-side drivers, such as material costs, labor structures, wage costs, and production scale, and demand-side factors, including policy incentives, price sensitivity, and supporting infrastructure accessibility. EV adoption is treated as a downstream outcome of these conditions, yet it also plays a reinforcing role. In other words, higher adoption can lead to greater scale, stronger learning effects, and increased institutional support, thereby enhancing cost competitiveness over time.

In the case of China, the model reveals a self-reinforcing feedback loop supported by strong government intervention. On the supply side, labor costs, operational costs, technological progress, vertical integration, and learning-by-doing drive down the cost of produced goods. As (Orangi et al., 2024) notes, battery costs have dropped by 97% largely due to learning effects and economies of scale. Industrial policies play a central role, subsidizing key firms and coordinating supply chains to allow EV manufacturers to scale production while further reducing costs. In contrast, Germany's EV sector faces fragmented institutional frameworks, slower adoption rates, and less vertically integrated supply chains. Without a comparable feedback dynamic between scale, cost reduction, and policy coordination, German competitiveness is more vulnerable to structural inertia.

On the demand side, consumer subsidies, regulatory preferences, and widespread investment in charging infrastructure reduce the cost of ownership and increase accessibility, accelerating adoption (Taormina & Ainpudi, 2021). As adoption rises, sales volumes grow, which fuels further cost reductions through learning-by-doing, reinforcing the cycle (Barwick et al., 2025). The outcome is a dynamic advantage: falling costs feed rising demand, which in turn supports further investment and innovation. For Germany to remain competitive within this system, it must address both sides of the model—enhancing battery RD, expanding public investment, and implementing more strategic industrial policies to counterbalance China's scale-driven advantage.

2.2 Drivers of Cost and Technological Competitiveness: A Literature Overview

The global automotive sector's transition to electric vehicles is fundamentally altering its landscape, presenting substantial hurdles for established manufacturers, particularly in Germany. As competition

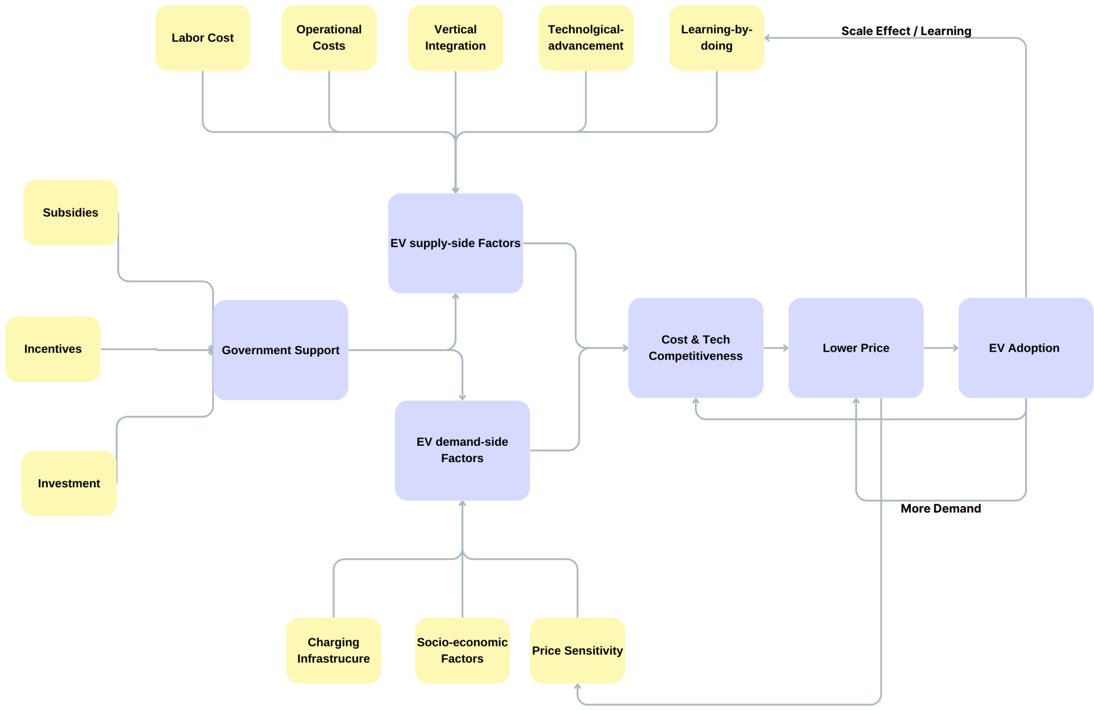

Figure 14:
Conceptual Model of Structural Drivers of EV Cost Competitiveness
This model outlines the supply- and demand-side factors influencing EV cost competitiveness and adoption. It highlights the reinforcing loop between adoption and cost reduction and compares China's integrated advantage with Germany's fragmented structure.

intensifies, Chinese firms are gaining ground through significant cost advantages, robust supply chain control, and technological agility. To explain this divergence, it is essential to examine the structural economic and institutional factors influencing production strategies and competitiveness, as identified and discussed within the academic literature.

German automakers, for instance, often face persistent obstacles such as relatively high labor and energy costs, rigid institutional frameworks, and pressures arising from financialization that can lead to short-termism. These constraints can limit strategic flexibility and contribute to a growing trend of offshoring both production and innovation activities to lower-cost regions. National and EU-level policy frameworks also play a crucial role, either reinforcing or mitigating these pressures.

This section of the literature review synthesizes existing research on the cost dynamics, labor frictions, supply chain transformations, financial governance, infrastructure readiness, and policy incentives that collectively shape the competitiveness of EV production. It draws on economic and strategic literature to assess how these forces influence German and Chinese automakers differently.

The following table outlines five key dimensions that structure this analysis, representing interconnected factors ranging from production costs to government policy. These dimensions form the theoretical basis for the comparisons developed throughout this chapter and are critical for understanding the competitive landscape.

Table 1: Framework of Cost and Competitiveness Dimensions in the EV Industry

Dimension	Subcomponents	Relevance
Material and Production Costs	Battery pack cost, raw materials (lithium, cobalt, graphite), vertical integration, supply chain control	China's dominance in battery production and raw material control lowers EV costs and creates strategic dependencies for competitors.
Learning-by-Doing	Cumulative output, innovation diffusion, patenting intensity, experience curves	Chinese firms benefit from scale-driven cost reductions, accelerated by government subsidies and innovation feedback loops.
Labor and Institutional Structures	Unit labor cost, collective bargaining, co-determination, offshoring, financialization pressures	Germany's rigid labor institutions, high wages, and increasing financialization constrain transition speed and incentivize offshoring of both production and R&D.
Socio-Economic & Infrastructure Factors	Household income, price elasticity, housing type, access to charging, urban mobility readiness	Adoption is heavily skewed toward high-income and homeowning consumers; infrastructure access reinforces income-driven uptake gaps.
Government Incentives and Policy Design	Purchase subsidies, tax breaks, infrastructure investment, public fleet conversion, regulatory certainty	Long-term policy coherence (e.g., Norway, China) outperforms fragmented or short-term approaches; infrastructure support often more impactful than subsidies alone.

2.3 Production and Material Costs

The pricing of EVs is fundamentally shaped by development in battery technology and the structure of global raw material supply chains. Battery costs have significantly declined due to various reasons detailed in this subsection. THe trajectory of future cost reductions is subject to uncertainty though, especially as marginal gains become harder to achieve and input material costs rise. In parallel, the supply of critical raw materials has become a key determinant of both price stability and geopolitical risk in EV manufacturing. China's dominance in owning these rare materials or their refining process is unanimous in the literature. However, the cost advantages of vertically integrated firms, the longer-term effects of battery recycling, closed-loop systems, and international governance initiatives remain more speculative.

2.3.1 Technological Advancements and Cost Reductions in Battery Production

(Ralls et al., 2023) provides a comprehensive review of the role of lithium-ion batteries (LIBs) in the EV sector, focusing on their economic and manufacturing dimensions. The paper emphasizes that battery manufacturing accounts for a substantial portion of total EV cost, with particularly expensive stages including coating/drying and formation/aging. Innovations such as solvent-free dry coating have emerged to reduce these costs and shorten production time.

The commercially available LIB types for EVs—LFP, NCM, and NCA—each offer trade-offs in terms of performance, stability, and resource requirements. The choice of chemistry has direct implications for material sourcing and production cost, with cobalt- and nickel-based chemistries facing volatility due to supply risks. The authors note that materials like cobalt remain a key driver of battery cost variability, especially in German supply chains more reliant on global imports.

The study also outlines efforts to optimize battery pack formats (cylindrical, prismatic, pouch), which affect both integration cost and thermal performance. Battery Management Systems (BMS) are highlighted as critical for prolonging lifespan and maintaining efficiency—though their cost impact is more moderate compared to cell chemistry. Finally, the paper underlines the importance of recycling, circular economy policies, and nanostructured materials for long-term cost control, though these advances are still limited in commercial impact.

Figure 15 illustrates the structural components of lithium-ion batteries, which remain the dominant technology in electric vehicle (EV) manufacturing. The performance and cost of LIBs are primarily shaped by the properties of the anode, cathode, and electrolyte materials, as well as the efficiency of charge-discharge cycles. These technical features influence the battery's lifespan, energy density, and ultimately, its contribution to the total cost of an EV. Understanding the composition of these components is essential for assessing cost differences between producers with different sourcing strategies and technological capabilities.

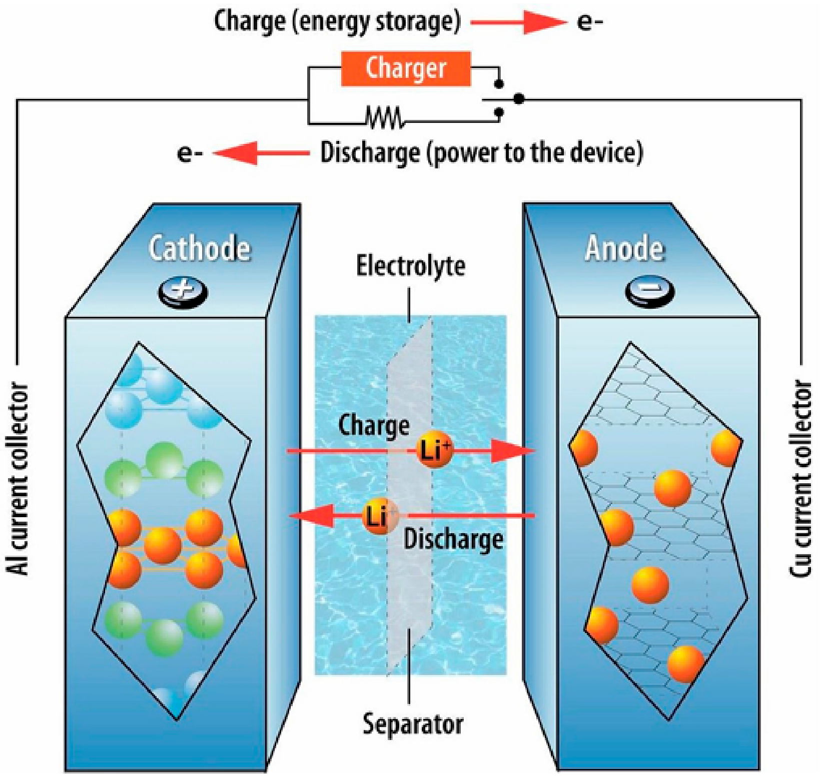

Figure 15: An illustration highlighting the key structural elements of lithium-ion batteries (LIBs). Source: (Nzereogu et al., 2022)

(Orangi et al., 2024) examines the economic trends and future projections regarding battery costs. A historical decline in the cost of batteries is mentioned, where 97% reduction since the commercialization of the first battery car by Sony has occurred. The trend indicates an 85% reduction in costs for the last decade. This decrease is often linked to the concept of **Learning Rates**, where costs decrease as production volume accumulates and technological advancement are made. Several factors, such as manufacturing scale, technological advancement in battery materials, design, and manufacturing process, are crucial for cost reduction. Considering the specific application of the battery in EVs can influence cost considerations and targets. The study states that different projections for future battery costs are proposed by different studies based on varying scenarios and assumptions about technological progress and market development. The overall context for these economic discussions is the increasing cost competitiveness of batteries for applications like EVs as they strive to reach parity with ICE vehicles.

Figure 16 illustrates the historical and projected cost trajectories of lithium-ion battery (LIB) cells between 2010 and 2030, based on multiple sources including manufacturers and independent forecasts. The black line traces the average cost trend, showing a steep decline from over \$450 per kWh in 2010 to roughly \$100 by 2023. The dashed orange line represents a commonly referenced cost threshold of \$75/kWh, which is often cited as the point at which EVs achieve full price parity with internal combustion engine vehicles. Both the LFP and NCX scenarios shown suggest that this threshold could be reached before 2030 under current learning and scaling dynamics.

(Lechner et al., 2024) presents a systematic review of the costs trend of Li-ion battery packs for Battery Electric Vehicle (BEV) manufacturers, analyzing over 80 different estimates reported between 2007 and 2014. Results indicate that industry-wide cost estimates declined by approximately 14±6% annually from 2007 to 2014, from above US\$1,000 per kWh to around US\$400. More noticeably, the

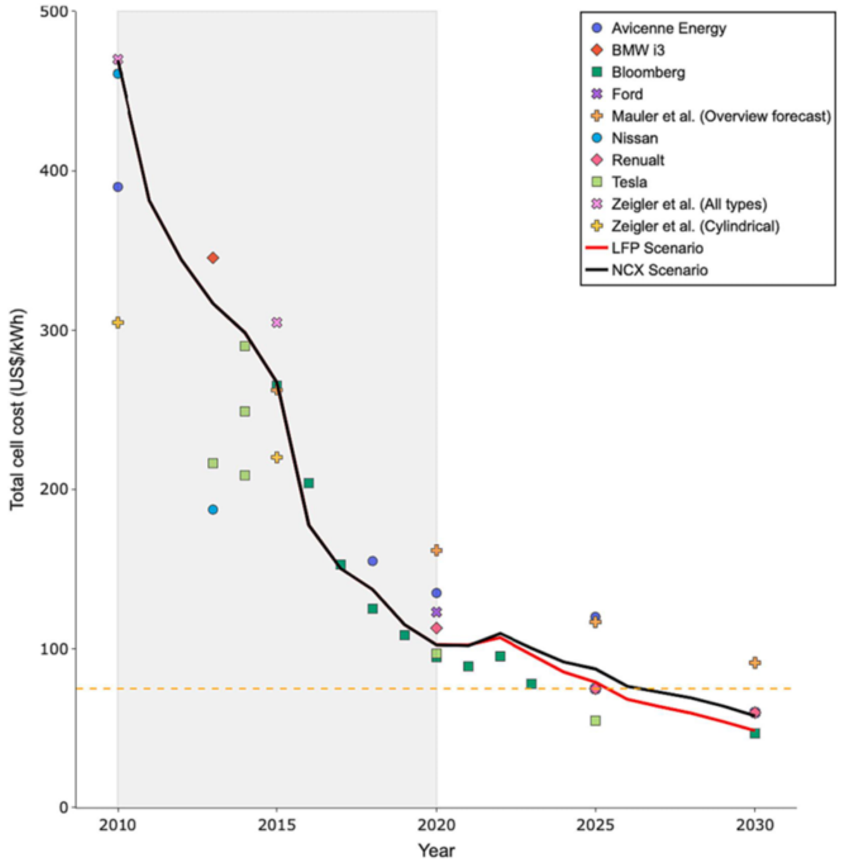

Figure 16:
The historical (2010–2020) and forecasted (2020–2030) pricing trends for lithium-ion battery (LIB) cells are illustrated, with the dashed line marking the targeted cost benchmark of 75 US$/kWh at the cell level.
Source: (Orangi et al., 2024)

cost of battery packs used by market-leading producers was even lower, at US$300 per kWh. This paper also mentions learning rates as one of the most important factors of this decline, where the declining rate is to be estimated between 6% and 9%, aligning with previous studies. Additional important factors mentioned in this study are economies of scale and R&D improvements in the battery materials.

These findings indicate that Li-ion battery pack costs were declining rapidly, and the costs for market leaders were significantly lower than previously reported findings. The authors emphasize that the most critical factor for the mass-market adoption of affordable BEVs is their relative cost, with the battery being the key cost difference compared to internal combustion vehicles. They also estimate that achieving price parity with ICEs would require battery costs to fall to around $150. The study also highlights the potential for large-scale battery production facilities to drive down costs further. Investments in gigafactories, like the Tesla-Panasonic plant, aim for substantial cost reductions through economies of scale, with projections of around US$200 per kWh at high production volumes.

(Mauler et al., 2021) confirms a significant historical decline in Li-ion battery costs, mainly driven by improvements in cell chemistry, process technologies, and increased production scale. This trend is in line with the findings from (Lechner et al., 2024). The review of 53 studies in this paper reveals a large variance in forecasted battery costs, resulting from differences in applied forecasting methods and underlying assumptions. By consolidating 360 extracted data points, the author derives a general pack cost trajectory reaching $70 per kWh in 2050. Despite the general expectation of declining costs, the study highlights that large cost uncertainties exist on both technological and chronological levels, which will continue to challenge researchers and industry. The authors have used four main forecasting methods including technological learning, literature-based projections, expert elicitations, and bottom-up modeling.

(Chandler, 2021) analyzed the remarkable 97% cost decline of Li-ion batteries since their introduction, attributing over 50% of this reduction to R&D. Particularly, advancements in chemistry and materials science were identified as the most significant contributors, outweighing the impact of economies of scale. This study uses over 15,000 data points, including academic articles, industry reports, and legal filings. The author emphasizes the importance of sustained R&D investment, even after a technology is commercialized. These insights aim to guide policymakers and industry planners in prioritizing investment strategies for reducing the cost of energy storage technologies. While various efforts contributed to cost improvement, the dominant role of R&D, particularly in chemistry and materials, is a key takeaway. This study emphasizes that significant progress and cost reduction stemmed from a broad range of initiatives rather than the efforts of a few individuals.

2.3.2 Supply Chain Dependencies and Critical Raw Materials

(Niri et al., 2024) provides a comprehensive review of challenges in the EV battery supply chain amid rapidly growing global demand. Projections of over 300 million EVs on the road by 2030 imply sharp increases in demand for key raw materials such as lithium, cobalt, nickel, and graphite. The paper emphasizes that global reserves of these minerals are geographically concentrated, particularly in South America, Africa, and parts of Asia, which introduces long-term supply risks and geopolitical dependencies for battery manufacturers.
Several challenges are identified in the supply chain ecosystem:

- **Land Use Conflicts**: Localizing battery production can trigger competition over land resources, especially in densely populated or ecologically sensitive areas.
- **Energy Intensity**: Battery manufacturing is highly energy-intensive, contributing significantly to the carbon footprint of EVs.
- **Supply Sustainability**: As mineral demand outpaces discovery and extraction, there is increasing concern that cumulative demand may exceed currently accessible resources, potentially raising costs and delaying production timelines.
- **Recycling and Secondary Resources**: Recycling presents a partial solution. Some countries aim to meet up to 15% of annual raw material needs through secondary sources, but large-scale closed-loop systems remain underdeveloped.

The study concludes that while closed-loop recycling and process optimization offer promising solutions, meeting future EV targets will require coordinated investment in extraction technologies, recycling capacity, and international regulatory standards.

The paper concludes that while progress has been made, more technological efforts, investments, and regulations are needed. Closed-loop recycling is promising, but further advancement and transparent global data systems can drive the technology and the policy alignment.

(Barman et al., 2023) explores the supply chain and processing economy for critical raw materials used in lithium-based EV batteries, which are expected to hold a 77% market share by 2030. The authors outline the multi-stage battery value chain, ranging from mineral extraction and refining to synthesis, cell manufacturing, and recycling, emphasizing that the cost structure is shaped by both material sourcing and the energy-intensive processes required to produce high-purity compounds such as lithium carbonate, lithium hydroxide, and cobalt and nickel sulfate.

A central theme in the study is China's dominant role not just in raw material access, but also in refining and production. The country processes over 70% of cobalt, controls 80% of graphite supply, and leads global output in manganese and battery-grade materials. This centralized control contributes to competitive cost advantages in battery production. The paper also highlights that five companies are responsible for over 75% of the global production of any key battery material, while a few Chinese firms dominate the manufacture of cathodes, anodes, separators, and electrolytes.

Lastly, the study notes that battery recycling and second-life applications are becoming increasingly relevant, especially in China, which accounts for around 50% of global EV battery recycling capacity. The reuse of EV batteries for stationary storage, where batteries retain more than 80% of their original capacity, may offer future avenues for material cost reduction and supply stabilization.

Recent literature converges on the notion that the transition to EVs introduces significant structural shifts in the automotive supply chain, particularly around access to raw materials and the emergence of new technological pathways. (Jagani et al., 2024) investigates the automotive industry's transition to EVs, highlighting supply chain transformations and the shifting role of suppliers. The paper examines the relationship among suppliers, Original Equipment Manufacturers (OEMs), and new disruptive entrants. The research notes the resilience of the ICE vehicle supply chain to change due to geopolitical issues surrounding raw materials. It compares the ICE and EV supply chains, stating that the EV supply chain has a broader scope for innovation. (Rajaeifar et al., 2022) emphasizes the criticality of raw mineral materials for EV production, such as lithium, cobalt, and graphite, due to supply risks that could lead to price volatility. The author notes that over half of global cobalt and copper mining operations are now under Chinese ownership, emphasizing the strategic value of these resources. (Kumar et al., 2021) identifies major barriers such as inadequate battery recycling systems, limited reuse options, disposal issues, and a lack of sufficient charging infrastructure. The study also underscores China's dominance in graphite production—accounting for approximately 70%, and its control over 24% of global reserves. (Zhao et al., 2022) explores pricing optimization strategies for EV batteries across three domestic Chinese recycling streams influenced by government subsidies. They further highlight the role of policy in shaping pricing dynamics within the EV battery recycling sector, calling attention to the need for greater state support in scaling recycling efforts.

(Ali et al., 2017) argues that ensuring a sustainable supply of minerals for a growing global population and the transition to a low-carbon society requires better resource governance. The author highlights the relationship between mineral resourcing and climate change, stating that clean technologies rely heavily on mineral inputs. The authors mention the key challenges facing future mineral supply such as geological constraints, economic factors such as short-term driven investment in exploration leading to high fluctuations based on commodity prices; social and environmental pressures, governance issues; and time lags (long delays between mineral discovery and project development). The paper suggests a need for global resource governance and outlines six specific measures.These actions include establishing international agreements on mineral production targets, assessing the environmental and social effects of mineral extraction and use, enhancing collaboration in exploration efforts, and promoting research and innovation in new extraction technologies, harmonizing global best practices for responsible mineral resource development, and developing maps and inventories showing the availability of recyclable metals. The authors emphasize that current international environmental policy lacks a crucial resource dimension to meet ecological and development goals. They suggest that existing international organizations like the International Resource Panel and the Intergovernmental Forum on Mining, Minerals, Metals, and Sustainable Development could be linked to enhance resource planning. In conclusion, the article advocates for proactive international planning and governance to ensure a sustainable mineral supply in the face of increasing demand driven by population growth and the transition to a low-carbon economy.

(Tan & Keiding, 2024) examines the global supply chains of cobalt and lithium. The paper results indicate a highly concentrated nature of these supply chains, with few countries dominating key stages, such as mining, refining, and the production of cathode materials. The paper mentions China's dominant role in refining both metals and cathode materials. Using the Herfindahl-Hirschman Index (HHI) and the World Governance Index (WGI), the top 10 companies control around 80% of global mining and refining production for both cobalt and lithium. The authors emphasize the significant overseas investments by multinational companies, which reduce the costs and risks for these firms. By analyzing company ownership, the discrepancy between the geographical distribution of production and the production is attributed to the nationality of companies controlling those assets. For instance, Switzerland's dominance in cobalt resources is due to Glencore, a Swiss-based company with huge overseas mining operations in the DRC, Australia, and Canada. The authors also explore the trend of vertical integration within the lithium battery industry, where companies expand their activities across different stages of the supply chain. Upstream mining companies are engaging in refining, while downstream battery manufacturers and automotive companies are investing in mining and refining to secure a reliable supply of raw materials. More than half of the top 46 companies involved in the cobalt and lithium supply chains in 2019 demonstrated some degree of vertical integration.

(Seaman, 2024) examines Europe's increasing dependence on China for critical raw materials essential to its decarbonization strategies. The study highlights how Europe has shifted from reliance on fossil fuels to dependency on minerals such as gallium, lithium, graphite, and rare earths, which are central to EV technologies and broader green transitions. This reliance is not driven by geology alone, but by

China's long-term industrial strategy, which has established dominance across the downstream supply chain. While China's share in mining has decreased, it continues to control the majority of refining and processing operations—accounting for 85% of global refining, over 90% of rare earth magnets used in EV motors, and 75% of global anode battery supply chains. In graphite, China produces nearly all spherical graphite and dominates the production of natural graphite anodes.

The paper also explores how these supply chain advantages may be leveraged as tools of economic statecraft. Examples include China's 2023 export license restrictions on graphite, and its ban on rare earth magnet production technologies, both interpreted as strategic responses to U.S. and EU trade measures. In response, Europe has launched multiple policy initiatives aimed at reducing its vulnerabilities. The Critical Raw Materials Act sets goals for the EU to domestically extract 10% of its minerals, process 40%, and source 25% from recycling by 2030. It also sets a cap of 65% dependency on any single external supplier. While the paper acknowledges the limitations of mineral dependency as a coercive tool, it argues that sustained dependence can shape industrial choices and drive policy adaptation among importing states.

2.4 Learning-by-Doing and Cost Efficiency in EV Battery Production

(Goetzel & Hasanuzzaman, 2022) investigates the cost trends of BEVs in Germany to predict when they will reach purchase price parity (PPP) with comparable ICEs and evaluate their total cost of ownership (TCO). While BEV sales have increased significantly in some markets, their global share remains marginal. The cost of owning a BEV is a major hurdle in further adoption. The research conducts a learning rate analysis on BEV retail prices in Germany from 2015 to 2020 to forecast price parity. This top-down approach adapts methods from prior studies. The analysis is done using vehicle pairing (BEVs identified and pairing with comparable ICEs were conducted) and cost breakdown (retail prices were segmented into powertrain and ancillary costs, 18% and 82% respectively), Electrification Cost (the difference between the BEV MSRP and ICE's ancillary cost), and Specific Electrification Cost. Learning rate Analysis and Price Forecasting were conducted to compare the costs and an estimation for the price parity between 2020 and 2030. Learning rates observed from 2015 to 2020 were 23% ± 2% in the small-size BEVs, 29% ± 6% in the mid-size BEVs, and 24% ± 4% in the luxury BEVs. The estimated years for achieving price parity were 2024 for luxury vehicles, 2026 for mid-size, and 2030 for small-size BEVs. These estimations also reveal that to reach price parity 19 million luxury vehicles, 42 million mid-size vehicles, and 600 million small-size vehicles were necessary based on the 2020 data. The paper also explores the total cost of ownership for each BEV segment. According to the results in the study, the small-size vehicles were 30% more expensive, the mid-size had a disadvantage of around 10%, and the luxury vehicles disadvantage was only 3%. However, in 2020, considering government subsidies, most BEVs were already cheaper to own than ICEs in Germany.

