Emerging digital trends (and threats) in the car industry:

Future of Software-Defined Vehicles

Adapt Institute

Editorial

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Executive Summary

The automotive industry is undergoing a transformation driven by the emergence of ***software-defined vehicles (SDVs)***. Nature of the vehicles changes as they are increasingly defined not only by hardware, but by integrated software architectures with high-performance computing, artificial intelligence (AI), cloud connectivity, and over-the-air (OTA) software updates that enable or enhance new capabilities such as advanced automation or personalized entertainment. This shift is reshaping supply and value chains, competitive dynamics, and business models.

While multiple works have focused on the topic of SDVs from technical, technological or economic perspective, this multidisciplinary report examines SDVs through a ***strategic foresight lens***, combining qualitative analysis, expert interviews, and horizon scanning. Its objective is to identify and test key assumptions and uncertainties, develop ***plausible scenarios of the future*** and offer recommendations linked to SDVs with particular relevance for Slovakia and the EU. The proposed scenarios are not meant to serve as predictions, but rather as tools to support strategic thinking and planning under uncertainty.

Market projections suggest strong growth in this sector. SDVs also attract new market entrants, mainly tech firms and digitally native manufacturers, intensifying competition and challenging incumbent carmakers' organisational structures, skills, and business models. However, the SDV transition introduces ***significant uncertainties and potential risks***. Cybersecurity and data protection emerge as central challenges, as SDVs continuously collect, process, and transmit large volumes of sensitive data. The rise in cyberattacks on vehicles highlights vulnerabilities with implications not only for consumer trust, but also for physical safety, critical infrastructure, and national security. Consequently, ***security, privacy, and resilience*** transpire as core dimensions of automotive quality and competitiveness.

Various enablers are required to be in place for the SDV market transition to happen: appropriate regulation, innovation of advanced hardware and software, consumer demand, functioning cybersecurity, or existing infrastructure (including energy and data centres). This report analyses the interplay between these and other factors of a robust enabling ecosystem, with a setback in one area potentially spilling over, creating setbacks in others.

Based on these dynamics, ***four plausible scenarios for the period up to 2040 are proposed***:

1. ***"Traditional automotive market"*** with a stalled transition and return to traditional cars (non-SDVs);
2. ***"Niche SDV market"*** with adoption limited by factors such as cost, complexity, and regulation;
3. ***"SDV evolution"*** characterised by incremental adoption and strong regulatory guardrails;
4. ***"SVD revolution"*** enabled by aligned innovation, infrastructure, and regulation.

The report concludes that SDVs offer substantial opportunities for innovation, safety, and new value creation, yet also pose systemic risks if security, privacy and broader societal trust are not adequately addressed. For policymakers, success depends on enabling ecosystems rather than relying solely on regulation. For industry actors, adaptability, (cyber)security-by-design, and balanced hardware-software strategies will be decisive. The way these challenges are addressed and managed will shape the future competitiveness and resilience of the automotive industry and the future satisfaction and security of its customers.

Introduction

The car of tomorrow is no longer just a vehicle. It is a data centre on wheels.

This report focuses on the digital transformation - or what from a 2026 perspective might become a ***revolution*** - happening in the automotive industry globally. At the heart of it lie software and software-enabled features that transform modern vehicles into platforms. So-called ***software-defined-vehicles***, or SDVs, are vehicles serving as data centres on wheels and the technological base for constant, continuous innovations. The SDVs separate hardware from software and have consolidated electrical/electronic (E/E) architectures, allowing for over-the-air (OTA) updates and upgrades, automation or autonomy and constant connectivity.[1] These new vehicles are also changing the whole industry,[2] bringing in new service-based business models as well as new organizational processes.[3] Moreover, shift to SDVs brings forward new players entering the market - be it new car-making companies mainly from China and the U.S., or companies that had previously focused on other types of technology - such as software, artificial intelligence (AI), or telecommunications. Incumbent car makers now engage more deeply with software development partners and adopt digital-first design practices.[4] This transformation of the industry and the car itself is - despite its profound and complex effects and implications - often overshadowed in analyses and reports by the industry's "green" transition to electric vehicles (EVs).

Several works have been published on the topic of SDVs but mostly focus on technical, technological or wider economic aspects. This report's main added value lies in its holistic ***multidisciplinary approach***[5] and in applying ***strategic foresight methodology***. It rests on the qualitative analysis of empirical data, including open-source information as well as ten semi-structured interviews with high-level experts from the industry producing unique insights and data. As SDVs are a quickly emerging field, a thorough, data-based analysis - including horizon scanning, assumptions testing, key uncertainties and change drivers identification as well as scenario-building - can serve as a valuable contribution to the ongoing debates - not just academic, but also in policymaking and business spheres. This report also offers a set of recommendations relevant for both public and private actors and stakeholders based on the analysis of risks and opportunities. Strategic macro-level analysis provided here does not attempt to provide niche technical or technological insights.

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1 Windpassinger, H. (2025). *The software-defined vehicle: The architecture behind the next evolution of the automotive industry.* https://www.ibm.com/think/insights/the-software-defined-vehicle-the-architecture-behind-the-next-evolution-of-the-automotive-industry [Accessed on: December 18, 2025].

2 *"According to J.D. Power's 2025 China Tech Experience Index, software-defined vehicles are emerging as the auto industry's new organizing principle."* Fusheng, L. (2025). *Foreign brands double down on smart driving.* https://global.chinadaily.com.cn/a/202508/04/WS68900cbfa310c0209d01acec.html [Accessed on: December 18, 2025].

3 Bezerra, M. (2024). *SDV Market Tracker: 2024 Analysis.* https://www.wardsauto.com/software-defined-vehicles/sdv-market-tracker-2024-analysis [Accessed on: December 18, 2025].

4 Walz, E. (2025). *'Break the silos': Software-defined vehicle development requires new approach.* https://www.automotivedive.com/news/autotech2025-software-defined-vehicles-middleware/750945/; Bezerra, M. (2024). *SDV Market Tracker: 2024 Analysis.* https://www.wardsauto.com/software-defined-vehicles/sdv-market-tracker-2024-analysis [Accessed on: December 18, 2025].

5 *This concerns, for instance, issues of human rights and freedoms as well as individual and national security, and the impact SDVs might have on these areas. These, in essence, are strategic consequences that lie beyond strictly economic, technical, technological or managerial-focused debates and works. This report is integrating elements, aspects, and factors from various disciplines and backgrounds.*

THE DIGITAL DISRUPTION OF THE "OLD-SCHOOL" ANALOGUE MOBILITY

The SDV marks the new frontier of mobility - a vehicle with features, safety capabilities, and user experience that are primarily driven by software rather than hardware. This evolution reflects a broader digital disruption in the industry. Consulting firm McKinsey & Co. projects that the global automotive software and electronics market will reach $462 billion by 2030, significantly outpacing growth in traditional vehicle sales.[6] In this "software-first" era, vehicles are becoming connected, intelligent, and upgradable. Integrated high-performance computing systems can process trillions of data points in real-time. Comparisons with smartphones can perhaps work regarding their functionality, however, vehicles are subject to far more stringent safety and regulatory requirements, acknowledging their wide impact on economy as well as safety and security (both individual and national) and individual rights and freedoms (such as movement or data privacy).

DEFINING AN SDV

An SDV is not simply an electric or autonomous vehicle, although those technologies often overlap. At its core, an SDV is any vehicle where software controls key functionalities - powertrain, braking, infotainment, and safety systems - and can be updated over-the-air (OTA) without replacing hardware. SDV integrates electronic and electrical systems and separates hardware from software, allowing modular upgrades, improved lifecycle management, or service-based user experience. For the purposes of this report, we will be using a definition proposed by De Vincenzi et al (2024):[7]

"SDV is an in-vehicle solution that enables the abstraction and management of hardware vehicle components through software to create a scalable architecture with both centralized and distributed local and remote controls. Additionally, all vehicle software components must support OTA updates"

De Vincenzi et al, 2024

Disclaimer: For the purposes of this report, we use the term SDV, where appropriate, to also encompass Autonomous Vehicles (AVs) as these are, essentially, software-enabled. However, the SDV exists independently of full autonomy; while all AVs require SDV capabilities, not all SDVs are autonomous.[8]

REPORT SCOPE & STRUCTURE

This report examines the implications of the software-defined transformation in the automotive sector. It applies the method of strategic foresight to ***identify critical assumptions and uncertainties***, followed by the ***key change drivers***, thus allowing for modelling of four ***distinct plausible scenarios.*** In conclusion, it presents a ***set of recommendations***, ***highlighting key opportunities and risks*** regarding this emerging trend from the perspective of Slovakia as a European Union (EU) Member State.

The SDV is an ***emerging field*** with few national specifics. This report addresses developments at a global and regional (EU) level, with particular relevance for Slovakia as a major auto manufacturing hub. Observations are, however, also relevant to other global regions and countries. Slovakia, akin to the Republic of Korea and other export-driven economies, is deeply embedded in global automotive supply chains. While national policy levers are limited, aligning with international standards and participating in shared frameworks - regarding trade, but also innovation or cybersecurity - is essential.

6 Boigon, M. (2024). *Even as they compete, automakers increasingly share resources for open-source software* https://www.autonews.com/technology/open-source-automotive-software-becoming-more-common/ [Accessed on: December 5, 2025] and Burkacky, O. et al. (2023). *Outlook on the automotive software and electronics market through 2030.* https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/mapping-the-automotive-software-and-electronics-landscape-through-2030 [Accessed on: December 5, 2025].

7 De Vincenzi, et al. (2024). *Contextualizing Security and Privacy of Software-Defined Vehicles: State of the Art and Industry Perspectives.* 10.48550/arXiv.2411.10612.

8 Cesa, E.,Milavec, R. (2023). https://www.autonews.com/sponsored/software-defined-vehicles-will-transform-auto-industry/ [Accessed on: November 13, 2025].

Methodology

The report provides a qualitative analysis of open-source information concerning the future of the automotive sector with specific focus on the SDVs and their possible transformative impacts, complemented by unique data collected in ten semi-structured interviews with high-level experts from the industry.

A distinctive feature of the report is the integration of key elements of strategic foresight approach and the logic of the generic strategic foresight process framework throughout the research.[9]

The input phase encompassed scoping including ten research interviews, followed by a multidisciplinary horizon scanning, mapping the most significant patterns in the political, social, economic, technological and legal domain.

Based on this initial phase, the key ***assumptions*** and critical ***uncertainties*** were defined to describe current expectations and the outlook for the future development of the automotive sector. Subsequently, the main ***change drivers*** were identified to highlight the key forces that will determine the trajectory, impacts and extent of SDV adoption.

These elements were further analysed and interpreted using cascading and cross impact analysis techniques. In this process, two key uncertainties were recognized - these represent the main axes in the 2x2 matrix scenario development. This technique was used to propose ***four exploratory scenarios*** of plausible alternative developments up to 2040.

The scenarios were also subject of a structured brainstorming session during a participatory seminar in Šamorín, Slovakia, on November 20, 2025, featuring senior-level experts and decision-makers from the industry. Ultimately, the scenarios served as a framework to identify the key ***recommendations*** listed in this report.

9 Voros, J. (2003). *A Generic Foresight Process Framework.* Foresight: The Journal of Futures Studies, Strategic Thinking and Policy, Vol. 5, No. 3., pp. 10-21.

What do we know?

The underlying assumption is that the SDV ***market is poised for significant growth*** over the next decade. While market size estimates vary, most forecasts project substantial expansion. SDV applications are expected to become increasingly widespread, driven by features such as OTA updates and deep software integration. These elements enhance vehicle efficiency, enable greater customization, and are likely to become key determinants of competitiveness for carmakers. The introduction of SDVs has the potential to fundamentally redefine vehicle functionality and user experience, catalysing a broader transformation of the automotive industry - causing a ***"digital revolution"***. However, the pace of full migration to SDVs may vary across regions, depending on factors such as infrastructure availability, regulatory frameworks, and local consumer preferences determined by age,[10] urban vs rural divides and social trends.

Estimates for the global software-defined vehicles market vary by methodology. BCC Research projects the market at about USD 391 billion in 2024, rising to approximately USD 1.6 trillion by 2030 (Compound Annual Growth Rate (CAGR) ~27.3% for 2025-2030).[11] Coherent Market Insights estimates the market at USD 134.73 billion in 2025, with growth to USD 733.93 billion by 2032 (CAGR ~27% over the 2025-2032 period).[12]

SDV-related (in)security presents a major vulnerability - cybersecurity, remote control or access (enabled by "x-by-wire" technologies), data security and reliable connectivity are all issues that need to be addressed on top of traditional car vulnerabilities related to reliance on critical infrastructure, supply chains of key components or critical raw materials. This new dimension of SDV vulnerability has not only technical and technological aspects, but also impacts individual rights and freedoms, as well as individual and national security,[13] requiring a new, more holistic and complex approach to SDV security.

