P3 X KELRIDE

APPLICATION SCENARIOS FOR AUTONOMOUS TRANSPORTATION

Economic limitations of highly automated shuttle services and possible solutions for a profitable scaling of the auton-omous mobility landscape

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Summary

Autonomous mobility has seen growing importance across Germany and Europe in recent years, even though the field largely remains in the conceptual phase. Germany, in particular, implemented a comprehensive regulatory framework at an early stage compared to other countries, laying the groundwork for the safe and structured deployment of autonomous mobility initiatives. While technological challenges continue to dominate the discourse, the underlying assumption of economic viability for emerging mobility solutions is rarely scrutinized. Financial metrics remain opaque—both to external observers and project stakeholders.

This study draws on direct participation in a pilot project funded by the German Federal Government, operating within Europe's largest contiguous service area for highly automated shuttles. Combined with expert interviews involving key stakeholders, a holistic Total Cost of Ownership (TCO) analysis has been developed. The analysis disaggregates costs across various layers of the autonomous system architecture and examines critical sensitivity factors.

Although public transportation typically relies on subsidies and lacks the routing flexibility of free-floating mobility services, it still serves as a relevant benchmark for potential cost targets. Going forward, autonomous mobility services must withstand TCO comparisons with conventional on-demand offerings—and surpass them in the medium to long term to achieve viability. The economic evaluation of the examined pilot project reveals that due to substantial development overhead, break-even operation is currently unfeasible under any tested operational scenario. Nonetheless, the analysis shows that optimizing key cost drivers could yield savings of approximately 75% relative to the baseline scenario with restricted operating conditions. Despite this, overall costs would still remain above competitive thresholds.

However, the outlook for future deployment scenarios is considerably more optimistic. Based on the empirical results of the KelRide project—and assuming the availability of a scalable, Level-4-capable vehicle platform—further cost reductions between 66% and 94% appear attainable compared to the already optimized Level-4 scenarios.

Consequently, the strategic selection of suitable deployment environments is critical for unlocking scaling potential and justifying the associated development costs. This paper concludes with a set of actionable recommendations to support the progression toward cost parity with conventional mobility services.

1. Introduction

Following the invention of the automobile, autonomous driving represents the most significant innovation in the evolution of mobility. Rapid advances in artificial intelligence (AI), robotics, and sensor technology—alongside the deployment of the first robotaxis on public roads—are further accelerating its relevance (Minx & Dietrich, 2015, p. 7).

The research presented in this paper is grounded in the KelRide project, which offers a globally unique opportunity to lift the veil and conduct an in-depth cost analysis of a highly automated shuttle service.

KelRide Project Overview

KelRide was carried out between January 2021 and June 2024 in the district of Kelheim, Bavaria. The

project, involving six consortium partners, was funded by the German Federal Ministry for Digital and

Transport (BMDV). Its primary objective was to implement a weather-independent, highly automated on-demand ridesharing service to complement the existing regional public transportation network. Responsibilities across the consortium were clearly defined, as illustrated in *Figure 1*.

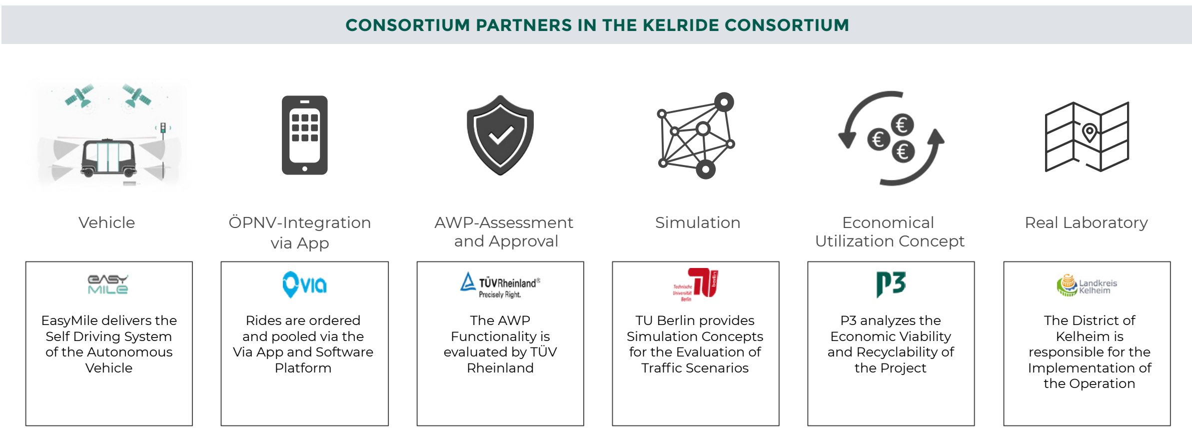


Figure 1: *Responsibilities of the consortium partners within the KelRide project (P3 diagram)*

For day-to-day operations in Kelheim, up to five highly automated and fully electric EZ10 shuttles developed by EasyMile were deployed. Over the course of the project, the service area was gradually expanded. In its final stage, it constituted the largest contiguous autonomous operating zone in Europe, covering approximately 30 kilometers of road infrastructure and 45 virtual stops. The service operated five days per week in an on-demand format, providing mobility to residents of the Kelheim district.