Figure 17 illustrates projected price trajectories and total cost of ownership (TCO) scenarios for battery electric vehicles (BEVs) relative to internal combustion engine (ICE) vehicles across small-size (A/B), mid-size (C/D), and luxury (E/F) market segments. The upper graph displays BEV and ICE pre-tax MSRP projections from 2020 to 2030, under high- and low-cost assumptions. The results suggest that BEVs are expected to reach purchase price parity with ICE vehicles at different timeframes across segments—earliest for luxury vehicles, followed by mid-size and small-size models. Figure 18 panels depict 5-year and 10-year TCO outcomes in EUR/km, highlighting that despite higher upfront prices, BEVs are projected to offer lower ownership costs over time, particularly in the mid-size and luxury categories. These projections underscore the role of learning effects, economies of scale, and ownership duration in shaping the economic viability of BEVs.

(Barwick et al., 2025) investigates the learning-by-doing (LBD) rates on cost reductions in EVs, with a special focus on the Chinese market. LBD accounts for 35.5% of battery cost reductions between 2014 and 2020, and the estimated LBD rate is 7.5%, meaning each doubling of cumulative output leads to 7.5% cost reduction. Projections in this paper predict faster approach to price parity with ICEs, with battery pack prices expected to reach $75US\$$.kWh^{-1} by 2027. Patent data has been used as a proxy for innovation intensity, which correlates strongly with production scale and cost decline. The paper quantifies that a 40% cost reduction occurred with each doubling of inventive activity, measured via cumulative battery-related patent filings. The paper also has a breakdown of cost reduction drivers as R&D investments account for 54% of observed cost reductions, and economies of scale at 30%. The authors

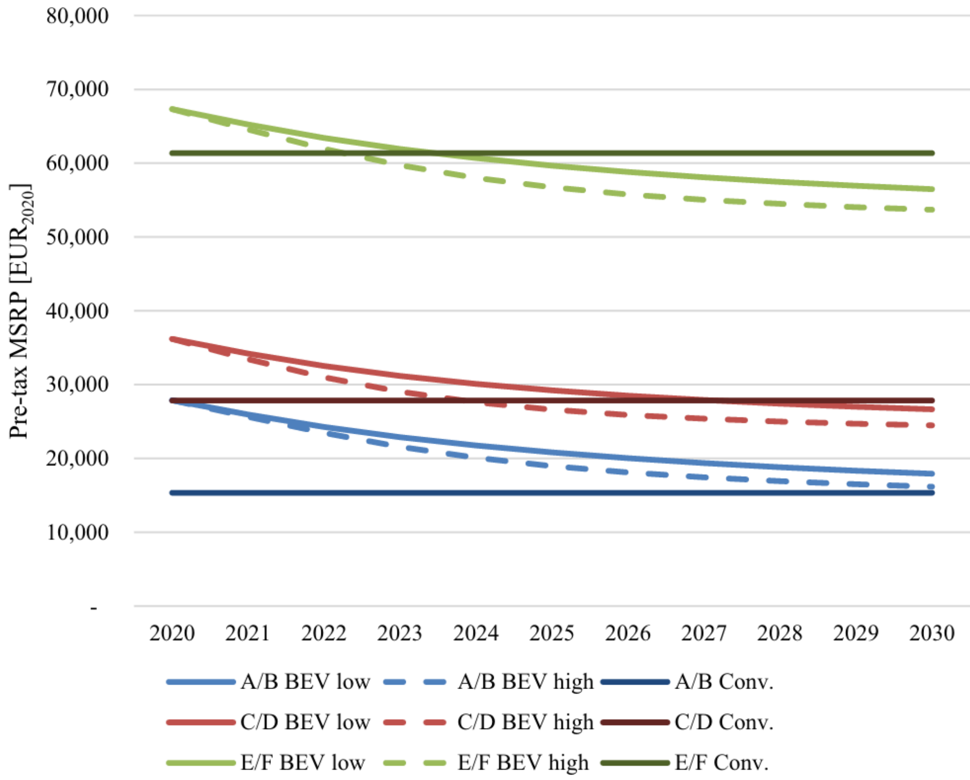

Figure 17:
BEV Price Parity Scenarios - A/B, C/D, and E/F are small-size, mid-size and Luxury BEVs, respectively - (Goetzel & Hasanuzzaman, 2022)

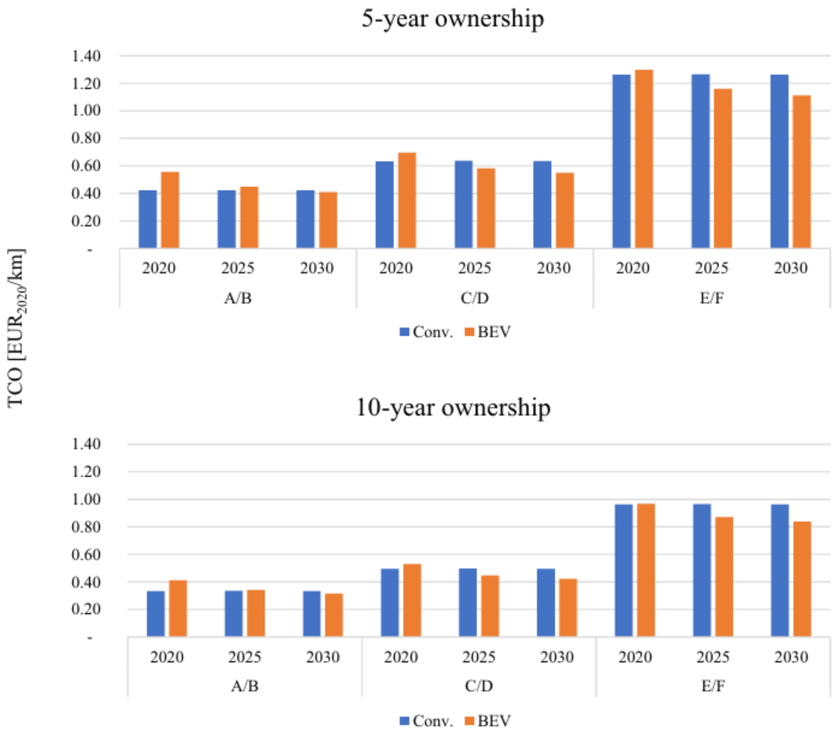

Figure 18:
Future Total Cost of Ownership Results (Without Considering Subsidies) - (Goetzel & Hasanuzzaman, 2022)

also accentuate the positive feedback loop between government subsidies, production scale, innovation, and demand growth. These subsidies in China have resulted in amplifying effects, making scale and cost learning faster than in the EU or US. LBD is expected to play a diminishing role over time as the industry matures, and R&D and supply chain optimization become more critical. The paper suggests that countries investing now in large-scale battery and EV manufacturing ecosystems will reap long-term industrial and climate benefits.

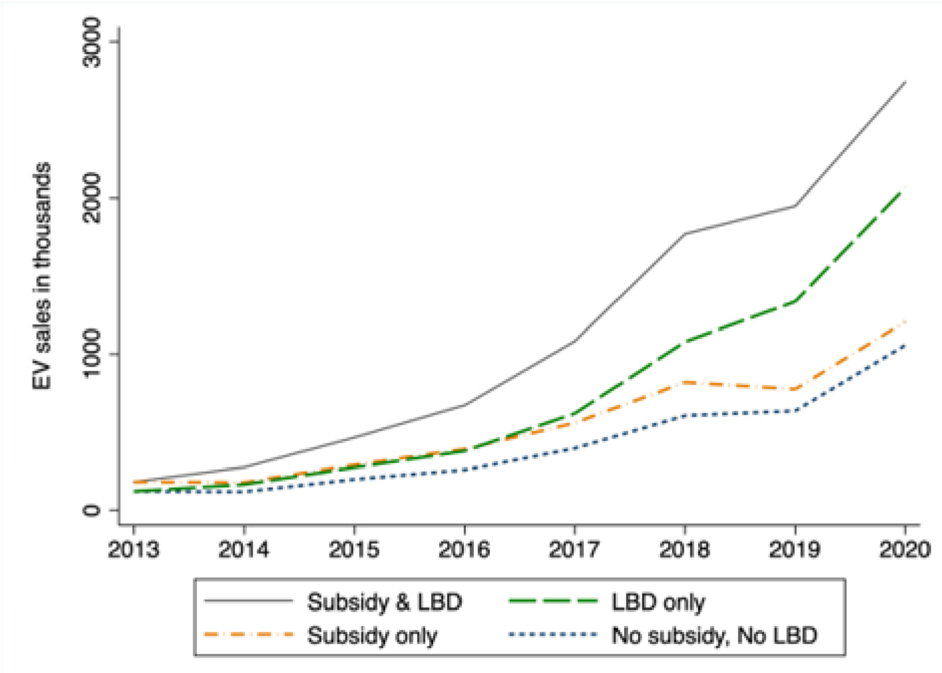

Figure 19:
Impact of Subsidies and LBD on Global EV Sales (Barwick et al., 2025)
Note: The figure depicts EV sales in the 13 leading EV markets under different policy configurations. The uppermost solid black line represents sales outcomes when both LBD and consumer subsidies are applied. The second line, shown in dashed green, reflects scenarios with LBD but without subsidies. The third, orange dash-dot line illustrates sales under subsidy-only conditions, while the lowest dotted blue line corresponds to outcomes with neither LBD nor subsidies. The data indicate that LBD significantly enhances the sales-boosting effect of subsidies.

(Ziegler et al., 2021) investigates the improvements and cost decline of the global Li-ion battery technology from 1992 to 2016, reporting significantly higher learning rates. This study estimates a 20% decrease in real price per energy capacity for all cell types and 24% for cylindrical cells for every cumulative doubling of market size. This study suggests that most estimations are lower than the actual amount of the effect caused by learning by doing. According to the authors, the Chinese market report quantifies a 40% cost reduction with each doubling of inventive activity, which is in line with the estimated 40.1% for all cell types in the paper. The paper also suggests variations in learning rates among various types of cells. Moreover, the paper mentions that when energy density is factored into the definition of service, the yearly reduction in real price per unit of service rises to 13–17% across different cell types, including cylindrical ones. Correspondingly, learning rates improve to 20–27% for all cell formats, reaching 24–31% for cylindrical cells.

(Schuyler Matteson and Eric Williams, 2015) investigates the design of the government subsidy program for EVs in the U.S. The primary focus is on how net public investment is affected by the frequency of subsidy reductions—referred to as tapering intervals—and how uncertainty in learning rates influences the scale of required public investment. The paper utilizes the concept of the experience curve, which describes the empirically observed power law decline of cost as a function of cumulative production. This experience curve is built based on the similarity of Li-ion batteries to that of consumer electronics due to similarities in cell materials and chemistry. Findings reveal that results can vary significantly depending on the assumed learning rate. For example, government subsidies range from $24 to $34 billion under a 9.5% learning rate. In contrast, with a 22% learning rate, the required public investment drops to between

$2.1 billion to $2.6 billion. Overall, the annual growth rate of the EV market necessary to achieve targeted cost reductions within a specified timeframe is shown to be highly sensitive to the chosen learning rate.

2.5 Labor and Institutional Structures

The German automotive industry's cost structure is shaped not only by relatively high wages and strong labor protections, but also by a broader set of pressures that have driven corporate restructuring over the past decades. As global competition has intensified and electrification has disrupted legacy technologies, firms have responded by reconfiguring their labor models and investment strategies. While labor institutions such as co-determination and sectoral bargaining remain influential, their reach has eroded in the face of growing financialization and the strategic use of offshoring to lower-cost regions. These developments are not isolated; they are structurally connected. Financial pressures—stemming from shareholder expectations, investor influence, and capital market metrics—have reinforced managerial priorities focused on cost discipline and operational flexibility. In this context, offshoring and the decentralization of RD and production have emerged as key tools for reducing labor intensity and reallocating high-value functions to emerging markets. The following subsections examine these dynamics in greater detail: first, the evolution of Germany's labor and employment structures; then, the strategic logic of offshoring and market expansion; and finally, the ways in which financialization has reshaped firm behavior, governance, and labor relations across the automotive value chain.

2.5.1 Unit Labor Cost and Labor Institutions in Germany

(Dupuis et al., 2024) examines the challenges facing Germany's auto workforce amid the shift from ICE to EV production, emphasizing the role of national institutional settings, evolving policy frameworks, and sector-specific risks. Germany's industrial relations system is shaped by strong institutions such as sectoral bargaining, vocational training, and co-determination, supported by structured unions like IG Metall and well-organized business associations. Co-determination, which gives workers representation on supervisory boards, provides access to strategic information and enhances labor influence in corporate governance. These features are complemented by sector-wide collective bargaining, robust employment protections, and formal rights to negotiate restructuring processes.

The paper also notes that IG Metall's leverage spans associational, institutional, structural, and ideational power. Recent union mobilizations have focused on securing employment, safeguarding training, and ensuring fair burden-sharing during the transition. However, structural challenges persist. Union membership and collective bargaining coverage are declining, with many auto workers now employed outside union agreements. Atypical contracts and greenfield sites—such as Tesla near Berlin and ACC in Kaiserslautern—remain difficult to organize due to weak legal mandates for union engagement. These trends, combined with heightened competitive pressure and the eventual phase-out of EV subsidies, may lead to further cost pressures, offshoring, and erosion of collective labor power.

(Krzywdzinski et al., 2023) also investigates the German automotive transition from ICE to EV and its impact on production and employment. The German automotive industry's longstanding focus on ICE engine optimization, combined with the Dieselgate scandal, initially delayed investment in alternative technologies. However, the EU's strong climate policy pressure, coupled with the COVID-19 crisis and substantial government subsidies and support for sectoral innovation, has led to a radical and rapid acceleration of the transition to electric vehicles. The study examines the changing strategies of German automotive companies regarding electromobility, such as Volkswagen, Daimler, and BMW. However, these firms vary in their degree of commitment and strategic approach. VW has set a high EV market share target and is investing heavily in its own battery supply chain, while Daimler is focusing on the premium market. BMW, on the other hand, while having an early start with the electronic model, the transition among German automotive suppliers is even more complex. While most of these suppliers acknowledge the dominance of electromobility, many are proceeding with a "double-tracked approach" of exploiting the existing ICE markets while investing in the new EV segment. The paper provides case studies of Bosch, ZF Friedrichshafen, and Mahle, illustrating how their varying dependencies on ICE technology shape the challenges and restructuring efforts they face. The paper also discusses the role of the IG Metall and the use of employment pacts to manage the transition. IG Metall has adopted a new stance to actively support electromobility under the condition of a "Fairer Wandel" (fair transition), and is engaged at national and company levels to secure employment through collective bargaining, re-skilling programs, and influencing policy.

The paper also reviews various forecasts regarding the employment implications of this transition in Germany. These studies, using micro-level and macroeconomic input-output models, present indefinite results, oscillating between significant job losses and potential gains. An important factor impacting these varying estimates is whether battery production will be located in Germany, with studies assuming domestic battery production generally predicting fewer job losses or even job gains. Other important factors in these estimations include the development of demand, production volumes, and the ability of the German automotive industry to sustain its premium strategy and succeed in export markets.

Table 2: Reconstructed summary of employment impact estimates from selected studies on BEV transition in Germany. Based on data from (Krzywdzinski et al., 2023)

Reviewed study (and scenario)	**Analytical perspective**	**Year in which BEVs reach 50% share of production**	**Expected production volume (number of cars)**	**Expected net employment increase/decrease in the automotive industry**
(Bauer et al., 2019) (ELAB); scenario 2	Micro-analysis of direct employment effects on automotive production	2030 (40% BEV; 20% PHEV)	~5.75 million (2030)	2030: loss of 90,000 jobs out of 810,000 in 2016 (battery production mainly not in Germany)
(Diez, 2017); scenario 'evolutionary diffusion'	Micro-analysis of direct employment effects on automotive production	2030 (50% BEV; 20% PHEV)	~5.75 million (2030)	2030: loss of 16,000 jobs out of 613,000 in 2015 (battery production mainly in Germany); or loss of 55,000 jobs (battery production mainly not in Germany)
(Peters et al., 2012)	Macroeconomic input-output model	–	~5.5 million (2030)	2030: gain of 17,600 jobs on 700,000 in 2010 (battery production mainly in Germany)
(Schade et al., 2014); scenario 'technological break (pessimistic)'	Macroeconomic input-output model	2030 (50% BEV + PHEV)	~7.3 million (2030)	2030: gain of 192,000 jobs on 700,000 in 2010 (battery production partially in Germany)
European Climate Foundation (2017); TECH scenario	Macroeconomic input-output model	2040 (49% BEV; 18% PHEV)	–	2040: loss of 5,000 jobs from 2016 level [but considerable increase in employment in overall economy]
(Mönnig et al., 2018)	Macroeconomic input-output model	(2035: 23% BEV)	~5.0 million (2030)	2030: loss of 50,000 jobs out of 830,000 in 2018 (battery production mainly not in Germany)
(Kaul et al., 2019); scenario 'increasing electrification'	Macroeconomic input-output model	2035 (48% BEV)	~6.5 million (2030)	2035: loss of 130,000 jobs out of 920,000 in 2017 (battery production mainly not in Germany)
(Schade et al., 2020); scenario 'e-road'	Macroeconomic input-output model	2025–30 (2030: 71% BEV; PHEV 21%)	~5.8 million (2035)	2035: gain of 7,000 jobs on 975,000 in 2018 (battery production in Germany); [considerable employment increase in overall economy]

*Not all studies provide this information; the expected share of BEVs and PHEVs are contained in brackets.

Interestingly, (Weng et al., 2024) challenges the widely held belief that the transition to EVS requires 30% fewer assembly workers than ICEs. The study utilizes publicly accessible information on automotive production and workforce metrics to show that labor demands have risen in U.S. manufacturing facilities that have completely shifted to producing battery electric vehicles (BEVs). The paper studies three cases of Alameda (Tesla), Oakland (GM Orion), and McLean (Rivian), and in all these cases, the labor intensity is at least as high, if not more than the ICE assembly process. The study reveals three factors

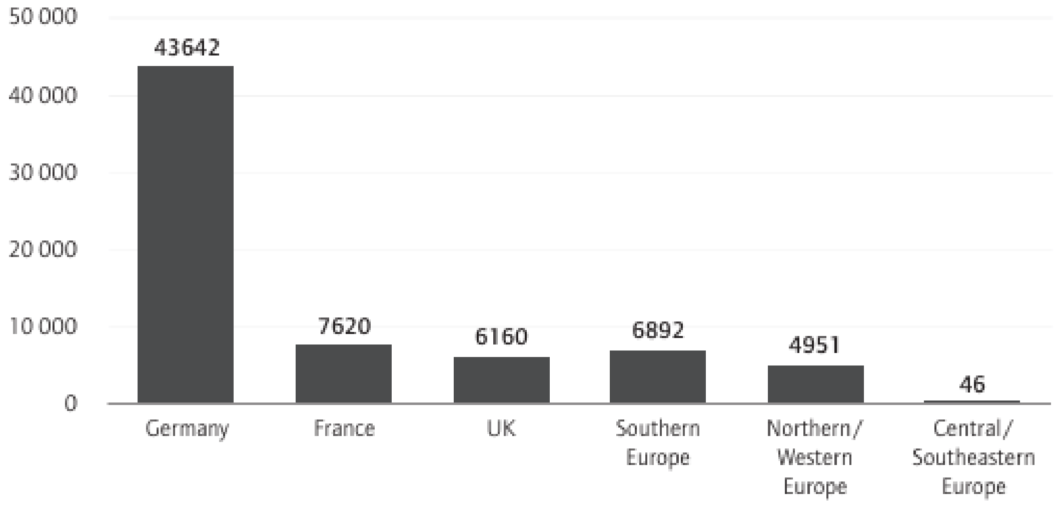

Figure 20:
Reported net job losses in the European automotive sector based on press data from 1 March 2020 to 1 November 2021. (Krzywdzinski et al., 2023)

that may contribute to the higher labor intensity in BEV assembly. The first factor is **investment in manufacturing technology development**, where companies might higher more experts like engineers to improve their technology. The next factor introduced is **higher vehicle complexity**, where first-time BEV makers often produce premium vehicles, which tend to be more complex than the mass market ICEs. Lastly, **vertical integration** is mentioned as an important factor as companies like Tesla in Alameda are choosing to design and manufacture more components in-house. The findings suggest that the risk of rapid and widespread job displacement at vehicle assembly plants due to the BEV transition might be less significant than many fear.

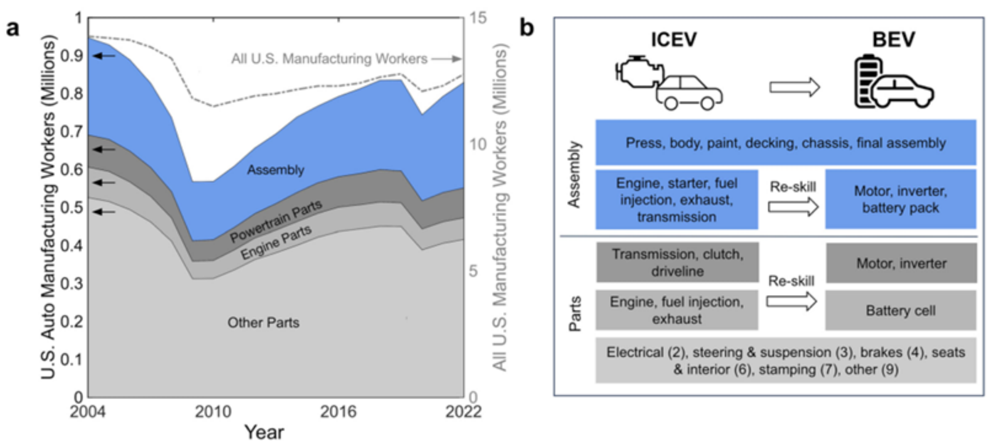

Figure 21:
Overview of U.S. automotive sector employment form 2004 to 2020 and automotive job categories (Weng et al., 2024)

(Schwabe, 2020) explores the impact of electromobility on the German automotive supplier industry at the firm level, with a focus on their strategic responses to the technological shift away from ICE vehicles. The author aims to address the gap in understanding how individual German automakers are doing to prepare for a future EV-dominated market. To gather insights, the study employed semi-structured interviews in a qualitative format with key individuals from the supplier segment. The results reveal diverse approaches towards electromobility among suppliers, ranging from deep concerns for those highly dependent on ICE technology to positive views from those with adaptable products. Hence, the strategies adopted by companies also vary considerably, including product diversification into other sectors, market diversification in the automotive industry, investment in new production opportunities, and product development. The study highlights that suppliers with a "captive" relationship with Original equipment manufacturers (OEMs), characterized by high dependency and switching costs, face significant challenges but are exploring diversification as a necessary long-term strategy. The article emphasizes the strategic importance of risks posed by electromobility to product portfolios, capital access, and R&D resources, where the companies with low product risk and high access to resources are more likely to improve their value capture. As a result, the author states that vertical mobility (functional upgrading) within existing automotive production networks is generally seen as a more viable and attractive strategy for "captive" suppliers. Furthermore, the ability to adapt internal capabilities is crucial for improving a company's competitive and bargaining position.

2.5.2 Offshoring and Market Expansion Strategies in the Automotive Industry

(Head & Mayer, 2019) investigates the determinants of offshoring in the automotive sector, focusing on factors such as cost competitiveness, brand scale, and model complexity. The study finds that while global offshoring has expanded, accounting for up to 40% of total production by 2016, offshoring aimed at serving home markets remains limited, peaking at 10%. Low-price models from high-income countries are the most likely to be offshored, while high-complexity models remain primarily domestically produced. The decision to offshore is shaped by both cost advantages of low-wage countries and model-specific comparative advantages, including factor endowments and skill requirements.

Figure 22 illustrates global production shifts from 2000 to 2016. Panel 1 shows China's rapid rise in both vehicle production and consumption, reflecting a demand-driven expansion model. Panels 2a and 2b highlight export-oriented offshoring patterns in Central and Eastern Europe and Mexico, which serve as cost-competitive peripheries to Western Europe and North America. Together, these patterns reinforce the view that offshoring remains geographically concentrated and strategically selective, shaped by both regional trade dynamics and firm-level cost strategies.

(Dividino et al., 2024) examines the evolution of multinational R&D centers in emerging markets (EMs), focusing on the Volkswagen Group's decentralized R&D strategy. The study highlights a shift from a headquarters-centric model toward granting greater autonomy to EM subsidiaries, allowing them to shape their own innovation strategies. This decentralization is particularly pronounced in locations such as China and India, where the combination of highly skilled, low-cost labor and local technological capabilities has enabled R&D centers to evolve into global innovation hubs. The findings suggest that MNEs are increasingly restructuring their R&D strategies to take advantage of regional labor markets and technological ecosystems, reinforcing the strategic role of labor cost and skill availability in shaping offshoring decisions.

(Pavlínek, 2023) analyzes the transition of the automotive industry in Eastern Europe (EE) from producing ICE vehicles to EVs. The article argues that foreign firms are the primary drivers of this transition, while the role of governments and local firms is considerably low. Unsurprisingly, this transition is much slower compared to Western Europe (WE), and EE will likely continue producing ICE for a longer duration. This is partly due to EE's reliance on its competitive advantage of low production costs, including favorable geographic location, EU membership, and especially lower labor costs. Although foreign investments have led to significant growth of the industry in EE, this growth has been accompanied by a distinct division of labor, with EE specializing in production functions and WE concentrating on higher value-added functions like (R&D) and strategic decision-making. The paper also mentions the limits to growth due to the exhaustion of the labor surplus in the 2010s, leading to shortages and increased wages. Despite this growth, the functional upgrading, particularly in R&D, has been limited. The article argues that EE will not be a center of innovation for electromobility, with R&D mainly conducted in the home countries of foreign firms. The high degree of foreign control means that corporate decisions made abroad will ultimately shape the trajectory of EE's EV transition.