The frequency of cyberattacks on cars increased by 225 percent from 2018 to 2021.[14] In 2024, ransomware attacks targeting the mobility sector spiked, with 108 ransom cases and 214 data breaches reported globally. For example, one ransomware hit CDK Global, a top U.S. software provider for 15,000 car dealerships, shutting down operations for nearly three weeks and causing significant financial damage.[15]

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10 Jordhamo, J. (2025). *The vanishing young car buyer: New vehicle registrations drop for 18-34-year-olds.* https://www.spglobal.com/automotive-insights/en/blogs/2025/06/new-vehicle-registrations-drop-for-18-34-year-olds [Accessed on: November 2, 2025].

11 BCC Research (2025). *Revolution on Wheels: Software Defined Vehicles Market to Reach $1.6 Trillion by 2030.* https://www.bccresearch.com/pressroom/eng/software-defined-vehicles-market-to-reach-$16-trillion?srsltid=AfmBOorG4FvjQ2hkAjB5ueWFU7EdD-a3nSL_36bigA-N8WpPmYfq5_eX [Accessed on: September 5, 2025].

12 Open PR (2025). *Software Defined Vehicle Market 2032 Industry Overview, Evolution Growth Rate and Future Forecasts 2025-2032* |Tesla, Volkswagen, Toyota, BMW. https://www.openpr.com/news/4102992/software-defined-vehicle-market-2032-industry-overview [Accessed on: August 25, 2025].

13 Lingras, S., Basu, A. (2025). *"The Security of Autonomous Vehicle Software and its National Security Implications,"* Eur. J. Appl. Sc. Eng. Technol., Vol. 3, No. 1., pp. 180-188, Jan-Feb 2025. DOI: 10.59324/ejaset.2025.3(1).16

14 Bradley, T. (2022). *Cyber attacks on cars up 225 percent: how hackers could be targeting your vehicle are targeting the automotive industry.* https://www.express.co.uk/life-style/cars/1632500/hackers-target-drivers-cyber-attacks-cars [Accessed on: December 18, 2025].

15 Kiley, D. (2025). *Upstream: Auto Industry Cyber Attacks Rising.* https://www.wardsauto.com/vehicles/upstream-auto-industry-cyber-attacks-rising [Accessed on: September 8, 2025].

Geopolitical, geoeconomic and technological shifts can rewrite the global car making map. China and the U.S. are currently ahead in the SDV race, though Europe strives to catch-up.[16] Incumbent carmakers are trying to react either through building their own in-house capacities, joint ventures, or through "in the region for the region" strategy (for instance, Volkswagen Group in China as part of the "In China, for China" strategy is systematically expanding its local technology competence by AI-powered, highly automated driving system specially developed for China's complex traffic environment),[17] while some just cooperate directly with Chinese software and autonomous-driving companies (for example, BMW China expanded its partnership with Momenta to co-develop an AI driver-assistance system using large-model algorithms for Chinese roads; Audi is adding Huawei's Qiankun driving-assist tech to both gasoline and electric models, while Mercedes-Benz has chosen Momenta as its Advanced Driver-Assistance Systems supplier in four models to be launched in China from 2025 to 2027).[18]

Tech giants entering the car market further accelerate the impact of geopolitical competition - business landscape is changing, with more weight tilting towards the new players entering the market, primarily tech companies, which serve both as suppliers as well as enablers of SDV shift, integration and usage. For instance, Nvidia's DRIVE platform is used as a computing foundation by many car makers (e.g. General Motors, Toyota, Mercedes-Benz),[19] while Google's Android Automotive operating system has been adopted by 13 major automotive groups representing 20 brands as of mid-2024.[20] Some companies are even becoming new players in their own name, such as Xiaomi. Its debut sedan, the SU7, racked up 88,898 pre-orders in just 24 hours.[21] Similarly, Huawei's automotive unit (Yinwang) delivers software and autonomous driving modules to various car makers (also called Original Equipment Manufacturers, or OEMs).[22] However, tech-native EV startups and Chinese brands are outpacing many legacy automakers in the race toward SDVs.[23]

AI integration is a key enabler to SDVs success. AI is expected to redefine what a car is capable of doing: from autonomous driving and real-time decision-making, analysing and combining data from various SDVs sensors to in-vehicle experience and personalization, predictive maintenance, diagnostics and cybersecurity. AI is also expected to ensure communication with other cars to improve traffic flow and will be a decisive factor in value extraction from data collected in SDVs.

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16 Eddy, N. (2025). *VW, BMW, Mercedes, top suppliers form European software alliance to counter U.S. tech dominance.* https://www.autonews.com/technology/ane-german-automotive-industry-software-alliance-0627/ [Accessed on: September 9, 2025].

17 Aschhoff, R., Ludewig, Ch. (2025). *Volkswagen Group in China presents new AI-powered ADAS system for the next generation of intelligent electric vehicles.* https://www.volkswagen-group.com/en/press-releases/volkswagen-group-in-china-presents-new-ai-powered-adas-system-for-the-next-generation-of-intelligent-electric-vehicles-19203 [Accessed on: August 16, 2025].

18 Reuters (2024). *Mercedes to use Momenta software in 4 models, accelerate China comeback, sources say.* https://www.reuters.com/business/autos-transportation/mercedes-use-momenta-software-4-models-accelerate-china-comeback-sources-say-2024-11-29/ [Accessed on: August 18, 2025]; *Foreign brands double down on smart driving.* https://global.chinadaily.com.cn/a/202508/04/WS68900cbfa310c0209d01acec.html [Accessed on: December 18, 2025].

19 NVIDIA (2025). *NVIDIA DRIVE Partner Ecosystem.* https://www.nvidia.com/en-sg/solutions/autonomous-vehicles/partners/ [Accessed on: November 4, 2025].

20 Business Wire (2025). *Software-Defined Vehicle (SDV) Architecture Market 2025-2035: Strategic Insights for OEMs, Tier-1s, and Tech Giants - A New Blueprint for Modern Vehicle Systems - ResearchAndMarkets.com* https://www.businesswire.com/news/home/20250616808676/en/Software-Defined-Vehicle-SDV-Architecture-Market-2025-2035-Strategic-Insights-for-OEMs-Tier-1s-and-Tech-Giants---A-New-Blueprint-for-Modern-Vehicle-Systems---ResearchAndMarkets.com [Accessed on: August 12, 2025].

21 Oi, M. (2024). *Xiaomi: Electric car buyers told they face six-month wait.* https://www.bbc.com/news/business-68705711 [Accessed on: July 12, 2025].

22 Financial Times (2024). *'A different animal': inside Huawei's nascent EV business* https://www.ft.com/content/9760cd8e-b6ea-4dcd-96fa-e80432c3c8b0 [Accessed on: July 12, 2025].

23 *According to Gartner's 2024 Digital Automaker Index, Tesla leads with a 76.9% score, followed closely by Nio (71.2%) and Xpeng (66.8%). By contrast, established automakers such as Toyota (26.8%), GM (39.9%) and Mercedes-Benz (38.8%) remain far behind.* - Jones, L. (2025). These automakers lead the race to debut software-defined vehicles. https://www.autonews.com/technology/ane-eu-us-china-sdv-software-0818/ [Accessed on: August 15, 2025].

For a start, Volkswagen and Mercedes Benz have already rolled out a ChatGPT-based voice assistant.[24]

New business models and organizational adaptations will be needed for the OEMs and suppliers to adapt to the changing technological and business landscape. Growing individualization of cars, cost-cutting and development-time-compression are major trends. SDVs can generate new revenue streams, with OTA capabilities seen as a possible game changer - continuous remote updates and improvements to the vehicle can provide various options for new sources of revenue other than just selling new vehicles, also changing consumer preferences and behaviour. Organizational and cultural changes, especially in legacy car makers, will be required to adopt more software-cantered approaches and offer more flexibility and agility.

24 Cooney, P. (2024). *More Automotive Brands Roll Out Conversational AI for the Car.* https://sarinsight.com/moreautomotive-brands-roll-out-conversational-ai-for-the-car/ [Accessed on: August 25, 2025].

What don't we know?

SDVs competitiveness may become a critical uncertainty. A key question is whether the features and services provided by SDVs will come to dominate the new car market or whether, for a range of reasons, they will only capture a minor share of it. There is the possibility of a partial shift back towards non-SDVs (or, more specifically, models with limited/selected SDV functionalities) driven by factors such as high cost, complexity, privacy and safety concerns, or inadequate infrastructure. This might mirror the (possibly temporary or partial) trend we currently observe concerning internal combustion engine (ICE) cars, including hybrids. Factors such as lack of seamless hardware-software integration, delays in electrification, export controls and trade wars, hard and soft security (such as cyber and data), software or hardware failures can limit the SDVs competitiveness and adoption.

According to the 2024 Kaspersky survey, 71% of drivers said they would consider buying an older car to avoid invasive data harvesting.[25]

Shifts in consumer preferences and public perception of SDVs are hard to predict[26] and ***can redefine the future approach to cars and car ownership.*** Consumer preferences are continually developing. Based on generational, cultural, socio-economic or regional factors, they can play out in different ways. The younger, tech-savvy generation might demand only SDVs as new cars, but at the same time may prefer shared transport or even refuse car ownership as a concept, ultimately resulting in lower demand for passenger vehicles. Older generations might be less prone to buying SDVs, but at the same time maintaining preference for privately-owned vehicles, some with preference for traditional driving, at least as an optional setting, while others preferring autonomy. Public attitudes might be further influenced by unexpected incidents and accidents caused by the SDVs, their successful application in everyday practice, resting on a well-functioning infrastructure, seamless connectivity and/or other enablers for effective performance of SDVs.

Talent scarcity or availability may become a decisive element of success in SDV development and production. AI and software experts, but also traditional car (hardware) engineers, will be subject of growing global race for talents.[27] In addition, automotive industry moving towards SDVs will involve not just geopolitical, but increasingly also cross-sectoral competition - for instance, the automotive industry will have to fight for software experts with other software-based industries, while hardware engineers might be pulled into the defence industry, especially in Europe. Talent scarcity is a top-tier strategic risk for the EU automotive industry.[28]

Investments and state support will be essential to creating the enabling ecosystem for SDVs. Success in shaping this ecosystem will make the difference between winners and losers in this emerging, re-defined car market. Creating a positive case for SDVs and thus generating relevant demand for this new form of mobility will be crucial to incentivize either public or private investments, ideally resulting in a public-sector-enabled, private-sector-led partnership.

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25 Kaspersky (2024). *Kaspersky survey: 71% of drivers would buy a car with less tech to protect their privacy.* https://usa.kaspersky.com/about/press-releases/kaspersky-survey-71-of-drivers-would-buy-a-car-with-less-tech-to-protect-their-privacy [Accessed on: September 12, 2025].

26 S&P Global (2023). *What connected-car services are consumers willing to pay for?* https://www.spglobal.com/mobility/en/research-analysis/what-connectedcar-services-are-consumers-willing-to-pay-for.html [Accessed on: September 8, 2025].

27 Tong, A., Cai, K. (2025). *OpenAI, Google and xAI battle for superstar AI talent, shelling out millions.* https://www.reuters.com/business/openai-google-xai-battle-superstar-ai-talent-shelling-out-millions-2025-05-21/ [Accessed on: August 29, 2025]; Chen, W. (2025). *Meta's AI lab is stacked with Chinese talent, drawing attention back home.* https://www.scmp.com/tech/big-tech/article/3316858/metas-ai-lab-stacked-chinese-talent-drawing-attention-back-home [Accessed on: August 21, 2025]. *Alibaba's world-leading AI lab becomes a target for talent poaching by Chinese rivals. Meta's AI lab is stacked with Chinese talent, drawing attention back home.* https://www.scmp.com/tech/big-tech/article/3321270/alibabas-world-leading-ai-lab-becomes-target-talent-poaching-chinese-rivals [Accessed on: August 25, 2025].

28 Mehta, A. (2024). *Auto sector scrambles to retool workforce for electric and automated future.* https://www.reuters.com/sustainability/climate-energy/auto-sector-scrambles-retool-workforce-electric-automated-future-2024-11-19/ [Accessed on: August 26, 2025].

The scope and content of regulation can both facilitate and curb SDV business. SDVs, just like other high-tech sectors, are highly sensitive to new regulation. As an emerging technology, it is reasonable to expect a growing body of regulation in the SDV field. Security and safety of the new technology, integration of AI and privacy will certainly raise a lot of legal as well as ethical questions. The key issue will be whether the new regulation will be enabling, or impeding (or even halting) to the business or its key parts.