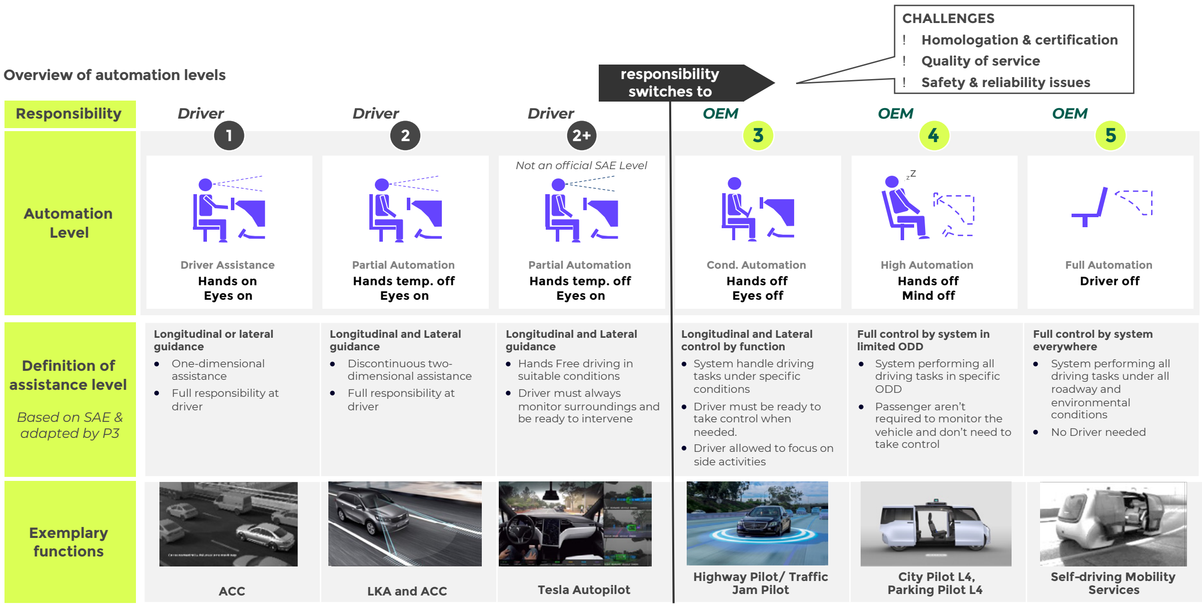
2. Basics of Autonomous Mobility

This chapter outlines the foundational concepts deemed essential for the context of this paper. It begins with an explanation of the levels of driving automation as defined by the SAE J3016 standard issued by the Society of Automotive Engineers (SAE), followed by a presentation of the autonomous Mobility-as-a-Service (MaaS) ecosystem.

2.1. Degrees of automation according to SAE level

The levels of driving automation as defined by SAE J3016 (SAE International, 2021) are illustrated in *Figure 2*. The first three levels—Level 0 through Level 2—describe driver assistance functions. Automated vehicle control begins at Level 3. From Level 4 onward, no fallback to a human driver is required, although the vehicle can only operate fully autonomously under specific, well-defined conditions. These operational boundaries are referred to as the Operational Design Domain (ODD). In contrast, SAE Level 5 represents full automation, requiring the system to safely operate the vehicle under all conditions, at any time and in any location.

Within the scope of the KelRide project, operations were conducted at SAE Level 2, meaning a safety driver was always present onboard. This driver remained responsible for safe operations and could intervene in emergency situations. However, meaningful economic benefits within the context of Mobility-as-a-Service (MaaS) only begin to materialize from Level 4 onward. Scalability at this level is primarily enabled by the removal of the human driver as the largest cost factor, replaced instead by a remote technical supervisor capable of monitoring multiple vehicles simultaneously. The greater the vehicle-to-supervisor ratio (1:X), the more cost-efficient the operation becomes.



ACC = Automated cruise control, LKA = Lane keeping assist, ODD =Operational Design Domain

Figure 2: *SAE J3016 – Levels of autonomous driving. Based on SAE International (2019)*

2.2. Mobility as a Service Layer-Model

The P3 MaaS Layer Model is used to analyze autonomous mobility ecosystems (see Figure 3). The Mobility-as-a-Service domain is represented using a five-layer framework (cf. Kaempfer, 2024). Within the scope of this study, it is essential to segment cost analyses according to this structure in order to enable a robust and well-founded assessment.

Figure 3: *P3 MaaS layer model to describe the autonomous mobility ecosystem (Kämpfer, 2024)*

3. Problem Definition

The implementation and operation of autonomous mobility services face major challenges, particularly in terms of high development, capital, and operational costs, as well as a constrained funding landscape. To establish a sustainable business model for autonomous mobility, these cost factors must be significantly reduced. In particular, the currently hesitant investment environment in Europe poses a major barrier to the development of scalable solutions across the autonomous vehicle ecosystem. While technological challenges often dominate public and industry discourse, the economic viability of emerging mobility concepts is rarely questioned. Financial metrics frequently lack transparency—both for external observers and for stakeholders directly involved.

Against this backdrop, the present study investigates the economic viability of highly automated shuttle services. The analysis is based on the KelRide project, which provides a globally unique opportunity to gain detailed insights into the cost structure of such services. The aim of this study is to transparently present the cost structure of an autonomous mobility service and to identify key levers for transitioning from pilot operations to economically viable service models.

While the KelRide project represents the largest contiguous deployment area for autonomous vehicles in Europe, it is not unique in a global context. Figure 4 presents a selection of international pilot projects operating autonomous vehicles on public roads, including KelRide. It becomes evident that numerous pilot projects have been implemented and are currently in operation in the United States, China, and Germany. In the U.S., Waymo stands out, having deployed autonomous vehicles in cities such as San Francisco, Los Angeles, Phoenix, and Austin, where it already offers paid services to customers.

In China, the market is even more competitive, with a wide range of providers operating autonomous fleets within designated test zones in various cities—also offering rides for a fee. In Germany, several pilot projects are underway, primarily driven by technology providers such as EasyMile, Mobileye, and Holon. However, most current pilot initiatives are limited in scale, both in terms of fleet size and geographic reach, and are not yet designed for scalable service operation. Although cities like Hamburg aim to operate up to 10,000 autonomous vehicles by 2030, no profitable autonomous mobility service has yet been realized anywhere in the world (BMDV, 2023).

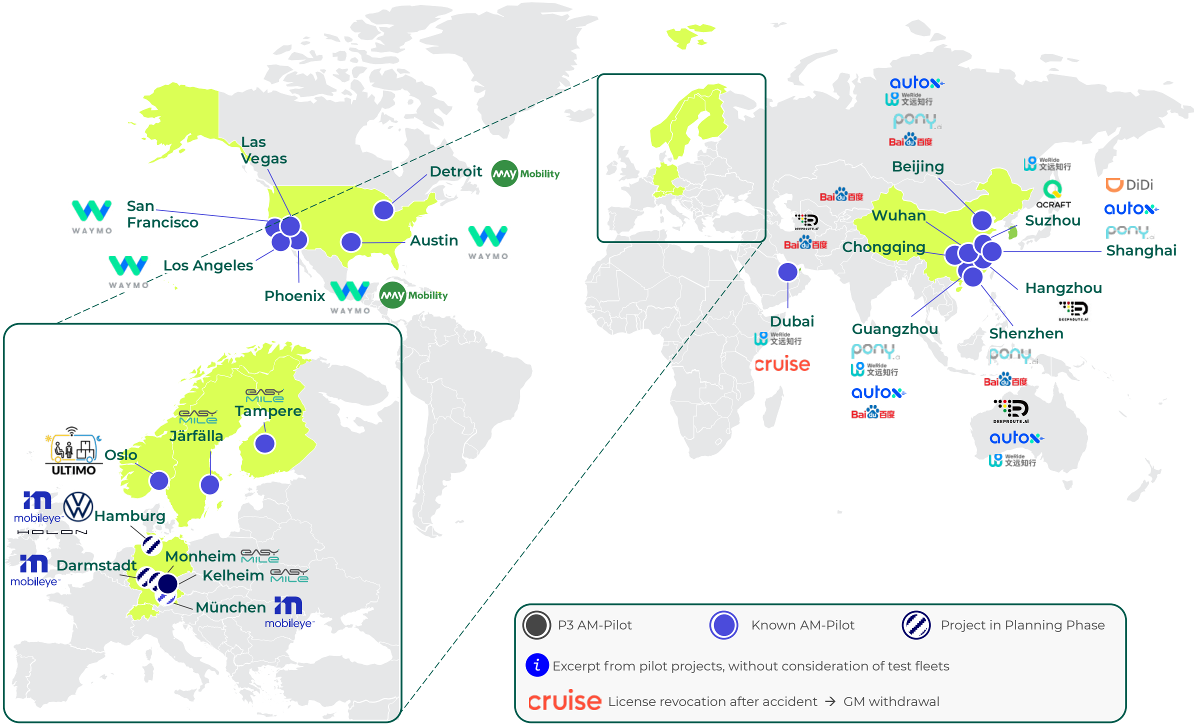


Figure 4: *Extract from pilot projects, not including test fleets (source: P3 AM, 2024)*