In their study, (Gu et al., 2023), investigate the opportunities and challenges faced by Chinese EV manufacturers as they expand into European markets. The large market size of EVs in Europe and Europe's long-term goals of replacing ICE cars with EVs. Chinese firms show superiority over specific technological areas, such as battery technology, propulsion, and control systems. Also, Additionally, China maintains a competitive edge in software development due to rapid advancements in its IT sector and strong government support, particularly in emerging areas like autonomous driving. Moreover, stemming from the capital market and support from subsidies and policies, Chinese firms have substantially more financial power. Their qualified products are approved in the EU, where closeness to suppliers and

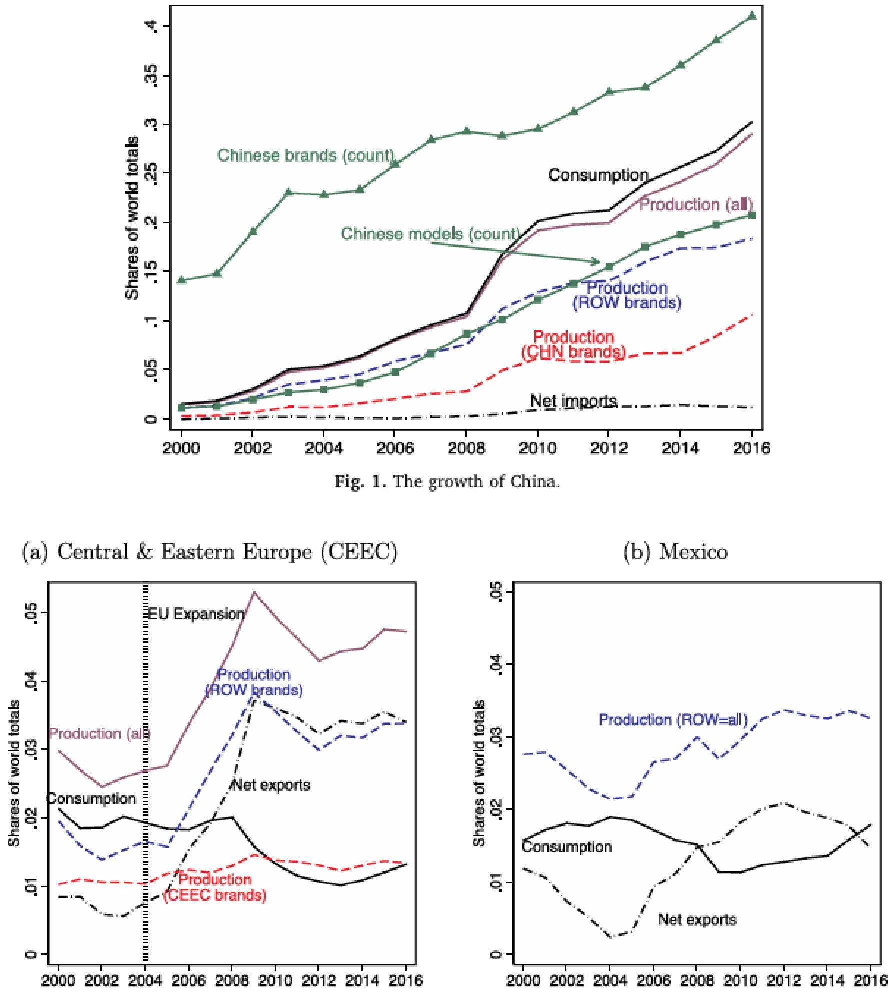

Figure 22:
Changes in Global Vehicle Production and Offshoring Trends (2000–2016) - Source: (Head & Mayer, 2019)

markets can significantly benefit Chinese firms. However, several barriers hinder their expansion. These include difficulties in transferring patents due to differing regulatory standards, limited brand recognition, persistent negative perceptions associated with the “Made in China” label, the lack of local manufacturing facilities, and the complexity of forging relationships with host-country stakeholders. These factors collectively pose significant obstacles to the successful integration of Chinese EV firms into the European automotive landscape.

(Krpata, 2021) analyzes the structural risks facing Germany’s automotive industry in the context of digitization, global competition, and the shift away from internal combustion engines. Despite its global footprint—75% of cars made in Germany are exported, and over 70% of German-brand vehicles are built abroad—the sector faces declining market share, particularly in China and the U.S. The paper raises concerns over Germany’s dependency on the Chinese market, where local manufacturers are advancing rapidly in both volume and technological quality. There is growing fear of a “Kodakization” scenario, in which German ICE producers risk being outclassed by Chinese EV firms that dominate their home market before expanding globally. In addition, the study warns that technological decoupling between the U.S. and China could disrupt German firms’ global operations. China’s strategic investments in EV supply chains, especially in battery production, are seen as reinforcing its competitive edge. The potential erosion of Germany’s domestic RD and high-value manufacturing capabilities raises concerns about the long-term vitality of the sector. A weakening of this industry, the paper argues, would represent a systemic threat to Germany’s economic and social model, particularly in regions heavily dependent on auto-sector employment.

2.5.3 Financilization of the Automotive Industry

(Neto et al., 2020) examines the corporate ownership networks of leading global automakers, highlighting varying degrees of financial dependence and shareholder influence across regional groups. The study finds that American firms show the highest exposure to financial institutions, often relying on passive investment funds with significant leverage over strategic decisions. In contrast, Asian automakers, particularly in Japan and China, exhibit more state-linked or domestically rooted ownership structures, with comparatively lower reliance on global capital markets. European manufacturers fall between these models, with financial institutions playing a strong role but often shaped by regional or historical ownership configurations. The case of Volkswagen, which maintains directed majority ownership, underscores the strategic insulation offered by more concentrated control. These differences in financialization are relevant for understanding how automakers vary in their capacity to pursue long-term innovation strategies or maintain employment commitments during periods of transition.

(Darcillon, 2015) analyzes the impact of financialization on labor market institutions in 16 OECD countries between 1970 and 2009, with specific attention to collective bargaining and employment protection. The study finds that the rise of shareholder value orientation has contributed to the decentralization of bargaining structures, erosion of union power, and greater wage and employment flexibility. In Germany, despite historically strong institutions like codetermination and works councils, significant shifts occurred in the 1990s. These included a decline in collective bargaining coverage, greater flexibility in employment contracts, and reforms favoring minority shareholders, which reoriented corporate governance toward shareholder interests. The study also notes that while key institutional features formally remained, they increasingly served "insider" constituencies, reinforcing insider–outsider labor market dynamics. These changes have been particularly visible in the manufacturing sector, including the automotive industry, where cost pressures and corporate restructuring have aligned closely with broader financialization trends.

(Kädtler & Sperling, 2002) investigates how financialization has shaped the German automotive industry, distinguishing between external financialization—the influence of financial markets—and internal financialization, where firms adopt financial metrics to guide strategic decisions. The paper argues that the shift in power toward shareholders is not strictly based on production efficiency, but rather reflects a political process wherein financial actors impose standardized norms and expectations. Despite pressures to align with shareholder value metrics, firms often struggle to meet financial targets due to the inflexibility of production systems, especially in high-quality or specialized manufacturing. The study suggests that financial logics and operational constraints remain in tension, and that strategic management plays a key role in mediating between capital market demands and industrial realities.

2.6 Socio-Economic and Infrastructure Effects on EV Adoption

A growing body of literature emphasizes that household income and charging infrastructure access are the two most critical factors influencing EV adoption. Higher-income households are consistently more likely to adopt BEVs due to their ability to manage high upfront costs, while lower-income groups exhibit limited price elasticity, even with subsidies. At the same time, access to public or home-based charging significantly increases adoption likelihood—though its effect is strongest when combined with affordability. Other factors such as education, housing type, and political preferences have been found to influence adoption behavior, but they remain secondary to financial and infrastructural determinants. Together, these findings highlight the need for integrated policy strategies that target both cost barriers and infrastructure gaps to support wider and more equitable EV uptake.

(Burra, Al-Khasawneh, & Cirillo, 2024) analyzes how charging infrastructure and socio-economic characteristics influence EV adoption, with a particular focus on income sensitivity and accessibility barriers. The study finds a strong positive correlation between household income and EV ownership, indicating that higher-income households are more responsive to EV adoption incentives, while low-income groups remain constrained by the high upfront costs, even when public charging is readily available. This highlights the limited price elasticity among low-income segments, suggesting that financial incentives alone may be insufficient without broader cost reductions.

Charging infrastructure emerges as an equally critical factor. The availability of both DC fast charging and Level-2 charging stations, particularly within residential proximity, significantly increases the likelihood of EV adoption, especially for middle- and high-income households. However, charging alone does not meaningfully raise adoption among lower-income groups unless accompanied by greater affordability.

The paper also mentions other contextual influences such as housing type, teleworking potential, and suburban residence, all of which can shape EV readiness by affecting access to charging and mobility needs. Overall, the findings underscore the combined importance of income and infrastructure, both of which condition the pace and equity of EV adoption across different social groups.

(Rahman & Thill, 2024) provides a literature review on the factors influencing EV adoption, with emphasis on both socio-economic and structural enablers. The study highlights household income as a critical determinant, with higher-income groups significantly more likely to adopt EVs due to their greater ability to absorb the upfront purchase cost. Middle-income households tend to adopt hybrid or plug-in hybrids first, while low-income adoption remains limited—reflecting strong evidence of price inelasticity among the latter.

The availability of charging infrastructure is also found to be a key enabler, though the literature notes a gap between infrastructure supply and demand. Increasing access to public and home-based charging options is repeatedly identified as necessary for broader EV diffusion, especially among urban and middle-income users.

The paper also identifies financial incentives—including subsidies, tax cuts, and rebates—as powerful motivators that improve the economic feasibility of EV purchases across income brackets. While other socio-economic variables such as education, age, marital status, and political affiliation are also discussed, these are generally secondary to cost-related and infrastructure-access factors. Overall, the review reinforces the dual importance of affordability and charging access in shaping adoption patterns.

(Brückmann et al., 2021) analyzes battery electric vehicle (BEV) adoption in four German-speaking cantons of Switzerland, a region characterized by the absence of strong EV policy or domestic auto manufacturing. This allowed the study to isolate individual-level factors affecting adoption. Among the findings, household income emerged as a significant determinant, with higher-income groups showing greater likelihood of adoption, consistent with broader findings on price sensitivity and affordability barriers.

The study also highlights property ownership, particularly detached homeownership, as a factor correlated with higher BEV uptake—likely due to easier access to home charging. Interestingly, while charging infrastructure availability was positively associated with BEV adoption, the effect was statistically insignificant, possibly due to the dominance of home charging in the studied regions or insufficient data granularity on charger types.

Other factors such as technology affinity, political alignment, and household vehicle composition were also correlated with adoption, though these are more context-specific and less directly related to cost structure. The study concludes that in the absence of policy incentives, income and charging access remain among the strongest structural predictors of EV adoption.

2.7 Government Incentives and Policy Effects on EV Adoption

A substantial body of research underscores the pivotal role of government incentives in shaping EV adoption. Both direct financial instruments—such as purchase subsidies, tax exemptions, and scrappage schemes—and complementary policies, including charging infrastructure investment and regulatory support, are shown to significantly influence market dynamics. Studies consistently find that subsidies are effective, especially when they are part of a coherent and long-term strategy. However, the impact varies across contexts: while Norway's success is attributed to decades of stable incentives, findings from China suggest that infrastructure and non-financial incentives can sometimes outperform cash subsidies. Emerging research also highlights the need for targeted subsidy calibration—accounting for consumer heterogeneity, market maturity, and behavioral frictions like EV anxiety. Together, these insights show that EV policy design must align both economic incentives and institutional capacity to foster adoption and long-term competitiveness.

(Lechowski et al., 2023) analyzes the role of EU-level regulation and domestic political-economic factors in shaping EV industrial policy responses in France and Germany. The study focuses on three key drivers of intervention: the revival of industrial policy thinking, increasing economic pressure on the automotive sector, and the structure of government-industry coordination.

In France, the COVID-19 pandemic triggered a sharp decline in automotive production and sales, prompting a €45 billion general recovery package, followed by an €8 billion sector-specific plan—Le plan automobile. This strategy aimed to position France as a European EV leader within five years. The government extended support through demand-side subsidies (e.g., a scrappage scheme and EV buyer incentives), contributing to a rise in EV registrations (from 11% in 2020 to 19% in 2021). On the supply side, France allocated competitive funds to support innovation and restructuring, including investments in battery technology, hydrogen, and SME modernization. In total, more than €1.5 billion was directed to RD, supplier support, and retraining.

Germany, also affected by COVID-19, launched a €7 billion automotive recovery initiative within a broader €130 billion national package. Despite fewer job losses, the program aimed to accelerate the transition to sustainable technologies. Key measures included doubling buyer subsidies for EVs (€6000 for BEVs, €4500 for PHEVs) and allocating €3.5 billion for electromobility and battery RD, along with €2 billion for industrial upgrading.

The study notes that while both countries pursued generous stimulus programs, their approaches diverged. France focused more heavily on centralized state-led support, with weaker institutional coordination. In contrast, Germany emphasized tripartite policymaking and bottom-up industrial transformation, involving firms, research institutes, and trade unions more directly in shaping policy priorities.

(Figenbaum, 2017) analyzes Norway's unprecedented success in BEV adoption by tracing 25 years of policy development. The study attributes the rapid growth of the BEV market to a long-term, consistent policy framework that combined generous demand-side incentives with evolving regulatory and infrastructural support. These incentives included full exemption from registration tax and VAT, reduced company car taxation, toll and parking exemptions, and privileged road access (e.g., use of bus lanes). Such measures progressively lowered the effective cost of BEVs relative to ICE vehicles and created viable early market niches, particularly in urban and fleet contexts.

Over time, policy stability enabled niche markets to expand, aided by improvements in battery technology and pressure from EU emissions targets. The return of major automakers to BEV production and the introduction of more competitive models helped the market mature. By 2015, BEVs accounted for 18% of all new passenger vehicle registrations, with adoption heavily concentrated among multi-car, higher-income households.

The study introduces four explanatory hypotheses—niche dynamics, regime shift, governance strategy, and timing of opportunity—but emphasizes above all the importance of policy continuity and coherent incentive design over decades as the foundation for Norway's leadership in EV adoption.

(Zhang et al., 2024) investigate the effectiveness of EV purchase subsidies in China between 2016 and 2019 using a three-dimensional panel dataset covering 316 cities. The results indicate a significant increase in the adoption rate of EVs, but a negative impact on EV imports. According to this study, the average purchase subsidy per vehicle in 2018 was 36,890 CNY (around €4400), representing 18.5% of the average manufacturer-recommended retail price for EVs, which was reduced by 40% by 2019 and ultimately canceled at the end of 2022. Based on the results, a 1000 CNY increase in the pre-vehicle purchase subsidy would have led to a reduction of more than 275,000 tons of lifetime-of-use CO2 emissions. The effects of subsidy were examined in this paper based on regression analysis and negative binomial estimations. The regression analysis shows an increase of 0.35 new domestically produced electric vehicles per range class in a city per month, and the binomial estimations suggest a 5% increase in the registration of new domestically produced electric vehicles for every 1000 CNY increase in subsidies. Furthermore, the impact of 1000 CNY on imported cars and registrations of domestic vehicles are estimated to be 2% and 3%, respectively.

(Chen et al., 2021) explores how government incentives have influenced electric vehicle (EV) adoption across 61 Chinese cities between 2009 and 2018. The study evaluates subsidies targeted at both public (e.g., electric buses and commercial EVs) and private (individual consumers) sectors. Incentives are categorized into financial forms—such as direct subsidies, tax exemptions on vehicle purchases, and toll waivers—and non-financial or convenience-based measures, including the construction of charging stations, removal of purchase restrictions, and implementation of odd-even license plate rules. The analysis shows that city buses exceeding ten meters in length could receive subsidies covering approximately 50% of their purchase cost. Although EV adoption was primarily influenced by expanded charging infrastructure and rising fuel prices, financial subsidies alone did not significantly drive uptake. Notably, in the public transport sector, convenience measures—especially investment in charging infrastructure and relaxed purchase restrictions—proved highly effective in boosting EV adoption. Conversely, financial incentives like purchase subsidies and tax exemptions were found to be less impactful than anticipated. The study proposes that limited effectiveness in the private EV segment may be attributed to the popularity of micro EVs with minimal subsidy eligibility, appeal of non-purchase restrictions in lottery-based licensing cities, and speculative investment trends in EVs.

(Taormina & Ainpudi, 2021) argues that the direct subsidies have no correlation with the market share of EVs. The authors state that these could be due to different factors such as culture, economic status, regional differences, infrastructure development, lack of awareness, and lack of investments in R&D. (Abas & Tan, 2024) examines different government incentive policies regarding the EVs market. This research indicates that while purchase subsidies on EVs are more effective than similar taxes on ICEs, a combination of subsidies could have a greater impact on EV adoption. The author notes that the price volatility of energy has a minor effect due to lower operational costs in the EV market. The study also suggests that governments should replace their fleet of vehicles with EVs to increase the number of EVs at ean arly stage of adoption. Moreover, (Wu et al., 2022) argues the inverse relationship between the optimal level of subsidies and competition intensity, and that subsidy cuts can lead to a reduction in EV sales. Sales volume-based subsidy schemes are more efficient than sales-revenue-based ones. While the government might reduce subsidies as competition increases, the socio-economic factors can drive EV adoption.

Recent advancements in EV adoption modeling have not only explored the cost-based analysis, but also behavioral frictions and heterogeneous consumer preferences. (Li & Wang, 2023) developed a two-stage Stackelberg game framework that captures the interplay between a social planner (setting subsidies) and a monopolistic manufacturer (setting EV and ICE vehicle prices), in a market segmented into green and non-green consumers. The authors' focus on EV anxiety is a key notion in the model proposed in this paper. EV anxiety is defined in the paper as a combination of range, resale, and charging uncertainty, which interacts with consumer environmental preferences to shape demand elasticity. The results of the model show that while subsidies are generally effective at expanding EV adoption and improving consumer and producer welfare, total social welfare gains are restrained and non-linear. Specifically, subsidies only enhance overall welfare if the perceived environmental benefit of EVs exceeds a critical threshold, and if subsidy levels are carefully optimized to avoid over-incentivization. Interestingly, the model indicates a dual role of EV anxiety: on one hand, it dampens demand by lowering the willingness to pay but simultaneously enables higher pricing power for producers in segments where anxiety is reduced. These effects generate ambiguous outcomes for both EV adoption and pricing strategies. The paper proposes the importance of complementary instruments in subsidies, including public investments in infrastructures, R&D for battery and vehicle innovation, and targeted customer education. This layered understanding contributes to a growing strand of literature emphasizing that effective EV policy requires dynamic calibration, not only to market costs but also to shifting social attitudes and behavioral constraints.

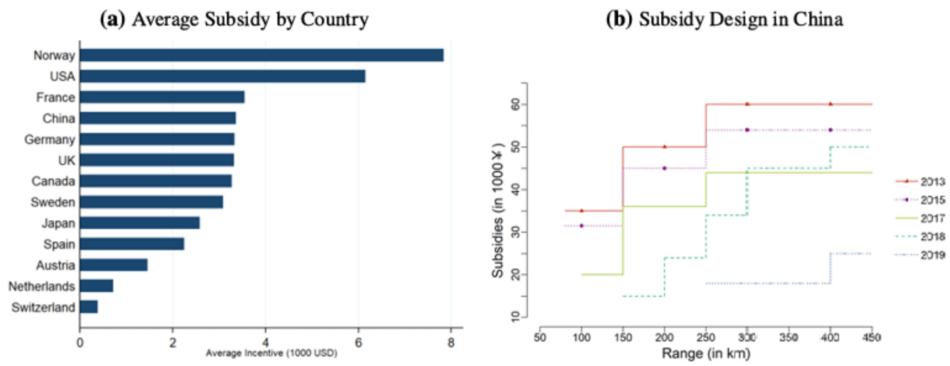

Figure 23:
EV Subsidies; Panel (a) illustrates cross-country comparisons of average subsidies provided to qualifying EVs over the period 2013–2020; Panel (b) displays the subsidy structure for battery electric vehicles (BEVs) in China, with incentive levels determined by the vehicle's driving range (Barwick et al., 2025)

2.8 Electric Vehicle Demand Elasticities in Europe

Own-price elasticity of demand is one of the fundamental concepts in demand theory, which measures the percentage change in quantity demanded resulting from a unit change in price, holding all other variables constant. In the case of EVs, understanding price elasticity is crucial for designing effective subsidy policies, forecasting adoption rates, and assessing how responsive consumers are to changes in upfront vehicle costs. Given that EVs have higher initial costs, excluding subsidies and taxes, the elasticity of demand with respect to price determines the degree to which financial incentives can shift consumer preferences. This section is reviewing the previous studies regarding the own-price elasticity of EVs for different regions, particularly Germany and European Union Countries, where the effect of prices is crucial in the EV adoption rates.

Recent empirical literature finds that EV demand is highly price-elastic in many European countries. Structural and reduced-form estimates for Germany—Europe's largest auto market—indicate own-price elasticities in the range of –2.0 to –4.0, meaning that a 1% price increase leads to a 2–4% reduction in EV sales. For example, (Heid et al., 2024) estimates an elasticity of –1.99 using a structural model that integrates vehicle choice with a charging behavior module and electricity market equilibrium. In a related policy evaluation, (Haan et al., 2025) use a difference-in-differences design to assess Germany's federal EV purchase subsidy and derive an implied elasticity of –3.16, suggesting that price reductions via subsidies are a key driver of demand. This sensitivity is reinforced by evidence that charging infrastructure availability amplifies adoption, acting as a complement to price incentives (Burra, Sommer, & Vance, 2024).

A similar pattern is found across other European countries. In the United Kingdom, Mandys and Taneja (2024) estimate that a £1,000 increase in price leads to a 3–5% reduction in EV uptake, implying elasticities in the range of –1 to –2. Interestingly, they also find that price sensitivity for EVs is comparable to that of fossil-fuel vehicles, and no significant "green preference" premium is detected. One of the most comprehensive studies comes from Norway, where (Fridstrøm & Østli, 2021)) uses over 1.8 million new car transactions to estimate both own-price and cross-price elasticities. They report an EV own-price elasticity of –0.99 for battery electric vehicles (BEVs) and –1.72 for plug-in hybrids (PHEVs), while cross-price elasticities are positive: for instance, a 10% increase in gasoline car prices boosts BEV demand by 3.6%, and diesel price increases lead to similar substitution effects. Importantly, they also estimate an elasticity of EV demand with respect to electricity price of only –0.18, suggesting that fuel cost advantages are robust even under rising electricity prices. This is consistent with the much lower cost per kilometer of electricity relative to gasoline or diesel.

At the multi-country level, a 2023 World Bank study estimates that a $1,000 reduction in EV price leads to a 2.9% increase in sales, confirming an average elasticity around –0.9 to –1.0. It also finds that a 10% increase in charging station availability raises EV adoption by 3–8%, further reinforcing the role of infrastructure. Notably, across all contexts, income elasticity is also high: (Haan et al., 2025) and (Briceno-Garmendia et al., 2023) report that wealthier regions adopt EVs at significantly higher rates, even under uniform national incentives, with some studies estimating income elasticities as high as +8.0.

3 Methodology

3.1 Research Design

The overarching goal of this research is to unravel the complex reasons behind the persistent retail-price gap between the Chinese and German automotive productions. This disparity, as highlighted in the Executive Summary, is not merely a quantitative difference but a symptom of profound structural shifts impacting the global automotive industry. To comprehensively address this multifaceted problem, the methodological approach is designed to be holistic, combining diverse data sources and analytical techniques to provide a nuanced understanding of the underlying drivers.

3.1.1 The Overall Approach

Understanding the EV price gap necessitates a deep dive into various supply-side factors that influence production costs, coupled with an analysis of how these costs translate into market prices and ultimately affect EV adoption. Since the focus of this study is the supply-side factors, the retail prices have been used before any forms of intervention from governments, to acquire an acceptable measure of firms' prices regarding their products. The approach is fundamentally comparative, focusing on Germany, a traditional automotive powerhouse and Europe's most important automotive sector, and China, the dominant region in EV production and innovation. This comparative lens allows for the isolation and analysis of the specific advantages Chinese manufacturers possess and the constraints German firms face.

To ensure that various aspects are analyzed in a comprehensive manner, this study structured a new data-set, based on existing datasets regarding both regions. Also, in order to be able to compare the prices during the timeline, web-scraping on different valid resources was implemented, which allows for cross-comparison of various aspects of the supply-side. The decision to employ a variety of data sets and analytical methods stems from the inherent complexity and data opacity within the global automotive supply chain. Detailed, firm-level cost data, especially proprietary information on production processes and supply chain contracts, is rarely publicly available. To overcome this, a pragmatic strategy was adopted:

- **Diverse Data Collection**: Retail price data for popular EV models in both Germany and China was meticulously gathered. For the Chinese market, a comprehensive dataset from Kaggle was leveraged, allowing for the investigation of the most sold vehicles from 2021 to 2025 across specific regions. This dataset facilitated comparisons between regional manufacturers, analysis of their price trends, and identification of differentiations, while excluding geographical and regional factors that could vary based on production location. For German and other comparable models, existing datasets were supplemented with targeted web scraping from validated regional sources. The diversity of data not only allowed for the validation of prices but also for the establishment of rigorous and real prices during the 2021 to 2025 period. Consequently, this research has gathered data regarding the trends and differences of the overall sectors in both regions, along with a comparable dataset that allows for price comparison between comparable brands.
- **Targeted Benchmarking**: To ensure comparability, the focus was placed on mid-size, non-luxury EV segments, specifically benchmarking leading companies like Volkswagen (VW) and BYD. These companies represent significant market shares in their respective regions and offer comparable vehicle classes, allowing for more direct and meaningful cross-market price comparisons. The web-scraped data allowed for the extraction of prices for models that were comparable in battery capacity, range, and overall benchmark across the two countries and from famous brands. Based on this compiled data, a cost differentiation for the customers was then derived.
- **Decomposition of Cost Drivers**: It was recognized that the price gap is unlikely to be attributable to a single factor. Therefore, distinct analytical methods were employed to quantify the contribution of specific drivers:
  - **Labor and Energy Costs**: While often cited, their precise impact needs quantification. National statistical data (e.g., Germany's Statistisches Bundesamt) was used for direct labor cost proportions, and input-output tables were then utilized to estimate the more complex indirect labor cost effects flowing from upstream industries. Energy costs, despite their geopolitical prominence, were rigorously assessed and found to have a negligible direct impact on the final retail price within the real-price framework.

  - **Learning-by-Doing (LBD)**: The rapid scaling of EV production, particularly batteries, suggests significant efficiency gains. Previous data from literature, specifically Orangi et al., was incorporated to understand historical battery cost trends up to the beginning of the timeline. Aggregate data from EV-Database was then used to find the number of EVs produced in Germany, China, and worldwide. Applying Wright's Law, a well-established concept for modeling experience curves, a learning rate that explains the overall trend was fitted and used for further predictions, based on production in different regions or overall global output, to quantify the LBD effect.
  - **Vertical Integration**: Recognizing the strategic advantage of firms like BYD in controlling their supply chains, a proxy measure was devised based on observed price differences within the highly competitive Chinese market. Specifically, after isolating the effects of labor, energy, material, and learning-by-doing, BYD's average prices were compared to the average prices of other Chinese brands to estimate the cost benefits derived from vertical integration.

- **Impact Assessment**: Finally, to translate findings into actionable insights, the concept of own-price elasticity of demand was integrated. By applying established elasticity ranges for European markets to the identified price gaps, the potential impact of narrowing this gap on EV adoption rates could be estimated.