Geopolitics. High concentration of automotive supply and value chains impacting SDVs brings high exposure, vulnerability and volatility.[29] Access to critical raw materials and advanced components such as semiconductors, sensorics and connectivity infrastructure becomes essential (e.g., battery-grade lithium, nickel and rare-earth magnets are already on the EU and the United States (US) strategic raw materials lists and come from a narrow group of countries), with the EU being especially vulnerable.[30] Political decisions can severely impact global trade (trade wars, export restrictions, weaponization of trade, protectionism) and with it the successful development and adoption of SDVs - at least in selected regions or countries.[31] At the same time, any ruptures in related industries (AI, telecommunications, etc.) can also directly negatively impact SDV development and applications, expanding the scope of relevant policies and regulations regarding SDVs to connected sectors and industries. Restrictions, volatility and uncertainty, however, can also lead to more (speedy) innovation and differentiation.

Cybersecurity and data security. As SDVs are constantly connected and collect, analyse and transmit large amounts of data, data privacy and security, along with physical security, emerge as central concerns for both the OEMs and the customers. Large-scale cyberattacks on SDVs could trigger lawsuits and/or multi-billion-dollar recall and repair bills, cripple supply chains and erode consumer confidence, with knock-on effects for broader economic stability and individual as well as national security. Certainty about who, how and where will collect, store, own and use the data will be central for SDV business to attain consumer confidence. Similarly, effective protection against hackers taking control of the vehicle or some of its functions or accessing critical infrastructure through an SDV is poised to become a focal point. With data being a very valuable commodity, OEMs, suppliers, as well as governments might wrestle to own and control them. Enhancement and wider application of various AI and AI-enabled technologies and tools can both further increase the risks, and offer more solutions, serving as a double-edged sword.

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29 Luman, R., Manthey, E. (2025). *China's export restrictions on rare earths causes alarm for automotive industry.* https://think.ing.com/articles/chinas-crackdown-on-rare-earth-causes-alarm-automotive-industry/ [Accessed on: August 13, 2025].

30 *Consider, for example, dependency on China for various materials and components relevant for the SDVs, but also on the US for chips used in cars.* Huang, R., Kubota, Y. (2025). Trade War Exposes China's Dependence on U.S. for Auto Chips. https://www.wsj.com/world/china/trade-war-exposes-chinas-dependence-on-u-s-for-auto-chips-41df1ae7 [Accessed on: July 17, 2025].

31 *Consider the example of 2025 Chinese export restrictions on rare earth elements.* Automotive News China (2025). The world's auto supply chain is in the hands of a few Chinese bureaucrats. https://www.autonews.com/china/an-china-supply-chain-bureaucrats-0606/ [Accessed on: July 24, 2025]; Automotive News Europe (2025). *Auto companies 'in full panic' over rare earths bottleneck.* https://www.autonews.com/manufacturing/ane-rare-earth-crisis-escalates-0609/ [Accessed on: July 24, 2025]. *Or the example of U.S. issuing a final rule to ban imports of Chinese and Russian connected vehicles (i.e., SDVs), as well as key hardware and software components, that could be "used to spy on Americans or potentially even take control of their vehicles."* Palmer, D. (2025). Commerce finalizes rule banning 'connected' cars from China, Russia. https://subscriber.politicopro.com/article/2025/01/commerce-finalizes-rule-banning-connected-cars-from-china-russia-00198071 [Accessed on: July 24, 2025].

Factors shaping the future

In this section, the report highlights and further analyses four critical drivers of change that will shape the future developments in the world of SDVs: ***cybersecurity and data, geopolitical and geoeconomic factors, changing customer preferences and new business models, and key technological developments.*** The aim is to provide a brief analysis of the present situation as well as highlight potential strategic consequences.

1. CYBERSECURITY AND DATA: CAR INDUSTRY'S NEWEST CHALLENGES

Securing the data - ownership, access, storage, monetization and exploitation - along with minimizing risks of remote control have become two central challenges for the automotive industry globally. They could be categorized as:

- ***"Hard security"*** issues (protecting against remote exploits, ensuring system integrity and therefore individual physical and national security), and

- ***"Soft security"*** issues (protecting data security and therefore individual privacy, data flows and ownership).

With SDVs becoming the new standard, vehicles, their users, and surrounding environment and infrastructure all face new threats on top of the existing ones - from data breaches to remote control exploits. SDV may generate up to 1,400 GB of data per hour[32], collecting complex information - including sensitive, personal and behavioural data - that is constantly being transmitted. With greater connectivity comes greater vulnerability.

Data can be breached if not properly secured, ***introducing cybersecurity as a core requirement*** for the automotive industry for the first time in history. This concerns both vehicles as well as the whole production and supply chains.[33] Public, commercial or malicious actors, on individual or national level, can be involved with varying motivations for data ***exploitation*** (including through so-called backdoor access), ranging from purely financial ones to control, surveillance, or espionage.

Moreover, ***SDVs face risks of remote access and control*** through multitude of access points, interfaces and technologies such as "x-by-wire" or "Vehicle-to-everything (V2X)", making cybersecurity not only a matter of data safety and privacy or product/brand trustworthiness, but also of personal, ***physical freedom*** of movement and, by extension, of ***national security***. On top of existing hardware vulnerabilities, SDVs practical functionality is also impacted by software issues (e.g., successful updates, connectivity, etc.).

A 2015 demonstration of a Jeep Cherokee being hacked, forcing a recall of 1.4 million vehicles, triggered a broader industry reckoning with rising cybersecurity issues.[34] Eleven years later, ***the risks have become far more complex*** with not only new technical and technological developments, but also due to rapidly changing global geopolitical and geoeconomic environment. More specifically, focus is being put on Chinese-made connectivity modules and SDVs that might collect data abroad and share it under national intelligence laws.[35]

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32 Sydow, A. (2024). *Security concerns regarding Chinese connected cars: A short overview.* https://kinacentrum.se/en/publications/security-concerns-regarding-chinese-connected-cars-a-short-overview/ [Accessed on November 4, 2025].

33 For example, see Automotive News Europe (2025). Jaguar Land Rover cyberattack fallout spreads to suppliers. https://www.autonews.com/jaguar-land-rover/ane-jlr-cyberattack-suppliers-production-0917/ [Accessed on November 4, 2025].

34 Schmeken, H. (2024). *Kybernetická bezpečnosť v automobilovom priemysle: Nové povinné predpisy* https://www.dqsglobal.com/sk/preskumat/blog/kyberneticka-bezpecnost-v-automobilovom-priemysle-nove-povinne-predpisy [Accessed on November 4, 2025].

35 Duffy, K., Fendorf, K. (2024). *In the Age of AI, Personal Data Security Is National Security.* https://www.cfr.org/article/age-ai-personal-data-security-national-security. [Accessed on November 4, 2025]. and Sydow, A. (2024). *Security concerns regarding Chinese connected cars: A short overview.* https://kinacentrum.se/en/publications/security-concerns-regarding-chinese-connected-cars-a-short-overview/ [Accessed on November 4, 2025].

Upstream 2025 Cybersecurity Report assesses that yearly automotive cybersecurity incidents grew from 57 attacks in 2017 to 409 in 2024, with cumulative cyber-attacks growth from under 180 in 2017 to nearly 1,900 by year-end 2024 - signifying a more than tenfold increase. The diversity of cybersecurity attack vectors also continues to grow, with backend servers for telematics, connected car apps and mobility apps becoming the largest attack vector at 66% of all cyberattacks in 2024 (compared to 43% in 2023).[36]

Regulation is trying to catch up with this shift with international frameworks mandating and/or regulating cybersecurity standards and pushing for secure-by-design architectures. These include UNECE WP.29 or the UN Regulation No. 155 and No. 156 working alongside ISO/SAE 21434 which all aim, essentially, at protecting vehicles from cyberattacks throughout their lifecycle.[37]

Car makers may pursue ***different strategies*** in order ***to increase cybersecurity and data protection*** in SDVs thus impacting the industry landscape:

1. ***Closed-loop***, in-house solutions resembling Apple's controlled iOS ecosystem, offering stronger security and control but limiting user choice as well as putting more financial burden on the developer;

2. ***Open systems*** shared among multiple users, akin to Android, promising flexibility and more affordability but creating additional risks; or

3. ***Limited systems*** focused only on essential software functions. The above-mentioned solutions can be developed either individually, or among a few different regional partners following "in the region for the region" strategy, or even globally, resulting in either shared global or regional systems, or in different systems limited to individual brands.

OEMs can also decide to outsource development of solutions to third parties (tech companies, cloud operators, suppliers), thus shifting control away from them. Development strategies might also include relying on a new technology (e.g., blockchain or cloud-based platforms managing access rights, enforcing security policies and separating business and private data).

36 Juliussen, E. (2025). *Automotive Cybersecurity: Attacks Keeps Growing.* https://www.eetimes.com/automotive-cybersecurity-attacks-keeps-growing/ [Accessed on November 5, 2025].

37 *Note that the EU regulation such as NIS2 do not directly regulate products, i.e., the vehicles themselves or the software. Instead, they regulate and oblige organizations that provide essential or important services such as the transport sector (including the car makers and their suppliers).*

Strategic consequences:

- For the industry as well as the regulators, finding the right ***balance between innovation and security*** and ***between new features and capabilities and safety and reliability becomes crucial.*** The long-term winners in the SDV market may be those who can integrate connectivity, new functionalities and software sophistication while ***ensuring safety, privacy, and operability even under hostile conditions.*** As (cyber)security becomes a core requirement for the automotive industry as well as one of the core elements in an SDV for consumers, the ***perception*** and criteria of automotive quality are likely to evolve: tomorrow's luxury may not be defined by hardware (alone), but primarily by software, including ***guarantees of cybersecurity, privacy, reliance and resilience.***

- ***Governments*** start to ***play a more proactive, critical and qualitatively different role in the industry***, given complex implications of SDVs for individual and national security, privacy, critical infrastructure as well as for geopolitical competition - particularly in reflection of the current U.S. and Chinese dominance in the SDV sector.

- ***Atomization*** of software and cybersecurity systems will likely negatively impact the seamless usability and flexibility while also putting substantial financial pressure on OEMs. On the other hand, it will likely provide more (cyber)security for users. Tensions and pressures in finding effective solutions may drive a ***consolidation*** as automakers increasingly develop proprietary software and seek control over cybersecurity as well as mobility data as a valuable commodity. Alternatively, there will be a ***shift of power and control towards tech companies*** and/or suppliers away from the OEMs.

- In reaction to rising connectivity and thus potential vulnerabilities, emphasis could be put on "take back control" highlighting (analogue) functionality in disruptive environment or circumstances, resulting in ***fragmented market*** with partially revived demand for simpler, less-integrated and/or older (used) cars; higher-end new SDVs offering enhanced protection (through subscription and/or hardware); and/or cheaper SDVs offering lower and/or limited protection. Rising complexity of vehicles might also lead to questioning the sustainability and long-term usability of SDVs.

- ***Regulators*** might ***overreact*** to the new challenges ***prioritizing security and safety over innovation***, impacting technological development and application as well as economic opportunities and growth.

2. THE GEOPOLITICAL AND GEOECONOMIC LAYERS: AGE OF UNCERTAINTY AND FRAGMENTATION

The global automotive industry is being reshaped by increasing geopolitical uncertainty and geoeconomic fragmentation driven by the trade tensions, protectionism and tech-lead shifts. Once dominated primarily by the EU, U.S. and Japan, ***the sector's centre of gravity has been shifting to China*** (and India). EU carmakers face domestic challenges such as high development and production costs, and high regulatory burden, as well as rising Chinese competition both in China and in the EU, and most recently must tackle the new U.S. tariffs imposed in 2025.[38] In this quickly and constantly changing landscape and shifting geoeconomic map, the ***EU's automotive sector's competitiveness is endangered, with serious impact*** not only on the industry as such,[39] but potentially ***on the SDV development and application*** in particular.

While the average modern car contains around 1000-1500 advanced chips, newer SDVs can contain much more - up to 3000.[40] Super-fast chips enabling SDV capabilities can already handle complexity "akin to the human brain" with as much as 254 trillion operations per second.[41] Moreover, although SDVs extend beyond electric vehicles (EVs), both are closely linked through the electrification trend.[42] According to the IBM study, 74% of automotive executives anticipate that by 2035, vehicles will be fully software-defined and driven by AI, while new vehicles will feature at least some level of powertrain electrification.[43] EVs require two to three times more semiconductors than ICE vehicles, with semiconductor content per EV ranging from $1,500 to $3,000 compared to $400 to $600 in traditional cars. Overall, semiconductor-based systems are becoming a dominant cost driver in the auto industry, rising from 18% of a car's cost in 2000 to 40% in 2017, with projections reaching 45% by 2030.[44] Over the last 20 years, the EU's share in global manufacturing capacity across all types of microchips has fallen significantly, from 24 % in 2000 to only 9 % in 2020.[45]

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38 Lawder, D. (2025). US *implements EU trade deal, 15% autos tariffs retroactive to Aug 1.* https://www.reuters.com/sustainability/society-equity/us-confirms-eu-autos-auto-parts-15-tariffs-started-aug-1-2025-09-24/ [Accessed on: October 5, 2025].