4. Methodical Approach

4.1. Structure of the TCO model

The Total Cost of Ownership (TCO) approach is a widely used methodology for calculating and analyzing the overall costs of a project across its entire lifecycle. The TCO model developed by P3 forms a central component of this paper and is employed to examine the economic aspects of the KelRide autonomous shuttle project in greater detail. It incorporates various cost categories and enables a granular analysis of the cost structure. The assessment, shown in Table 1, includes project-specific adaptations and is aligned with the P3 Layer Model framework.

Layer 0: Project Basics	Layer 1: SDS & ODD	Layer 2: Vehicles	Layer 3: Fleet Operation	Layer 4: Mobility Services
• Costs for project man-agement overall project • Communication costs such as marketing and website	• Development and validation of the All-Weather-Proof (AWP) functionality • ÖPNV integration • Integration of a ridesharing API	• Vehicle-side project management • Vehicle inspection and approvals	• Personnel costs – operators • Maintenance contract-Personnel costs – fleet control center	• Costs for on-demand app, customer sup-port, and service • Development of a synthetic demand model • Impact analysis and simulations

Table 1: *Exemplary cost items in the KelRide layer model*

4.2. Methodical procedure for creating the future scenarios

Following the cost analysis of the KelRide development project, a sensitivity prioritization was conducted using an ABC analysis to identify the most critical cost drivers. These key sensitivities were then examined in a detailed sensitivity analysis. In the next step, various scenario simulations—referred to here as “follow-up projects”—were used to explore changes in the most sensitive parameters. Finally, a Greenfield analysis was carried out to define the requirements for a future vehicle platform. This served as the basis for assessing potential future scenarios independently of the specific conditions observed in the KelRide project (see Figure 5):

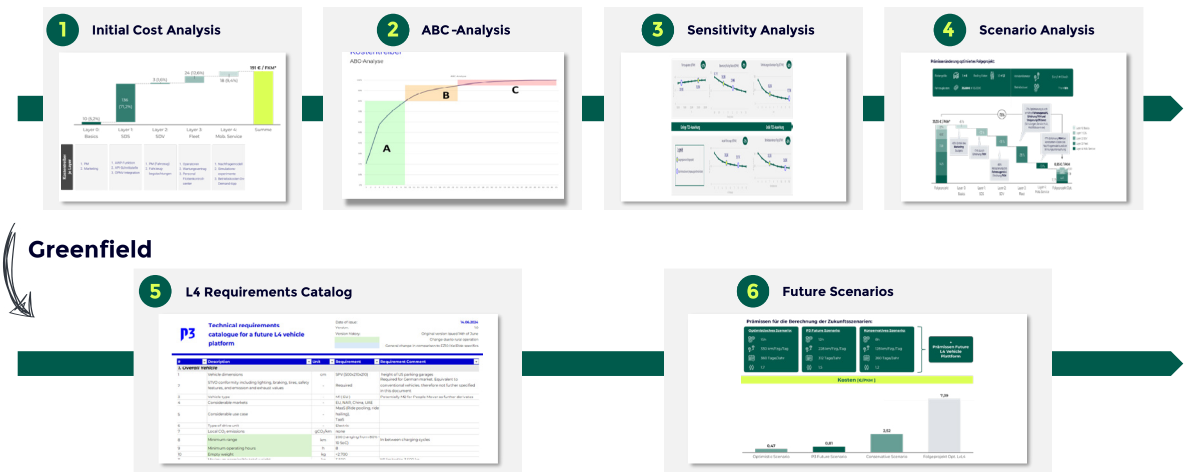


Figure 5: *Methodological approach in this paper. Economic analysis under project specifics, followed by Greenfield approach (P3 illustration)*

4.3. Description and characteristics of the follow-up projects

The following section describes three scenarios with regard to their optimization potential, applicability to future projects, and projected timeframes (see Figure 6).

a) **Scenario "Follow-Up Project":** This scenario estimates the financial impact of replicating the KelRide project in a comparable environment (i.e., similar topography, service area size, and population) while excluding development costs. All other assumptions remain consistent with the reference configuration of the KelRide development project.

b) **Scenario "Optimized Follow-Up Project":** This scenario includes the optimization of key parameters as identified in the sensitivity analysis, while continuing to use the EZ10 vehicle platform, Level 2 operation with an onboard safety driver, and a comparable operational environment.

c) **Scenario "Optimized L4 Follow-Up Project":** This scenario represents an evolution of the "Optimized Follow-Up Project," transitioning to Level 4 operation with remote technical supervision. The expected timeframe for this operational mode is between 2026 and 2027.

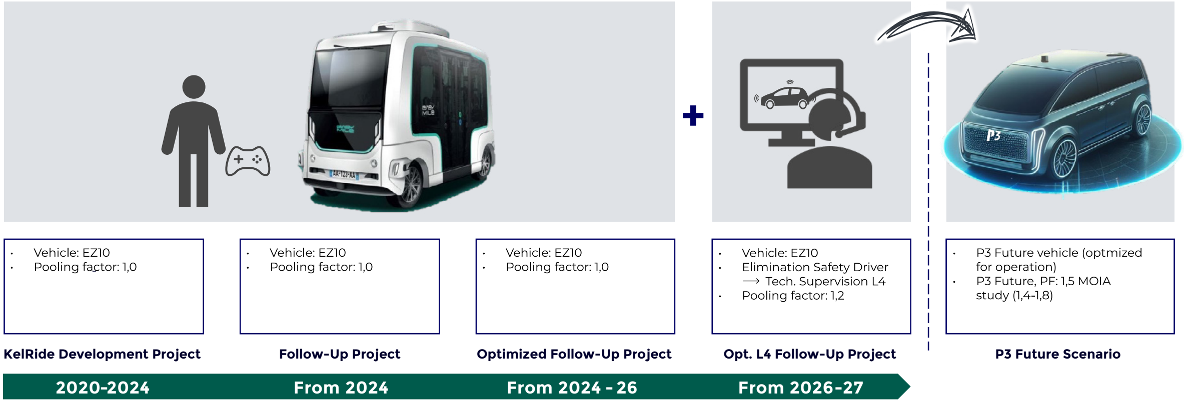


Figure 6: *Scenario overview and characteristics (P3 illustration)*

This approach represents the evaluation of the current state and serves as a starting point for the analysis of future scenarios.