It is important to note that these analyses have been conducted with a conservative approach. This means that the estimated contributions of individual cost drivers (such as labor costs, which at 16.3% are at the higher end of some literature estimates) are presented at their maximum justifiable levels within the framework. This rigorous approach ensures that the resulting unexplained "residual gap" represents a robust minimum expected value, underscoring that the true magnitude of non-production-related factors contributing to the price differential is likely even greater. By systematically breaking down the problem, leveraging diverse data, and applying appropriate analytical tools, this methodology aims to provide a comprehensive and empirically grounded explanation for the EV price differential, moving beyond anecdotal evidence to quantify the contributions of various structural and strategic factors.

To enhance the clarity and understanding of the complex dynamics discussed, particularly concerning China's innovation capacity and the EU's technological positioning, the following figure is included. This visual representation serves to summarize key aspects of the analysis, making the intricate relationships and comparative advantages more accessible and comprehensible for the reader.

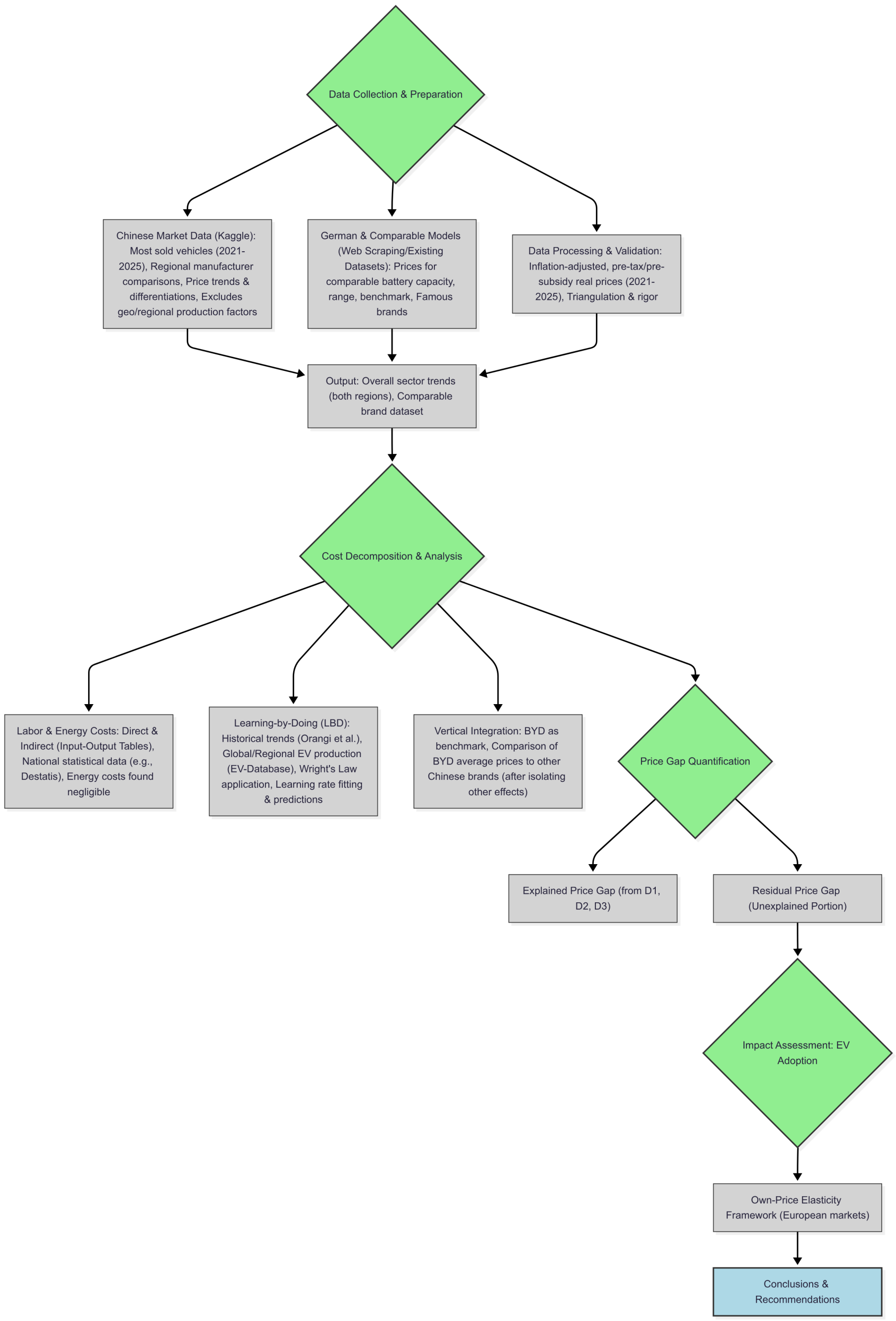

Figure 24:
This figure provides a comprehensive visual overview of the research methodology, from initial data collection and preparation through the decomposition of cost drivers, price gap quantification, and impact assessment on EV adoption. It illustrates the multi-faceted approach taken to analyze the complex factors influencing the EV price differential between Chinese and German manufacturers.

3.2 Data Collection and Processing

The empirical foundation of this thesis rests on a systematic collection and structuring of EV price data from Germany and China over the period 2020-2025. Given the absence of centralized, publicly accessible historical databases, the data-gathering process required cross-referencing, multiple sources, translation of foreign-language materials, and direct manual validation of price points.

3.2.1 Germany

For the German market, the data collection process began with identifying the most frequently sold BEV models based on Kraftfahrt-Bundesamt (KBA) registration data and publicly available EV sales statistics. This process was conducted by examining historical data on the most reputable sources. The data gathered regarding different models were processed, and the jointly mutual data in different platforms were chosen. The selected models include a wide range of domestic producers and relevant foreign entrants (Tesla, Fiat, Hyundai) that have a major footprint in the German market. The domestically produced vehicles were examined further.

Price data were extracted from various sources, such as the EV Database, manufacturer websites, archived product brochures, press releases, and verified third-party automotive platforms. The important point considered in this process is the variety of EV options and characteristics in various regions. These variations result from firm strategies, regulatory mandates, and institutional differences. Accordingly, the data were gathered based on the targeted region, Germany. Moreover, EVs are available with different variations and options, which can significantly change the initial price of the model, in some cases even more than the base costs. Hence, the prices were gathered based on the initial price of each EV model, which is also the minimum range price for a specific model. For instance, the EV Database, ev-database.org, provides country-specific data, and German specifications were used. Where possible, the base model with the most consistent market presence was chosen. To keep consistency regarding different prices in different periods, the specified data such as range, battery capacity, and efficiency.

These data were then organized chronologically by model and year, from 2020 to 2024, with 2025 estimates included where available. Some of the most sold models had inconsistencies in their pricing as their production began after the specified timeline or their production was stopped.

Model	**2020 Price (€)**	**2021 Price (€)**	**2022 Price (€)**	**2023 Price (€)**	**2024 Price (€)**	**2025 Price (€)**
VW ID.3	€38,987	€31,960	€35,460	€39,995	€39,995	€39,995
VW ID.4	N/A	€36,950	€36,950	€40,335	€40,335	€40,335
VW ID.5	N/A	N/A	€46,515	€48,970	€48,970	€48,970
VW ID.7	N/A	N/A	N/A	€57,990	€54,795	€54,795
Cupra Born	N/A	€37,220	€38,600	€39,370	€41,450	€41,450
Cupra Tavascan	N/A	N/A	N/A	N/A	~€53,240	~€53,240
BMW i4	N/A	€59,200	€59,200	€59,200	—	—
BMW i5	N/A	N/A	N/A	€70,200	€70,200	€70,200
BMW iX1	N/A	N/A	€55,000	€55,000	€55,000	€55,000
Audi Q4 e-tron	N/A	€44,700	€44,700	—	€45,600	€45,600
MB EQA	N/A	€47,541	€50,777	€52,205	€52,205	€52,205
MB EQB	N/A	€55,311	€52,550	€53,978	€53,978	€53,978
MG4 Electric	N/A	N/A	€28,420	€28,420	€34,990	€34,990
Smart #1	N/A	N/A	~€36,990	€34,990	€34,990	€34,990
Škoda Enyaq iV	N/A	€38,850	€33,800	€33,800	~€42,100	~€42,100
Dacia Spring	N/A	€20,490	~€21,790	~€21,790	~€20,800	~€20,800
Tesla Model 3	~€42,900	€42,990	~€49,990	€43,990	€40,990	~€41,990
Tesla Model Y	N/A	€57,970	~€56,990	€43,990	€44,890	~€44,890

Table 3: Historical Price of Popular EV Models in Germany and Europe (2020–2025). Tilde (~) indicates approximate prices.

3.2.2 China

Germany's data presented in the 3 allowed for a more focused procedure on China's market. Although there is a relative lack of data on China's market, due to various reasons such as different platforms and data availability overall, a small number of comprehensive datasets regarding the retail prices of Chinese vehicles during the time were found and investigated. One of these data sets, obtained from Kaggle provides substantial monthly data for the period 2020 to 2025, including retail prices, brands, and models of different cars sold in China.

The dataset titled "China Automobile Sales Data" contains 38,806 rows and 10 columns in (a CSV format), providing detailed information about automobile sales in China over time. In the following section, each attribute is briefly described.

- **model**: The specific name of the car model in Chinese.
- **units_sold**: Number of units sold in the recorded month.
- **make**: The manufacturer or company producing the model.
- **low_price**: The minimum retail price for the vehicle, in thousand Chinese Yuan (CNY).

- **high_price**: The maximum retail price for the vehicle (in thousand CNY).
- **year_month**: The date (year and month) of the sale record (format: YYYY-MM-DD).
- **is_ev**: Indicates whether the car is an electric vehicle (EV).
- **body_type**: The body classification of the car (e.g., SUV, Sedan, Hatchback).
- **brand**: The brand under which the model is sold (e.g., Tesla, BYD).
- **brand_country**: The country of origin for the brand (e.g., China, United States).

Unlike in Germany, where the data was structured by brand and model, the Chinese data set required significant pre-processing, wrangling, and cleaning. The first step in pre-processing involved translating the model and brand names, which was conducted using googletrans 4.0.2 python package (Link). Following the translation stage, the dataset underwent a thorough cleaning and pre-processing phase. Incomplete, missing, or inconsistent data were identified and appropriately handled, whether through exclusion - if the missing data involved critical fields such as model name or unit sales, or by standardizing non-essential variations. For instance, different spellings or formats in brand or model names, resulting from the translation process, were harmonized for internal consistency. The recorded dates were standardized to facilitate temporal grouping by year and month.

Following the preprocessing steps, the non-EV vehicles were excluded from the analysis. Since the dataset also included other types of vehicles besides EVs, a filtering mechanism was applied based on the fuel type field. This ensured the analysis remained centered on pure EV models, aligning with the scope of this thesis. Furthermore, to prepare the data for trend analysis, monthly EV prices were aggregated by model and grouped by year, which allowed for obtaining annual averages. Aggregation also helped mitigate the impact of temporary outliers or volatile short-term pricing changes that could otherwise distort broader trend interpretation.

The aggregation and grouping were done considering the brand country's origin. This was necessary to obtain the necessary data in line with the thesis objective, comparing Chinese and German vehicle price trends. For the German vehicles, all complete data were obtained. Although there were data about more than 25 German different models, those models that did not span the specified period, 2021 to 2024, were excluded. This filtering resulted in a consistent dataset covering 13 different German EVs. This selection ensured that subsequent analyses would not be skewed by vehicles with sporadic or minimal market presence. However, the Chinese-made EVs were more than enough and were ranked based on their sold units.

As can be seen in the attribute description, two price ranges were included in the dataset, minimum price and maximum price. After converting the prices to euros using the exchange rate, a validation step was conducted by sampling 2024 price points. This analysis revealed that the initial prices in China were well in line with the minimum price attribute. The minimum prices then were obtained and averaged based on the year considered the initial price of EV vehicles in China. Lastly, in preparation for visual and statistical analysis, the dataset was refined to include prices and unit sold between 2021 and 2024. A copy of the results was also modified for further visualization in Tableau.

Furthermore, the prices of vehicles were converted into real prices based on the year 2021. This conversion makes the analysis more robust in terms of real output, which is critical to the analysis in this research. For the period considered in the analysis, there is a stark contrast between the macroeconomic factors affecting both countries. While Germany, alongside other European Union members suffered from supply shocks due to the Russian Invasion, the Chinese economy has been dealing with different issues, such as dampening overall demand. The inflation rate for both countries is computed via using the monthly data from Federal Reserve Economic Data, Fred, with monthly price data grouped into yearly data and applied to both datasets.

In summary, the Chinese EV dataset was systematically cleaned, transformed, and aggregated to enable meaningful comparison with the German dataset. These efforts ensure that subsequent evaluations of pricing trends, cost structures, and adoption patterns rest on a coherent and reliable empirical foundation.

3.2.3 Limitations

While the methodological approach offers valuable insights and conclusions in the following section, several limitations should be acknowledged. The most notable constraint is data accessibility. Since firm-level data, particularly proprietary cost structures, supply chain contracts, and internal pricing strategies, this study relies exclusively on secondary sources and market-level data. This may limit the granularity of the analysis, especially in investigating detailed cost formations at the firm level.

In the case of data analysis of Chinese EVs, data collection proved to be challenging. As said, limited access to centralized or official databases means that alternative sources, translated datasets, were employed. Hence, potential inconsistencies inherent to such sources cannot be fully ruled out. That being said, the point statistics, such as the average prices and trends driver from the dataset are broadly in line with known market behaviors and media-reported benchmarks for leading models. Moreover, although the dataset proved minimum and maximum vehicle prices, it does not capture variation introduced by optional add-ons, or after-sale modifications, which could significantly affect final retail pricing. This limitation was addressed by standardizing all data to entry-level model prices but remains a source of possible distortion when comparing cross-market affordability.

As mentioned in the data collection, model selections, especially for German EVs in China, were restricted to those with available data spanning the 2020-2024 period. Consequently, this temporal constraint may exclude notable EVs with shorter production lifecycles or delayed market entries, which may introduce selection bias. However, including all the top-sold German vehicles in the German and EU markets should result in a reliable conclusion. Another limitation is the exclusion of government incentives and subsidies, which are known to play a significant role in EV adoption. The assumption made here is the initial prices for both markets are without subsidies, which allows for subsidy implementation in later discussions.

Despite these limitations, the methodology was designed with transparency and consistency in mind. The resulting data set and analytical output closely align with public pricing information and market trend reports, providing a credible empirical basis for a broader comparative analysis.

3.3 Estimating the Contribution of Labor and Energy Costs in Price Differences

3.3.1 Labor Costs Proportion in the Automotive Industry

As mentioned above, higher operational costs, including energy and labor costs, are repeatedly mentioned as the main reason for the comparative advantage of automotive manufacturers in China. To assess the extent to which labor and energy costs contribute to the observed retail price differences between German and Chinese EVs, this research integrates sectoral cost structure data from national statistical databases. Specifically, data from Germany's Statistisches Bundesamt (Destatis) on the cost structure of manufacturing enterprises, and more narrowly, the category "Manufacture of motor vehicles, trailers, and semi-trailers" (NACE C29), were used to estimate the share of labor and energy inputs in total production costs. According to the most recent data (2020–2022), labor costs represent approximately 12.25% of total production costs (average share of wage costs from 2008 to 2024), while energy costs only comprise around 0.6%. The data from Destatis can verify this, as the dataset Material and goods received in manufacturing (code number: 42241-0001) shows the percentage of types of input goods and materials, where the ratio of energy input to raw materials is only 0.01. However, the effect of energy prices has again been implied in the calculation by discounting prices on a yearly basis, 2021, where the inflation effect, the most important outcome of increasing energy prices, has been considered.

3.3.2 Labor Costs and Productivity in Germany

In this research, the effect of wage differences in the two countries will be investigated. The difference in wages can have both direct and indirect effects. For the direct costs, the proportion of the wage shares would be obtained in the industry, where Germany Destatis could be a valuable source in this investigation, there is not much available data on the Chinese automotive sector. Based on German statistics, the proportion of labor wages to turnover in the automotive industry is 16. 525% in 2010 and 16. 603% in 2024. The data also reveal that gross wages in 2024 are 61,993,708 thousand euros, averaging more than 783,096 persons employed, which yields a yearly average of €79,000. Considering OECD data on the average working hours of a German worker in a year, 1332 hours per year for each worker, the average hourly wage in the automotive industry in Germany is €59.43 per hour. Moreover, for the calculation of indirect effect, average wage of Germany is considered as €24.59 according to Destasis, which is adjusted based on the last year growth, resulting in €25.12 for 2024. Finally, the productivity in Germany is

€63.00 in 2023 according to (Amlinger et al., 2024). This amount is considered the same for the automobile sector and the average of all sectors.

3.3.3 Labor Costs and Productivity in China

On the other hand, considering the difficulty of the Chinese sectorial data, more aggregated data has been considered for this comparison. This should not diminish the labor cost effect, as the average share of labor costs should be higher in the automotive industry, compared to all sectors, as for the case of Germany (€59 to €25.12). The average wage of Chinese workers is calculated based on the data available on the National Bureau of Statistics of China. Chinese worker average annual wage in 2022, is 114,029 RBM. Considering 2200 hours of work per Chinese worker, and the exchange rate of 1RBM = 0.12€, the hourly wage of a Chinese worker is €6.2 in 2022. Taking into account the lower trend of China's average wage growth based on the same data, a growth of 6% is considered, based on the growth of 6, 7% in 2022, which yields €6.99. Also, the labor productivity.

The labor productivity for China in the automobile sector is 293,808 RBM per year, which translates to €16.31 per hour in 2015 according to Global Economic Data, Indicators, Charts & Forecasts. Furthermore, the average of China's labor productivity is 173,898 RBM per year or €9.65 per hour. Considering the growth rate of average labor productivity of 0.07 per year, the labor productivity in the automotive sector should be €27. For further illustration, these point statistics are formatted in a table 4.

Category	**Germany (2024)**	**China (Estimated 2024)**
Hourly Wage (Automotive)	€59.43	€6.99
Hourly Wage (Overall)	€25.12	€6.99
Labor Productivity (Automotive, €/hour)	€63.00	€27.00
Labor Productivity (Overall, €/hour)	€63.00	€9.65

Table 4: Comparison of Labor Costs and Productivity in Germany and China (2024)

3.3.4 Energy Costs

In the case of Energy cost comparisons, based on IEA and Eurostat datasets, industrial electricity prices in Germany are typically between €0.15 and €0.20/kWh. These numbers are typically between €0.05 and €0.08/kWh in China. Given that energy costs account for 0.6% of the total production cost, the effect of this disparity on final vehicle pricing is minimal. Thus, for the purpose of this analysis, energy cost differences are considered negligible in their contribution to retail EV price gaps.

3.3.5 Modeling Indirect Labor Cost Effects Using the Leontief Framework

To estimate the indirect impact of wage differences between Germany and China on the automotive industry, this study applies a Leontief input-output model. The Leontief model, introduced by Wassily Leontief, is a linear algebraic representation of the interdependencies among various sectors of an economy. It allows for the quantification of how changes in one sector propagate through others via intermediate inputs.

The central purpose of employing the Leontief framework here is to capture the indirect cost burden imposed by labor costs in upstream industries that supply inputs to the automotive sector. While direct wage costs can be identified easily through cost structure data, indirect costs arise from the wage components of other sectors whose outputs are used in automotive production.

To estimate the indirect impact of wage differences between Germany and China on the automotive sector, this study employs the Leontief input-output model. This model captures the interdependencies between sectors in an economy, showing how output from one industry is used as an input in another. The Leontief price model is expressed as:

$$\mathbf{p} = (I - A^{\top})^{-1} \cdot \mathbf{v} \tag{1}$$

where:

- $\mathbf{p}$ is the vector of sectoral prices (per unit output),

- I is the identity matrix,
- A is the technical coefficients matrix, where each element a_{ij} represents the input from sector i required to produce one unit of output in sector j,
- $A^\top$ denotes the transpose of the technical coefficients matrix,
- $\mathbf{v}$ is the vector of value-added components per unit of output (including wages).

In this research, the input-output coefficients A were taken from the *OECD's domestic Leontief inverse matrix for Germany (2020)*. The column corresponding to the automotive sector (code `TTL_C29`) was extracted, and the automotive sector's self-input was removed to isolate the upstream effect. The result indicates that approximately **62.73%** of the value of automotive output derives from other domestic sectors. For comparison, historical data from Destatis show that this share was **68.4% in 2010** and **67.5% in 2014**, suggesting a decline in external input dependency—possibly due to increased in-house production or offshoring of less expensive input components.

Since full sector-by-sector wage data for all input sectors is not consistently available, we adopt an aggregated estimate. According to Destatis, the average wage share across manufacturing sectors in 2024 was **16.603%**. This average was applied uniformly to all upstream sectors as a proxy for indirect labor intensity.

The actual simulation of indirect labor cost differences—between the German wage regime and a Chinese wage-equivalent scenario—is carried out in the *Results and Discussion* section.

3.4 Cost Reduction in Production through Learning-By-Doing

As shown in this research, wage differentials could not explain the price difference between Chinese-built and German-built EVs. Hence, this study focuses on the learning-by-doing phenomenon, a well-known concept whereby unit costs decline as cumulative production increases. EVs have seen a dramatic cost decrease in recent years, with battery packs having roughly 97% since their debut, from around 1000 kWh in 2010 to 100 in 2025. However, battery's share of the total EV manufacturing cost has hovered around 40-50% according to reports and studies. The annual EV production have surged around 5 times, where the total of EVs produced worldwide has increased from less than 15 million EVs in 2021 to 57 million in 2024 according to The International Energy Agency (IEA). Consequently, manufacturers have improved yields, optimized processes, and standardized designs. These gains drive down per-unit costs independently of material prices or labor rates. Since China's share in global electric vehicle production has been increasing, this factor could explain some of the price differences between the two regions.

To quantify this effect, we isolate the electrification subsystem, battery pack plus electric motor and power electronics for two main reasons. First, these parts are what sets apart the EVs from the ICEs have experienced the steepest volume ramp-up, and is most sensitive to process improvements. The second reason for this approach is that the remainder of the vehicle, including chassis, body, interior, infotainment, and general assembly, remains technology and process mature, essentially mirroring legacy ICE production in both Germany and China; therefore, we assume comparable baseline efficiency there. Moreover, to isolate the effects of learning by doing, the raw-material price swings (lithium, cobalt, nickel) have been controlled by adjusting these inputs. Finally, to estimate the characteristic learning rate b, Wright's law ('experience curve") is used.

3.4.1 Identifying the Key Components for Learning-By-Doing

EVs differ significantly from conventional ICE vehicles, yet they share quite important manufacturing components affecting their production cost. These components include Chassis/body (common with ICE for some parts, plus EV-specific floorplan, crash structures), Suspension and braking (almost identical to ICE), Interior (seats, dashboard, infotainment; same or slightly modified), Engineering and overhead (design, integration, testing), Sales, general & administrative (SG&A), warranty, financing, and profit. As pinpointed in the literature review, the price difference between ICEs and EVs comes from the premium on the electrification section of the vehicle. Hence, it is significantly important to separate these costs to investigate the effect of learning-by-doing. To ensure the validity of estimations regarding the proportion costs of different components, data from various sources has been investigated, such as the International Council on Clean Transportation Light-Duty EV Cost and Consumer Benefits Report (URL Link), and

U.S. Department of Energy (DOE) Incremental Purchase Cost Methodology Report (URL Link).

This research analysis assumes that the mentioned non-incremental are mature through years of optimization by the auto-manufacturing industry, and hence should have minimal effect on the cost production. The same argument could be applied to powertrain components in EVs. These components include the inverter, electric device module, DC converter, high-voltage cables, etc. These components are mostly based on consumable goods and their real price should not change radically in the next decade or so. This is also demonstrated in the ICCT report, considering a 2% change in the price of these components from 2022 to 2030. Thereby, the main component investigated in this research is the overall battery pack, which has been examined widely in academia and reports.

DOE's estimates the battery costs as $9,185 in 2025 and $10,995 in 2022 for a 72 kWh battery pack. Moreover, ICCT data shows that a 50 kWh battery pack cost around $6,500 in 2022. Both reports estimations of battery costs are roughly the same, $130/kWh. This research will compare these numbers with the cumulated EV production to investigate the effects of learning rate, and whether these rates are compatible with the EVs produced in different timelines (2015-2021, and 2021-2025).

By drawing on multiple estimates and cross-referencing different sources, this research finds that approximately 25% of the total EV purchase price is attributable to the battery. For example, ICCT estimates place the total manufacturing cost of an electric vehicle at around $25,000, with the battery accounting for roughly 26% of this figure. Similarly, the U.S. DOE estimates battery pack costs at $9,185 and $9,929 for compact and midsize BEVs, respectively. Given total purchase prices of $33,690 and $36,394 for these vehicles, the battery's share corresponds to approximately 27% of the retail price. These values are consistent with broader industry assessments. Figure 25 illustrates the cost breakdown of ICE and electric vehicles across major component categories, as compiled by Thunder Said Energy.

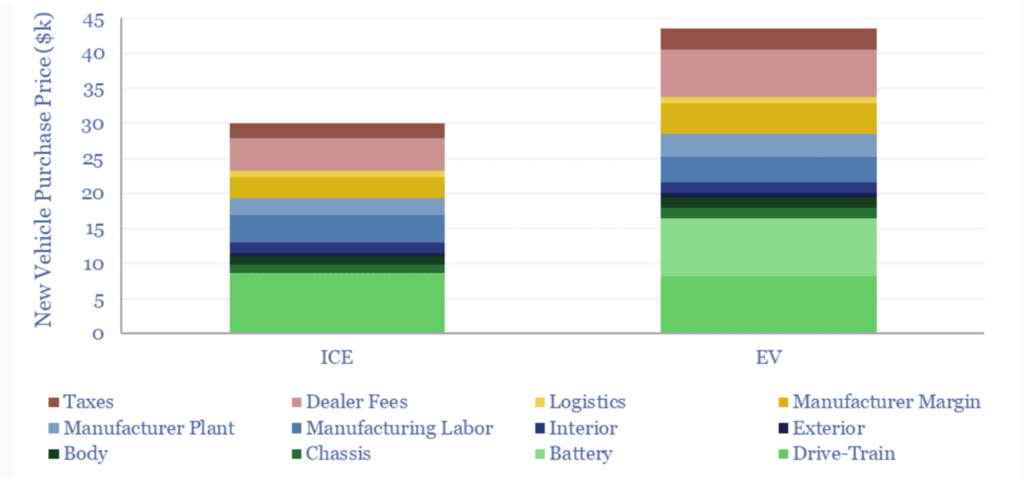

Figure 25: Electric vehicle cost breakdown by component, *Source: Thunder Said Energy*

3.4.2 Input Materials Fluctuations

Examining total battery pack costs and their long-term trends requires incorporating the cost of raw input materials into the analysis. As discussed in the theoretical review, critical minerals play an essential role in battery manufacturing, and their highly volatile prices can significantly influence final pack costs. To validate observed cost trends in battery production, this study assesses the impact of fluctuations in raw material prices. In parallel with evaluating the battery pack's contribution to overall EV purchase prices, this analysis also considers the share of raw materials in the total battery pack cost. Drawing from multiple sources and cross-referenced data, this study utilizes figures published by Argonne National Laboratory (URL Link).