39 *See, for instance, ACEA's August 2025 letter to the European Commission.* The European Automobile Manufacturers' Association (2025). Joint ACEA-CLEPA letter to President von der Leyen. https://www.acea.auto/files/Joint-ACEA-CLEPA-letter-to-President-von-der-Leyen.pdf [Accessed on November 10, 2025].

40 Polar Semiconductor (2023). *How Many Semiconductor Chips Are in a Car? [Infographic].* https://polarsemi.com/blog/blog-semiconductor-chips-in-a-car/ [Accessed on November 4, 2025].

41 Gibbs, N. (2025). *European automakers highlight their technology leaps at Munich auto show.* https://www.autonews.com/technology/ane-technology-munich-iaa-show-automakers-0917/ [Accessed on: October 13, 2025].

42 *Over the next 10 years, the simultaneous rollout of autonomous driving, electrification, and software-defined vehicles will bring new mobility applications.* Hodgson, J. (2023). *The Software-Driven Megatrends Shaping the Automotive Industry.* https://www.instrumentation.co.za/ex/abi_auto_trends.pdf [Accessed on: November 8, 2025].

43 IBM (2024). *IBM Study: Vehicles Believed to be Software Defined and AI Powered by 2035.* https://newsroom.ibm.com/2024-12-12-ibm-study-vehicles-believed-to-be-software-defined-and-ai-powered-by-2035 [Accessed on November 4, 2025].

44 Ramsey,J. (2020). 40% of a new car's cost is electronic systems. https://www.autoblog.com/features/car-electronics-cost-semiconductor-chips [Accessed on: October 17, 2025]. Yole Group (2024). *Electrification and autonomy: a semiconductor content boost to $1,000 per car by 2029.* https://www.yolegroup.com/press-release/electrification-and-autonomy-a-semiconductor-content-boost-to-1000-per-car-by-2029/ [Accessed on: October 17, 2025].

45 Curia Rationum (2024). *EU's industrial policy for microchips put to the test.* https://www.eca.europa.eu/en/news/NEWS2024_01_NEWSLETTER_01 [Accessed on: October 3, 2025].

By 2040, it is estimated that ***software could account for up to half of a car's total value***[46], revealing ***new value and supply chains vulnerabilities*** and making ***access to the critical technologies, components and materials a defining factor of competitiveness.*** China has a strategic geopolitical leverage over these new supply chains and trade relations.[47] Such concentration creates systemic risks for other actors, namely the EU, which already depends on extra-EU suppliers for accumulators and semiconductors.[48] At the same time, while ***dominating rare earth, battery materials, or legacy chips***, China itself - together with the EU - remains ***reliant on the US for advanced semiconductors***[49], creating a relationship of mutual vulnerability. As issues such as advanced chips supply have become not only an industrial concern but a matter of national security, the EU acts towards acquiring its own capacities in semiconductors and batteries through new alliances, joint ventures, and partnerships although actual success remains to be seen.[50]

Between 2010 and 2024, global vehicle production rose from 77.6 to 92.5 million units, but the balance among major producers shifted significantly. China grew from 18.3 million (23.5%) to 31.3 million (33.8%), cementing its position as the dominant global hub. India strengthened its role, rising from 3.6 million (4.6%) to 6.0 million (6.5%), while Mexico, South Korea, and Germany all lost ground, each sliding from around 5-8% shares in 2010 to about 4-5% in 2024. Overall, the industry's centre of gravity shifted decisively towards China, with India emerging as an important secondary growth driver, while China, India, and Indonesia shared the highest relative growth, each expanding output by around 70%.[51] Production capacities and their effectiveness and productivity continue to be an important factor also when it comes to SDVs and their future.

46 Jones, L. (2025). *These automakers lead the race to debut software-defined vehicles.* https://www.autonews.com/technology/ane-eu-us-china-sdv-software-0818/ [Accessed on November 10, 2025].

47 Automotive News Europe (2025). *European supplier plants are shuttered due to rare earth shortage* https://www.autonews.com/europe/ane-china-exports-tariffs-rare-earths-evs-0604/ [Accessed on: October 28, 2025].

48 See, for instance Dahl, J. Haeck, P. (2025). Netherlands-China chip war terrifies European car industry. https://www.politico.eu/article/car-sector-fears-sequel-pandemic-era-microchip-shortages/ [Accessed on: October 28, 2025].

49 Intel-owned Mobileye and Nvidia are among the leading players in the field of advanced driver-assistance systems (ADAS) and autonomous driving. Qualcomm sees strong interest in ADAS codeveloped with BMW. Gibbs, N. (2025). https://www.autonews.com/bmw/ane-qualcomm-demand-bmw-codeveloped-adas-0925/ [Accessed on: October 28, 2025]. Also see Trade War Exposes China's Dependence on U.S. for Auto Chips. Huang, R. & Kubota, Y. (2025). https:// www.wsj.com/world/china/trade-war-exposes-chinas-dependence-on-u-s-for-auto-chips-41df1ae7 [Accessed on: November 15, 2025].

50 *Building full semiconductor manufacturing and ecosystem capacity - from design to packaging - requires at least 10 years, possibly longer.* CSIS (2025). *The Semiconductor Ecosystem and Export Controls.* https://www.gsis-hamburg.com/executive-briefing-21-august-2025 [Accessed on: October 20, 2025].

51 *International Organization of Motor Vehicle Manufacturers. Figures include passenger cars, light commercial vehicles, minibuses, trucks, buses and coaches.* OICA (2025). *Production Statistics.* https://oica.net/production-statistics/ [Accessed on: October 21, 2025].

With ***China and the U.S. having the key means to drive the technological frontier in SDVs*** both in terms of materials and technology, the EU companies are responding with a multi-track approach. Some are cooperating with Chinese or U.S. firms, trying to pool resources, share the financial burden of development, adopt an "in-the-region-for-the-region" strategy, or simply acquire and accelerate their know-how.[52] In addition, despite facing more competition and pressures in China, it remains a very important market for EU companies.[53] On the other hand, EU OEMs are focusing on developing and making their own SDVs,[54] even striving for onshoring and potentially also localization and local content regulation[55] along the lines of an EU strategic discussion concerning the leadership in SDV technology and innovation, as well as skilled labour.[56]

In 2024, China led the world with about 300,000 AI patent applications, followed by the U.S. with around 67,800 applications, Japan (26,400), India (26,000), and South Korea (23,700). Notably, Samsung Electronics alone filed over 6,000 AI patents worldwide.[57] From 2010 to 2022, roughly 49,000 patent families related specifically to autonomous-driving technology were filed worldwide, with China again dominating the landscape with about half of all filings, with the U.S. contributing around 17%.[58]

EU companies are investing in new platforms and (software) architectures, but ***whether innovations can offset structural cost disadvantages and/or existing and new supply dependencies remains critically uncertain. These dynamics will have a direct impact on the future of the SDV development, production and application.*** However, EU OEMs also realize that structural factors resulting in higher labour, energy and overall regulatory costs make it difficult for Chinese brands to replicate their domestic price advantage within the EU market.[59]

52 For instance, *Renault and Porsche, respectively, have recently opened important R&D centers in China.* Randall, Ch. (2025). China, Renault opens R&D centre in China. https://www.electrive.com/2025/01/20/renault-opens-rd-centre-in-china/ [Accessed on: October 21, 2025]. Wohlrapp, V. (2025). *Porsche opens first integrated R&D hub outside Germany in Shanghai.* https://newsroom.porsche.com/en/2025/company/porsche-china-research-development-hub-opening-shanghai-41022.html [Accessed on: December 7, 2025]. *VW set up a joint venture with American company Rivian.* Rivian (2024). Faster, Leaner, More Efficient:Rivian and Volkswagen Group Announce the Launch of their Joint Venture. https://rivian.com/en-GB/newsroom/article/rivian-and-volkswagen-group-announce-the-launch-of-their-joint-venture. [Accessed on November 10, 2025].

53 European Chamber of Commerce in China (2025). *European Confidence Survey 2025.* https://europeanchamber.oss-cn-beijing.aliyuncs.com/upload/documents/documents/European_Chamber_Business_Confidence_Survey_2025%5b1278%5d.pdf [Accessed on: October 10, 2025].

54 *For example, BMW's iX3 is considered brand's first full-SDV.* Bolduc, D. A., Ciferri, L. (2025). *BMW says iX3, with 4 'superbrains' and 800 km range, is its first 'true' software-defined vehicle.* https://www.autonews.com/bmw/ane-bmw-ix3-neue-klasse-global-launch-0905/ [Accessed on: October 10, 2025]. *One of its key features, and automated driving system, has been co-developed by BMW and U.S. company Qualcomm.* Qualcomm (2025). *Qualcomm and BMW Group Unveil Groundbreaking Automated Driving System with Jointly Developed Software Stack.* https://www.qualcomm.com/news/releases/2025/09/qualcomm-and-bmw-group-unveil-groundbreaking-automated-driving-s [Accessed on November 10, 2025].

55 Bloomberg (2025). Europe´s Auto Suppliers Push for EU Content Rules to Shield Jobs. https://www.bloomberg.com/news/articles/2025-09-29/europe-s-auto-suppliers-push-for-eu-content-rules-to-shield-jobs [Accessed on: November 5, 2025].

56 *In a recent strategic discussion between the European Commission and the representatives of the EU car industry, focus was also put on "accelerating innovation in autonomous and connected vehicles"*, Council of the European Union (2025). Third Strategic Dialogue with the European Automotive Industry, 12 September 2025 https://www.parlament.gv.at/dokument/XXVIII/EU/34226/imfname_11513492.pdf [Accessed on: November 5, 2025]. *In 2023, the EU Commission launched the SDV platform under the broader Digital Vehicle initiative to boost Europe's leadership in next-generation mobility. In August 2025, it opened applications for the European Connected and Autonomous Vehicle Alliance (ECAVA) to support strategic guidance and foster collaboration among automotive stakeholders in Europe and globally in this area.* Paulweber, M. et al. (2025). *Technology Roadmap of the European-driven Open SDV SW Platform Initiative.* https://federate-sdv.eu/wp-content/uploads/2025/09/2025-SDVTechnologyRoadmap-Whitepaper-ver-1.0-final.pdf [Accessed on: November 10, 2025]. European Commission (2024). *The future of European competitiveness.* https://commission.europa.eu/document/download/ec1409c1-d4b4-4882-8bdd-3519f86bbb92_en [Accessed on: November 10, 2025].

57 Rapacke Law Group (2025). *AI Patents by Country Revealed: The Top 15 Nations Dominating the 2025 Landscape.* https://arapackelaw.com/patents/ai-patents-by-country/ [Accessed on: September 28, 2025].

58 Questel (2022). *Autonomous Driving and Smart Transportation.* https://www.questel.com/wp-content/uploads/2022/12/BAIDU-REPORT-LONG-FINAL-VERSION%20.pdf [Accessed on: October 10. 2025].

59 Zemko (2025). *Ideme do protiútoku, vravia nemecké automobilky o súboji s Čínou. Čo ukázal autosalón v Mníchove.* https://e.dennikn.sk/4846224/ideme-do-protiutoku-vravia-nemecke-automobilky-o-suboji-s-cinskou-konkurenciou-co-ukazal-autosalon-v-mnichove/ [Accessed on: October 14, 2025].

Strategic consequences:

- The pace in SDV development globally is currently set by ***China and the U.S., both leading the frontier technologies.*** For ***EU*** carmakers, this may be a critical period as they ***risk losing market share in the SDV sector***, along with their edge in innovation, research and development, and ***leadership in shaping the overall future of mobility.***

- Global supply chain trends show a ***shift towards both decoupling and derisking***, driven by regionalisation and diversification. Decoupling would disrupt technology transfer and reinforce global inequality. It would also demand massive investments, political will, complex coordination, expertise[60] and time - making any kind of full split unlikely and more probable only as a gradual process over the years. Derisking can accelerate innovation in SDV-related fields like AI, OTA, or autonomous driving, and help strengthen key existing domestic EU capacities (e.g., in extreme ultraviolet lithography). However, this process also raises questions about the ownership and control of new "domesticated" SDV-related supply and value chains, since many investments (e.g., in mines or refining facilities) may come from non-EU sources.[61]

- Growing protectionism is pushing the automotive sector towards the ***"in the region for the region" model*** requiring local production, sometimes even development and software ecosystems. Local content regulations are mandating a certain share of ***locally produced components*** - which could include SDV-relevant components (e.g., sensors), software, or data processing - as part of the regionalisation of the automotive industry. While each region is building its own "digital stack sovereignty," the EU might be prioritizing security and strict standards, resulting in SDV software divergence, lower modularity, and/or increased overall (regional) compliance burdens (e.g., GDPR).

