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Designing Automation

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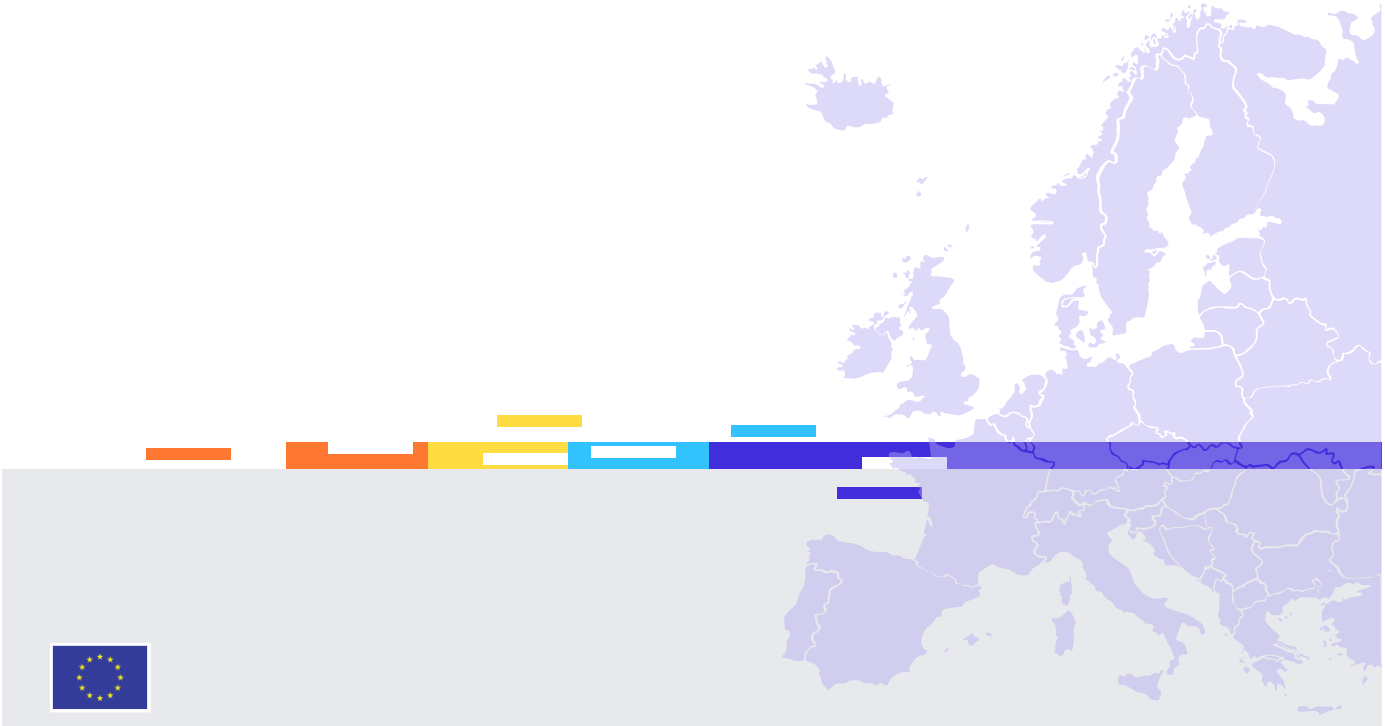

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Executive summary

The main goal of Hi-Drive's socioeconomic impact assessment was to investigate the welfare effects of highly automated driving (AD) and its enablers for society and users of automated vehicles. A cost-benefit analysis was performed to compare the costs and benefits of this technology. For the analysis, we incorporated estimated scaled-up data from impact assessments on safety, efficiency and the environment, as well as data from Hi-Drive's Global survey of the general public, in addition to external data sources for the estimation of the associated costs.

A snapshot approach was employed to quantify the impacts of AD and its enablers at different penetration levels. This is a static approach used to compare differences in outcomes between current traffic conditions and the estimated outcomes for a scenario where specific fractions of passenger cars in current traffic were operated using automated vehicles.

The Safety, Efficiency and Environmental impact assessments were performed for two configurations of automated driving functions (ADFs): ADF without enablers and ADF with enablers (EADF). Two baseline scenarios with manual driving were considered: *Traffic today traffic* reflecting the current traffic situation, and *ADAS-adjusted baseline* reflecting the current traffic situation including full penetration of mandatory automated driving assistant systems (ADAS) in passenger cars. The primary operational design domain (ODD) of ADFs were motorways and urban roads. As these ADFs contain built-in ADAS sensor components that also operate outside their ADFs' ODDs, their impacts of driving on rural roads were also considered in the safety assessment.