5. Results

Within the TCO model, several key parameters remain constant across all future scenarios to ensure comparability. All scenarios are based on a project duration of 36 months. Similarly, the service area, the total length of the covered road network, the population of the target city, as well as the operational hub costs, electricity price per kWh, and the specific characteristics of the autonomous vehicles are held constant.

5.1. TCO KelRide development project and follow-up project scenario

The initial cost breakdown of the KelRide development project was compiled in cooperation with the consortium partners and based on the prevailing framework conditions. The project initially launched with only two vehicles, and due to the high development effort, a reliable service could not be provided to users for an extended period. Based on these findings, a pooling factor of 1.0 was defined for the calculations, equating one vehicle-kilometer (VKM) to one passenger-kilometer (PKM). In December 2023, with the final expansion of the operational area, the fleet size was increased to five vehicles, leading to an improvement in overall service quality.

For the “Follow-Up Project” scenario, all development and redevelopment costs incurred during the KelRide project were excluded. This scenario is intended to illustrate the cost structure of a subsequent project under similar conditions in a target city with characteristics comparable to those of Kelheim. Operational parameters are kept consistent with the Kelheim service model, including a daily operating time of seven hours, a daily mileage of 35 kilometers, 250 operational days per year, and staffing with five full-time equivalent (FTE) safety drivers. Additionally, a constant fleet size of five vehicles is assumed for the entire 36-month project duration. The results of the TCO analysis demonstrate that eliminating development costs significantly reduces total cost of ownership. The cost per vehicle-kilometer (VKM) decreases from €190.98 to €35.35, representing a reduction of 81% (see Figure 7).

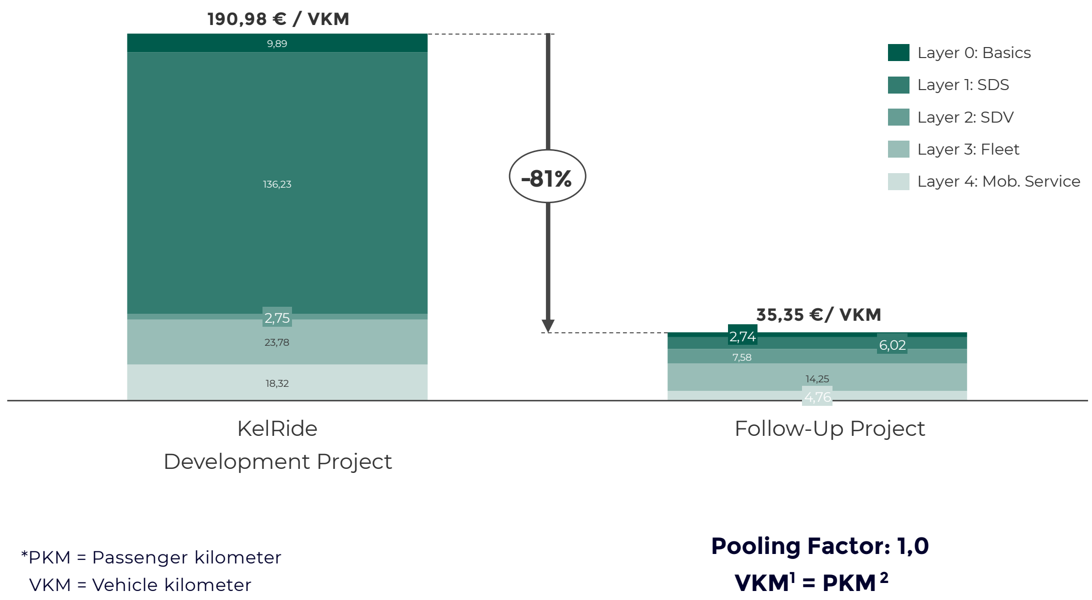


Figure 7: *TCO comparison: development project vs. follow-up project scenario (P3 illustration)*

Despite the significant cost reduction of 81% compared to the development project, it must be emphasized that the follow-up project remains economically unviable and overly expensive. A key insight is that, under the given assumptions—particularly the limited operational parameters—neither cost coverage nor profitability can be achieved. Operating expenditures (OPEX) increasingly outweigh capital expenditures (CAPEX), placing a stronger focus on vehicle utilization and operational efficiency.

ABC Analysis and Identification of Major Cost Drivers:

An ABC analysis was conducted to identify the main cost drivers. Vehicle depreciation emerged as the largest cost component, accounting for 20.4% of total costs, followed by maintenance and repair costs (12.9%), personnel costs for safety drivers (12.6%), and software licenses for the self-driving system (SDS) (11.9%). Together, these four top “Category A” cost items represent 57.8% of the total cost structure.

5.2. Results of the sensitivity analysis

The sensitivity analysis identified key factors influencing the Total Cost of Ownership (TCO) and assessed their impact. The analysis considered six primary levers: vehicle mileage per hour, operating hours per day per vehicle, pooling factor, fleet size, vehicle acquisition costs, and electricity cost per kilowatt-hour (kWh).

As shown in Figure 8, the evaluated sensitivities demonstrate that operational parameters have a significant influence on TCO. Increasing vehicle mileage from 5 km/h to 10 km/h results in a 50% reduction in TCO. Extending daily operating hours from 7 to 10 hours per vehicle reduces TCO by an additional 25%. The pooling factor, which reflects vehicle utilization efficiency, also has a substantial impact. Increasing the pooling factor from 1.0 to 1.2 leads to a 17% reduction in TCO.

In contrast, other parameters have a less pronounced effect. Expanding the fleet size from five to eight vehicles results in a 12% reduction in TCO, while lowering the vehicle cost from €315,000 to €165,000 reduces TCO by 9.7%. Finally, electricity costs have only a marginal impact on TCO due to the relatively low driving distances observed in the project.