- A divide between the EU's industrial interests and its strategic security goals might reveal a ***lack of coherence between political and business priorities*** and lead to ***widening of the gap between geoeconomic, geopolitical and security approaches*** directly impacting the industry and SDV development and adoption.

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60 *Consider, for instance, that Chinese car maker BYD boasts around one million employees, supported by 11 major research institutes and 110,000 engineers. This allows the company to file some 32 patents daily.* Piston (2024). BYD Has Nearly One Million Employees and 110,000 Engineers. https://www.piston.my/2024/12/31/byd-has-nearly-one-million-employees-and-110000-engineers/ [Accessed on: October 22, 2025].

61 See, for instance Lobina, D. R. (2025). *In Estonia, a new rare-earth magnet plant powers Europe's green transition.* https://www.euronews.com/my-europe/2025/09/15/in-estonia-a-new-rare-earth-magnet-plant-powers-europes-green-transition [Accessed on: September 20, 2025].

3. EVOLVING CUSTOMERS AND CHANGING BUSINESS MODELS: NEW PRODUCTS AND PREFERENCES RE-SHAPE CONCEPTS AND STRUCTURES

Two possibly game-changing and mutually dependent phenomena will shape the automotive market in what we expect to become an SDV driven transformation: ***changing customer preferences and increasingly software-defined capabilities.***

Whereas in the past, automotive evolution was mostly driven by hardware mechanical engineering, material perfection and design development, the SDV-led car transformation will add a new layer: ***software, data and connectivity***, which can significantly redefine the understanding of car quality, appeal and safety.

Currently, the older generation (> 55) accounts for nearly half of all new car registrations, with the 35-54 age group representing slightly above 40%.[62] If these patterns continue, in the horizon of 2040, Millennials (1981 - 1996) will become a defining element of the market, followed by Gen Z (1997-2012). While their motivations and preferences may evolve over the next years, trends emerging among Millennials will likely remain fundamental: ***tech-savvy attitudes, and more environmentally cautious approaches***, with ***security, safety***[63] and the economy of cars remaining constant expectations.

Personalisation may become one of the key features of SDVs as they will be defined not only by (limited) hardware features, but also (practically unlimited) software add-ons. This will open a much broader scope of car adjustments and will make it easier to respond to demographic, generational, regional (including urban/rural), or socio-economic changes, preferences and divisions. An important question will be, whether software remains brand or car-group specific, or if an emerging trend of cross-industry software - brand-agnostic systems, universally adoptable by multiple carmakers - prevails.[64]

What will define SDV's quality and appeal? Traditionally, hardware related qualities, such as material, craftsmanship, performance, comfort, design and physical security were associated with top brands. In the market dominated by SDVs, ***attention can gradually shift towards hi-tech capabilities and software, cyber-and data security.*** The ability to provide this software-based-added-value may differentiate leaders from followers. Hi-tech newcomers to the SDV market can become the trendsetters and thus redefine the list of top-brands. Subsequently, the above-mentioned software integration models - closed-loop, open or limited models, and their region and/or brand focused variants, can become decisive for customer choice.

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62 *Between 2007 and 2017, a major shift occurred in who buys new cars in the US Half of those buying a new vehicle in 2017 were over the age of 55 compared with around 30 % in 2007. New car purchases by 35 to 54-year-olds have been decreasing from 50 % to 35 %.* Buchholz, K. (2019). *Older Americans Now Buy Majority of New Cars.* https://www.statista.com/chart/20048/us-buyers-of-new-car-by-age-group/ [Accessed on: November 2, 2025].
This trend has been confirmed also by later data: The share of new vehicle registrations by adults aged 18-34 has fallen from 12% in 2021 to below 10% in 2025. Adults aged 55+ now make up nearly half of all new registrations and have held the largest share for eight consecutive quarters, since Q2 2023. Jordhamo, J. (2025). *The vanishing young car buyer: New vehicle registrations drop for 18-34-year-olds.* https://www.spglobal.com/automotive-insights/en/blogs/2025/06/new-vehicle-registrations-drop-for-18-34-year-olds [Accessed on: November 2, 2025].

63 Olsson, L. E., Friman, M., Lättman, K. and Fujii, S. (2020). *Travel and life satisfaction - From Gen Z to the silent generation. Journal of Transport & Health.* Vol. 18. https://doi.org/10.1016/j.jth.2020.100894 [Accessed on: September 9, 2025].

64 *According to the RunSafe Security's 2025 Connected Car Cyber Safety & Security Index, concerns are especially high around AI-based features, with 85 % of surveyed drivers in U.S., UK and Germany saying that they would worry more if AI systems came from outside suppliers and 37% of drivers said they would switch to another brand if their preferred vehicle were found to be vulnerable to cyberattacks.* Shar, G. (2025). *Connected Car Cybersecurity Concerns AI & Performance Anxiety.* https://www.autoconnectedcar.com/2025/08/connected-car-cybersecurity-concerns-ai-performance-anxiety/ [Accessed on: November 2, 2025].

According to RunSafe Security's 2025 Connected Car Cyber Safety & Security Index, cybersecurity is becoming a defining factor in car-buying decisions. The survey of 2,000 drivers in Germany, the UK and the U.S. highlights a shift in consumer behaviour as cars evolve into SDVs. 87% of respondents consider cybersecurity a purchase driver, with 35% willing to pay a premium for enhanced protections. 70% would consider buying an older, less-connected vehicle to reduce risk. 79% of drivers prioritize physical safety over data privacy, and 76% worry that cyber intrusions could trigger accidents or put their lives in danger.[65]

A new approach to car ownership can revolutionise the market. While car ownership currently prevails[66] over other mobility modes, this ratio has been declining, and this trend can be further accelerated by cost and/or environmental impact concerns.[67] In addition, SDVs (especially autonomous ones) will make it easier to hire or share rather than own a car. Shift to Mobility-as-a-Service (MaaS) and Shared mobility, including peer-to-peer models (similar to AirBnB in house rental services) can accelerate, redefining customer preferences from product ownership to service usage and consequently redefining business models from product sales to providing services.

68% of Gen Z (1997-2012) still perceive personal vehicle ownership as valuable. It is notably lower compared to 90% of baby boomers (1946 - 1964), yet it signals that cars remain important for Gen Z. While main concerns shaping Gen Z car buying trends are financially driven, they are also more concerned with environmental impact than older generations, which is reflected in their willingness to pay a premium above the cost of a comparable ICE vehicle.[68] Private-car usage dominates today's overall mobility mix for older generations (77% among >45 years old), but this trend is changing in the younger generations (49% among 30-45 years old, and 42% among <30 years old).[69] However, a significant number of younger consumers in many markets are interested in giving up vehicle ownership altogether in favour of a subscription model.[70]

Besides demography, ***geography*** should be also considered. In the upcoming decades, high population growth is predicted primarily for sub-Saharan Africa, Middle East and North Africa (MENA) and South Asia.[71] At the same time, these regions are also projected to record above average economic growth.[72] The combination of a young population and economic growth potential makes these regions attractive future demand segments for SDVs. While a major breakthrough may not yet occur in the next decade,

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65 Idem.

66 *In 2024, 74% of people in the U.S. aged between 18 and 64 owned their vehicle.* Bunce, B. (2024). *Car ownership statistics 2025.* https://www.consumeraffairs.com/automotive/car-ownership-statistics.html [Accessed on: November 15, 2025]. *Likewise, 88% of Europeans still own a car in their household, but one in three European car owner could consider not having a personal car in the future.* Chandeze, E. (2023). *Mobility: one in three European car owner could consider not having a personal car in the future.* https://www.ipsos.com/en/mobility-one-three-european-car-owner-could-consider-not-having-personal-car-future [Accessed on: November 15, 2025].

67 *Changes in mobility habits in Europe were mainly triggered by two dimensions: environmental concerns, and cost. Two thirds of Europeans (64%) say they had to review their mobility habits due to inflation and fuel costs. The same proportion say that they have already changed their daily mobility habits to be greener.* Idem.

68 Urban Science (2024). *The Future of Automotive Sales: Adapting to Gen Z Car Buying Trends.* https://www.urbanscience.com/resources/future-automotive-sales-adapting-genz-car-buying-trends/ [Accessed on: December 7, 2025].

69 McKinsey & Company (2023). *Europe's Gen Z and the future of mobility.* https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/europes-gen-z-and-the-future-of-mobility [Accessed on: December 7, 2025].

70 Deloitte (2024). 2024 Global Automotive. https://www.deloitte.com/nl/en/Industries/automotive/perspectives/global-automotive-consumer-study.html [Accessed on: December 8, 2025].

71 UN (2024). *United Nations World Population Prospects 2024.* https://www.un.org/development/desa/pd/world-population-prospects-2024 [Accessed on: December 8, 2025].

72 IMF (2025). *IMF World Economic Outlook October 2025.* https://www.imf.org/en/publications/weo/issues/2025/10/14/world-economic-outlook-october-2025 [Accessed on: December 8, 2025].

due to economic limitations, this period could be strategically important for preparing expansion into these markets - if more affordable, low-cost SDV models are developed. Given the relatively low current economic level and the dominance of younger consumers, vehicle price and overall lifetime costs are likely to be a decisive factor in gaining dominant market share in these regions.

Growing SDV dominance on the markets may also require ***new or adapted internal organizational structures and procedures*** - "ways of doing things." Software and particularly AI integration will make innovation cycles much faster. If they want to stay competitive in the AI and SDV race, European legacy automakers need to accelerate their transitions.[73] Chinese automakers are emerging as the driving force behind the sector's worldwide transformation, setting new standards for speed, efficiency, and innovation.[74] Focus on agility and cost needs to be at the centre of response to transformation,[75] in which SDVs represent a challenge for legacy carmakers, but should also be seen as an opportunity to catch up with new competitors.

New business opportunities - ***service-oriented and software-centred*** - will enable new revenue streams, such as subscriptions for advanced features, remote diagnostics, and data-driven mobility services. Fully harnessing these opportunities will also require new organizational structures - from development and design, through production, to marketing and sales. Consequently, new products and services may emerge, not directly linked to driving but stemming from a huge amount of data collected by SDVs. Data itself will become a product.

According to McKinsey estimates the global automotive software and electronics market is expected to reach $462 billion by 2030, representing a 5.5 % CAGR from 2019 to 2030, outpacing the overall automotive market growth - the market for passenger cars and light commercial vehicles (LCVs) is projected to grow at a 1% CAGR in the same period.[76]

73 Jones, L. (2025). *European automakers need to act fast to stay competitive in the AI race.* https://www.autonews.com/technology/ane-europe-automakers-ai-trail-china-investment-0612/ [Accessed on: December 3, 2025].

74 Dyer, S., Zhang, Y. (2025). *AlixPartners 2025 Global Automotive Outlook: China's "New Operating Model" Redefines Speed, Efficiency, and Market Leadership in Automotive Industry Amid Accelerating disruptions.* https://www.alixpartners.com/newsroom/2025-alixpartners-global-automotive-outlook-china/ [Accessed on: December 4, 2025].

75 Wakefield, M. Bergbaum, A. (2025). *With disruptions increasingly frequent, a new operating model focused on agility and cost is needed to survive and prosper in the increasingly competitive auto market, says AlixPartners outlook.* https://www.alixpartners.com/newsroom/2025-alixpartners-global-automotive-outlook/ [Accessed on: December 4, 2025].

76 Burkacky, O. et al. (2023). *Outlook on the automotive software and electronics market through 2030.* https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/mapping-the-automotive-software-and-electronics-landscape-through-2030 [Accessed on: December 5, 2025].

Strategic consequences:

- ***Shift in value creation.*** Businesses will need to adapt to new conditions in which software will account for a growing share of vehicle's value, while also shifting the vehicle's functions beyond mobility, into the realm of services. At the same time, these services and the data they generate will create a new source of revenue and business opportunities, though capturing that value will hinge on product design, regulatory compliance and security.

- ***Longevity, value and lifecycle costs of cars.*** The relationship between vehicle hardware and software is reshaping how long cars remain valuable and usable. Currently, electric vehicles (EVs) tend to depreciate faster than their gasoline counterparts, which poses a challenge to the EV business model. SDVs offer a potential remedy by extending the lifespan and maintaining the value of cars through over-the-air (OTA) updates that improve performance, safety, and user experience over time. However, this advantage can backfire. If software updates become costly or technologically demanding, they may increase overall lifecycle costs and create compatibility or software obsolescence issues, forcing owners to replace vehicles more frequently. For OTA updates to be part of the solution, instead of another problem, they must remain affordable, reliable, and technologically sustainable.