The major components of the socioeconomic evaluation are the benefits of the safety impacts (approximately €22 to €40 billion) and increased travel time costs due to lower traffic efficiency (€6.8 to €7.5 billion). Compared to these impacts, the estimated benefits of energy consumption and CO_2 emissions are smaller (€0.5 to €1.8 billion). Expected benefits for automated vehicle users, as they are able to combine work or relaxation while the vehicle operates in automated mode and enjoy increased comfort represent another substantial component (€23 billion). Overall, the total economic value of these impacts for society is estimated to range from €38 to €58 billion, at a 30% penetration rate of passenger cars with automated driving, under the *ADAS-adjusted* and *Traffic Today* baselines, respectively.

Costs associated with implementation of automated driving systems in passenger cars at EU level were estimated as minimum, maximum and average costs. When compared to the corresponding benefits, these estimates yield an average benefit–cost ratio of 1.8 for the

Traffic-Today baseline and 1.2 for the *ADAS-Adjusted* baseline, indicating that the benefits of automated driving and its enablers clearly outweigh the costs.

Glossary

Term	Definition
AD	Automated driving
ADF	Automated driving function. A common feature addressed by a group of automated driving systems.
ADAS	Advanced driver assistance systems
ADF	Automated driving function
AEB	Advanced emergency braking
AV	Automated vehicle
BADF	Baseline ADF or ADF without enablers
Baseline	Set of data to which the performance and the effects of the technology under study are compared.
AD	Connected and automated driving
CAV	Connected and automated vehicle
CDF	Common data format
C-ITS	Cooperative Intelligent Transport Systems
EADF	Baseline ADF or ADF without enablers
Enablers	Technological tools (SW, HW, Methodology) that have the potential to enable new vehicle automated function/s and/or upgrade existing vehicle automated function/s.
EU	European Union
GLOSA	Green light optimal speed advisory
HDV	Heavy-duty vehicle
ISA	Intelligent speed assistance
L3	SAE level 3 (driving automation)
LKA	Lane keeping assistance
ODD	Operational design domain. Operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics.
V2I	Vehicle to infrastructure
V2V	Vehicle to vehicle
V2X	Vehicle to everything
VKT	Vehicle kilometres traveled

Term	Definition
GDP	Gross domestic product
VSL	Value of statistical life
ALKS	Automated Lane Keeping Systems
SAE levels	The Society of automotive engineers defines 6 levels of driving automative ranging from 0 (fully manual) to 5 (fully autonomous)
MAIS	Maximum abbreviated Injury Scale
VSL	Value of statistical life

1 Introduction

1.1 The Hi-Drive project

Connected and automated driving has developed into a megatrend in the digitalization of society. AD has the potential to drastically change the way in which transportation works and has wide reaching impact. SAE Level 3 (L3) Automated Driving Functions (ADFs) were piloted in Europe by the L3Pilot project during 2017–2021. Hi-Drive built on the L3Pilot results and advancing the European State-of-the-Art from SAE L3 'Conditional Automation' to the level 'High Automation'. This is done by performing demonstrations, as part of large-scale trials, which test the robustness and reliability of AD functions under demanding and error-prone conditions, with a special focus on:

- Connected and automated vehicles (CAVs) driving under challenging conditions including variable weather and traffic scenarios as well as complex road infrastructure
- Connected and secure automation providing vehicles and/or their operators with information from beyond the line of sight and on-board sensor capabilities
- Complex interactions with other road users as part of normal traffic
- Factors influencing user preferences, comfort and trust, consumer acceptance of Automated Driving (AD)

The project's ambition is to extend the AD's operational design domain (ODD) so as to improve on the present situation, which frequently requires the human driver to reassume control of the vehicle. As experienced in the EU flagship pilot project L3Pilot, driving from A to B with a prototype L3 Automated vehicle (AV) encountered several ODD boundaries. Hi-Drive has been addressing these key challenges which are currently hindering the progress of automated driving. The concept builds on the idea of achieving widespread and continuous ODD, whereby automation could operate for longer periods and the interoperability assured across borders and brands. Hi-Drive strives to extend the ODD and reduce the frequency of take-over requests by selecting and implementing technology enablers which support highly capable AD functions, operating in diverse driving scenarios including, but not limited to, urban traffic and on motorways. The removal of ODD fragmentation is expected to give rise to a gradual transition from conditional automation towards higher levels of AD.