While the exact material composition varies by battery chemistry, reliable estimates are available for the current dominant design in EV applications—lithium iron phosphate (LFP) batteries. According to the Argonne report, cell materials accounted for approximately 63% of the total battery pack cost in 2024. Cathode materials—including nickel, cobalt, manganese, and lithium—collectively contributed around 40% of the total cost. Anode materials, primarily graphite with possible silicon-based additives, were responsible for an additional 10–15% of the overall battery pack cost.

The critical minerals mentioned above are subject to substantial price volatility, which can significantly influence the final cost of battery packs. A sharp surge in prices during 2022 led to increases of up to tenfold for some materials, substantially raising both battery production costs and overall EV purchase prices. This impact is reflected in the projected battery cost trends shown in Figure 16. To account for such volatility in the analysis, this study examines the price trends of key raw materials. In order to filter out short-term price spikes, the analysis focuses on data from 2021 onward. This choice is motivated by two primary considerations. First, EV adoption accelerated significantly after 2021, leading to a sharp increase in demand for critical battery inputs. Second, the most notable divergence in battery pack costs between Chinese and German manufacturers also emerged during this period.

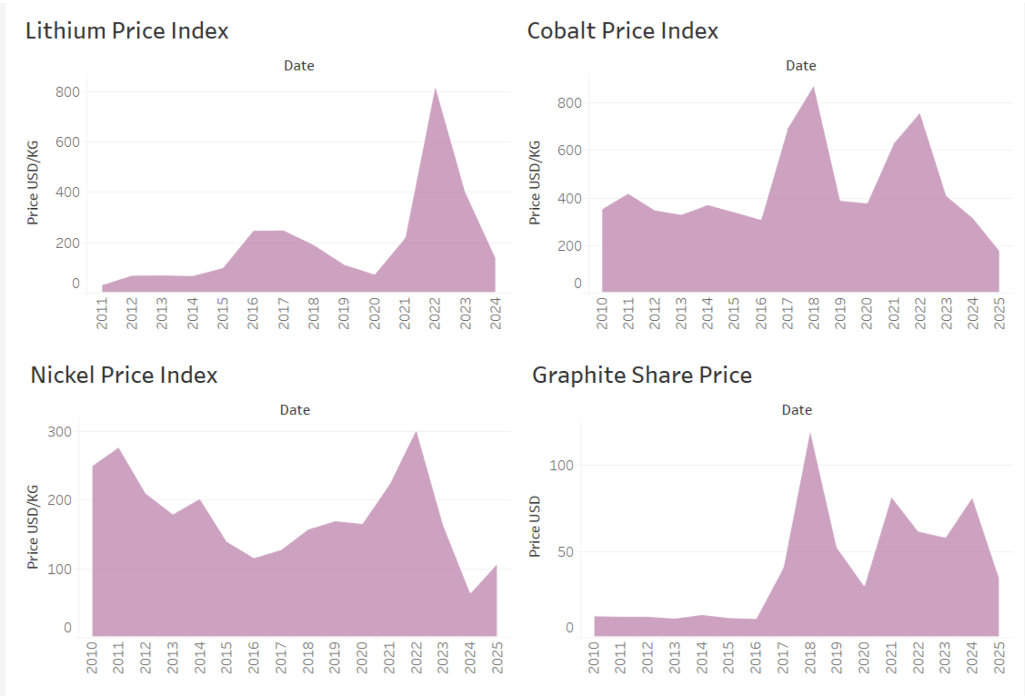

Figure 26:
Monthly Price of Crucial Raw Input Materials in EV Battery Pack *Data Source: Investing.com*

As illustrated in Figure 26, although prices of key minerals used in EV battery packs are subject to high volatility, many have returned to their 2021 levels. For example, lithium carbonate prices peaked at over \$80,000/ton in late 2022 but declined to \$14,000/ton by early 2024 — close to 2021 levels. A similar trend was observed for cobalt (from \$80,000/ton to \$30,000/ton) and nickel (from \$50,000/ton to \$16,000/ton). These reversions significantly eased raw material cost pressures by 2024. Based on their estimated contribution to total battery pack costs—10–15% for nickel, 5–8% for cobalt, 6–10% for lithium, and 5–7% for graphite—the aggregate impact of recent input price fluctuations appears limited. While the price spikes of 2022 and 2023 temporarily disrupted the declining cost trend of battery packs, as reported by Orangi et al. (2024), commodity prices have since normalized. Therefore, this study treats the influence of mineral price volatility on long-term battery cost trends as negligible. In addition, manufacturers actively adjusted material compositions in response to these price surges—particularly during 2022 and 2023—further mitigating their impact on production costs during that period.

3.4.3 Wright's Law and Learning-by-Doing

Wright's Law, also known as the experience curve, expresses the empirical observation that unit costs tend to decline as a function of cumulative production. It is commonly used to model learning-by-doing effects in manufacturing industries, including battery and electric vehicle production. The general form of the equation is:

$$C(Q) = C_0 \times (Q/Q_0)^{-b}$$

where:

- $C(Q)$ is the unit cost after producing a cumulative quantity Q,
- C_0 is the initial cost at baseline production ($Q = 1$),
- b is the *learning exponent*, representing the elasticity of cost with respect to cumulative output.

A more interpretable form is the logarithmic transformation of Wright's Law:

$$\ln C(Q) = \ln C_0 - b \cdot \ln Q$$

In this form, the learning exponent b can be estimated using linear regression on log-transformed cost and production data. The value of b determines the learning rate (LR), or the percentage cost reduction for each doubling of cumulative production, calculated as:

$$\text{Learning Rate (LR)} = 1 - 2^b$$

Analyzing the effect of cumulative electric vehicle (EV) production on unit costs requires accurate and representative data. For this purpose, the cumulative production values presented in this study are based on data compiled from the International Energy Agency (IEA) for the years 2010 through 2024. Battery cell price estimates are derived from empirical data published by Orangi et al. (2024), particularly as illustrated in Figure 16. This dataset consolidates observations from a wide range of industrial and academic sources, including BloombergNEF, Tesla, Ford, and Zeigler et al., and reflects multiple forecast and historical scenarios. Given its comprehensiveness and frequent citation, it serves as the foundation for cost modeling in this study.

Table 5 summarizes the battery pack cost estimates drawn from the **black line in Orangi et al. (2024)**, which represents the consolidated average trajectory across multiple industrial and academic sources, including BloombergNEF, Tesla, Ford, and Zeigler et al. This series is widely accepted as a benchmark for modeling cost trends in electric vehicle production.

Table 5: Battery pack cost estimates from 2010 to 2021 (black line average) *Source: Orangi et al. (2024)*

Year	Battery Cost (USD/kWh)
2010	475
2011	415
2012	375
2013	325
2014	310
2015	270
2016	195
2017	160
2018	135
2019	120
2020	105
2021	100

Battery pack cost estimates vary depending on the source, scope, and methodological definitions. For instance, Orangi et al. (2024) report a global average battery cost of approximately \$100/kWh by 2021, derived from a consolidated dataset that includes industrial data from BloombergNEF, Tesla, Ford, BYD, and others. This estimate reflects a blended cost trajectory across manufacturers and includes data from vertically integrated firms such as BYD and CATL, which benefit from lower production costs due to scale and integration. In contrast, the U.S. Department of Energy (DOE) and the International Council on Clean Transportation (ICCT) estimate pack-level costs at \$127–\$130/kWh for 2022. These higher figures reflect total system-level battery pack costs, inclusive of housing, battery management systems (BMS), thermal management, and wiring — components often excluded in cell-focused global averages. Furthermore, DOE and ICCT values capture the temporary surge in raw material prices in 2022, whereas the Orangi curve smooths such volatility for trend continuity. These distinctions underline the importance of scope clarity when comparing cost trajectories. Adjusting Orangi's figures upward by 25–40% to account for full-pack integration brings them closer to DOE and ICCT estimates, confirming internal consistency across sources despite apparent headline differences.

To evaluate the presence and evolution of a learning effect, this study applies the framework of Wright's law, which posits that costs decline as a power-law function of cumulative production. The standard logarithmic form is given by:

Initial observations indicate a relatively steep decline in battery costs up to 2021, followed by a flattening trend beginning in 2022. This inflection coincides with significant increases in raw material prices, suggesting interference with the traditional learning curve. To analyze this shift, learning rates are estimated across three time windows: 2010–2015, 2015–2021, and 2021–2024.

It is important to note that the production figures represent total electric vehicle units—encompassing both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs)—for Germany, China, and globally. While variations exist between BEV and PHEV technologies, their learning trajectories are assumed to follow a unified trend for the purpose of this study. Similarly, the impact of varying battery chemistries across different markets and manufacturers is not explicitly differentiated. Given the empirical formulation of Wright's law and the aggregate nature of industry cost data, such distinctions are considered secondary.

Table 6 presents detailed annual EV production and cumulative stock data for the global, Chinese, and German markets. These figures serve as the basis for the learning curve estimation conducted in the subsequent analysis.

Table 6: Annual and cumulative EV production by region (2010–2024) *Data Source: IEA*

Year	World		China		Germany	
	Produced	Cumulative	Produced	Cumulative	Produced	Cumulative
2010	7,000	7,000	1,420	1,420	140	140
2011	40,000	47,000	5,140	6,560	1,640	1,780
2012	118,000	165,000	9,860	16,420	3,400	5,180
2013	201,000	366,000	15,730	32,150	6,800	11,980
2014	330,000	696,000	73,000	105,150	13,500	25,480
2015	520,000	1,216,000	211,000	316,150	23,000	48,480
2016	780,000	1,996,000	339,000	655,150	24,000	72,480
2017	1,200,000	3,196,000	580,000	1,235,150	54,000	126,480
2018	2,050,000	5,246,000	1,090,000	2,325,150	67,000	193,480
2019	2,080,000	7,326,000	1,060,000	3,385,150	108,000	301,480
2020	2,970,000	10,296,000	1,140,000	4,525,150	390,000	691,480
2021	6,600,000	16,896,000	3,250,000	7,775,150	690,000	1,381,480
2022	10,200,000	27,096,000	5,900,000	13,675,150	830,000	2,211,480
2023	13,700,000	40,796,000	8,100,000	21,775,150	700,000	2,911,480
2024	17,500,000	58,296,000	11,300,000	33,075,150	570,000	3,481,480

4 Results and Discussions

4.1 Overview of Comparative Price Trends

The core objective of this thesis is to analyze the underlying reasons behind the struggles of the German auto industry in maintaining its comparative advantage in the EV sector in the face of rising competition from Chinese manufacturers. The intertwined relationship between EV adoption and various components has been introduced and investigated in prior sections. As discussed, there are numerous results and research on the effectiveness of higher income, subsidies, and pricing on the adoption of electric vehicles. Building on these insights, this chapter shifts focus toward pricing dynamics, which serve as a critical mechanism influencing EV affordability and adoption. In this context, a comparative analysis of EV prices in China and Germany offers a valuable lens for understanding underlying structural and strategic industry differences.

This section presents a foundational overview of the pricing trends uncovered during the investigation, based on the data compiled and visualized in Tableau. The results reveal a significant price difference between EVs sold in Germany and those available in the Chinese domestic market. As will be shown in the following subsections, this price differential is persistent across years and model categories, and cannot be adequately explained by differences in labor and energy costs alone. This finding prompts deeper inquiry into additional explanatory variables, including learning-by-doing efficiencies, vertical integration in production, pricing strategies, and possibly state-level industrial policy.

To better understand how labor costs contribute to these price differences, this chapter includes a detailed analysis of both direct and indirect labor costs. Direct labor costs are calculated based on wage shares in the automotive industry, while indirect costs are estimated using a Leontief input-output model. This model shows how wage costs from other sectors flow into automotive production.

Because some data for China—such as sector-specific wages and detailed input structures—were not available, the analysis uses average wage levels and aggregate wage shares as a practical estimate. These limitations are discussed in more detail later in the chapter.

The analysis shows that not only do electric vehicles cost significantly more in Germany, but German-made EVs are also priced notably lower when sold in China. The study tries to make comparisons at different levels, such as aggregate price averages on the two markets and comparable models and brands. This reinforces the notion that pricing strategies are not solely determined by production costs, but by market dynamics and firm-level positioning. To ensure robustness, this study conducts both aggregated price comparisons and model-specific breakdowns across markets. The cross-sectional patterns revealed in the data suggest a structurally persistent pricing gap, which sets the stage for the next phase of the analysis — estimating the potential effect of price differentials on EV adoption rates. The next subsections will unpack these trends with model-specific breakdowns, brand-level distinctions, and geographic comparisons.

4.2 Price Trend Analysis by Market and Brand

4.2.1 Average Price Trend in the German Market

The price trend analysis in the German market is shown based on the data presented in 3. According to the gathered data, the average price trend of the most sold EVs in Germany is depicted in Figure 27.

Figure 27 shows that the real prices of most popular EV models are between €42,000 and €45,000. Considering the price trend, the real prices fell by almost 10% from 2021 to 2022, but there was a spike in prices from 2022 to 2023. This is due to the inflation shocks triggered by the Ukraine conflict and its effect on global energy and raw material prices. The prices have again dropped, although by a small amount, in 2024, and should be declining to previous and even lower prices considering huge advancements in battery technology during recent years. It is worth mentioning that nominal EV prices are around 10% higher in 2024 compared to 2022, but the real prices have declined nonetheless. These trends suggest a potential for further price corrections if cost-saving innovations continue to scale.

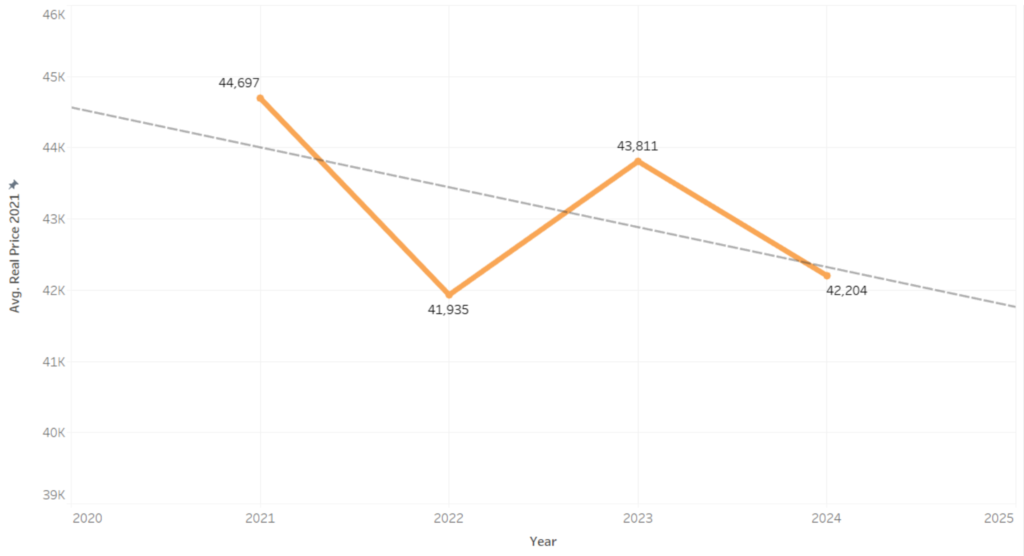

Figure 27: Average Price of Electric Vehicles in Germany (2021-2024). According to the data presented in Table 3

4.2.2 Average Price Trend in the Chinese market

Trend analysis of EV prices in the Chinese market is presented previously introduced dataset. These prices have been adjusted based on the inflation rate, considering 2021 as the base year. The dataset was processed to highlight the most popular models in the Chinese market, allowing clearer insights into pricing patterns. The availability of more data points, along with aggregation and grouping allowed for a smoother trend line, as depicted in Figure 28.

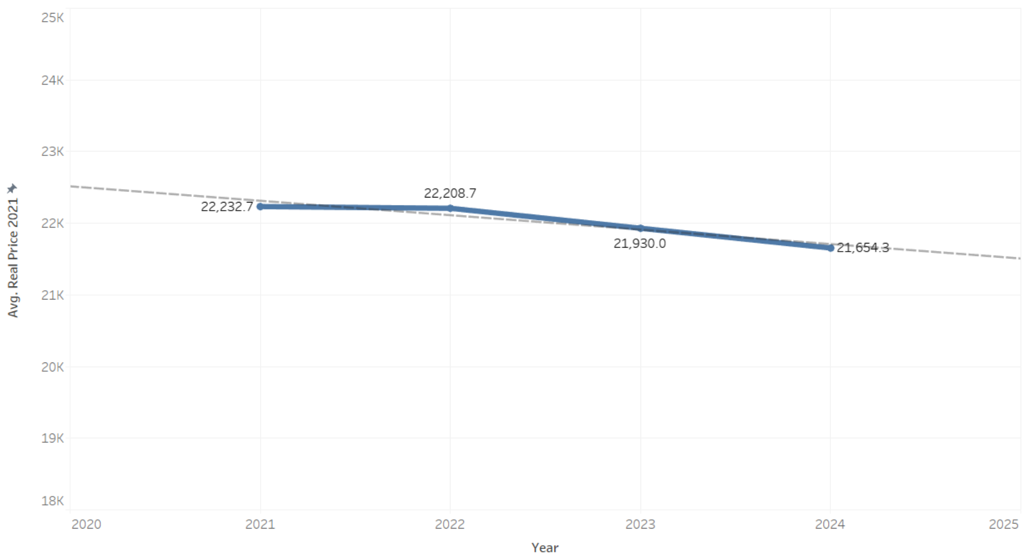

Figure 28: Average Price of Electric Vehicles in China (2021-2024).

4.2.3 Price Trends of German and Chinese Automakers in the Chinese market

Figure 28 shows that the average price of EVs sold in China was approximately €22,000, nearly half the average EV price in Germany. Additionally, there is a slightly declining trend in real prices of EVs sold in China over time. This trend has not been disrupted, as has been in the case of Germany, between the years 2022 and 2023, which is expected as China did not suffer from the supply-side shocks and the resulting inflation from the Ukraine War. While these data are not indicative of the overall average price of EVs in China, but the most popular wants considering the unit sold during a year. However, customer preference, design structures, and incentives can alter purchasing behavior, which does not allow for a valid comparison with the German EV market. As a result, the price lines for German and Chinese automakers were separated and illustrated in Figure 29.

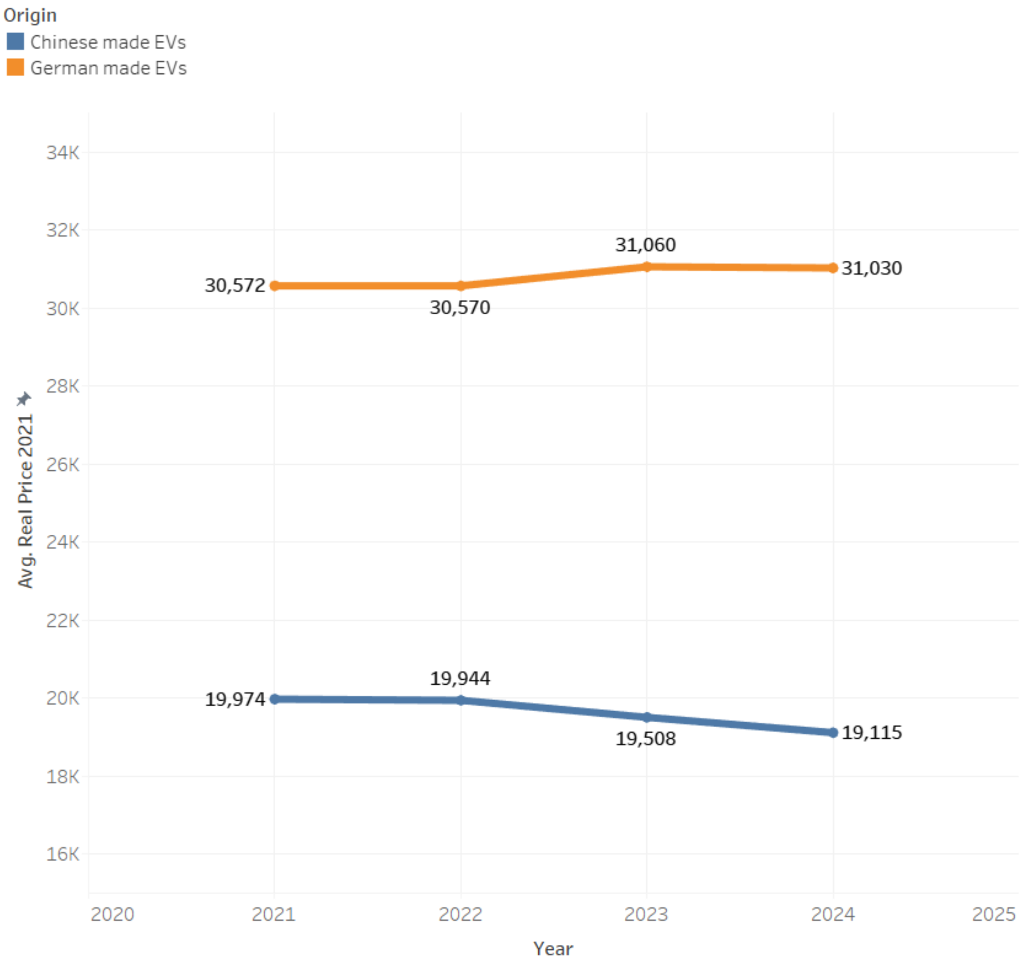

Figure 29: Average Price of Electric Vehicles Considering the Origin of the Auto Manufacturer in the Chinese market (2021-2024).

Figure 29 presents noteworthy trend lines regarding the German and Chinese automakers operating in China. First and foremost, it is evident that the average price of German manufacturers in China is approximately €31,000, around one-third lower than their average retail price in Germany. The vehicle models included in the analysis is generally similar to those highlighted in Table 3 for the German market.While most model types are consistent across both datasets, some differences exist due to market-specific regulations and customizations. For example, models such as the Mercedes-Benz EQA and EQB and Volkswagen ID.3 and ID.4 are sold in both regions. However, others, like the Volkswagen ID.6, are exclusive to China, whereas the ID.7 is designed for the European market. These distinctions reflect Volkswagen's market segmentation strategy, producing the ID.6 specifically for the Chinese consumer base, while reserving the ID.7 for domestic (German/European) sales. A pre-analysis of model specifications was conducted to confirm that the selected vehicles are comparable in terms of features and target segments, ensuring the validity of cross-market price comparisons.

Figure 29 reveals an interesting notion regarding the price trend of Chinese and German auto manufacturers. While the average real price of Chinese made EVs has declined by more than 4%, the prices for German made EVs have increased by 2% over the same period. Considering the nature of the Chinese market, the most competitive and advanced market in EVs worldwide, this trend could show a comparative disadvantage for German automakers compared to their local rivals.

Considering the starting higher prices for German EVs, along with their increasing price trend over the specified period, it should not be surprising to see German automakers lose market share in China, as mentioned before regarding the case of Mercedes-Benz and Volkswagen.This price increase is more plausibly attributed to rising production costs rather than to strategic markup or elevated profit margins. The intense price competition among domestic producers in China places downward pressure on retail prices, limiting the feasibility of aggressive pricing strategies for foreign brands.

Considering huge investments made by German automakers such as Volkswagen, the suffering of such firms in terms of operational profit could be due to their increasing, yet not-profitable strategies in China.

To further contextualize the pricing gap between Chinese and German EVs, Figure 30 presents a direct comparison of price trends between two leading manufacturers: Volkswagen and BYD. The data reveal that Volkswagen is struggling to compete with BYD on price, with a growing divergence in average EV prices over time. This disparity may reflect institutional constraints, differences in production efficiency, or contrasting pricing strategies. The sustained and widening price gap highlights the challenges Volkswagen faces in aligning its cost structure and market approach with the dynamics of the Chinese EV sector. In an environment where cost competitiveness is critical, this divergence may be symptomatic of broader structural inefficiencies or strategic mismatches.

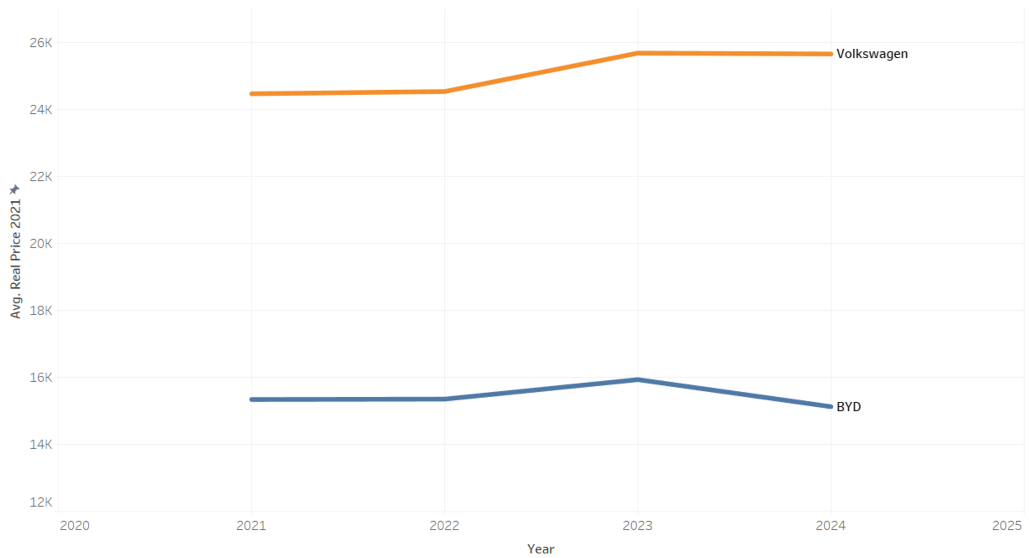

Figure 30: Average Price of Volkswagen and BYD EVs in the Chinese market (2021-2024).

4.2.4 Average Price of German EVs in China vs. Germany

A comparison of German-made EVs sold in both China and Germany reveals a significant price gap between the two markets. As shown in Figure 31, the same or comparable models are substantially cheaper when sold in China than in their domestic German market. This finding is particularly notable given that these vehicles are often produced by the same firms, sometimes even in joint ventures within China, yet are offered at much lower retail prices. The divergence raises important questions about pricing strategy, market adaptation, and cost pass-through mechanisms in international operations.