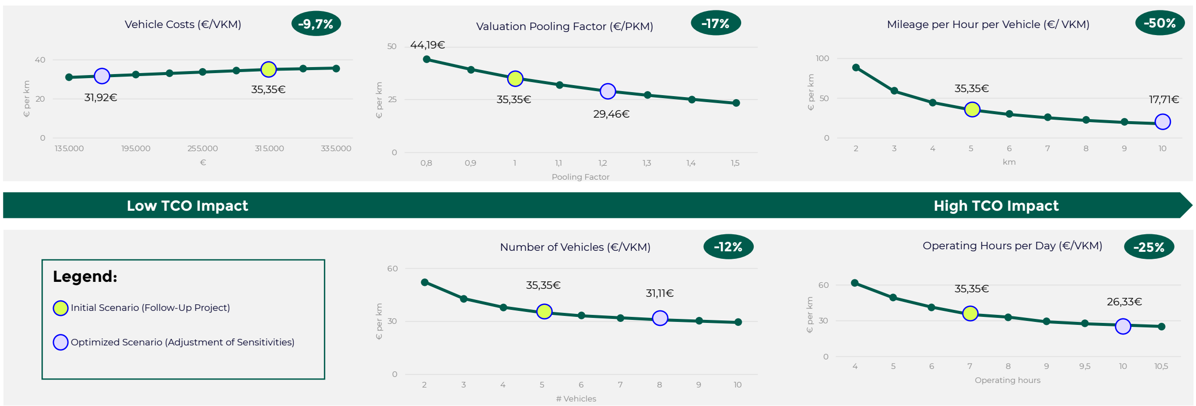


Figure 8: *Results of the sensitivity analysis (P3 figure)*

5.3. Scenario analysis of the optimized follow-up projects

Based on the preceding analyses, two optimized follow-up project scenarios were developed. Key assumptions specific to the KelRide project—such as the vehicle platform and the use of a designated mobility hub (with a maximum operational capacity of eight vehicles)—were retained, while the identified sensitivities were optimized within their respective practical limits.

Both scenarios are based on the adjusted assumptions and boundary conditions shown in Figure 9:

1. Increase in fleet size from five to eight vehicles (limited to eight vehicles due to the capacity constraints of the mobility hub)
2. Reduction in vehicle cost from €315,000 to €165,000 per unit
3. Increase in vehicle mileage from 5 kilometers per hour to 10 kilometers per hour
4. Extension of daily vehicle operating time from 7 to 10 hours (limited by battery capacity and charging speed)
5. Increase in pooling factor from 1.0 to 1.2

Optimized follow-up project with change of premise

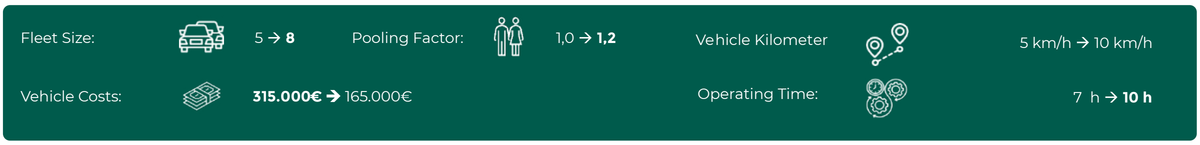


Figure 9: *Change in assumptions for the optimized follow-up project (P3 illustration)*

In addition, an optimized Level 4 (L4) follow-up project scenario was developed, building upon the optimizations of the previous scenario and incorporating L4 operations. In this setup, the onboard safety driver is replaced by remote technical supervision. A supervision ratio of 1:5 is assumed, meaning that one remote operator can oversee up to five vehicles simultaneously. This transition enables the decoupling of the one-to-one relationship between physical safety drivers and vehicles, unlocking significant operational efficiency gains.

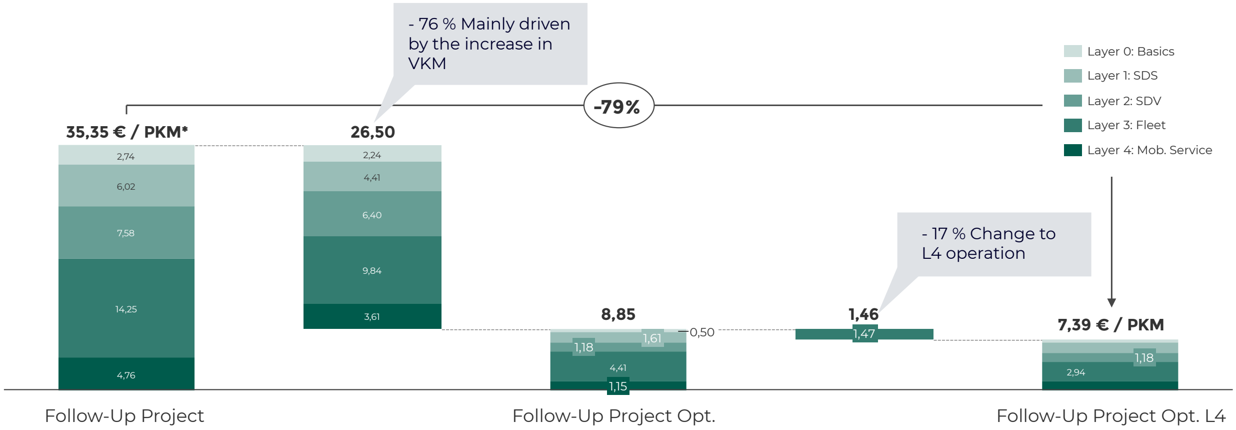


Figure 10: *Cost savings due to the elimination of safety drivers (P3 illustration)*

Figure 10 presents the results of the three follow-up project scenarios. Starting from the original cost of €35.35 per passenger-kilometer (PKM), optimizing the identified parameters leads to a 75% reduction in TCO, resulting in a cost of €8.85 per PKM. The introduction of remote technical supervision in the Level 4 scenario yields an additional cost reduction of €1.46 per PKM (−17%). This brings the total TCO for the optimized L4 follow-up project down to €7.39 per PKM, representing a total reduction of 79% compared to the baseline follow-up project scenario.

5.4. L4 List of requirements for a future-proof vehicle platform

The scenario analysis presented in Chapter 5.3 has demonstrated that the EZ10 vehicle platform implemented in the KelRide project acts as a limiting factor in several respects. Although software updates could have significantly enhanced the performance of the self-driving system (SDS), the inherent limitations of the base vehicle continued to prevent the realization of a commercially viable operation.

One potential approach to overcoming these challenges lies in the development of a scalable vehicle platform. The following section defines the requirements for a Level 4-capable vehicle platform in the form of a structured requirements catalog. This catalog, which is illustrated in Figure 11, encompasses seven key domains and is intended to serve as a potential blueprint for the development of future-ready autonomous vehicles.