Hi-Drive's evaluation focuses on three areas: 1) users; 2) AD performance and availability; and 3) assessment of impacts on safety, efficiency, environment, mobility, and the transport system. Furthermore, these assessments serve as input for the socioeconomic impact evaluation for the purpose of determining whether the benefits of higher automation to society outweigh its social costs. The project also engages in a broad dialogue with

stakeholders and the general public in order to promote Hi-Drive's results. Dissemination and communication of the project's activities are shared via demonstration campaigns in order to show off the project's achievements.

Overall, Hi-Drive has been working to create a deployment ecosystem by providing a platform for strategic collaboration. In accordance with this, the work includes an EU-wide user education and driver training campaign and a series of Codes of Practice for the development of ADFs and road-testing procedures, while also leading outreach activities for standardization, business innovation, extended networking with interested stakeholders, and coordination of parallel activities in Europe and overseas.

1.2 Overall Implementation Plan for Hi-Drive

The implementation plan for Hi-Drive follows the FESTA methodology. The FESTA Handbook (2021) compiles the expertise amassed since 2007 on the topic of testing and evaluation of driver support systems and functions. The FESTA methodology was designed for Field-Operational Tests (FOTs) using market-ready products. Therefore, it does not fully apply to studies with prototypical ADFs. Thus, some adjustment of the FESTA implementation plan, described as the "FESTA-V" structure, was necessary to accommodate the testing of AD.

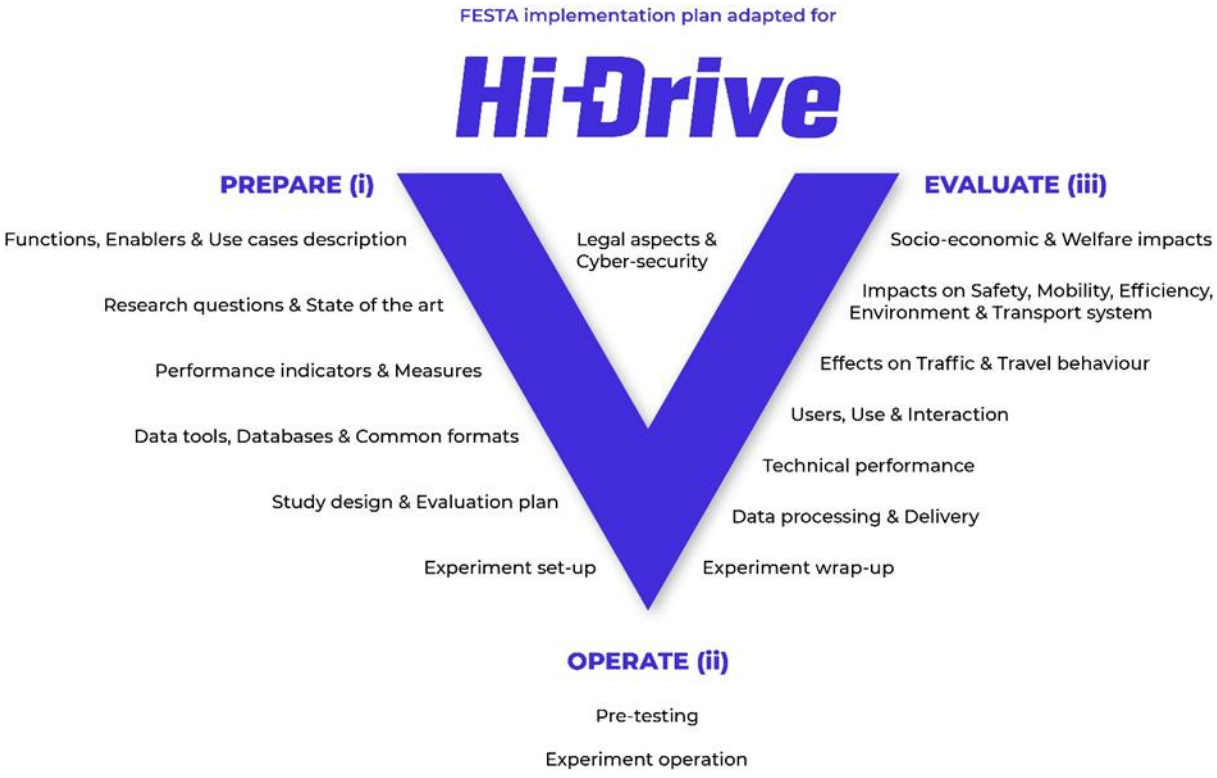

Figure 1.1: FESTA implementation plan adapted for Hi-Drive.