As mentioned frequently, one of the most commonly cited reasons for the EV price disparity between China and Western countries is the difference in labor costs. While labor costs are higher in Western Countries, specifically Germany, the magnitude of this difference does not appear sufficient to justify the observed gap in EV prices, even after inflation adjustment. Considering a shared production origin, comparable technological basis and platform, and manufacturing processes, German EVs sold domestically are priced 30-40% higher on average than their counterparts sold in the Chinese market. As previously

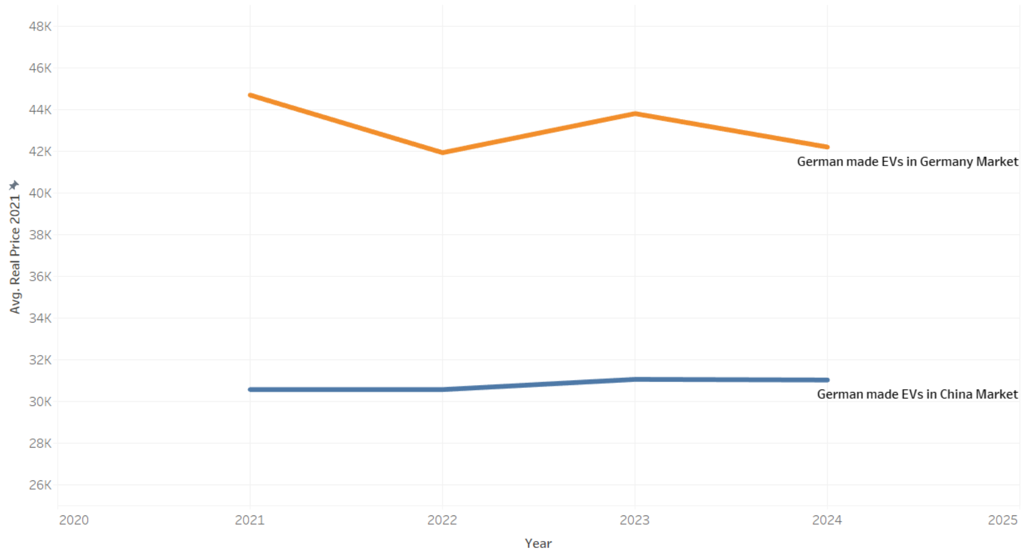

Figure 31: Average Price of German-made EVs in the two Targeted Markets (2021-2024).

considered, the share of labor and energy costs in the production of vehicles are set to be at 12.6% during the relevant period. Assuming a hypothetical scenario where German labor costs are 100%, the maximum justifiable price premium would be 12.6%. However, the observed price premium consistently ranges between 30% and 40%. These findings suggest that labor costs alone cannot account for the substantial price discrepancy between markets. This calls for further investigation into other structural and strategic variables such as vertical integration, supply chain efficiencies, and pricing strategies—particularly in China's EV ecosystem.

To deepen the analysis of pricing disparities, this subsection zooms in on Volkswagen (VW)—a core German automaker with substantial operations and market presence in both China and Germany. Unlike luxury brands such as Mercedes-Benz or BMW, VW predominantly targets the mass-market segment, where consumers are more price-sensitive. This makes it an ideal case for examining the effects of cross-market pricing strategies and structural cost differences.

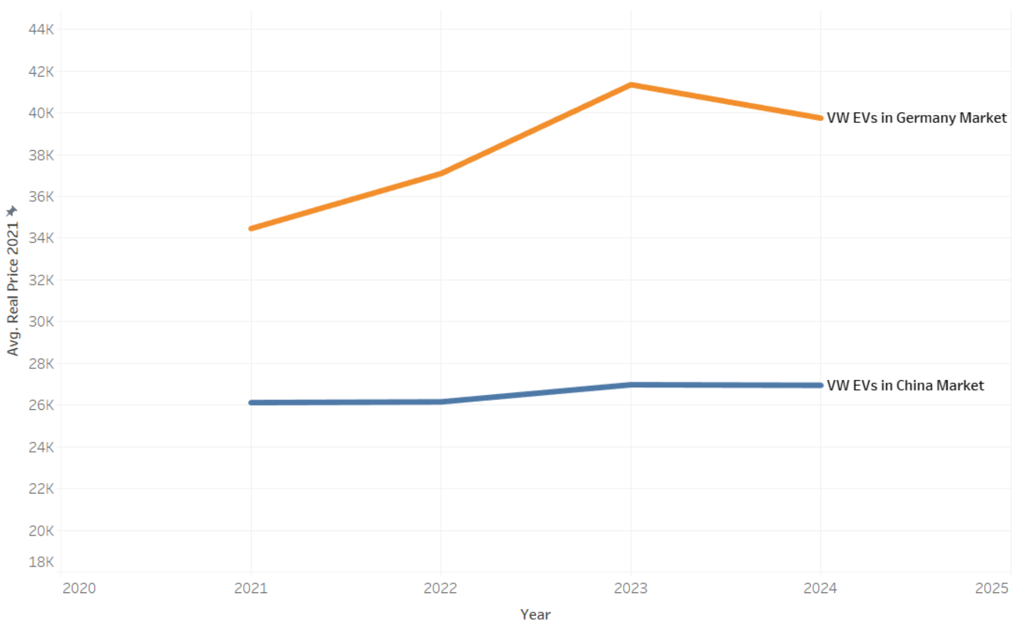

Figure 32: Average Price of Volkswagen EVs in the two Targeted Markets (2021-2024).

As shown in Figure 32, even after adjusting for inflation (real prices, 2021 base), VW EVs exhibit a consistent and widening price gap between the Chinese and German markets, with German domestic prices averaging €10,000–€13,000 higher across the period 2021–2024. This pattern is particularly significant because VW primarily competes in the mid-market segment, where the price elasticity of demand tends to be higher. In such segments, relatively modest price differences can substantially impact consumer purchasing decisions and, consequently, EV adoption rates. These findings challenge the sufficiency of conventional cost explanations and point toward deeper structural differences in pricing strategy, localization advantages, and market orientation. Therefore, the price difference in mass-market EVs such as VW can significantly hinder Germany's competitiveness to accelerate domestic EV adoption.

4.3 Benchmarking EV Performance and Value: A China–Germany Comparison with Focus on BYD and Volkswagen

While the price trends and their difference could create crucial questions about differences in both markets, it is necessary to make sure this comparison is based on models that exhibit similar technological and overall qualities. Chinese automakers, as mentioned before, will have difficulty in proving to customers that their EVs do not embody the prevalent mindset regarding the goods made in China. These EVs are not just only cheap, but comparable in terms of design, technology, after-sale services, options, and different trims. Since batteries are the most integral part of EVs, a comparative analysis has been made on different models and brands from various regions. This analysis could indicate that Chinese firms are not only competitive in terms of the final cost of goods, but the quality of their final product. As Figure 33 shows, most of the Chinese EVs have the same range and battery specifications as the German vehicles. While the figure shows some German models with higher range or/and battery, the price difference is quite substantial.

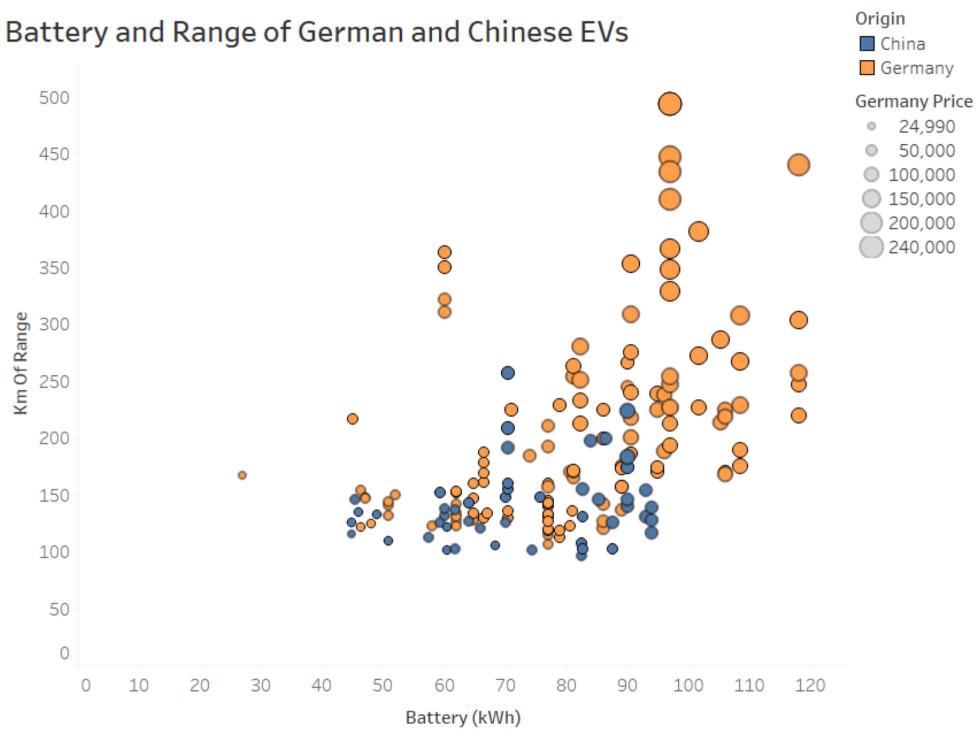

Figure 33:
Range of EV models and their Battery specifications (kWh) in China and Germany.
The size of each point is proportional to the price model.

To further illustrate the state of the Chinese EVs within the global market, another analysis has been made. This time, the variables used in producing this graph are price per kWh battery and km of range. Moreover, Figure 34 indicates the distribution of the price per range and battery of car manufacturers form 4 different leading regions. It can be seen again that the Chinese are providing a better ratio in both terms and that the German carmakers are unique in their luxury vehicles, which separate them from other regions like Japan and the U.S. An important point is that the price ratios are in terms of Vehicle prices in Germany. Hence, the Chinese EVs have substantially higher prices than their domestic market, due to different reasons mentioned earlier, such as tariffs, shipping costs, marketing, etc.

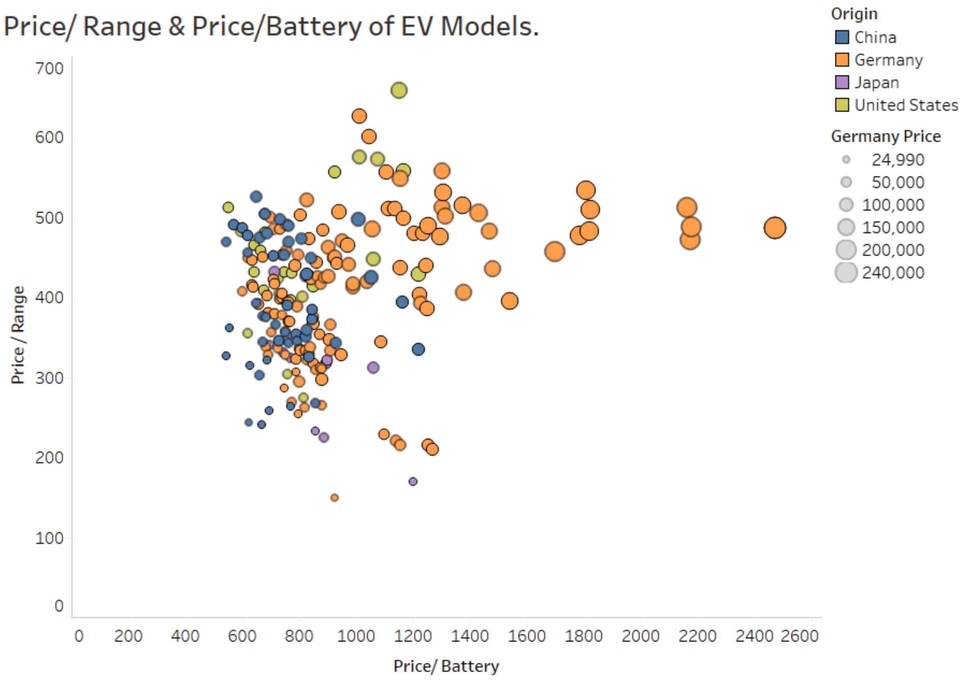

Figure 34:
Unit price per Range (km) and Battery (kWh) of Leading Car Manufacturers.
The size of each point is proportional to the price model.

4.3.1 BYD/Volkswagen Cross-sectional Price Analysis

Ensuring the comparability of prices between EVs in terms of battery capacity and range, this research, the two leading car manufacturers from each region has been selected for further investigation. Since Chinese vehicle are subjected to different regulations, and the data regarding all German-made EVs in China were not available, the two leading firms have been chosen for this analysis. As illustrated in Table 7 comparable and available models in both regions were chosen for this analysis.

Brand	Model	Battery (kWh)	Origin	Range (km)	Efficiency (Wh/km)	Price Germany (€)	Price China (€)	Difference in price
BYD	ATTO 3	61	China	330	183	€37,990	€16,296	57%
BYD	SEAL 82.5 kWh AWD Excellence	83	China	490	168	€52,990	€28,776	46%
BYD	DOLPHIN 60.4 kWh	61	China	340	178	€37,990	€15,576	59%
BYD	HAN	85	China	475	180	€69,020	€21,576	69%
BYD	SEAL 82.5 kWh RWD Design	83	China	500	165	€46,990	€22,776	52%
BYD	TANG	86	China	355	243	€71,400	€28,776	60%
BYD	SEAL U 71.8 kWh Comfort	72	China	340	320	€41,990	€22,776	46%
BYD	SEAL U 87 kWh Design	87	China	405	215	€44,990	€28,776	36%
BYD	DOLPHIN 44.9 kWh Active	45	China	255	176	€29,000	€11,976	59%
BYD	DOLPHIN 44.9 kWh Boost	45	China	255	176	€32,000	€13,656	57%
VW	ID.4 Pro	77	Germany	435	177	€46,335	€25,428	45%
VW	ID.3 Pro	58	Germany	350	166	€39,995	€17,747	56%
VW	ID.7 Pro	77	Germany	475	162	€53,995	€28,533	47%

Table 7:
Comparison of BYD and VW EV Models: Specifications and Prices in Germany vs. China
All prices are current 2025 prices.

As Table 7 shows the analysis is based on a sample of $n = 13$ data points representing the percentage price difference between comparable German and Chinese EV models.

The data points are given by:

$$X = \{57, 46, 59, 69, 52, 60, 46, 36, 59, 57, 45, 56, 47\}$$

1. Calculation of the Sample Mean ($\bar{x}$)

The sample mean is a point estimate of the population mean, calculated as the sum of all data points divided by the sample size.

$$\bar{x} = \frac{\sum_{i=1}^{n} X_i}{n} = \frac{689}{13} \approx 53.00\%$$

2. Calculation of the Sample Standard Deviation (s)

The sample standard deviation measures the dispersion of the data around the mean. Since the sample size is small, we use a denominator of $(n-1)$ to ensure an unbiased estimate of the population standard deviation.

$$s = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{x})^2}{n-1}} = \sqrt{\frac{806}{12}} \approx 8.19\%$$

3. Construction of the 95% Confidence Interval

A 95% confidence interval for the population mean difference is constructed using the t-distribution, which is appropriate for small sample sizes. The formula is:

$$CI = \bar{x} \pm t_{\alpha/2,n-1} \times \frac{s}{\sqrt{n}}$$

where:

- $\bar{x}$ is the sample mean (53.00%)
- $t_{\alpha/2,n-1}$ is the t-critical value for a two-tailed test with $\alpha = 0.05$ and 12 degrees of freedom. This value is approximately 2.179.
- s is the sample standard deviation (8.19%)
- n is the sample size (13)

Substituting the values into the formula, we get:

$$CI = 53.00 \pm 2.179 \times \frac{8.19}{\sqrt{13}}$$

$$CI = 53.00 \pm 4.95$$

The resulting 95% confidence interval is **(48.05%, 57.95%)**.

4.4 Direct and Indirect effects of Labor Cost on Production Cost

4.4.1 Direct Effect

In this part, the direct effects of labor costs on production costs will be investigated. Based on various reports, German automakers have pointed out the difference between labor costs as a reason for off-shoring or having products with higher initial prices. This analysis would help to evaluate such claims and whether German auto manufacturers' recent struggles could be mainly due to the gap in wages in Germany compared to China.

As described in the methodology section, labor costs approximately represents 12.25% of total production costs in Germany. Based on the results of Table 4, the hourly wage at German in the automotive industry is €59.43, compared to that of €6.99. Hence, the ratio of average wages in Germany in comparison to China is approximately 8.5. This ratio should be adjusted based on the labor productivity in two regions, which would make the ratio 3.64. The difference of direct labor costs then is 8.88%.

It is important to note that the productivity in China for the automotive sector is almost three times than the average productivity (27.0 to 9.65), while the amount is the same for Germany (63 to 63). Considering higher labor productivity in the German automotive sector results in an even lower direct effect from the differences in labor.

4.4.2 Indirect Effect

The indirect effects of labor costs are estimated based on the Leontief coefficients. Multiplying the vector of how much the output of the automotive sector drives from other domestic sectors (62.73%), by the average wage shares in the other sectors (16.6%) results 10.41%, which is the share of wages of other sectors in the automotive sector. Considering the differences in average wages in the two countries, the indirect effect of labor costs is 7.5%.

4.4.3 Labor Costs Effect

After computing both indirect and direct costs, our estimates reveal that labor costs account for 16. 3% difference in vehicle production costs between Germany and China. While the results of this analysis provide insight into how labor costs affect automotive production costs in Germany and China, they are accompanied by several limitations.

First, detailed input-output and wage data for the Chinese automotive sector were not available. As a result, the Leontief-based model uses only German data to estimate indirect labor costs. If Chinese input structures are significantly different, for example, if more parts are imported or labor shares vary by industry, this could affect the results.

Second, the average wage data used for China are based on the national average across all sectors. Actual wages in the Chinese manufacturing or automotive sector may be higher, which means that the wage gap, and therefore the estimated labor cost effect, may be overstated.

Third, this study focuses exclusively on labor costs. Other important factors of production cost are not considered, such as energy prices, land costs, logistics, taxation, and regulatory compliance. These non-wage costs can vary significantly between Germany and China and may influence overall competitiveness just as much as wages do.

Fourth, the analysis assumes a static cost structure and does not consider technological changes. For example, the rise of electric vehicle (EV) production is expected to reduce labor needs and shift cost structures toward capital and automation. As this trend grows, wage differences may become less relevant over time.

Finally, the model uses average values and national-level data. Differences between firms, production methods, and regional wage levels are not captured, although they can have a major impact on real-world production decisions.

4.5 Learning Rates and Wright's Law effects on Battery Production

4.5.1 Using Worldwide Trends

According to IEA data as represented in Table 6, the EV production has increased 172 times between 2010 and 2015, 12.89 times between 2015 and 2021, and 2.46 times between 2021 and 2024. Based on these cumulative data, and the data extracted from (Orangi et al., 2024) graph, a learning rate table for different periods has been constructed in the following.

Table 8: Estimated Wright's Law Parameters for Global EV Production and Battery Costs

Time Period	**Learning Exponent (b)**	**Learning Rate (%)**
2010–2015	–0.1095	7.31%
2015–2021	–0.3774	23.02%
2010–2021	–0.2000	12.95%

Table 8 presents the estimated learning parameters for the global electric vehicle market based on cumulative EV production and corresponding battery pack cost data from 2010 to 2021. The results are drawn from applying Wright's Law to the relationship between cumulative global EV output (as per IEA data) and average battery pack costs (sourced from the historical pricing benchmark in Orangi et al., 2024).

The results show that the learning exponent for the full period 2010–2021 is $b = -0.2000$, corresponding to a learning rate of 12.95%. However, a closer inspection of the segmented periods reveals a stark difference in the pace of learning. From 2010 to 2015, the learning rate was only 7.31%, while from 2015 to 2021 it increased significantly to 23.02%.

This difference is reflective of both market dynamics and technological maturity over these two distinct phases of EV evolution. The 2010–2015 period can be considered an early adoption phase for EVs, where production volumes were still low, consumer awareness was limited, and battery technologies were nascent. Manufacturers were still experimenting with designs, chemistries, and integration methods. Consequently, the rate of cost decline during this phase was relatively modest.

In contrast, the 2015–2021 period coincides with the acceleration of mass-market EV adoption. Major automakers entered the market with scalable models, competition intensified, and battery cell production became increasingly standardized and localized. These developments contributed to more substantial cost reductions, as reflected in the higher learning rate.

Importantly, the 23.02% learning rate derived for the 2015–2021 global period is in close alignment with the empirical findings of Goetzel and Hasanuzzaman (2022), who estimated learning rates in the range of 23–29% for different segments of the German market. While Goetzel's analysis focused on the retail cost of different classes of BEVs and ICE comparators in Germany, the similarity in magnitude supports the credibility of our globally-derived estimates.

Given this convergence, and the observed flattening of cost decline since 2021 due to material price fluctuations, we adopt a learning rate range between the 2010–2021 average (12.95%) and the post-2015 accelerated rate (23.02%) as the basis for future forecasting. This band reflects both historical empirical data and forward-looking realism in the face of maturing EV production capacity and evolving battery technology cost structures.

The next section applies this learning rate range to project battery costs from 2021 to 2024 under different cumulative production growth scenarios.

4.5.2 Projected Battery Costs for 2024 Based on Learning Trends

Using the cumulative global EV production values for the years 2021 and 2024, this section applies the Wright's Law formulation to project average battery pack costs under two empirically derived learning rates. The baseline cost is set at $100 per kWh in 2021, as reflected in the consolidated estimates from Orangi et al. (2024). Table 9 shows the results.

Table 9: Projected 2024 Battery Costs Based on Cumulative Production Growth (2021–2024)

Learning Rate Scenario	**Learning Exponent (b)**	**Projected 2024 Cost (USD/kWh)**
Based on 2010–2021	–0.2000	$78.06
Based on 2015–2021	–0.3774	$62.66

As shown in Table 9, the projected battery cost for 2024 ranges between $78.06 and $62.66 per kilowatt-hour depending on the assumed learning rate. The lower bound is derived from the steeper learning observed between 2015 and 2021, which reflects a phase of accelerated industrial scale-up and competitive optimization. The higher bound corresponds to the longer-term learning trend from 2010 to 2021, which captures both early-stage inefficiencies and later improvements.

To further illustrate the cost evolution under different learning dynamics, Figures 35 and 36 below present projected battery price trajectories using two empirically derived learning exponents. These projections apply Wright's Law to cumulative EV production data between 2021 and 2024, using a baseline battery price of $100/kWh in 2021 as established by (Orangi et al., 2024).

Figure 35 depicts the projection using a conservative learning exponent of -0.200, resulting in a global learning rate of approximately 13%. Under this scenario, projected battery pack prices fall moderately, with China reaching the lowest price levels (around $94/kWh by 2024), followed by the global average and then Germany. The graph clearly shows regional divergence in learning outcomes, with Germany's

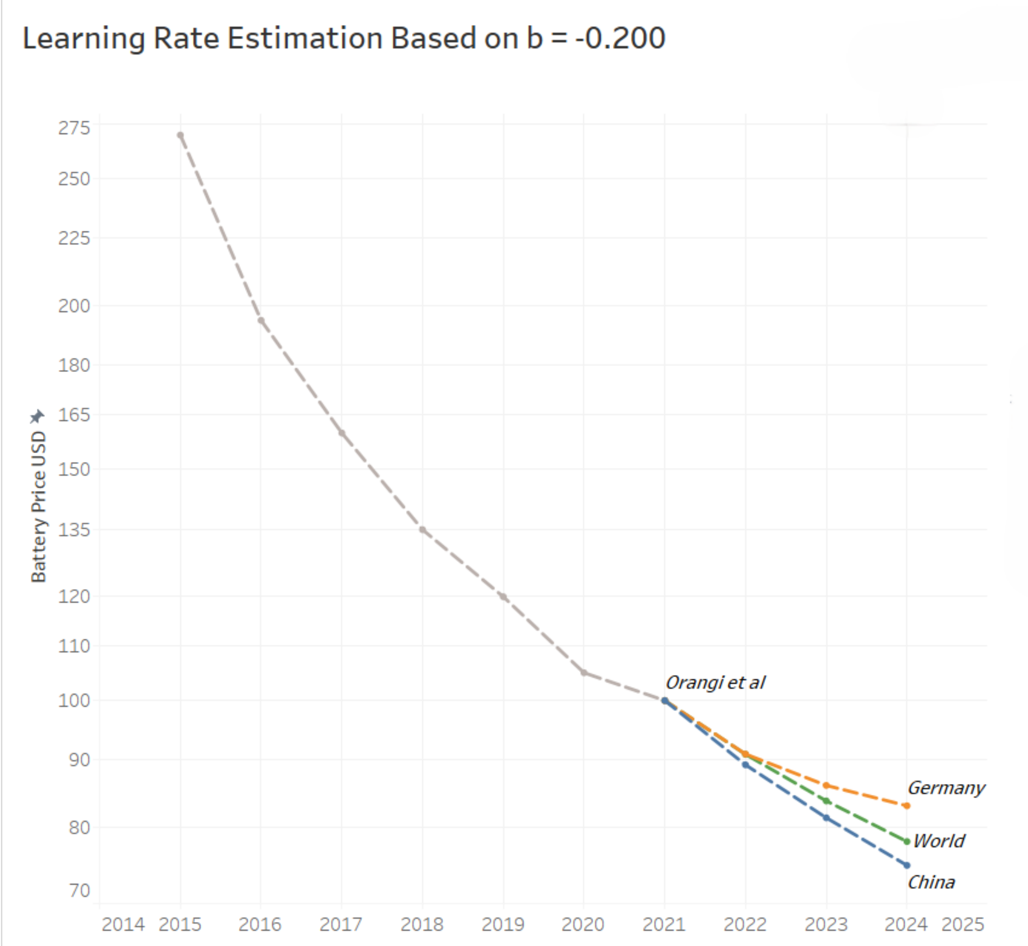

Figure 35:
Projected battery price trends (2021–2024) using a learning rate of 13% (b = -0.200), showing slower decline in Germany compared to China and global average.

price decline slowing compared to China's steeper drop, highlighting persistent inefficiencies or delayed scaling in the European context.

Figure 36, on the other hand, adopts a steeper learning exponent of -0.3774, corresponding to a 22.6% learning rate. This scenario is grounded in the rapid cost decline seen from 2015 to 2021, as estimated by Orangi et al. and others. Here, the price drop is more aggressive: China's projected pack prices dip close to \$80/kWh, while the world average approaches \$85/kWh, and Germany remains at a higher threshold above \$100/kWh. This outcome underscores the impact of early scale accumulation and integration — advantages that Chinese firms like BYD and CATL have sustained due to massive domestic EV adoption, production clustering, and streamlined supply chains.

Importantly, both figures validate a core hypothesis of this thesis: China's cumulative output advantage directly translates into faster learning and lower marginal costs. Since learning-by-doing is logarithmically dependent on cumulative production, the exponential rise in China's EV output post-2020 inherently grants it a cost advantage. This cost differential, clearly visualized in both Figures A and B, aligns with the observed battery pricing gaps discussed earlier — where China enjoys a price advantage per kWh in 2024 relative to Germany. These projections help isolate the pure learning component of the cost gap, independently of raw material prices or chemistry differences, and will later be used to contextualize the share of total cost differentials attributable to learning dynamics.