L4 Vehicle Platform Requirements Catalogue

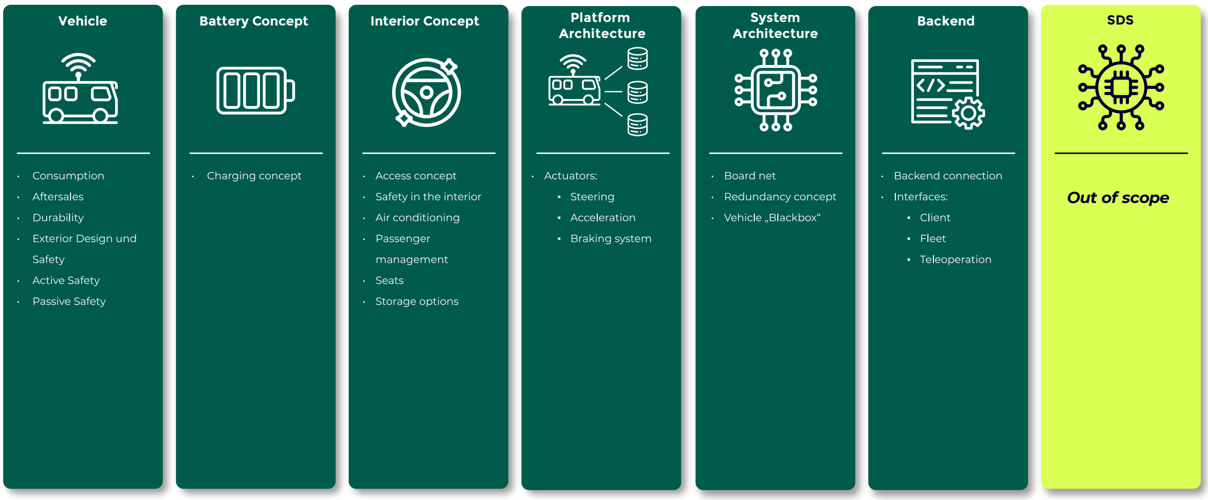


Figure 11: *Development of the L4 requirements catalog for a future vehicle platform (P3 illustration)*

In particular, the pillars “Vehicle Architecture,” “Battery Concept,” and “SDS Capabilities” offer substantial potential for reducing Total Cost of Ownership (TCO).

Regarding vehicle design, key influencing factors include energy consumption, total mileage, and operating hours over the vehicle’s lifetime. Lower energy consumption enables longer driving ranges and extended operating times between charging cycles, thereby increasing both total mileage and operational hours. As outlined in Chapter 5.2, increasing daily operating hours is a critical lever for lowering operational costs.

In terms of the battery concept, two main factors determine the TCO: battery capacity and charging speed. Developing and integrating higher-capacity batteries can increase daily range and extend operating time, leading to lower cost per vehicle-kilometer (VKM). The introduction of fast-charging capabilities would significantly reduce charging time and improve vehicle availability by minimizing idle time at the mobility hub. This, in turn, increases overall operating hours and lowers VKM costs.

Further development and expansion of SDS (Self-Driving System) capabilities can also positively influence TCO. High SDS availability ensures continuous vehicle operation. System failures, on the other hand, result in operational downtime. Improving reliability not only enhances service quality but also increases user trust.

Other pillars of the requirements catalog—such as the platform architecture, system architecture, and backend infrastructure—are not discussed in detail here. While their direct impact on TCO is comparatively smaller, adherence to their respective technical specifications is nonetheless essential to enable a safe and inclusive service.

Beyond vehicle-specific requirements, infrastructure and operational reliability are critical to the economic viability of a shuttle service. Optimizing infrastructure through cost-effective and flexible solutions—such as modular garage systems or reuse of existing facilities—can reduce capital expenditure (CAPEX). In the KelRide context, the use of low-volume electric vehicles and their battery systems introduced specific requirements for storage infrastructure, which led to elevated costs. A scalable vehicle platform offers a key opportunity here: if technical requirements are designed to eliminate the need for vehicle-specific infrastructure, autonomous fleets can be more easily integrated into traditional depots and operational environments.

5.5. P3 Future scenarios

Having identified the key barriers to scaling Autonomous Driving (AD) Mobility-as-a-Service (MaaS) and proposed potential solutions, this chapter focuses on analyzing the potential of AD MaaS services using a Greenfield approach. The analysis is conducted independently of the specific circumstances of the KelRide project.

Methodology

Building on the Level 4 requirements catalog outlined in Chapter 5.4, several operational parameters—such as operating hours, mileage, number of service days, pooling factor, and other key performance indicators—were deliberately adjusted to develop three forward-looking scenarios. These adjustments are intended to overcome the limitations identified in the KelRide project and to significantly improve previous outcomes by enabling more efficient operations, particularly with regard to reducing cost per passenger-kilometer (PKM).

Care was taken to ensure that the resulting future scenarios present a realistic representation of a next-generation autonomous mobility service. The specific parameters and boundary conditions for each scenario are summarized in Table 2.

Table 2: Framework conditions of the scenarios (P3)

	Optimistic Scenario	P3 Future Scenario	Conservative Scenario
Operating Hours / Day [h/d]	15	12	8
Mileage / Day [km/d]	330	228	128
Operating Days / Year [km/ a]	360	312	260
Pooling Factor	1,7	1,5	1,2

Scenarios

The foundation for scenario development is the P3 Future Scenario, which is considered a realistic projection given the implementation of a new Level 4 vehicle platform and the resulting improvements in operational efficiency. This scenario assumes the following operational parameters: 12 hours of daily operation across six days per week (312 operational days per year), a daily mileage of 228 km per vehicle (corresponding to an average speed of 19 km/h), and a pooling factor of 1.5.

Based on this reference scenario, two additional future scenarios are defined: one with a conservative interpretation of operational parameters and the other with a more optimistic outlook.

In the conservative scenario, key parameters are significantly reduced. Daily operating time is limited to 8 hours, with operations occurring five days per week (260 operational days per year). The average speed is assumed to be 16 km/h, resulting in a daily mileage of 128 km per vehicle—reflecting the performance observed in the optimized KelRide follow-up projects. The pooling factor is set to 1.2, also based on KelRide's optimized scenario.

The optimistic scenario significantly increases operational parameters within the feasible limits of a Level 4 platform. Vehicles are assumed to operate 15 hours per day, covering 330 km per day—equivalent to an average speed of 22 km/h. Operational days are extended to 360 per year, and the pooling factor is increased to 1.7. This assumption is informed by a study conducted by MOIA on an autonomous on-demand MaaS service in Hamburg (Kagerbauer et al., 2021), which projected even higher pooling values. For this project, however, a deliberately more conservative pooling factor was adopted in collaboration with the Technical University of Berlin.

For all three future scenarios, the service area is expanded significantly—from the original 1.3 km² and 30 mapped road kilometers (as of January 2024, at the start of the KelRide development project) to 100 km² and 500 mapped road kilometers.

Discussion of Scenario Results

Figure 12 visualizes the key outcomes of the future scenarios, including the assumptions and parameters described above. The TCO results are presented in euros per passenger-kilometer (PKM). For benchmarking purposes, the costs of the optimized Level 4 follow-up project are compared with those of the future scenarios.

In addition, the calculated TCO values are contrasted with end-user prices for comparable mobility services such as taxi rides, Uber, and KEXI* services. This provides readers with relatable reference points for evaluating cost competitiveness.