Figure 1.1 illustrates the FESTA implementation plan adapted for Hi-Drive. The plan is divided into three phases: (I) prepare, (II) operate, and (III) evaluate. In the beginning of the preparation phase (I), ADFs, the technology enablers, and their use cases and associated test scenarios across multiple test environments (test track, open road, simulation) are selected and described in detail. Then, an initial list of research questions has been drawn up and divided up into high-, medium-, and low-level questions. The State-of-the-Art has then been summarised for the topics covered by these research questions. The feasibility of each research question is then checked from the perspective of data availability, suitability of the experimental design and procedures, availability of research tools, methods and external data sources, and availability of resources (e.g., project duration and human) required.

Thereafter, the performance indicators and other data, which are used to answer the research questions, are defined and the relevant evaluation tools are calibrated. Based on these requirements for evaluation, five lists—one for each different data category[1]—with the required information are defined. In the following step, these lists are merged into one signal list which specifies all the signals needed. Besides the signal list, a Common Data Format (CDF) applicable to the project evaluation is specified for collecting, storing, and sharing the signals. The data to be shared for evaluation is agreed upon with the data providers. Various databases and data tools are defined for data processing and storage.

The experimental design and procedures allow for testing highly automated driving and its technology enablers, and for the provision of data for evaluation purposes. The plans for all operation sites are approved between the site owners and those defining the methodology for evaluation.

An evaluation plan is then developed for all the research questions with a view to specifying the methods, tools, and data to be used, scenarios to be addressed, and to plan the dependencies, i.e., linking the inputs and outputs as well as their timeline.

The experiment setup includes preparation of test vehicles, testing of selected parts of the technology and use cases, obtaining permissions (e.g., for test drives on public roads), selection of participants, and implementation of data logging.

The operation phase (II) starts with the pre-testing step, by running all the phases of the project on a small scale to ensure that all the processes and tool chains function as intended. Afterwards, the experiment operation for collecting the actual data begins.

[1] The data categories are closely linked to the different databases which will become the tool for making the data available for evaluation: Experiment metadata, questionnaire data, performance indicator data, time series data, aggregated time series data. Details in D4.2 *Data for Evaluation* by Fahrenkrog et al., 2023.

The evaluation phase (III) starts with the delivery of collected data. In this phase, it is also important to report all the deviations from the plan and any system updates made during the data collection phase. The data are converted to CDF, processed, and delivered to the evaluation team, where the plans are implemented and the evaluations carried out. The final step is the documentation and publication of the results.

Within SP7 Effects, the first deliverable presents the evaluation of the technical performance of the Hi-Drive enablers and AD-functions based on the driving data collected (D7.1 *Technical Evaluation Results*). Three deliverables address the different impact areas considered as part of the impact assessment (D7.3 *Effects on Safety*, D7.4 *Effects on Mobility, Efficiency and Environment* and D7.5 *Socioeconomic Effects*). The results of the different impact areas are summarised in one deliverable to provide an overview of the main findings of the impact assessment (D7.2 *Effects*).

1.3 Objectives and structure of the deliverable

The objective of this deliverable is to present a comprehensive evaluation of the societal impacts of automated driving. The deliverable is structured as follows: The evaluation begins by defining the scope of AD's socioeconomic impacts, followed by an overview of the analytical approach and data sources. Findings are then presented, integrating the expected societal impacts into an overall cost-benefit assessment. The results conclude with a brief discussion of considerations for future dissemination.

2 Scope of the socioeconomic impact evaluation

2.1 Introduction

The purpose of the socioeconomic impact evaluation is to provide an overall evaluation of automated driving (AD) and its enablers in terms of the costs and benefits for society. The analysis builds on and expands the evaluation of Level 3 automated driving functions (L3 ADFs) in the L3Pilot project (Bjorvatn et al., 2021; Bjorvatn et al., 2025). The research task is to clarify the welfare effects of all estimated impacts due to AD and its enablers.

2.2 AD-equipped cars and their functionality

Connected and automated driving provides vehicle connectivity "vehicle to vehicle" (V2V) and "vehicle to infrastructure" (V2I). It allows vehicles to connect with one another and with roadside units, as well as ensuring increased coordination and improved performance. Essentially, these AD functions/enablers expand the ODD, in which vehicles are able to operate in automated mode.

AD extends the amount of time which drivers can engage in alternative activities compared to manual driving. Although AD reduces the need for continuous manual driving, it still requires drivers to have the same driving skills as those required for conventional vehicles. Drivers must be able to resume manual control by takeover requests and when driving on rural roads.