- ***Software and data control.*** SDV transformation will bring forward a strategic question: who will collect the SDV-generated data - OEMs or software companies? And ultimately, who will produce and control the software - OEMs themselves, or outsourced software companies? Cybersecurity in automotive will become a whole new domain. This can result in the ecosystem transformation: a new competition between traditional OEMs and software-driven entrants or creation of strategic partnerships between OEMs, software companies, cloud and cybersecurity providers and the entry of tech giants into mobility and automotive platforms.

4. KEY TECHNOLOGIES DEVELOPMENT: AI, OTA, AUTONOMOUS

The development of SDVs is being shaped by three key technological vectors: ***artificial intelligence (AI), over-the-air (OTA) connectivity and updates***, and ***autonomous driving.*** These are interlinked and could collectively be considered key ***"enablers"*** and/or ***"enhancers"*** of the SDV and SDV-led digital transformation in the automotive industry. These technologies enable and/or enhance capabilities unique to SDVs, making cars not just transport devices but adaptive, intelligent platforms.

AI can be seen as the most decisive and impactful enabler, making not only all phases of vehicle development and production faster and more efficient (e.g., using virtualization or digital twins), but also ***dramatically changing capabilities of the vehicle itself*** - in terms of real-time decision-making, advanced automation, traffic and accident management, predictive maintenance, cybersecurity, or almost limitless in-vehicle personalization. Machine learning allows continuous improvement, while edge AI ensures real-time processing in safety-critical contexts. Usage of various AI enhanced, extended or enabled capacities, however, also brings questions of sustainability, accountability,[77] and ***protection of individual privacy*** (with enhanced surveillance potential).

While it is hard to calculate exactly how much data will be produced and how much electricity will be needed by and for the SDVs specifically, various predictions suggest substantial growth in both areas for EVs[78] and autonomous vehicles.[79] Data centres in the U.S. used around 200 terawatt-hours of electricity in 2024. AI-specific servers within these data centres are estimated to have used between 53 and 76 terawatt-hours. By 2028, the power going to AI-specific purposes is expected to rise to 165-326 terawatt-hours per year. Apart from the need to generate such extra power, this also raises questions regarding sustainability, as it could generate massive amounts of emissions.[80]

OTA updates will redefine the vehicle lifecycle. Secure, agile and practically continuous deployment of both safety-critical and user-centric features extends value, permits adaptability, reduces recalls, and introduces new business models such as subscription-based services. Combined with V2X connectivity, OTA also supports cooperative driving and real-time traffic management, embedding SDVs into broader mobility ecosystems. However, as cars are not smartphones in terms of an average lifecycle, hardware limitations or cybersecurity breaches impacting functionality over the whole SDV lifecycle (circa 15 years) regarding OTA updates might present a severe limitation.

77 See, for instance CNN (2025). *Tesla ordered by Florida jury to pay $329 million in Autopilot crash.* https://edition.cnn.com/2025/08/01/business/tesla-autopilot-crash-lawsuit [Accessed on November 4, 2025].

78 Spencer, T., Singh, S. (2024). *What the data centre and AI boom could mean for the energy sector.* https://www.iea.org/commentaries/what-the-data-centre-and-ai-boom-could-mean-for-the-energy-sector [Accessed on November 4, 2025].

79 Peterson, P. (2020). *Autonomous Cars as a New Generation of Data Center Requirements.* https://www.colocationamerica.com/blog/data-centers-and-autonomous-cars [Accessed on November 4, 2025].

80 O'Donnell, J., Crownhart, C. (2025). https://www.technologyreview.com/2025/05/20/1116327/ai-energy-usage-climate-footprint-big-tech/ [Accessed on November 4, 2025].

Autonomous driving represents the most visible transformation. It relies on AI-driven perception and decision-making, advanced sensor fusion (lidars, radars, cameras), and massive computing power. OTA updates also enable constant improvements. It is scalable and can be deployed on various levels, allowing for gradual and/or more targeted advancements and applications. Features like Automatic Emergency Braking (AEB) and Advanced Driver Assistance Systems (ADAS) are becoming a standard in all new vehicles. AEB is already mandated in the EU for all vehicles[81] (and in the U.S. after 2029[82] for all new light-duty vehicles).[83]

China is the leader in autonomous vehicle testing, operating more driverless cars (across 16 cities) than any other country. Its robotaxis are often cheaper than human-driven rides, supported by national regulations for deployment. Beyond the self-driving revolution taking place in the U.S. and China, European startups like Wayve are beginning to gain traction in the industry.[84]

The development, production and usage/integration of SDVs, however, depends on a robust enabling ecosystem: advanced hardware (semiconductors and chips, antennas, actuators, and sensors such as lidars, radars, or cameras) available in necessary quantity, quality, time and price; reliable telecom infrastructure (5G/6G coverage, satellite networks); advanced and robust cloud services; and large-scale data centres (requiring vast amounts of electricity). These ***form the backbone of real-time decision-making, OTA updates, and AI-driven autonomy.*** Enabling regulation is yet another critical factor encompassing development, production and application in all aforementioned areas, with ***setbacks in one area potentially spilling over and resulting in setbacks in other(s).***

These new technologies and capabilities also introduce ***new vulnerabilities. Industrial espionage***, especially around autonomous technologies, is a growing concern, with direct implications for national security. The ***dual-use potential*** of SDV technologies in defence and security applications highlights the strategic value of R&D in this sector - an area where some OEMs already leverage prior defence industry experience.

In sum, the convergence of AI, OTA, and autonomy enabling SDVs existence and usage, is itself enabled by centralized architectures, powerful computing, and robust connectivity. These technologies do not simply upgrade vehicles - they redefine them into ***software-first, adaptive, and security-sensitive platforms***, reshaping industry dynamics, global competitiveness, and societal frameworks alike. The digital revolution in the automotive industry rests on developments in these areas.

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81 European Commission (2019). *Road safety: Commission welcomes agreement on new EU rules to help save lives.* https://ec.europa.eu/commission/presscorner/detail/en/ip_19_1793 and Wood, I. (2024). *New EU safety regulations mandate the use of ADAS.* [Accessed on November 4, 2025]. https://www.autonomousvehicleinternational.com/news/legislation/new-eu-safety-regulations-mandatethe-use-of-adas.html [Accessed on November 4, 2025].

82 NHTSA (2024). *NHTSA Finalizes Key Safety Rule to Reduce Crashes and Save Lives.* https://www.nhtsa.gov/press-releases/nhtsa-fmvss-127-automatic-emergency-braking-reduce-crashes [Accessed on November 4, 2025].

83 Goodson, J. (2025). *How AI and automation are changing our driving experience.* https://www.weforum.org/stories/2025/08/how-ai-and-automation-are-changing-our-driving-experience/ [Accessed on November 4, 2025].

84 Nestor M. et al. (2025). *The AI Index 2025 Annual Report, AI Index Steering Committee, Institute for Human-Centered AI, Stanford University, Stanford, CA,* https://doi.org/10.48550/arXiv.2504.07139 [Accessed on: December 4, 2025].

Strategic consequences:

- As SDVs development and application requires advancement of the aforementioned technologies, relevant laws and regulations (e.g., permitting testing of autonomous driving) might create ***significant differences between regions*** and countries, resulting in a fragmented market.

- Enablers of software will require massive energy supply, e.g. to power data centres. The growing pursuit of ***energy security and/or self-sufficiency*** and strategic policy alignment in this field will become critical.

- With accelerated adoption of ever new (and more advanced) tech, the purchase ***price*** as well as ***maintenance costs might rise*** which will in turn impact customer decisions. SDVs, as EVs, may also require repairs that need multiple additional labour hours compared to ICE vehicles, resulting in 30% higher labour costs on average (data for 2024).[85]

- OTA updates are still (relatively) slow to complete, endangering the practical usability of SDVs. Nevertheless, when this issue is solved and OTA updates prove to be adding new value to an aging hardware (vehicle), they might help ***shrink the market for new cars.*** Effective ***long-term OTA updates*** might help slow down fast depreciation of new vehicles.

- As ***road traffic crashes*** kill over a million people each year (and injure 20-50 million more[86]), ***pressure*** on introducing new technologies designed ***to help drivers avoid accidents*** or reduce their severity ***will mount***, especially, in urban and congested areas and lower-speed environments, leading to higher levels of autonomy (as research indicates that autonomous cars may be significantly safer than human-driven ones).[87] However, as more autonomy requires more robust and advanced (and thus more expensive) systems as well as complex regulation, the mass market might stabilize at a partially rolled-back lower levels of autonomy (e.g., Level 2 Plus or Plus Plus).

- Wider ***application of SDVs will require sufficient energy/electricity supply*** (especially for the data centres) and appropriate ***energy infrastructure.*** Difficulties in these fields might negatively impact the SDV market. Different circumstances in respect to energy and infrastructure availability might also result in significant regional differences regarding SDV development, production and/or application.

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85 Krumlauf K., Bahnsen, E. (2025). *The Forces Shaping the U.S. Car Parc in 2025 and Beyond.* https://www.cccis.com/reports/crash-course-2025/q1 [Accessed on November 4, 2025]. Goodson, J. (2025). How AI and automation are changing our driving experience https://www.weforum.org/stories/2025/08/how-ai-and-automation-are-changing-our-driving-experience/ [Accessed on November 4, 2025].

86 CDC (2025). *Global Road Safety.* https://www.cdc.gov/transportation-safety/global/index.html [Accessed on November 4, 2025].

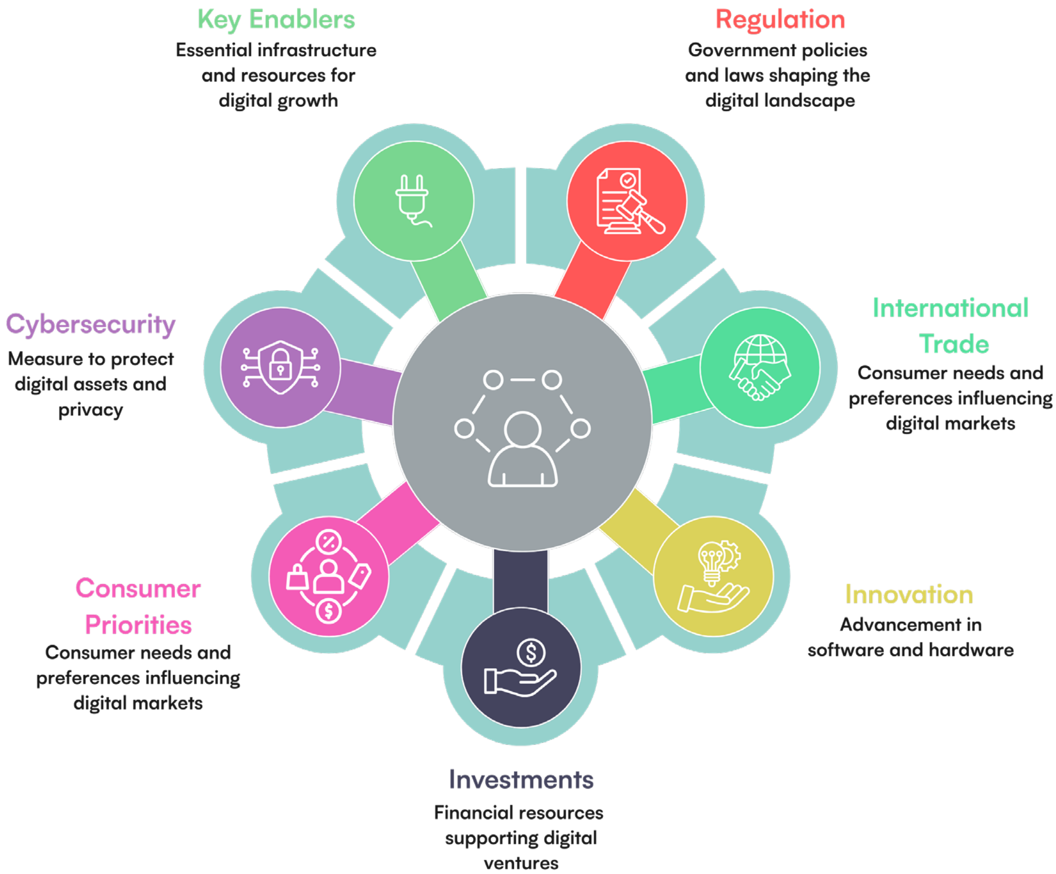
87 See Artificial Intelligence Index Report 2025, available online at: https://hai.stanford.edu/assets/files/hai_ai_index_report_2025.pdf [Accessed on November 4, 2025].