4.5.3 Battery Cost Forecasts under Different Learning Scenarios

Battery pack cost estimates reported across the literature differ depending on methodology, scope, and assumptions. Orangi et al. (2024) present a widely cited benchmark of \$100/kWh for the year 2021, based on an industry-wide average of cell-level costs. However, higher system-level estimates—ranging

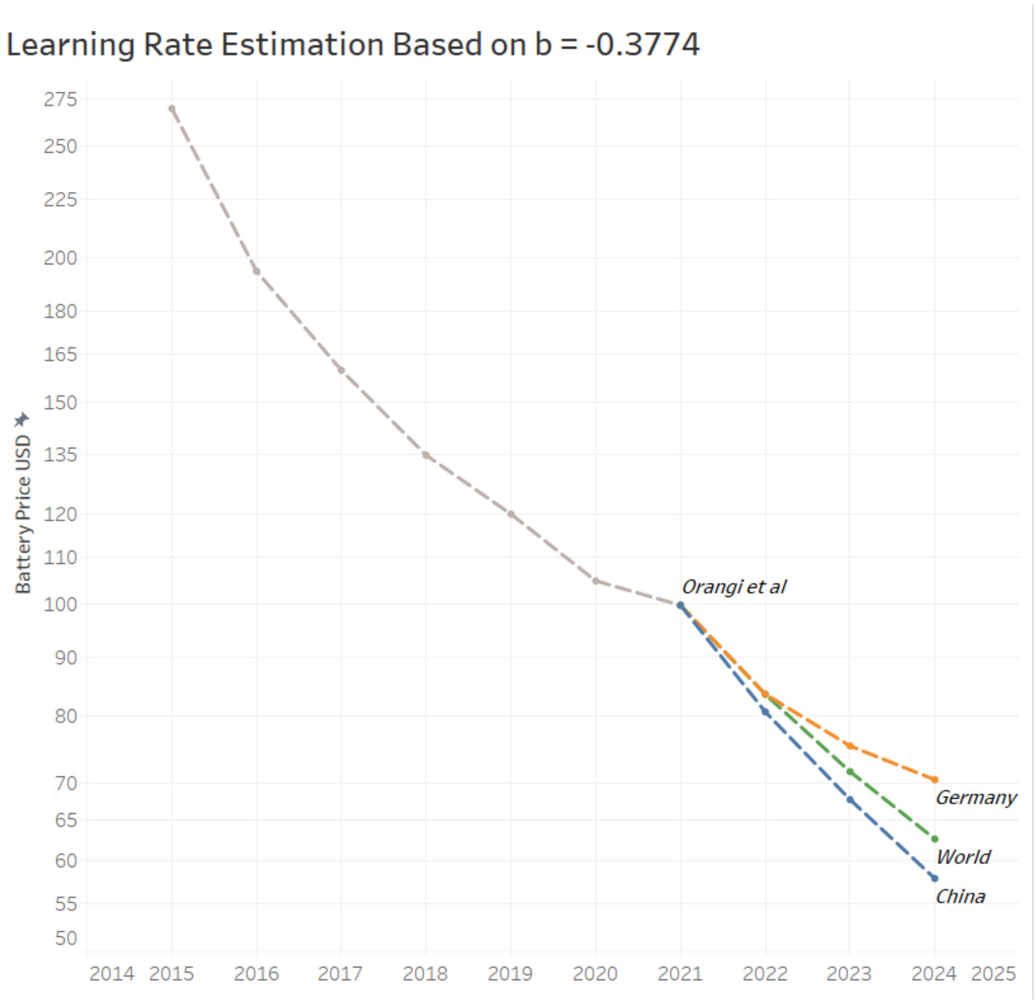

Figure 36:
Projected battery price trends (2021–2024) using a higher learning rate of 22.6% (b = -0.3774), highlighting China's steeper cost reduction due to faster cumulative production growth.

from \$127 to \$130/kWh—are reported by agencies such as the U.S. Department of Energy (DOE) and the International Council on Clean Transportation (ICCT). These include costs for thermal management, battery housing, and battery management systems (BMS), often excluded from cell-focused datasets.

To align Orangi's projections with these full package estimates, a 25-40% adjustment is applied in all years. This results in a harmonized data set that enables comparison between methodologies. To capture the uncertainty range in technological learning, two learning rates have been used:

- A moderate learning rate ($b = -0.2000$) representing the full period from 2010 to 2021, capturing gradual industry development.
- A higher learning rate ($b = -0.3774$) based on the period 2015-2021, during which the global deployment of electric vehicles accelerated rapidly.

The following tables present battery cost forecasts for 2015–2024 under both learning scenarios, along with their adjusted counterparts. These projections provide a spectrum of plausible outcomes and benchmark current policy and industry targets.

Taken together, the two tables illustrate the sensitivity of long-term cost projections to learning rate assumptions. Even under conservative learning (12.95%), average battery pack costs decline from \$100/kWh in 2021 to just over \$78/kWh by 2024. Under steeper learning conditions (23.02%), the cost could fall to \$62.66/kWh—approaching parity with ICE vehicle component costs. These findings demonstrate the critical role of cumulative production and learning-by-doing in accelerating EV affordability.

These projections are based on a cumulative production increase from 16.9 million EVs in 2021 to 58.3 million in 2024, a 2.46-fold expansion. As Wright's Law implies, each doubling in cumulative output

Table 10: Battery Cost Forecasts (2015–2024) Using Learning Rate $b = -0.2000$

Year	Orangi Estimate (USD/kWh)	+25% Adjusted	+40% Adjusted
2015	$270.00	$337.50	$378.00
2016	$195.00	$243.75	$273.00
2017	$160.00	$200.00	$224.00
2018	$135.00	$168.75	$189.00
2019	$120.00	$150.00	$168.00
2020	$105.00	$131.25	$147.00
2021	$100.00	$125.00	$140.00
2022	$90.99	$113.73	$127.38
2023	$83.84	$104.80	$117.37
2024	$78.06	$97.58	$109.28

Table 11: Battery Cost Forecasts (2015–2024) Using Learning Rate $b = -0.3774$

Year	Orangi Estimate (USD/kWh)	+25% Adjusted	+40% Adjusted
2015	$270.00	$337.50	$378.00
2016	$195.00	$243.75	$273.00
2017	$160.00	$200.00	$224.00
2018	$135.00	$168.75	$189.00
2019	$120.00	$150.00	$168.00
2020	$105.00	$131.25	$147.00
2021	$100.00	$125.00	$140.00
2022	$83.67	$104.59	$117.14
2023	$71.70	$89.62	$100.38
2024	$62.66	$78.33	$87.73

results in a predictable cost decline, governed by the empirically estimated learning exponent.

4.5.4 Country-Level Forecasts Using Learning Rates from 2015–2021

Although global trends provide valuable information on industry-wide cost evolution, national-level learning dynamics can vary significantly. These differences arise from disparities in production volume, technological specialization, government support, and supply chain integration. Hence, this section estimates 2024 battery costs using Wright's law and country-specific cumulative EV production and learning rates for China and Germany over the period 2015–2021.

Table 12 presents the learning exponents (b) and the corresponding learning rates for both countries. These values were derived using cumulative EV production figures and battery pack cost data between 2015 and 2021.

Table 12: Country-Specific Learning Parameters Based on 2015–2021 Data

Country	Learning Exponent (b)	Learning Rate (%)
China	–0.2577	16.4%
Germany	–0.2467	15.7%
World	–0.3774	23.0%

To ensure consistency between cases, the battery pack cost is set at $270/kWh in 2015 for both China and Germany. Country-specific cumulative EV production increased from 239,400 to 22.4 million units in China and from 30,040 to 2.08 million units in Germany between 2015 and 2024.

Table 13 shows the projected 2024 battery pack costs under two scenarios: (i) using each country's own learning rate, and (ii) applying the steeper global rate as an external benchmark. These help gauge how national scaling compares to the broader international context.

Table 13: Projected 2024 Battery Costs for China and Germany with Full-Pack Adjustments

2*Scenario	China			Germany		
	Base	+25%	+40%	Base	+25%	+40%
Using Country Learning Rate	\$83.79	\$104.74	\$117.31	\$94.86	\$118.58	\$132.80
Using Global Learning Rate	\$63.50	\$79.38	\$88.90	\$72.79	\$90.99	\$101.91

The results reveal that China benefits from a steeper reduction in battery costs compared to Germany due to its significantly higher cumulative EV output. Under local learning rates, China's projected battery pack cost in 2024 is \$83.79/kWh, compared to Germany's \$94.86/kWh. When applying the global learning rate, the projected costs drop further to \$63.50 and \$72.79, respectively.

These comparisons underscore the importance of production scale in shaping the rate of learning-by-doing. China's aggressive expansion in EV manufacturing has not only closed the technology gap but also facilitated accelerated cost reductions. Meanwhile, Germany's gains—while meaningful—remain more gradual, reflecting its smaller scale of EV deployment in the given period.

As such, national industrial strategies that promote large-scale production and localization of battery supply chains can directly impact unit economics. These learning-based cost forecasts are instrumental for anticipating when price parity with internal combustion vehicles may be reached in different regions.

It is worth noting that both China and Germany are among the global leaders in EV manufacturing and technology development. Their learning rates, as presented above, may even underestimate the true efficiency gains achieved by firms headquartered in these countries. This is because their national cumulative production figures reflect only domestic EV deployment, while their leading manufacturers operate across multiple continents and benefit from global supply chains, platform standardization, and foreign production hubs.

For example, Chinese firms like BYD and CATL, as well as German automakers such as Volkswagen and BMW, have significantly scaled battery production and vehicle assembly in foreign markets. These cross-border learning effects are not fully captured by national production statistics, suggesting that the true learning experience of these firms likely exceeds what is implied by domestic cumulative output alone. These firms also benefit from their operational presence in different regions. For example, German automakers have been investing significantly in China, and in collaboration with their Chinese partners, in the form of joint plants, which could again accelerate the learning rate for these two leading automakers.

Furthermore, the historical battery cost curve derived from Orangi et al. (2024), represented by the "black line" in their figure, should be interpreted as a global industry average, consolidating a broad range of manufacturing contexts. While the absolute cost levels projected using this baseline may differ slightly across countries, the overall functional form of Wright's Law remains applicable. That is, while unit costs may be higher or lower due to local labor costs, energy prices, or taxation, the proportional cost reduction per doubling of cumulative production should remain relatively stable. The next subsection investigates in more detail the country-level deviations in absolute cost baselines considering the reports on costs for different automakers.

4.5.5 Effectiveness of Learning-by-Doing in Battery Cost Reduction

In this section, an estimation of the possible effects of the battery pack costs on the purchase price of EVs is presented. Based on Table 13, one can estimate the maximum share of battery costs in China and Germany, whether referencing domestic production or the overall EV market. Under the three scenarios in Table 13, the difference in battery total pack prices are 11.67% and 12.77% for the country-specific and global learning rates, respectively. These figures reflect pure learning-by-doing, where costs decline solely through cumulative production-driven process improvements. However, empirical battery-cost gaps often surpass Wright's Law predictions due to economies of scale, vertical integration, supply-chain clustering, chemistry choices, and aggressive cost-cutting among Chinese producers. As noted throughout this study, the absence of comprehensive data leads to variation among different analyses and reports, particularly regarding battery costs. This research thus draws upon multiple authoritative sources to define a range of possible effects rather than a single point estimate.

The most pronounced observed gap in the reported battery prices is for BloombergNEF (Link), where 32.4% difference can be observed based on the German automaker's battery price base. BloombergNEF's annual survey (Nov 2023) estimates the battery pack prices for Chinese and German automakers at $139/kWh and $94/kWh, respectively. Moreover, S&P Global Mobility (July 2024), (S&P Global Mobility, 2024), documents that Chinese LFP cell costs reach $50-55/kWh, levels Europe will only reach in subsequent years. Assuming that battery packs represent 27 % of total electric vehicle manufacturing costs (according to the ICCT and DOE analyses), this results in an impact on electric vehicle prices ranging from 3.15 % to 8.75 % of the total vehicle cost.

4.5.6 Explaining the Persistence of China–Germany EV Price Differentials

Despite China's cost advantage in battery manufacturing, supply chain, and technological advancement in the EV market, the price gap between Chinese and German EVs have remained relatively stable during the period analysed in this study, mainly depicted in Figure 27 and Figure 28. To explain this consistency, this research focuses on three factors, including the limited overall impact of deeper battery savings, divergent inflation dynamics, strategic price floors, and feature competition. The influence of these factors is explained below.

Limited Overall Impact of Deeper Battery Savings: While the battery-pack price saving could be essential in the competitiveness of manufacturers, its overall effect on the final purchase price is limited. In other words, even a 20% treated reduction in battery-pack costs would translate to roughly 5% decrease in the total vehicle purchase price.

Divergent Inflation Dynamics: The inflation trends in the two regions from 2021 to 2024 are expressing different behaviors, which could affect the results of the study. Since 2021, Europe (Including Germany) has experience high inflation, due to supply shocks mostly coming from the Russian Invasion, with Germany's CPI peaking at 8.6% in December 2022 and averaging close to 6-7% through 2022-23. In contrast, China has seen near-zero or even deflationary consumer-price changes, where inflation was just 0.23% in 2023, and early 2024 readings we often negative. As a result, the downward trend in nominal prices in China has been adjusted and is now more in line with Europe's rising trends, let alone the adjustment of real prices presented in this study. This difference is more vivid when analysing price trends in China, as can be seen in Figure 29 and Figure 30. The prices of German EVs in China have been increasing while their Chinese counterparts keep their prices in a slightly declining trend.

Strategic Price Floors: Battery and electrification price trends have been declining rapidly, converging to the price-parity point with most comparable ICEs. This notion has been widely mentioned in reports and academic research, which might alter the behavior of legacy ICE automakers, particularly German car manufacturers. The conventional ICE automakers have been enjoying years of profitable production under the ICE dominant design, and reaching to price parity of EVs could jeopardize the positioning of such firms. As many German OEMs are reluctant to push EV prices below a certain threshold, often around $US75/kWh battery pack because this is seen as the break-even point versus internal-combustion versions. Reaching that threshold removes a key marketing advantage of price parity, so further cuts yield diminishing strategic returns. This could translate into strategic pricing from automakers that results in keeping the EV prices at higher levels.

Feature Competition: China's highly competitive market has led OEMs to bundle novel features—from karaoke-style in-car entertainment to real-time AI driving assistants, to justify a price premium even as entry-level battery costs fall. For example, many new Chinese models now advertise built-in apps and experiences like "Sing When You're Winning," showcasing in-car karaoke and social features. These enhancements help sustain the retail price gap, despite underlying cost advantages.

The Cost Impact of Failed Ventures and AI Platforms on German EV Batteries:A further factor is the burden of legacy costs from several high-profile German battery ventures that never reached full production or ran significantly over budget, as well as the substantial investments in proprietary AI systems for battery design and manufacturing. For example, the TerraE (later Zelos Cell) consortium launched a €4 billion plan in 2017 for a 24 GWh plant in Mecklenburg-Vorpommern, only to collapse in 2019 after spending over €100 million on site preparation and engineering. Likewise, the InoBat Auto joint venture—backed by VW and Bosch—has repeatedly delayed its 2022–2025 capacity ramp-up, reportedly overrunning its budget by around 30 percent and passing higher pre-purchase prices onto its automaker partners. Even the Northvolt–VW Salzgitter gigafactory, initially slated to start production in 2022, slipped into late 2023 with a roughly 20 percent cost increase.

On top of these sunk and overrun costs, Volkswagen has invested heavily in a proprietary AI–driven "Battery Intelligence" platform designed to optimize cell chemistry selection, process parameters, and quality control in real time. Developing and integrating this machine-learning system—capable of predicting cell performance degradation and dynamically adjusting production lines—required hundreds of millions of euros in R&D, software integration, and sensor installations across multiple gigafactories. Until these AI tools achieve full scale and their costs are amortized over larger volumes, they contribute several additional euros per kWh to the average battery cost.

Together, these failed ventures and cutting-edge AI investments have been effectively socialized through higher cell-purchase contracts and state subsidies, adding notable embedded costs to each battery pack. This helps explain why retail EV prices in Germany have not declined as steeply as in China despite comparable process learning and technological advances.

4.6 Vertical Integration Effect

In this research, the price gap defined is based on the representative models, the most sold and popular EVs in Europe. These models are particularly based on Volkswagen and BYD models as discussed in Table 7. As mentioned in the theoretical background section, automakers such as BYD have lower production costs not only due to lower labor costs and learning-by-doing, but also due to the vertical integration effect, particularly evident in firms like BYD, which represents a nearly textbook case of full-spectrum integration. To quantify this, we draw on empirical pricing data within the Chinese domestic EV market, where German and Chinese firms, including BYD and VW, operate side-by-side under similar regulatory and cost conditions. This quantification is within the scope of this research, and this research acknowledges that quantifying the exact effect of this factor will require detailed logistic and cost data from different automakers.

Within the Chinese market, the average price of BYD EVs is approximately €15,000, whereas the average price of Chinese EV market average is approximately €19,000. This means that BYD price falls €4,000 below the Chinese EV market average, which this research interpret as a conservative estimate of the production cost advantage genretaed purely by vertical integration. This includes BYD's internalization of battery cell production (via FinDreams), upstream lithium and cobalt sourcing (through direct mine stakes), and consolidated control over powertrain, software, and vehicle assembly. Unlike German automakers who often rely on suppliers for battery cells and critical components, BYD has brought almost every major cost center in-house. These capabilities insulate it from market fluctuations and reduce coordination inefficiencies—benefits that are well-documented in both industry reports and academic literature.

Using this €4,000 cost advantage as a vertical integration effect, and expressing it as a share of VW EV prices in China (average around €25,000), we derive an upper bound contribution of 16% (4,000 / 25,000) attributable to integration. This 13% figure isolates the cost savings associated with BYD's supply-chain strategy alone, excluding differences explained earlier by labor and learning-by-doing (LBD) effects. Therefore, it can be understood as the maximum potential cost efficiency that German EV makers might achieve if they replicated BYD-style vertical integration. These effects can be excluded by considering the estimated effect of labor costs and learning by doing, which are assigned to the German price. This means that the upper bound 16% is translated into 16 * (1 - 0.163 - 0.0875), 11.99%.

Importantly, this study adopts a conservative approach by assigning only the lower bound estimate of 3.15% to the learning-by-doing effect, based strictly on cumulative production data. This avoids double-counting, as higher estimates found in literature often reflect improvements also attributable to vertical integration (e.g., in-house battery production accelerating learning cycles). Although these effects are analyzed independently, they are in reality deeply interwoven. Firms like BYD use integration to compress learning timelines, stabilize input costs, and minimize coordination inefficiencies—all of which reinforce their pricing advantage. Consequently, the cumulative interaction of these forces deepens the price-performance gap between Chinese and German EVs. German automakers' ability to narrow this gap depends on their willingness and capacity to adopt similar integration strategies, from cell manufacturing to software ecosystems. This insight lays the groundwork for the next section, which will examine the residual pricing gap and explore remaining factors beyond production-related cost drivers.

4.7 Residual Cost Gap and Remaining Drivers

While this analysis has attempted to attribute the cost difference between Chinese and German EVs to key quantifiable drivers — namely labor costs, learning-by-doing effects, and vertical integration — a notable portion of the price gap remains unexplained. Figure 37 visualizes the conservative estimates for these three drivers, and illustrates the residual cost share not directly attributed to production-side effects.

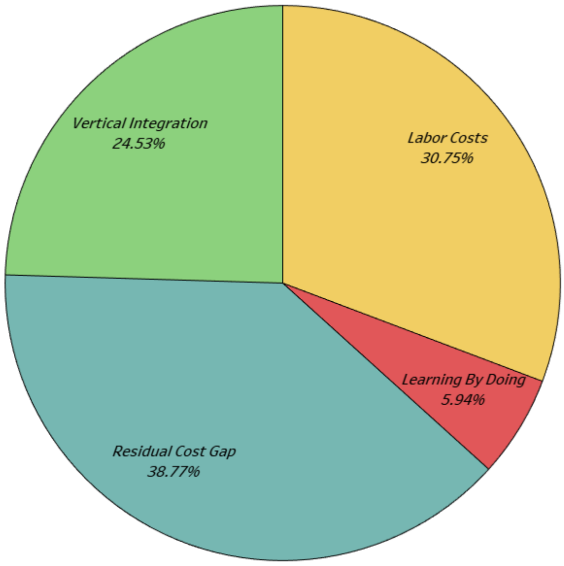

Figure 37:
Contribution of labor costs, learning-by-doing, and vertical integration to the EV price differential between Chinese and German automakers. The remaining unexplained portion ("Residual Cost Gap") reflects non-production-related or unobservable cost drivers not captured in this model.

These estimates are intentionally conservative. For instance, while this research applies a wage cost differential of approximately 16.3%, based on Eurostat and industry-level salary comparisons, multiple academic and consulting sources place the wage impact within a 5–15% range — depending on the manufacturing tier (cell, pack, assembly) and labor intensity assumptions.

Despite accounting for these key factors, approximately 20–25% of the total cost gap remains unexplained under this framework. This residual margin may stem from brand positioning, firm-level pricing strategy, regulatory compliance costs (e.g., EU safety/environmental requirements), and marketing/distribution overheads. Some of it may also reflect timing asymmetries — German OEMs are mid-transition toward battery localization and modular EV platforms, while Chinese automakers are already operating at mature EV economies of scale.

Importantly, the presence of this residual does not invalidate the model — rather, it underscores that price differentials in global EV markets are shaped by a broader constellation of strategic, institutional, and temporal factors, not all of which can be cleanly decomposed into production cost categories.

4.7.1 Effect of the Residual Price Gap on EV Adoption

Our decomposition shows a persistent *residual* price gap of roughly 20 % between Chinese and German mid-size, non-luxury EVs in Europe, after accounting for learning-by-doing, vertical integration, and labor costs. To translate this into its impact on EV uptake, we rely on own-price elasticities estimated for key European markets.

Structural and reduced-form studies for Germany—the continent's largest auto market—report own-price elasticities in the range of –1 to –3. For example, (Heid et al., 2024) estimate –1.99 using a structural vehicle-choice model, while (Haan et al., 2025) derive –3.16 from a subsidy evaluation. Similar magnitudes are found in France (elasticities around –1.1 to –2.5) and the UK (–1 to –2) (Mandys & Taneja, 2024).

Applying these elasticities to our 20 % residual gap implies that closing it entirely could raise EV sales in Germany and France by between

$$\underbrace{20\% \times 1.0}_{20\%} \quad \text{and} \quad \underbrace{20\% \times 3.0}_{60\%},$$

i.e. a 20–60 % increase in annual EV uptake. This range is a conservative estimate insofar as it isolates only own-price effects; complementary improvements in charging infrastructure, streamlined regulations, and targeted incentives could amplify responsiveness beyond these levels.

Contrastingly, high-income markets like Norway exhibit lower price sensitivity—own-price elasticities of –0.99 for BEVs and –1.72 for PHEVs—reflecting both stronger purchasing power and more mature infrastructure (Fridstrøm & Østli, 2021). That even Norway's relatively inelastic market responds at all underlines how high EV sticker prices remain a binding constraint elsewhere.

In sum, our findings suggest that policy measures aimed at shaving down this unexplained 20 % gap—whether through targeted subsidies, import-duty adjustments, or support for domestic scale-up—could unlock substantial gains in adoption, helping to close the distance between Europe's current trajectories and its climate and industrial targets.

5 Conclusions & Implications

This thesis set out to explain why Chinese-manufactured electric vehicles continue to undercut their German counterparts in Europe. By comparing inflation-adjusted, pre-tax/pre-subsidy retail prices and decomposing structural differences in the cost production process into learning-by-doing, vertical integration, and labor energy cost effects, roughly 60 % of the China–Germany price differential has been explained. Crucially, however, a residual gap of roughly 20 % per vehicle—considering the mid-size non-luxury average EV costs in Germany—persists beyond these factors. These competitive pressures matter not only for firms' balance sheets but for the livelihoods of over 700,000 domestic workers in Germany's automotive sector, making this challenge "too big to fail" for regulators, institutions, companies, and consumers alike. While this research does not claim that battery-electric vehicles are the definitive solution to climate and environmental goals, the broader literature treats EVs as the emerging dominant design in the global vehicle industry—underscoring the urgency of understanding and addressing Europe's cost disadvantage.

From a multi-level perspective, EVs have successfully moved from niche experimentation into the mainstream automobility regime under mounting landscape pressures (climate targets, urbanization, regulatory shifts). Yet this study does not purport to settle the debate over whether battery-electric vehicles alone suffice for deep decarbonization—grid emissions, life-cycle impacts, rebound effects, and broader transport-system innovations all play essential roles. Nevertheless, the literature consistently treats EVs as the emerging dominant design in the global vehicle industry, underscoring the urgency of understanding and addressing Europe's remaining cost disadvantage.

5.1 Restatement of the Problem & Objectives

Electric vehicle (EV) adoption in Germany and across Europe lags well behind policy targets, despite concerted efforts on infrastructure and incentives. A key barrier is persistent price differentials: Chinese-made models routinely undercut German-manufactured counterparts by several thousand euros on a real, pre-tax/pre-subsidy basis. Given an estimated own-price elasticity of EV demand of , narrowing this gap could materially accelerate uptake.

Electric Vehicles are pivotal to Europe's industrial and climate agendas, yet Chinese-made models systematically undercut their German counterparts on both European and Chinese retail markets, even before accounting for local purchase subsidies and taxes. To understand this persistent price gap, real pretax/pre-subsidy retail prices for Chinese and German EVs are adjusted for post-launch inflation divergence between Europe and China. Results of this study specify three regional cost drivers, **Labor & Energy Costs**, **Learning-by-Doing**, and **Vertical Integration**. Our conceptual model Figure 14 links these supply-side drivers to cost competitiveness, lower prices, and ultimately higher adoption through a reinforcing scale-learning loop.

To unpack this dynamic, this thesis:

- **Identifies the Real Price Gap**: Gathers and harmonizes retail-price data—via datasets and targeted web scraping—to compare inflation-adjusted, pre-tax/pre-subsidy prices of Chinese versus German EVs in the European market.
- **Explains the Gap**: Decomposes the observed differential into contributions from learning-by-doing, vertical integration, and labor-cost divergences (with energy costs found to be negligible).
- **Measures the Residual & Adoption Impact**: Quantifies the unexplained "residual" gap and, using the estimated own-price elasticity, translates it into its implied effect on EV adoption rates in Germany and Europe.

Anchored by our conceptual model (Figure 14), this structure links supply-side cost drivers to price competitiveness and adoption through a reinforcing scale-learning loop—highlighting where Europe's fragmented ecosystem falls short of China's integrated advantage.