Premises for the calculation of future scenarios:

Figure 12: *Results of the future scenarios (P3 illustration)*

Prices for comparable mobility services range from €2.93 to €3.89 per passenger-kilometer (PKM) for taxi rides, and from €1.80 to €2.50 per PKM for Uber services. This results in a price range of approximately €1.80 to €4.00 per PKM. In comparison, the conventional on-demand service in Kelheim (KEXI) demonstrates significantly lower costs—between €0.71 and €0.95 per PKM—representing a reduction of 60.6% to 75.6%. This is primarily due to government subsidies and Kelheim's specific fare structure. KEXI fares are based on a fixed price model of €3 or €4, depending on whether the ride occurs within the smaller or larger service zones.

a. **P3 Future Scenario:** This scenario represents a balanced approach that combines increased vehicle utilization with appropriately scheduled operational breaks for recharging and other tasks. With 12 hours of daily operation on 312 service days per year, a daily mileage of 228 kilometers per vehicle, and a pooling factor of 1.5, the resulting Total Cost of Ownership (TCO) is €0.81 per PKM—an 89% reduction compared to the optimized Level 4 follow-up project.

b. **Conservative Scenario:** This scenario applies significantly more pessimistic assumptions. With only 8 hours of operation per day, five days a week, lower average mileage, and a reduced pooling factor of 1.2, the resulting TCO is €2.52 per PKM. Despite these conservative parameters, this still represents a 66% cost reduction relative to the optimized Level 4 scenario.

c. **Optimistic Scenario:** Operational parameters are raised to ambitious yet feasible levels for a Level 4-capable platform. With a daily mileage of 330 kilometers, continuous operation over 360 days per year, and a pooling factor of 1.7, the TCO is reduced to €0.47 per PKM. This corresponds to a 42% reduction compared to the P3 Future Scenario and a 93.9% reduction compared to the optimized Level 4 follow-up project.

When benchmarked against the end-user prices of taxi and Uber services, both the P3 Future Scenario and the Optimistic Scenario show a clear cost advantage. Even under the Conservative Scenario, cost parity with traditional mobility services appears achievable. Only in comparison with the heavily subsidized KEXI on-demand service in Kelheim does the Conservative Scenario fall short in terms of competitiveness.

Scenario 1: P3 Future Scenario (a)

Description

The P3 future scenario describes a **balanced approach** that combines **increased utilization with adequately planned operational breaks**, which can be used for recharging and other operational tasks.

Premise

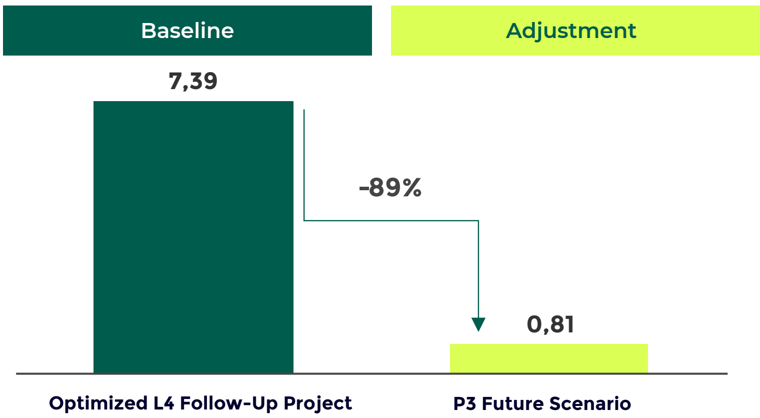
12 Hours/Day

312 Days/Year

228 km/Vhc./Day

1,5 Passengers

Results [€/PKM]



Results [€/PKM]

A **TCO result of €0.81 per PKM** is achieved. This result corresponds to a **reduction of 89%** compared to the optimized Level 4 follow-up project.

Scenario 2: Conservative Scenario (b)

Description

For the conservative scenario, the operational parameters are set **significantly more pessimistically compared to the baseline scenario**: with an operating time of only 8 hours on 5 days per week, a significantly lower average mileage, and a lower pooling factor of 1.2, this scenario is considerably more conservative.

Premise

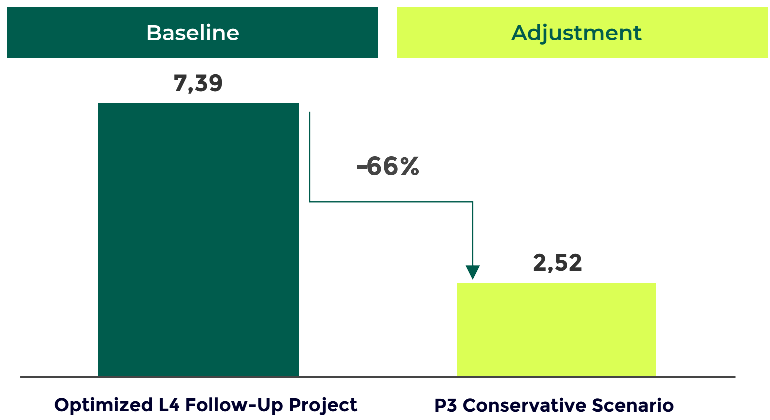
8 Hours/Day

260 Days/Year

128 km/Vhc./Day

1,2 Passengers

Results [€/PKM]



Results [€/PKM]

This results in **TCO costs of €2.52 per PKM**. Even under these very conservative assumptions for the operational parameters, the figure shows a **reduction of 66% compared to the optimized Level 4 follow-up project.**

Scenario 3: Optimistic Scenario (c)

Description

In the optimistic scenario, the operational parameters, as previously described, are further increased in order to achieve **high but still realistic vehicle utilization**. With a daily mileage of 330 kilometers, nearly continuous operation on 360 days per year, and a pooling factor of 1.7, the optimized scenario is created.

Premise

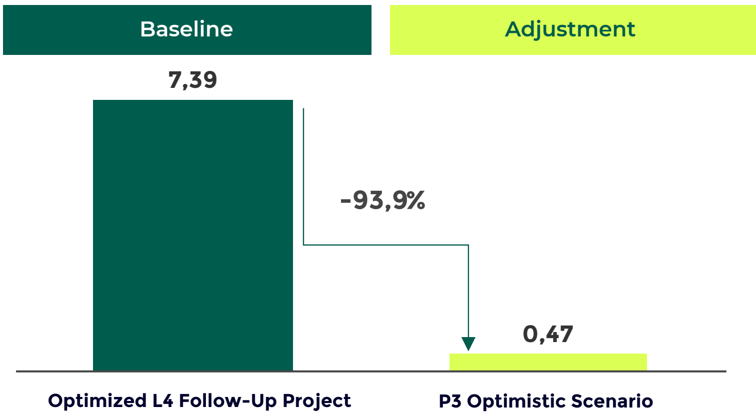
15 Hours/Day

360 Days/Year

330/Vhc./Day

1,7 Passengers

Results [€/PKM]



Results [€/PKM]

A **TCO** of €0.47 per PKM is achieved. This corresponds to a **reduction of 42% compared to the P3 future scenario** and a **reduction of 93.9% compared to the optimized Level 4 follow-up project.** When these results are compared to end-user prices for taxi services or the use of the Uber service, it becomes clear that the optimistic scenario **offers significant cost efficiency.**

6. Discussion of Solutions for Scaling Autonomous Mobility Services

6.1. Specific usability for municipalities and local authorities

A direct transfer of the project-specific findings from KelRide is not recommended based on the economic assessment outlined in Chapter 5. Even after implementing all identified optimization measures, no economically viable scenario could be identified that would serve as a scalable model for interested cities or municipalities.