2.3 Expected impacts of AD-equipped cars

Compared to conventional vehicles, AD-equipped vehicles are expected to generate impacts which directly affect the users of these vehicles. In addition, AD may affect other road users and, ultimately, society as a whole.

AV users may benefit directly in several ways:

1. AD is expected to ensure that situations with significant accident risk do not occur during the driving process and that they are also handled more efficiently than in manually operated vehicles, if they occur. As a result, AV users can expect a reduction in traffic accident risk involvement and should an accident nevertheless arise, a lower level of accident severity. Accident risk and accident severity reduction also imply a decrease in accident-related costs.
2. AD is expected to reduce the manual driving duration, which could make driving less strenuous. In automated mode, drivers are capable of being involved in alternative

activities, such as working, relaxation or recreation, as opposed to focusing purely on the task of driving itself.

3. When AVs are fully connected, drivers and passengers may benefit even more from the AD system's ability to communicate in real time with other AVs and road infrastructure. Vehicles with activated AD systems can receive information about congestion along their planned routes, allowing the system to reroute and avoid delays. As a result, AV users can expect fewer and shorter unexpected delays, leading to greater predictability in travel times.

These potential benefits entail a cost, i.e., the additional market price consumers must pay to acquire an AV, relative to a manually driven vehicle.

Whilst generating direct advantages for AV drivers, AD technology may also have external effects, which directly affect other road users:

4. As traffic accidents frequently involve two or more participants, lower accident risk for AVs would also reduce the accident risk for manually operated vehicles and other travellers. This is a positive externality, meaning that also other travellers will benefit when accident risk is reduced because of AD.

5. AVs differ from manually driven vehicles in terms of speed control, acceleration, and braking, and stricter adherence to speed limits may increase travel time. These differences may affect overall traffic flow efficiency for all vehicles on the road. This is an aggregate impact of AD that is typically not perceived by individual drivers, whether operating an AV or a conventional vehicle. It remains unclear whether this constitutes a positive or negative externality.

Indirectly, AD may also generate impacts that do not target any specific stakeholder but instead affect society as a whole.

6. To the extent that AVs operate in a way that influences overall traffic efficiency, both energy demand and CO_2 emissions, in turn, may be affected.

7. As AD is expected to reduce the costs of human injuries in traffic accidents, thereby reducing public expenditures related to such injuries and benefiting taxpayers in general.

Considering the impacts outlined above, we can assess their aggregated effect on society. The cost for society to achieve these benefits is not the market price for consumers, but the cost for producers to provide AD equipment, all taxes excluded (Boardman et al., 2018).

2.4 Key tasks for socioeconomic impact evaluation

A socioeconomic impact evaluation of AD and its enablers requires a clear and concise definition of the scope of investigation. In Hi-Drive, AD enables real-time communication with other AVs and the existing road infrastructure to some extent. However, in certain use case, advanced ADFs may require the deployment of additional roadside units, which are not yet integrated into the current infrastructure.

To conduct an overall evaluation of AD and its enablers, all impacts must be assigned a monetary value that reflects their effect on economic welfare. This enables comparison of different impacts along a common evaluative scale and allows for the integration of all related costs and benefits into an overall socioeconomic evaluation of AD of its enablers. When impacts are assessed using non-monetary scales, the choice of standard unit costs becomes decisive in determining the resulting economic values.

Furthermore, the economic value of all impacts must be calculated for the same time period. When evaluating events that occur at different points over several years, this is typically done by calculating net present values discounted to a specific year. In our analyses, all values have been expressed in 2024 prices.[2]

To ensure a reliable socioeconomic evaluation, it is essential to avoid double counting and to establish a well-defined and realistic baseline. This allows for a consistent detection of impacts, ensuring that the estimated effects genuinely result from the introduction of AD.

2.5 Outline of the socioeconomic evaluation

Prior to presentation of the socioeconomic evaluation results, we will provide a description of the analytical framework used for the economic evaluation of impact in Chapter 3 *Analytical Approach*. Chapter 4 *Data* describes the data sources which the estimation of the different impacts are based on. The presentation of findings starts in Chapter 5 *User Benefits* with consideration of AD's social welfare effects for those who acquire an AV and thereafter proceeds with Chapter 6 *Economic Impact on the EU* to provide an aggregate economic impact analysis, focusing on separate impact areas. In Chapter 7 *Transport Equity*, AD is considered in relation to its impact on transport equity. In Chapter 8 *Overall Socioeconomic Evaluation*, all expected impacts for society are incorporated into an overall cost-benefit

[2] Year 2024 provides the most up to date data, which is adjusted according to inflation as well as other factors. In addition, it reflects the price level at the time that our surveys were conducted, and this price level reflects how much extra participants were willing to pay to have AD installed in their car.

evaluation. Ultimately, the final chapter summarizes the main findings and provides a brief discussion of key issues relevant to the future dissemination of AD.