Scenarios

The scenarios presented in this chapter were developed by using the Royal Dutch Shell/Global Business Network (GBN) matrix approach.[88] Based on the preceding phases of this research, the scope of ***SDV adoption*** and the ***consumer attitudes*** towards SDVs were chosen as the two key dimensions of uncertainty, which then served as the main axis of the 2x2 matrix.

Consumer attitudes define the demand for vehicles with certain qualities and functions. Whereas "progressive" attitudes seek out software-centred functions and features, "conservative" ones gravitate towards hardware-centred qualities - with costs and reliability also being high priorities. ***Adoption*** is understood as the relative share of SDVs on the road, not their absolute number.

The four resulting combinations were elaborated into four comprehensive scenarios by reflecting upon ***seven core variables:*** regulation; international trade; software and hardware innovation; available investments (from third parties, joint ventures, or in-house); consumer priorities, attitudes, and purchasing power; (cyber)security, including reliability, safety, privacy, and freedom; and key enablers such as energy, data centres, infrastructure, and connectivity.



The resulting scenarios are constructed as descriptive and exploratory.[89] They are not normative, as they do not suggest the most probable or preferred future, however, ***public and private stakeholders*** can reflect on them normatively within their particular setting. The scenarios are not predictions - they explore alternative, plausible futures. In reality, these trajectories can be mutually non-exclusive: the future will likely blend elements of multiple scenarios, unfold differently across different regions, countries or continents or even shift from one pathway to another over time. The goal is to provide a

88 Bishop, P., Hines, A., T. Collins (2007). *The current state of scenario development: an overview of techniques. Foresight.* Vol. 9, No. 1, pp. 5-25.

89 Van Notten et al. (2003). *An updated scenario typology. Futures.* Vol. 35, No. 5, pp. 423-443. https://doi.org/10.1016/S0016-3287(02)00090-3 [Accessed on: December 2, 2025].

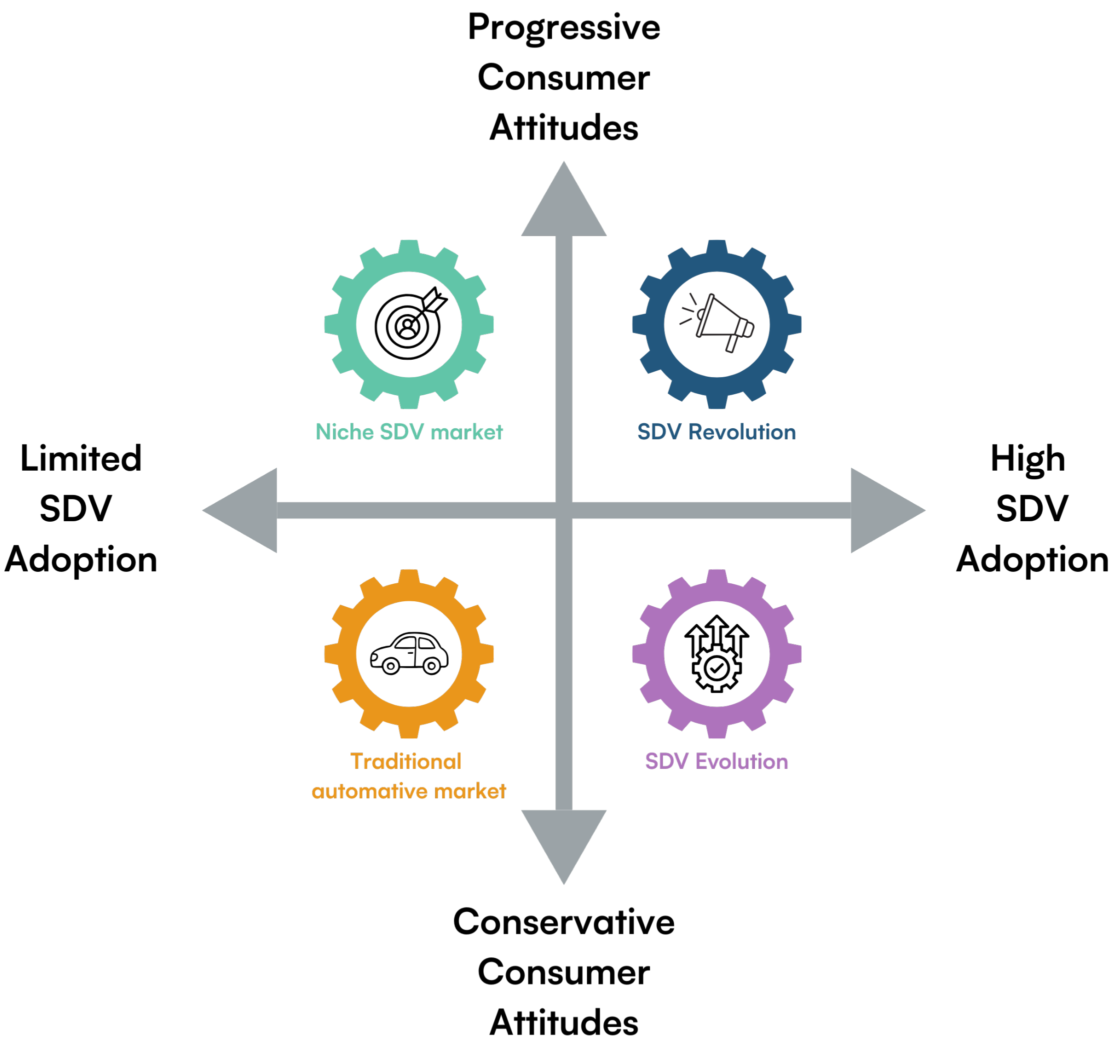
benchmark for testing the assumptions, policy-planning and strategy development - the most robust will be those assumptions, plans or strategies that will withstand, ideally, across all scenarios.

Although the scenarios primarily stem from current realities observed and analysed in Slovakia and the EU, they are deliberately framed in more abstract terms to retain global relevance; however, applying them to country-specific contexts would require further adaptation and narrowed-down focus. The time horizon for the scenarios was set for 2040.

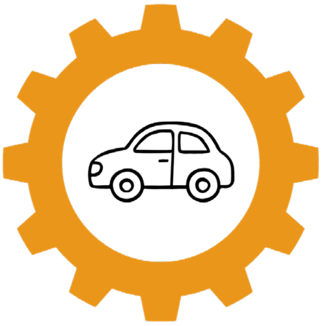
Two observations could be highlighted:

Firstly, while the dominant assumption today is that the automotive sector will follow linearly towards an SDV-driven future - possibly even an SDV "revolution" in which societies prosper economically and technologically - there are a number of reasons why such ***linear progress may not materialize.***

Secondly, even in the ***"revolutionary"*** scenario where we assume economic and technological progress and related ***benefits***, certain ***risks*** (such as excessive privacy intrusions, remote control or over-surveillance), might indeed not only persist but rise - perhaps unintentionally or largely unknowingly - with potentially major impacts on individual rights, freedoms, or security, both individual and national.



1. TRADITIONAL AUTOMOTIVE MARKET



Contrary to all expectations, SDVs have not become the defining architecture of the automotive market. Instead, adoption is limited to a very narrow segment of customers. For the vast majority of consumers and regions, traditional (non-SDV) cars remain the preferred option. The SDV transformation stalls, constrained by compounding failures in technology, regulation, economy, security, and public trust.

Real-world ***failures*** multiplied as SDVs faced increasing risks from software-hardware mismatches, lengthy or faulty OTA updates, and security breaches. These issues may disable safety-critical features - doors, windows, steering, accelerating, braking - while growing interdependencies amplify the likelihood of cascading system failures. Highly publicized incidents such as autonomous-driving crashes, misinterpretation of sensor data, or remote hacking attempts all spread virally on social media.

Such events cement an ***atmosphere of fear and uncertainty.*** Consumers begin to perceive SDVs not as necessary or attractive futuristic mobility but as often faulty and dysfunctional tools, and as potential physical or privacy threats under remote control. Physical safety and personal cybersecurity become tightly linked in public consciousness.

Following several high-profile SDV failures and autonomy-related fatalities, SDVs are being politicized and governments impose stringent ***regulations.*** These measures create a regulatory chokehold: compliance costs surge, many manufacturers withdraw from the SDV "race", and the remaining models are largely costly luxury products. As a result, the mass market reverts to cheaper, simpler, smaller, and minimally connected vehicles - essentially, non-SDVs. The market with older, ***second-hand cars*** also experiences significant growth.

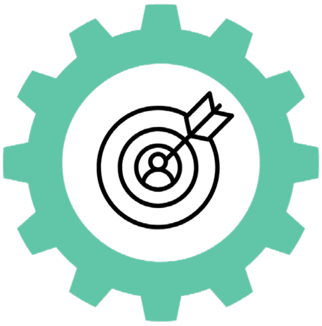
Public opinion turns against SDVs. Buyers prioritize mechanical/hardware reliability, privacy, control, and affordability over endless software features and automation. "Take back control of your car" becomes a successful political and marketing slogan. Public demand for non-connected cars surges, and OEMs quickly respond. SDVs, once marketed as the "smartphone on wheels," become associated with unwanted surveillance, unnecessary complications, and vulnerability to digital coercion or remote shutdown.

Geoeconomic fragmentation also chokes the foundations of the SDV transition. Protectionism fractures supply chains, export controls restrict access to critical chips and sensors, and key technologies become prohibitively costly or unavailable. Political limits on Big Tech drags down app ecosystems and cloud services, while talent shortages leave OEMs without the software and security expertise needed to sustain SDV development.

Slow progress in the physical and digital infrastructure with old power grids and a lack of data centres as well as fast charging network makes SDV adoption even harder. SDVs are more expensive than non-SDV cars because they rely on costly parts (chips, sensors, and software). For developing countries and lower-income buyers, these vehicles are simply too expensive to afford.

Faced with ***rising costs*** and ***declining trust***, automakers reduce OTA reliance, reinstate mechanical controls, abandon higher autonomy, and focus on durability and reparability. Marketing shifts to topics of "mechanical reliability, privacy, control, and zero hacking risk". Traditional, low-connectivity cars are the stable, secure default for most.

2. NICHE SDV MARKET



Consumers overwhelmingly value software-driven mobility. Most buyers - especially upper-class Millennials, Gen Z and Alpha living in cities - prioritize connectivity, advanced autonomous functions, software personalization, predictive maintenance, and continuous upgrades. These new priorities are complemented by traditional vehicle attributes such as price, design or durability. SDVs are now accepted and desired. Yet their actual adoption remains limited with only a minority share of the market. Rural, low-income, and middle-income segments continue to rely on traditional vehicles. Strained public budgets limit fiscal support for autonomous vehicles and fleets. ***Demand exists, but several (systemic) constraints prevent mass adoption.***

Developing and producing SDVs proves far more ***complex and expensive*** than anticipated. Software development, integration with advanced hardware, cybersecurity solutions, verification pipelines for OTA updates and multitude of safety-critical functions all demand massive investments, simulation environments and large specialized teams. Regional regulatory differences and uneven adoption force OEMs to maintain modular platforms, architectures and multiple software baselines. Car makers are chasing higher margins to achieve returns on their investments, ***pricing SDVs as premium products***, creating regional, generational and socio-economic splits.

While consumers expect rapid software iteration, ***OEMs face slower-moving realities*** such as mounting (safety and security) regulations, requiring lengthy validations for updates, especially considering hacking incidents. Car makers accumulate technical debt while trying to support both legacy platforms and new SDV architectures. As a result, promised features are rolling out slowly ***undermining early expectations of fast innovation.*** Pressure mounts and technology (adopted and integrated) often shows signs of prematurity, leaving customers dissatisfied.

Moreover, akin to challenges faced by the EVs earlier, SDV roll-out is constrained by ***missing*** data ***infrastructure*** and charging ***networks***. Network coverage limits practical use especially in rural regions, but often in dense urban regions alike, making updates, autonomy, and various real-time functions unreliable. High-performance chips and other advanced components remain supply bottlenecks due to prevailing high geoeconomic and geopolitical tensions.

As a result of concurrence of these factors, small, practical, relatively simple and - most importantly - widely affordable SDVs are practically missing on the market. On the other side of the spectrum, after initial excitement, customers become disinterested and unwilling to buy top-tier high performance SDVs (supercars), especially those without combustion engines, prioritizing mechanical feeling, driving experience and control, as well as hardware-centred qualities. The niche market primarily consists of the upper-middle class (where SDVs is often a second family car) but also includes company fleets in specific sectors such as city taxis or last-mile delivery.

In sum, by 2040, an established customer base - if not outright enthusiastic - is willing to buy an SDV, desiring various functions, features and capabilities they offer. However, the SDV market remains niche due to the abovementioned barriers.