5.2 Summary of Key Findings

Building on our twofold research agenda, (1) to decompose and explain the Chin, Germany EV price gap, and (2) to assess its adoption impact—we distill four central findings:

- **A Persistent, Large Price Differential.** German-made mid-size EVs in Germany retail at nearly double the price of comparable Chinese models in China. Furthermore, the same German electric vehicle models sold in China are priced 30 to 40% lower than in Germany, and between 2021 and 2024, the German model prices in Europe have trended upward while the Chinese model prices have declined, reflecting the shrinking market share of German brands in Europe.
- **Decomposition of Cost Drivers.** Our structural analysis attributes 16.3% of the China–Germany price gap to higher German labor costs (via direct Bundesstatistik data and a Leontief-model calibration), 3.15% to slower learning-by-doing (per Wright's law), and 13% to lower vertical integration in European value chains (benchmarked to BYD's integrated cost advantage). Energy costs proved negligible in our real-price framework.
- **An Unexplained Residual.** Even after accounting for these three factors, a residual price gap of approximately 20% remains.
- **Implications for Adoption.** Applying own-price elasticities of –1 to –3 to our 20% residual suggests that eliminating this gap could raise annual EV uptake in Germany and similar markets by 20–60%. This estimate isolates pure price effects and signals that complementary policies (infrastructure, regulation, targeted incentives) would only amplify adoption gains.

Each finding directly addresses our core questions: we first establish the magnitude of the retail price gap, then trace its explainable origins, highlight the remaining unexplained component, and finally quantify its tangible impact on EV adoption rates.

5.3 Integration of Results with the Conceptual Model

Our findings can be placed back into the larger conceptual framework (Figure 14) to show why there is a growing gap between the production and market share of German and Chinese automakers:

- **Cost Pass-Through Spurs Adoption**: Elasticity estimates imply a 20–60 % uplift in EV sales. Higher volumes would in turn accelerate learning curves and scale benefits, creating a virtuous cycle of lower costs and greater adoption.
- **Domestic Production Strengthens the Ecosystem**: Expanding EV assembly and component manufacturing within Europe would deepen local supply chains, support higher utilization of infrastructure, and foster innovation—benefiting firms, workers, and consumers alike.
- **Labor Cost Savings Are Marginal**: German auto wages in China average just 12.25% below Germany's overall manufacturing sector, leaving little room for further reductions. Considering the overall 16.3% effect, there is not much effect in bringing down the labor share, which contrasts with most findings and suggestions.
- **Policy Levers to Compress Margins**: Aligning import duties, enhancing competition, and targeting consumer subsidies can compel margin reductions at the point of sale—unlocking both social and industrial benefits without eroding firms' long-term viability.

In light of these results, we can conclude that there remains significant room to reduce electric vehicle prices—particularly by addressing the unexplained 20% residual cost gap—and that doing so would unlock substantial additional adoption, accelerating progress toward Germany's and Europe's climate and industrial targets.

5.4 Interpretation of findings

5.4.1 German Manufacturers' Strategic Pricing and Cost Pass-Through

The roughly 20% unexplained price gap suggests that German OEMs may be deliberately maintaining higher retail prices to protect profit margins and brand positioning. Several factors support this interpretation:

- **Brand as Margin Lever**: Premium marques such as BMW and Mercedes-Benz have historically commanded price premiums—and German EVs exhibit similar mark-ups, even as battery prices have fallen. Despite technological advances, the anticipated cost declines in battery packs since 2021 have not been fully passed on to consumers, implying a deliberate margin-preservation strategy.
- **Failed Cost-Reduction Investments**: German carmakers' forays into next-generation battery chemistries and gigafactory projects have often encountered delays and cost overruns. As a result, realized production costs remain elevated, which firms offset by holding retail prices steady.
- **Export-Driven Pricing**: With mounting investment in Chinese manufacturing hubs, German OEMs can export locally produced ICE and EV models to high-wage markets at consistent price points—leveraging favorable exchange rates and avoiding EU tariffs—while preserving intra-European price differentials.
- **Limited Competitive Pressure**: Europe's EV market remains dominated by a handful of legacy producers, affording them greater pricing power. In nascent segments like EV brake and differential systems—where German engineering exacts higher component tolerances—production costs are inherently higher, yet these are rarely reflected in retail price concessions.

5.4.2 Implications for Product Transition and Infrastructure

German OEMs' engineering-driven DNA and legacy ICE expertise have slowed their transition to fully optimized EV platforms:

- **Complexity Premium**: German EVs often retain mechanical subsystems (e.g. multi-speed gearsets, heavyweight braking assemblies) that increase production costs without commensurate performance gains—contrasting with simpler, lighter Chinese designs optimized for scale.
- **Infrastructure Constraints**: Full realization of EV cost reductions requires integrated charging and battery-swap networks; Europe's fragmented infrastructure rollout has limited firms' ability to achieve utilization economies, reinforcing price stickiness.
- **Policy and Regulation Gaps**: Inconsistent incentives across EU member states—and slower approval processes for battery recycling and second-life applications—have raised capital costs for German OEMs, costs which are ultimately embedded in consumer prices.

Together, these strategic, operational, and regulatory factors help explain why German EV prices remain elevated beyond what pure cost drivers would predict—and why closing the residual gap may require more than raw scale, but also a reorientation of product architecture and supporting infrastructure.

5.4.3 Drivers of China's Cost and Innovation Advantage

Although Chinese EVs confront import duties, limited brand familiarity, and substantial marketing obstacles, their penetration into European markets has increased. Vehicle imports from China to the EU climbed from 114,000 units in 2017 to 561,000 in 2022—a nearly fivefold increase, and in 2022, China accounted for 14% of all non-European auto imports. Within the 'new energy' category (battery electric and plug-in hybrid vehicles), the share of Chinese marques rose from 0.4% of EU sales in 2019 to just under 4% in 2022, while overall Chinese BEV/PHEV registrations in Europe expanded from 5% in 2015 to almost 15% by 2023.

Two complementary forces fuel this advance:

- **Mass Production and Vertical Scale**: China now produces 62% of the world's EVs and 77% of its EV batteries, with its two largest battery makers (CATL and BYD) alone accounting for over half of global lithium-ion battery output (Ezell, 2024).
- **Innovation Capacity**: Chinese research institutions contribute 65.4% of the world's high-impact publications on EV batteries—far outpacing the U.S. (11.9%)—and Chinese entities' share of global patents in electric propulsion rose from 2.4% in 2010 to 26.9% in 2020 (Ezell, 2024).

To reinforce the narrative laid out above, we include three illustrative charts:

Global BEV Manufacturer Shares (Figure 38): Highlights how Chinese brands like BYD not only close the gap with leaders such as Tesla but also occupy multiple spots in the top-10, underscoring China's rapid climb in volume and scale.

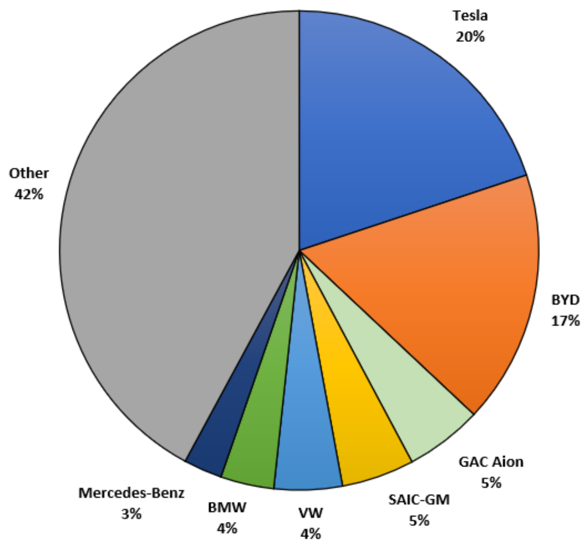

Figure 38:
Global market shares of top 10 BEV manufacturers year end 2023 (Ezell, 2024)

EV Battery Makers' Market Share (Figure 39): Shows CATL and FDB together controlling over 50% of global battery production—concrete proof of the vertical-scale advantage that drives down costs.

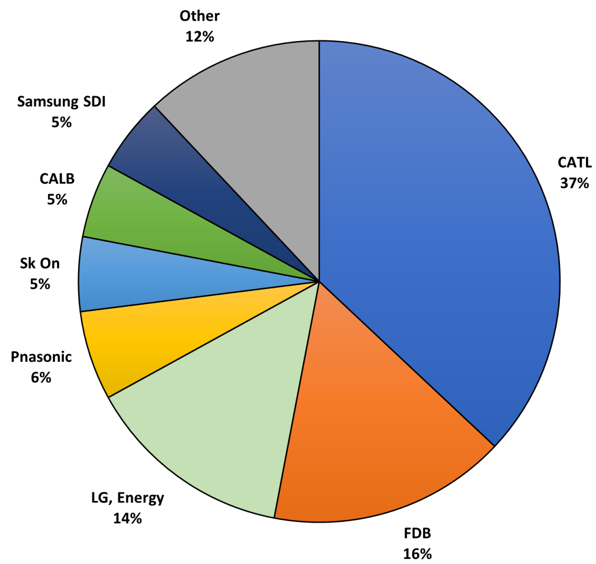

Figure 39:
Leading EV battery manufacturers global market shares 2023 (Ezell, 2024)

High-Impact Battery Research Publications (Figure 40): Demonstrates China's overwhelming lead (65.4%) in cutting-edge EV battery science, illustrating the innovation capacity that feeds into both product improvements and further cost reductions.

Both pillars rest on robust government backing. According to (Ezell, 2024) From 2009 to 2023, China injected over $230 billion in EV and battery subsidies, enforced local-content and technology-transfer requirements, and directed massive public R&D into battery chemistry and vehicle electrification. Complementing these industrial policies, provincial and national authorities have aggressively rolled out charging infrastructure and consumer incentives (e.g. free license plates, roadway-access privileges), cementing a virtuous cycle of scale, cost reduction, and further adoption .

Despite risks around state intervention and shifting subsidy regimes in China, major German automakers continue to pour investment into Chinese EV production, and to scale back jobs and capacity in Europe. This strategy reflects more than just cost-cutting: China offers a far more integrated EV ecosystem, with advanced battery supply chains, digital manufacturing infrastructure, and supportive

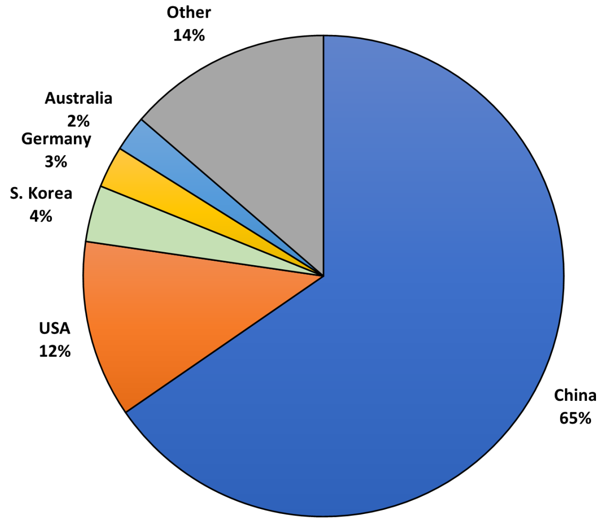

Figure 40:
Top five countries for high-impact publications about electric batteries in the ASPI Critical Technology Tracker dataset (Ezell, 2024)

local policies that together lower coordination costs and speed up innovation cycles. By contrast, fragmented European value chains and less mature charging and production networks make onshore EV scale-up slower and more expensive.

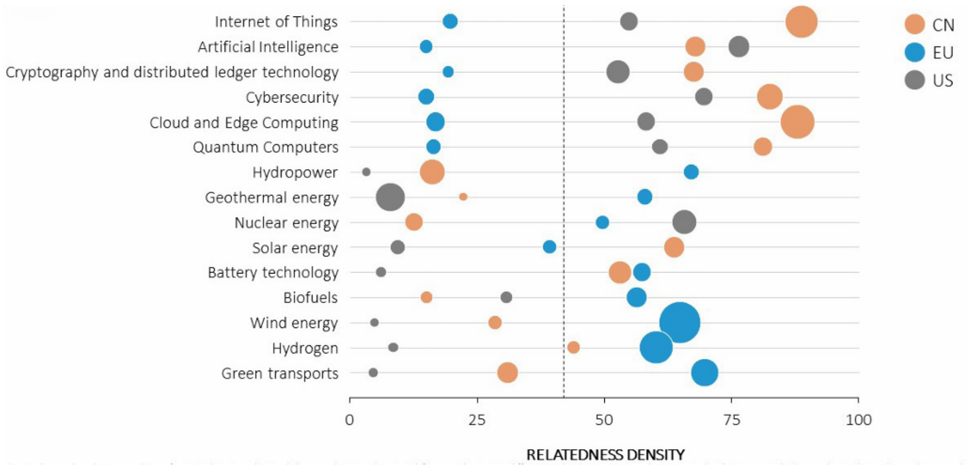

Figure 41:
The EU's position in complex (digital and green) technologies(Draghi, 2024)
Based on patent data: vertical axis = technology complexity (0–100), horizontal axis = relatedness density, bubble size = revealed comparative advantage in patenting.

Figure 41 shows China sitting to the right of the EU on both "Battery technology" and "Green transports," with much larger bubbles—signaling that China's existing industrial strengths are closely aligned with these high, complexity EV technologies and that its firms hold a dominant patent position. This infrastructure and innovation advantage reduces production lead times, compresses R&D cycles, and amplifies learning-by-doing—all of which translate into lower per-unit costs. German automakers, recognizing these efficiencies, have shifted more of their EV investments to China, even at the expense of domestic jobs, because the integrated Chinese ecosystem offers faster scale-up and deeper cost savings than Europe's more disjointed networks.

While Europe holds a solid comparative advantage in battery technology, considering its more room for progress compared to its 2022 state, it lags behind China in adjacent digital capabilities that increasingly define the EV value chain. China outpaces the EU in cloud and edge computing, artificial intelligence, and the Internet of Things—all fields, according to Figure 41.

These digital technologies are critical for next-generation EVs: over-the-air software updates, smart energy management, predictive maintenance, and connected-car services. Europe's less developed footprint here raises coordination costs between hardware (batteries, motors) and software platforms, slowing innovation cycles and keeping unit costs higher. In contrast, China's stronger integration of digital and green tech allows its manufacturers to compress RD timelines, rapidly roll out new features, and spread fixed software-development costs over much larger production volumes—further widening the price gap.

5.5 Implications & Suggestions for Industry and Policy

Our results point to a suite of strategic and policy measures to unlock faster EV adoption and strengthen Europe's competitive position.

- **Leverage Sino-European Technology Transfers**: German OEMs should deepen joint venture partnerships in China, importing proven battery, software, and AI innovations back into European assembly lines. By localizing more of the EV value chain on home soil, they can capture scale benefits without sacrificing the cost advantages unlocked offshore.
- **Maintain and Enhance Demand Incentives**: Subsidies, tax credits, and favorable financing terms remain essential to bridge the remaining 20% price gap for average workers. Policymakers should not only preserve existing schemes but also consider graduated increases tied to income levels, ensuring broader affordability without unduly straining public budgets.
- **Mobilize Domestic Resource Integration**: Europe's access to critical minerals, particularly those available in Ukraine, should be combined through an EU-wide framework that harmonizes extraction, processing, and recycling. A coordinated approach will reduce upstream costs, secure supply chains, and promote resilience against external shocks.
- **Invest in Next-Generation Infrastructure and Core Technologies** Beyond charging stations, targeted funding for software platforms, AI-driven energy management, and IoT-enabled vehicle diagnostics can drive further cost reductions and improve user experience. Public–private partnerships should prioritize open architecture standards to accelerate interoperability and competition. item **Deepen Firm-Level Cost Transparency**: German OEMs and industry associations should publish disaggregated wage, logistics, and overhead data across all European plants. This will clarify how regional wage differentials shape final prices and reveal untapped efficiency gains.
- **Stimulate Competitive Dynamics**: Reducing entry barriers, through simplified type approvals, shared R&D consortia, and small-volume manufacturing incentives, will invite new entrants and put downward pressure on prices. A more diverse supplier base will help Europe meet its climate targets while strengthening its domestic industrial ecosystem.
- **Promote Price-Pass-Through Pilots**: Select EV models could be trialed with partial pass-through of Chinese production savings—accompanied by targeted marketing—to test real-world demand responses and refine elasticity estimates.

By combining firm-level adjustments in pricing and production strategy with robust, targeted policy support, Europe can close the residual cost gap, accelerate EV uptake, and realize both its decarbonization and industrial-growth objectives.

5.6 Reconsidering the Trajectory: Complexities Beyond Conceptual Design and Implications for Future Progress

While theoretical frameworks provide invaluable lenses for understanding sociotechnical transitions, the European Electric Vehicle (EV) landscape reveals complexities that often supersede initial conceptual designs. This section consolidates the preceding analyses, offering a broader re-evaluation of the problem's inherent 'wickedness' and acknowledging critical nuances that complicate straightforward solutions. By moving beyond a singular focus on technological adoption, this discussion will illuminate the intertwined policy, market, and ethical dilemmas that shape the EV's trajectory as a dominant design, underscoring the dynamic interplay of values, institutions, and emergent technologies.

The rapid ascent of Electric Vehicles to a "dominant design" in sustainable mobility warrants critical examination. Often presented as the definitive solution to climate ambitions, this perspective risks falling into the "technofix" trap, where a singular technological answer is assumed to be the panacea for complex problems. A multi-level perspective (MLP) analysis reveals that the emergence of EVs as a regime-level incumbent is a consequence of dynamic interactions across niches, regimes, and landscapes. However, the critical question remains whether this dominant design truly aligns with broader, holistic climate objectives and fosters genuine societal progress, or if it merely perpetuates existing systemic challenges.

The European Union's commitment to climate neutrality by 2050 and the intermediate "Fit for 55" package of 2021 have significantly shaped the automotive sector, signaling a strong conviction in EV technology as a primary path to decarbonization. This policy framework includes a mandate for a 100% reduction in CO2 emissions for new cars by 2035, effectively phasing out the sale of new ICE vehicles. To accelerate adoption, many European countries significantly ramped up financial incentives for EV purchases between 2020 and 2022, often in response to post-pandemic economic stimulus efforts. This substantial investment has catalyzed a "self-fulfilling prophecy", where resources are poured into this chosen direction, further "locking-in" the technology, even if it leads to unforeseen problems. This inclination for "solutionism" often assumes current sociotechnical systems as background conditions, hindering the development of alternative problem definitions and solutions. (European Commission, 2021; Pesch, 2024)

However, from late 2022 and throughout 2023-2024, several key European markets, including Germany, France, and Norway, began to reduce or entirely phase out direct purchase incentives for EVs. This subtle shift in policy may stem from policymakers and regulators facing inherent "uncertainty" about relying solely on a single technological solution, particularly concerning the sustainability of their supply chains and the overall energy grid. Decisions are inherently "surrounded by uncertainty" and exclusively relying on a single knowledge base "turns alternative perspectives into obstructing factors". Furthermore, the significant influence of powerful, incumbent "legacy car makers" cannot be overlooked. New technologies often serve "the interests of incumbent agents, reinforcing political and economic inequalities". These established players can "lobby for regulatory support" and shape "promises" that "have the leverage to attract resources", potentially steering policy towards solutions that fit their established infrastructure rather than genuinely disruptive alternatives. The ongoing debates, for example, around acceptable Euro 7 emissions standards and the role of e-fuels for internal combustion engines, illustrate this tension, where established automotive interests seek to influence regulatory outcomes. (Lutsey & Nicholas, 2023)

A closer look at the production process of EVs, particularly their battery components, uncovers significant "new transaction costs" that are frequently overlooked in the prevailing narrative of environmental friendliness. The demand for critical raw materials like lithium, cobalt, and nickel for EV batteries creates profound social and ecological repercussions, often impacting vulnerable communities in the Global South. This dynamic suggests that the transition toward a sustainable energy system can paradoxically "reproduce the injustices of colonialism". These hidden costs, encompassing environmental degradation and the perpetuation of exploitative labor practices, represent unanticipated negative interdependencies that emerge from the very pursuit of efficiency in decentralized systems. Thus, the "environmental friendliness" of EVs, when considering their entire lifecycle and global supply chains, is far from straightforward. Ignoring these impacts is a form of "myopia that eclipses other environmental problems and other solutions".

Given these complex issues, a mere "catching up" strategy in EV production might prove counterproductive, reinforcing existing "path dependencies" and the "monopolistic tendencies" of the oligopolistic automotive industry. Instead, a more deliberate policy framework is imperative. If EVs are to remain a core component of Europe's climate strategy, the focus should shift from simply incentivizing consumer adoption to fostering genuine systemic transformation.

Europe should strategically push for advancements in underlying technologies like batteries, AI, and IoT, but with an explicit commitment to ethical design and democratic control. This means:

Batteries: Prioritizing research and development in sustainable battery chemistries, robust recycling infrastructure, and truly ethical sourcing to mitigate the "new transaction costs" associated with raw material extraction and disposal.

AI and IoT: Leveraging these technologies for smart mobility solutions, but rigorously enforcing "meaningful human control" and "explainable AI" to prevent "accountability gaps" and ensure that systems do not diminish human moral autonomy. Europe's regulatory frameworks, such as the GDPR, provide a foundational advantage in embedding societal values directly into technological design, thereby countering "unscrutinized beliefs" that often drive innovation.

Fostering a Level Playing Field for New Entrants: Governments should concentrate on providing the necessary infrastructure and regulatory environment not just for EVs, but for new entrants and diverse innovations in the broader mobility sector. This aligns with the imperative to "open up" the repertoire of solutions. This includes ensuring open and interoperable charging networks, fair data governance frameworks, and regulatory sandboxes that foster competition and innovation beyond the confines of established automotive players.

5.7 Recommendations & Future Research

Ultimately, the transition to EVs in Europe represents a 'collective moral experiment', revealing that technological progress is neither linear nor value-neutral. The dynamic interplay of market forces, political will, and deeply embedded sociotechnical systems necessitates a continuous re-evaluation of assumptions and a proactive engagement with emergent challenges. This nuanced understanding of the problem's 'wildness' and the limitations of a purely technical 'solutionism' thus forms the indispensable bedrock for the forward-looking recommendations and avenues for future research presented in the concluding chapters of this thesis.

This study was inherently exploratory, using aggregate and model-level data to surface broad cost and adoption patterns. To build on these insights, we offer the following suggestions:

- **Firm-Level Cost Structure Analysis**: Acquire plant-level data on wages, logistics, and manufacturing overhead across Europe to refine our labor-cost and scale-effect estimates.
- **Post-2022 Battery Cost Dynamics**: Investigate why battery price declines have plateaued despite input-material cost normalization, including firm investment patterns and technology-adoption delays.
- **Comprehensive Demand Elasticity Modeling**: Extend our own-price elasticity framework to include gasoline prices, income effects, and subsidy regimes—building a multivariate adoption model for the entire European market.
- **Broader Innovation Ecosystem Mapping**: Map the links between EV production and adjacent high-tech sectors (AI, IoT, advanced electronics) to quantify their contributions to cost reduction and consumer value.
- **Detailed Vertical Integration Assessment**: Conduct case studies on firms like BYD and Volkswagen to measure the magnitude of vertical-integration benefits at each supply-chain tier.

6 Limitations

While our analysis sheds light on key drivers of the China–Germany EV price gap, several limitations warrant careful consideration.

6.1 Methodological Constraints

The study relies on market-level and model-level retail prices rather than firm-level cost breakdowns. Detailed specification data, such as battery chemistry or motor power, were not uniformly available, necessitating reliance on cross-sectional comparisons. Furthermore, inflation and currency adjustments vary by market; broad regional indices were applied to harmonize prices, but firm-specific hedging and pricing strategies may introduce measurement error. To avoid overstating cost effects, conservative parameter estimates (e.g., lower-bound elasticities, minimal scale-curve slopes) were used. Nevertheless, unobserved state subsidies or preferential financing for Chinese firms could imply that actual cost advantages are larger than estimated.

6.2 Scope & Generalizability

The study's "population" comprises Europe's and China's mid-size, non-luxury EV segments, meaning results may not fully extend to luxury brands or commercial fleets. The analysis draws heavily on BYD and Volkswagen as representative of Chinese and German practices. While these firms dominate market share, smaller incumbents or newcomers could exhibit different cost structures. Additionally, rapid technological change (e.g., solid-state batteries) and shifting trade policies mean that the static 2021-2024 window may not fully capture future cost trajectories.

6.3 Practical Challenges

Comprehensive Chinese production and logistics data, such as factory-level output or sales by channel, remain scarce. Access to firm-internal ERP or SAP systems would significantly improve precision. Reports of labor-abuse allegations in some Chinese facilities are not quantified in this study but could imply unpriced externalities that distort cost comparisons. Lastly, German OEMs operate multiple plants across Europe and beyond; averaging their labor costs may understate local wage heterogeneity and offsetting efficiencies in lower-wage jurisdictions.

By acknowledging these constraints without undermining the core insights, this chapter highlights avenues for deeper, firm-level research and dynamic modeling as the industry continues to evolve.

7 Final Reflections

Undertaking this thesis has been a transformative journey—both intellectually and professionally. For over two decades, observers have noted Europe's lagging EV adoption, yet clear explanations remained elusive. As Germany's storied auto industry faces an unprecedented challenge from Chinese competitors, I came to appreciate how deeply the transportation sector underpins both regional and continental economic health.

Several insights emerged:

1. **Data Transparency Is Crucial.** Despite automotive manufacturing's strategic importance, detailed cost and operational data are often opaque. This shortage of firm-level information underscored the need for greater transparency and data sharing—among manufacturers, regulators, and industry bodies—to enable rigorous analysis.

2. **Complexity of Global Operations.** German OEMs operate across multiple regions, each with distinct wage structures, logistics networks, and regulatory frameworks. Mapping these dispersed activities revealed how difficult it is to track true cost drivers without comprehensive, harmonized datasets.

3. **Financialization and Efficiency.** Interviews and secondary evidence suggest that profit pressures and shareholder demands may have outpaced investments in operational efficiency. Legacy firms—while reporting strong earnings—appear to experience stagnating productivity and diminishing wage shares, highlighting a tension between financial returns and long-term competitiveness.

4. **The Human Dimension.** Conversations with industry professionals brought to light widespread frustration over strategic decision-making and organizational agility. These qualitative insights reinforced that cost-gap explanations extend beyond numbers to include governance, culture, and managerial practices.

Looking forward, I am eager to build on this work—whether through doctoral research or industry engagement—by combining quantitative rigor with direct collaboration with automakers and policymakers. In particular, I plan to explore dynamic policy tools (e.g. data-driven subsidies, carbon pricing) and governance reforms that can enhance transparency, align incentives, and accelerate Europe's EV transition.

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Declaration of AI (assisted) technologies in the writing process

During the preparation of this work, I used ChatGPT and Grammarly solely to improve sentence clarity, readability, and language quality. All content was carefully reviewed and edited by me, and I take full responsibility for the final version. These tools were used only as writing aids and not for generating original content.

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