According to P3's detailed analysis, continued financial and political support through isolated funding programs is not considered effective, as small-scale, project-specific subsidies are not advisable (see Chapter 6.3). Accordingly, the following chapters present a structured set of measures that offer realistic recommendations for the development of follow-up projects.

6.2. Recommendations for action and implementation approaches for a successful transformation of the autonomous mobility landscape in Germany and Europe

This study of the KelRide funding project reveals that the successful implementation of autonomous mobility requires a strategic and integrative approach. Identifying key action areas is essential:

Public perception: Acceptance of autonomous mobility must be increased through transparent communication and integration into the broader mobility mix.

Project execution: Large-scale, structured projects with clearly defined objectives and measurable success criteria are crucial.

Technological advancement: Innovations in software and hardware, as well as their integration into existing systems, must be actively pursued.

Political framework: Regulatory and funding instruments should be purposefully aligned with sustainable mobility goals.

Economic viability: A long-term financing strategy is essential to ensure sustainable outcomes.

Under these conditions, the authors of this paper propose launching a national flagship initiative, with a funding volume several times higher than that of current pilot projects and a project duration of five to eight years. This initiative should be carried out in the following phases:

Project Setup: Development of a comprehensive business case, including the definition of stakeholder roles, service concepts, partner selection, and integration into public transportation systems.

Pilot Phase: Implementation of pilot operations involving at least three consortia in major cities such as Hamburg, Berlin, and Munich. Each consortium should deploy a minimum of 50 vehicles to generate both operational and technological insights.

Evaluation: Assessment of outcomes and partner performance, along with the derivation of best practices.

Scaling: Expansion of fleets to at least 1,000 vehicles per provider by 2030, supported through government grants or credit guarantees.

6.3. Optimization of the project landscape through lighthouse projects

Previous autonomous mobility projects have often suffered from isolated, fragmented implementations, inadequate interregional coordination, and short-term funding cycles. In contrast, large-scale flagship projects offer a structured alternative by consolidating personnel and infrastructure resources. These centralized approaches promote knowledge reuse, reduce redundancies, and accelerate time-to-market.

By pooling experience and resources, flagship initiatives enable efficient project execution and support the development of sustainable structures. This minimizes repeated learning curves and enhances public perception through visible and measurable successes.

Fostering an Innovative Ecosystem

The proposed flagship funding program aims to establish a competitive and innovation-driven ecosystem. A key objective is to strengthen European providers by creating incentives for the localization of software development activities within Europe. This fosters technological sovereignty and reinforces Europe's position in the global race for autonomous mobility solutions.

Through this integrated strategy, a solid foundation can be laid for the successful transformation of the mobility landscape. In the long term, this will support the establishment of a sustainable, technologically advanced, and economically viable model of autonomous mobility—integrated as a core element of a future-proof transportation system.

7. Summary and Conclusion

The KelRide development project has generated valuable insights that can significantly influence the future planning and implementation of autonomous mobility services. It is essential to interpret these findings appropriately and derive the right conclusions.

In recent years, smaller autonomous pilot projects in Germany have served as test environments for operating autonomous vehicles on public roads. While notable technological progress—such as advancements in Autonomous Waypoint Planning (AWP) functionality—was achieved, these initiatives were primarily structured as development projects rather than being designed for scalability. As a result, several limitations became apparent, particularly in the areas of vehicle design, modal substitution, demand development, and economic viability, as documented in this report.

Nonetheless, the knowledge gained offers an optimistic outlook. One indicator is the rapid maturation of autonomous mobility systems, evidenced by the recent expansion of Waymo's service areas in San Francisco and upcoming deployments in Tokyo (Nagao, 2024). Coupled with the positive economic forecasts presented in this study, these developments suggest a promising overall trajectory for autonomous mobility.

The future scenarios outlined in Chapter 5.5 demonstrate that deploying a suitable vehicle platform can result in substantial cost reductions—contributing to the medium- and long-term profitability of autonomous MaaS solutions. Compared to current market prices, not only does cost parity appear achievable, but a clear cost advantage also becomes apparent.

One of the main remaining barriers to economic viability is the currently limited production volume of autonomous vehicles. Scaling up manufacturing could dramatically lower unit costs, benefiting both technology providers and end users. National flagship initiatives could provide a viable mechanism to facilitate such volume growth.

In summary, the KelRide project has delivered unique insights and practical experience that are critical to the further development of autonomous mobility services. The findings offer a solid foundation for future initiatives and will help address key challenges while unlocking the full potential of autonomous transportation solutions.

> ***In the coming years, it will be crucial to draw the right conclusions from pilot projects such as KelRide and translate them into bold and decisive actions at both national and European levels. This study demonstrates that the expectations regarding the economic benefits of autonomous mobility are well justified—yet current development frameworks do not allow these potentials to be fully realized.***

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Abbreviations and Definitions

ACC	Active cruise control (engl., zu Deutsch: Abstandsregeltempomat)
AD	Autonomous Driving (engl., zu Deutsch: Autonomes Fahren)
API	Application Programming Interface
AWP	All-Weather-Proof
BMDV	Bundesministerium für Digitales und Verkehr
CAPEX	Capital expenditure (dt. Kapitalinvestitionen)
FTE	Full-time-equivalent
FKM	Fahrzeugkilometer
LKA	Lane keep assist
MaaS	Mobility-as-a-Service
ODD	Operational Design Domain (dt. systembezogene Betriebsgrenzen)
OPEX	Operational expenditure (dt. laufende Betriebskosten)
ÖPNV	Öffentlicher Personennahverkehr
PKM	Personenkilometer
SAE	Society of Automotive Engineers
SDS	Self-driving system
SDV	Self-driving vehicle
SoC	System on a chip
TCO	Total Cost of Ownership
V2X	Vehicle-to-X (dt. Kommunikation von Fahrzeug zu allem)

Has this sparked your interest? Feel free to contact us!

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