Details regarding AD costs, the standard unit costs used in the socioeconomic evaluation and a theory-based microeconomic model to analyse individuals' willingness to pay for AD are provided in Annexes 1 to 3 respectively.

3 Analytical approach

The main aim of the socioeconomic evaluation is to clarify whether and to what extent AD can be expected to contribute to increased welfare. For the evaluation, we conduct analyses to estimate AD's impacts for drivers of connected and automated vehicles (AVs) and for society. The idea is to estimate the economic value of benefits and costs associated with AD, and to combine these components to carry out a thorough cost-benefit evaluation of AD. Positive welfare effects follow if benefits exceed costs, at the individual level (buyers of AVs buyers), as well as at the aggregate EU level.

The analytical approach in this evaluation is structured to assess the impacts of AD technology. However, since the investigated automation technology pertains to reflecting a specific stage in the ongoing development towards fully automated driving, it is not feasible to construct a baseline scenario that excludes this technology over the next 10–30 years. Instead, we employ a *snapshot approach*, narrowing the time perspective to assess the technology's impact on an annual basis. It allows us to compare today's traffic outcomes with estimated outcomes, where a fraction of the current traffic operates using AD. More importantly, this approach is the only way to construct a reference scenario without AD technology, which is the essential prerequisite for estimating the impacts of AD. For details on the methodology and evaluation framework, see chapter 4 in Hi-Drive Deliverable D4.5 *Effects evaluation methods* by Vater et al. (2023).

In the following sections, we will first describe how the snapshot approach forms the foundation for assessing the socioeconomic impacts of AD in relation to safety, efficiency, the environment, and user benefits. Subsequently, the snapshot approach is interpreted from an economic perspective. As part of the final stage, we present the baseline alternatives and AD market penetration rates which were applied in the socioeconomic analyses.

3.1 Counterfactual scenarios as basis for estimating impacts

Impacts on traffic safety and traffic flow, emissions and energy use are estimated according to the difference in travel outcomes over the course of a year, i.e., the difference between the current traffic situation and counterfactual scenarios, in which specific fractions of passenger cars are operated using AD. In the aggregate European-level analysis, we assess welfare impacts both at societal level, and at micro-level specifically for AV users, where only the impacts that directly affect this user group are considered.

Impacts related to user benefits and their economic value are derived from survey data by capturing the factors that influence how much extra on top of a standard car price people are willing to pay for AD. Thus, using information from Willingness to pay (WTP) serves as a

method of estimating the economic value of impacts such as increased travel time predictability, reduced driving strain and enhanced comfort.

Since survey respondents have no actual experience with AD, their answers implicitly reflect a counterfactual perception of how driving would be if AD were available today.

3.2 A static versus a dynamic approach

In the real world, the introduction of AD is a dynamic process. The rate at which AVs enter the fleet of vehicles is given endogenously, i.e., depending on to what extent drivers expect benefits of using AD will exceed its cost. Hence, the magnitude of impacts generated by AD will increase gradually over time. For example, AD is not the only factor that will influence traffic incidents. Traffic accidents are also influenced by other factors, such as vehicle construction, vehicle and road safety measures in general, and road infrastructure.

It is almost impossible to model such complex and dynamic processes properly. Therefore, applying a dynamic perspective to the estimation of safety, efficiency and environmental impacts is not possible. Instead, impacts are estimated using a static approach by comparing differences in traffic outcomes between traffic today and the estimated traffic outcomes if today's traffic operated using a specific AD penetration level. This means that AD introduction is an exogenously determined variable. In addition, impacts derived from survey data are also static, reflecting AV drivers' perception of how it would affect them, without considering how these impacts might change depending on how many other drivers adopt AD.

The static approach is a necessity as it is not feasible to construct a trustworthy reference scenario for a future without AD, given that AD technology will soon be available for market introduction. Therefore, the only viable approach towards addressing the economic impacts of AD is to adopt the static snapshot approach. The method narrows down the time perspective to one year. The essence of this approach is that the current traffic situation, where AD has not yet been implemented, is regarded as the baseline.