3. SDV EVOLUTION

SDVs have become the mainstream automotive architecture, yet their integration into society follows a cautious, evolutionary trajectory.

Developments are to a large extent ***policy and legislation driven*** - there are numerous incentives for the governments to foster SDV environment (improvement of road safety, geoeconomic competitiveness, environmental concerns, innovation support, data-based control and transportation governance). That is why the legislator supports SDV adoption either directly (regulation demanding features effectively applicable only in SDVs) or indirectly (providing subsidies or raising standards).

Further incentives come from the ***economy.*** Government support, innovations and scaling of production bring SDV prices down significantly, making them a strongly competitive option to traditional vehicles. They are also more suitable for new forms of car use beyond ownership - Mobility-as-a-Service (MaaS) or shared mobility. Insurance incentives play a powerful role: real-time telemetry and driver-assistance systems drastically reduce accident frequency, making non-SDV vehicles more expensive to insure. Strong momentum comes from large fleet operators - logistics firms, public transportation, or corporate mobility providers. Labour shortages and pressure for operational optimization accelerate SDV adoption.

However, public attitudes towards ***SDVs remain cautious.*** Customers balance security and privacy concerns with clear benefits - safer roads, fewer breakdowns, easier maintenance, entertainment and services. These benefits, together with policy, legislative and economic incentives, lead to incremental progress that, in the longer-term, results in growing dominance of SDVs on the roads.

To mitigate customer's concerns and prejudices, legislators emphasize control, cybersecurity resilience, and minimization of systemic risks. Controversies around autonomy and data use lead to a ***"precautionary modernization"*** approach. Governments mandate strict certifications for vehicle software and its cybersecurity. Rather than encouraging fully driverless use, legal frameworks prioritize human-in-the-loop operation. Level 4 and Level 5 autonomous capabilities are allowed only in very few geo-fenced corridors and mostly serve for experimental purposes, while the mass market stabilizes at Level 2 and Level 3 autonomy (with Level 2+ and 2++ capturing the most of it). "Kill-switch" features are introduced to turn-out non-essential SDV features by more conservative customers.

Innovation continues, but only within well-defined guardrails. To comply with stringent regulation, the industry converges towards a small set of certified SDV hardware-software stacks. These ensure interoperability and reduce risks, yet slow down experimentation and limit seamless usage, integration and virtually endless personalization of SDVs. SDV platforms become robust, modular, and upgradeable, but innovation focuses on incremental improvements desired by still conservative customers, rather than expanding radical new features.

The ***market remains fragile*** as social and political pressures call for loosening legislation and restoring customer choice and control over their vehicles. Automotive companies and governments are running extensive communication campaigns to make the progress toward SDVs irreversible, yet significant risks persist. Because this future is driven largely by policy and regulation, these areas represent the most likely sources of potential major disruption.

4. SDV REVOLUTION

SDVs are not a novelty anymore - they are a ubiquity. The ***enabling conditions*** are aligned: rapid innovation and advances in AI, dense data centres network supplied by sufficient electric energy, near-universal 6G connectivity, high-capacity charging infrastructure, and mature cybersecurity frameworks. Supply and value chains are stabilized, ensuring access to required materials and components with innovation providing workaround when necessary. Government incentives, public-private joint ventures, and major third-party investment accelerate not only vehicle production, but also software ecosystems that give SDVs their defining value, and invoke sales on a large scale.

The ***regulatory environment*** proves decisive. States enable and incentivize innovation clusters and testing, and ease structural pressures on the car industry, allowing for higher margins and thus more investments, while also mandating strong safety, reliability, and privacy protections. Fleet operators benefit from harmonized cross-border protocols, allowing autonomous SDVs to operate seamlessly across regions. For individuals, new, expert and independent verification and certification frameworks guarantee that software updates, AI driving models, and third-party applications meet rigorous oversight standards. Regulators also demand zero-trust cybersecurity layers, so SDVs can detect anomalous behaviour - physical or digital - within milliseconds. This is achieved with some, but very limited negative effect on SDV's seamless functionality.

The ***customer base*** evolves just as quickly. The shift towards valuing software capabilities becomes widespread across generations and geographies. Most customers also change their approach to vehicle usage and ownership. Rural families embrace SDVs for automated commuting, remote charging assistance, and improved safety in isolated areas. Urban professionals treat their vehicles as "third spaces": mobile offices in the morning, shareable commodities used for profit-making during the day, wellness pods in the evening, entertainment hubs on weekends. For many, SDVs are personalized sanctuaries in a new era of mobility, adapting lighting, temperature, scent, and interior configurations based on the user's (digital) profile. Mobility-as-a-Service (MaaS) expands into an "Airbnb for cars," where autonomous SDVs reposition themselves for rentals, guest settings load automatically, and payment is frictionless. Autonomous SDVs perform various tasks in tourism, agriculture, logistics and industrial operations and services, including taxi, public transportation, or middle-mile delivery.

Purchase power varies, but the market is well adapted. All customers find what they want and need: from small, light and relatively simple and cheap SDVs to ultra-luxury SDV-SUVs or high-performance SDV-hypercars. Besides hardware variations, entry-level SDVs offer modular software subscriptions - customers can buy a basic (physical) platform and then selectively activate functions: advanced autonomy, extended range, or premium entertainment such as immersive mixed-reality cabins and biometric personalization. The total cost of ownership drops thanks to predictive maintenance and ultra-efficient routing. Fatal road accidents occurrence drops significantly.

Cybersecurity and safety remain central societal concerns, yet trust grows as systems repeatedly prove resilient. Substantial investments bring returns in terms of customer trust and willingness to pay extra for safety and security measures. The vast majority accepts at least a partial trade-off between data and privacy and seeks convenience and capabilities of SDVs. Regulation ensures continuous expert verification and transparency. National security agencies, on the other hand, appreciate the encrypted telemetry streams and standardized emergency-override protocols that, for instance, make coordinated responses to crises easier.

(!) Persistent Risks

Despite economic progress and substantial technological advances, driven by SDV revolution, minimizing risks for consumers, vulnerabilities in connected mobility systems (SDVs) ***can never be fully eradicated****, leaving openings for misuse, exploitation, (remote) control, surveillance, and even espionage by national security agencies, hostile states, skilled hacker groups, terrorists, or private militaries -* ***especially*** *through* ***remote-control exploits during crises, conflicts and wars.*** *Even SDVs that are disconnected from the network can be hacked. Ironically, the small minority of analogue vehicles that might remain in service, largely vintage models or machines designed for remote or hostile environments, can now become strategic assets: their lack of connectivity shields them from systemwide cyberattacks and provides governments and private operators with a resilient backup layer. In emergencies, these vehicles might create an independent mobility network that complements the SDV ecosystem. In sum, in this variation (or rather an outcome, whether intentional or not) of the SDV revolution scenario, although economic indicators such as supply-demand balance and innovation trajectories look strong (and legacy OEMs have even caught up with or leapfrogged newcomers) the overall vulnerabilities and risks to individual freedoms, rights, and national security might have actually intensified.*

Conclusion: Recommendations

PUBLIC STAKEHOLDERS AND POLICYMAKERS:

- To ensure competitive edge and profitability for the industry, ***invest into key enablers (energy, telecom and charging infrastructure, AI, advanced hardware, cloud services, and data centres)***, not all new supply and value chains. Amid fierce global competition, focus should be put on enablers and enabling factors that will stimulate rather than regulate the market.

- As the main structural difference between the EU and Chinese manufacturers remains the costs of development, production, or even usage of vehicles, ***easing the regulatory pressures*** that lead to such "extra" costs in various sectors of economy (e.g., energy, labour, tax frameworks, emission standards, etc.) becomes equally critical.

- ***Fund SDV-relevant R&D, innovation clusters and test centres*** to allow for effective testing of new technologies and solutions before application (both hardware and software). Countries that will create best conditions for testing and experimenting in real world conditions might champion the digital transition brought by SDVs.

- ***Adopt multidisciplinary approach*** to automotive industry and SDVs, taking into account their ***new capabilities*** and thus a larger socio-economic and ***security*** (even defence) ***context, risks and implications*** beyond technical, technology and/or managerial/economic terms. Experts beyond traditional automotive-related fields should participate on the formation of new regulations and policies impacting SDVs aiming to balance out safety and security with innovation and progress.

- ***Adjust education*** of the future workforce (requiring new skills relevant for SDVs), but also of the SDV users (drivers) that will require ***new skills to use and operate the vehicles safely.*** Driving schools should also reflect on the changing nature of vehicles, incorporating new tools and methods to teach driving skills as well as other skills required for safe operation of the SDV (including privacy settings). ***Workshops and trainings*** should be required especially for the state employees or drivers of VIP personnel to address SDVs new capabilities and vulnerabilities. This is especially relevant given that many cybersecurity or data security risks rest on the human factor (i.e., exploiting human error).

- Create a system of ***independent and credible*** (expert) third-party verification ***mechanisms*** when it comes to vehicle ***cybersecurity*** and complex SDV-specific safety.

- ***Build strategic alliances*** with third states, such as South Korea or the US to learn ***best practices, pool resources*** in development (investing, creating partnerships or even joint ventures), or ***diversify the supply chains.*** Governments should play an active role in terms of economic diplomacy while investing in the domestic value-added capabilities to attract foreign partners. Such cooperation might include areas like software platforms, integration of infotainment and digital-cockpit features, AI services, reliable cloud back-end and global data-centre ties, autonomous driving technology, but also semiconductors.

- Support ***local content regulations relevant for SDVs:*** mandating local (EU) development, production and sourcing of key components such as sensors and actuators (for both economic and security reasons). Niche, specialized capabilities should be utilized.

- Governments should ***enable creative destruction in the industry.*** Fighting for survival of those that are non-competitive on the market will lead to a spiral of worsening public finances, economic health, and industry competitiveness.

PRIVATE ENTITIES AND DECISION-MAKERS:

- Expect volatile ***consumer preferences*** and attitudes, and ***regional disparities.*** Strategies for domestic and export markets will differ. Some (rising) export markets such as South Asia, sub-Saharan Africa, or MENA region, might see a growing rise of ***demand, primarily for simple and affordable SDVs.***

- Expect ***service-oriented*** and ***software-centred*** future (revenue streams). Complex mobility solutions and services will shape the future of the car industry. Cars may become a shareable commodity with potential to ***maximize*** not only ***comfort and specific personal preferences*** but also ***profit.***

- ***Focus should be spread over "traditional" qualities*** such as price, overall vehicle safety and security, longevity and life-cycle costs, reliability and design ***supplemented*** with new, software-enabled or enhanced features and qualities as top priorities. Neglecting any such priority poses a risk. A combination of hardware and software, as well as technology and technical qualities also gives potential edge to legacy OEMs with rich experience and heritage.

- ***Aim to leapfrog*** the first generation of SDVs to be competitive in the future and save resources. Software solutions can be (re)developed relatively quickly. Also, the newcomers in the car industry have attained the technological frontier relatively fast, but their ***development cycles*** might become longer in the future.

- ***Prioritize safety, reliability and trustworthiness*** over seamless use and/or number of tech features. ***New tech features should not come at the expense of safety, reliability, and trust.*** Security, privacy and freedom should lie in the centre of human-focused development and technology application.

- Prepare for ***regionalism and protectionism,*** bolstering local supply and value chains, adopting/strengthening in-region-for-region strategy. Consider strategic stockpiling of key components or materials.

- ***Embed vehicle (cyber)security and functionality in crisis, emergency and disruptive environments from the onset (development phase).*** Adopt an approach where everything can be hacked. Moreover, hacking attempts will likely rise with the number of (potential) targets, meaning that once SDVs become mainstream, hacking (involving remote control/operation, data control) will become worthwhile for various actors, including state entities.

- Follow strategies that ***balance exploiting*** existing strengths (tradition, heritage, customer base, hardware know-how, etc.) with ***exploring*** new technologies, approaches and processes (software-cantered). This is especially relevant for legacy OEMs facing multiple pressures, including ones on internal organizational changes. Exploration without exploitation carries a risk of losing existing base and strengths, while exploitation without exploration risks becoming obsolete and quickly falling behind competitors.

- ***Lobby for enabling structural factors for growth to be in place; do not rely on public subsidies and public incentive schemes.*** Building strategy and success on (expected) subsidies will not be sustainable as it is only a short-term solution at best; long-term success requires costs reduction and innovation. Purchase subsidies also help sustain fast depreciation of new vehicles, including SDVs.

- While battling high development and production costs through cost-saving strategies, ***avoid over-reliance on third-party technology*** with serious potential mid-term disadvantages (losing the competitive edge, as well as distinguishable uniqueness).

- ***Prepare for a market*** where ***advanced tech solutions*** can be accompanied by a rising demand for ***analogue solutions or back-ups*** to SDV-related risks.

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