3.3 The snapshot approach in an economic perspective

The economic interpretation of the snapshot approach is that it compares two scenarios—before and after an underlying exogenous change. For the aggregate economic impact analysis, this implies that society in both situations is in a steady state, where nothing happens except for the inclusion of different fractions of AD (Bjorvatn et al., 2021; Bjorvatn et al., 2025). For the analysis of welfare impacts in a micro-perspective, the individuals consider impacts they expect to gain from acquiring an AV, assuming everything else remains the same.

Such comparative static analyses are well known in economics. It is a partial analysis of what will happen if an exogenous change is imposed on the current situation. In our case, the exogenous change is the introduction of AD. The counterfactual situation will never occur. It is a constructed artifact making it easier to estimate the impacts that can be expected from this exogenous change. Then, the main research question to be addressed in the socioeconomic evaluation is:

> *How much higher (or lower) would annual welfare have been if a fraction of today's traffic had been operated with AD?*

To address this research question, we adopt two assumptions about how the economy works. These assumptions are often used in economic analyses of long-term steady state models (Bjorvatn et al., 2021; Bjorvatn et al., 2025), which is a theoretical prerequisite for the snapshot approach:

1. The economy is characterised by *sufficient competition* between all businesses and well-functioning markets. This means that prices of scarce resources, such as labour and capital used in the production of goods and services, reflect their shadow value to society, i.e., their opportunity cost. This implies that the producer prices of goods and services reflect their shadow cost to society, i.e., the value of goods and services are forgone when resources are used as part of their production.
2. There are *constant returns to scale* in production, which means that the unit cost of production is constant, independent of the production level. This means that when firms or industries scale up or down, the unit price of their production is constant.

In combination, these assumptions imply that any restructuring in car manufacturing or related industries resulting from the introduction of AD will take place without generating additional costs (or benefits) for society. At the micro level, certain industries are expected to expand, while others may reduce their activities. However, such industrial dynamics are not anticipated to cause any net disturbance in aggregate employment across society.

In addition, we make two further assumptions relating to the distribution of costs and benefits:

3. When it comes to *cost of public funds,* we consider the value of one Euro out of/into government coffers to be the same as the value of one Euro out of/into private pockets. This implies that the monetary value of impacts can be calculated by disregarding the distribution of costs and benefits between the public and private sector.
4. We also disregard *distribution of costs and benefits across different private stakeholders*. This implies that the value to society of one Euro in benefits or costs does not depend on who benefits or not, or whether they are rich or poor.

When discussing the cost-benefit analyses results, the assumptions relating to cost of public funding and distributional impacts may not be as fundamental. It is generally accepted that the cost of public funds exceeds the cost of private funding because taxation distorts the functioning of an economy (Boardman et al., 2018; NOU 2012:16), which will affect the estimated economic values.

3.4 Defining a baseline for estimating welfare impacts

The socioeconomic evaluation of AD is based on comparing traffic outcomes between scenarios that include AD and a baseline scenario without AD. By assigning monetary values to differences in safety, efficiency, and environmental outcomes, the benefits and costs of AD can be quantified. When relevant and reliable data on impacts are available, it is possible to assess the welfare effects of AD for society as a whole as well as for specific stakeholder groups.

The baseline scenario represents current traffic conditions, where AD has not yet been implemented. The reference year for simulations in safety, efficiency and impact assessments is 2023, which is the most recent year with comprehensive and reliable statistics on traffic volume, accidents, and traffic flow.

The impact assessments on Safety, Efficiency and Environment provide estimates for two configurations of ADFs:

- BADF – ADF without enablers (also referred to as baseline ADF)
- EADF – ADF with enablers

To capture the effects of ADFs, two baseline scenarios with manual driving are considered:

- Today's traffic: Current traffic situation without mandatory ADAS
- ADAS-adjusted baseline: Current traffic situation including full penetration of mandatory ADAS

Since July 2024, several Advanced Driver Assistance Systems (ADAS) have been made mandatory for all new vehicles in the EU (EU General Safety Regulation, July 6, 2022). [3] Previous studies (e.g., Scholliers et al., 2020; Bjorvatn et al., 2021; Costa, 2023) indicate that these ADAS features are expected to reduce both the number and severity of traffic accidents. As these safety improvements benefit society and travellers independently of AD

[3] Intelligent Speed Assistance (ISA), Automated Emergency Braking (AEB), Driver Drowsiness and Attention Warning (DDAW), Lane Keeping Assistance (LKA), Emergency stop signal and Event Data Recorder (Black Box).

deployment, the mandatory ADAS should be considered an integral part of the baseline when estimating AD-generated welfare effects.

Since mandatory ADAS represents a regulatory change that will generate safety-related impacts regardless of AD, the *ADAS-adjusted baseline* serves as the main reference for socioeconomic evaluation. However, the *Traffic today baseline* will also be considered for comparison purposes.

For the socioeconomic impact assessment, the analysis primarily considers the EADF, as the aim is not to evaluate single enablers in relation to the BADF, but to assess the impacts of AD and its enablers.

3.5 Estimated impacts and EADF dissemination

Impacts relating to safety, traffic efficiency and the environment are estimated for scenarios with 10% and 30% AD penetration rate relative to the current traffic situation. For scenarios with 30% and 50% EADF penetration, impacts are estimated relative to an ADAS-adjusted baseline, taking impacts generated by mandatory ADAS into account. In the socioeconomic evaluation, the focus is on the 30% EADF penetration scenario primarily since it allows us to consider the importance of impacts generated by AD technology and mandatory ADAS.

4 Data

The data used for the socioeconomic evaluation of AD impacts is presented as a list of sources, categorised according to the different types of impacts being evaluated. All AD-induced impacts are integrated into the overall socioeconomic evaluation. To ensure accuracy, it is crucial that the various impact estimates are compatible with each other, and the methods used to achieve this compatibility are clarified. Ultimately, the reliability of the estimated impacts is briefly discussed in the final section.

4.1 Estimated impacts and costs

The data used for conducting socioeconomic impact evaluation is based on different sources. The main estimates concerning safety, traffic efficiency and environment are based on scaling up estimates at EU level (27 European Union member states) and described in detail in deliverables D7.3 *Effects on Safety* (Sonntag et al., 2025) and D7.4 *Effects on Mobility, Efficiency and Environment* (Innamaa et al., 2025). In addition, we utilize data collected as part of the Hi-Drive Global Survey, reflecting the general public's views on AD (see 4.1.3 for details). To monetize the estimated impact, external data sources for standard unit costs are used. The following sections provide an overview of the data sources.

4.1.1 Data for assessing safety impacts

The safety impacts are estimated as part of several sequential steps:

- Real world AD testing
- Results from pilot testing are incorporated into simulation models
- Accident outcomes with AD are compared with manual driving with and without mandatory ADAS for each driving scenario in three different environments (motorway, urban, rural)
- Results are scaled up to EU-level

Up to 1000 simulations were conducted for each driving scenario. The general principle was to compare the human injury accident outcomes for manual driving and for AD, respectively, using computer simulations. Variations in injury accident outcomes per scenario in simulations necessitate an estimation of effectiveness (reduction or increase of injury accident risk, likelihood of different severities and frequency of relevant incidents potentially leading to an accident) per scenario.

The results of the simulations were then scaled up to EU27 level by matching the simulated driving scenarios with the accident types of the EU CARE accident database, while

considering changes in overall injury accident risk, accident severity and the changes in frequency of these driving scenarios due to the introduction of AD. For scenarios that could not be simulated, namely single-vehicle injury accidents, experts' estimates were used. European-wide accident analysis was then supported by national in-depth databases. Analysis was conducted on injury accidents according to the level of severity for different levels of AD penetrations.

To make economic estimates of the safety impacts, measured as an expected reduction in the number of traffic accidents according to injury severity, standard unit costs for the different types of accidents need to be calculated. Standard unit costs are based on historical data and are designed to reflect real costs for each of the different accident types. The calculation of standard unit costs for traffic accidents is explained in Chapter 5.1.2 and documented in detail in Annex A2.

4.1.2 Data for assessing efficiency and environmental impacts

The assessment of efficiency and environmental impacts was carried out using microscopic traffic simulations with PTV Vissim. These simulations provided direct results for travel time and delay, as well as detailed vehicle trajectories used to estimate tailpipe CO_2 emissions and calculate tractive energy use.

Two types of traffic scenarios were simulated:

1. Road-type-centric scenarios to assess the effects of BADF on motorway and urban networks.
2. Enabler-centric scenarios to evaluate the impacts of specific enablers, including cooperative merging, dynamic speed limits, GLOSA, and complex intersections.

All scenarios were simulated under both current traffic conditions and full ADAS baseline conditions. Regarding mandatory ADAS systems, only ISA was included in the efficiency and environmental simulations. In total, more than 20,000 simulation runs were conducted.

The effects observed in the simulated scenarios were scaled up to the EU27 motorway and urban networks by combining the estimated effect sizes per vehicle kilometre traveled (VKT) with VKT estimates for the corresponding conditions. This scaling utilised various data sources, including OpenStreetMap for road characteristics, traffic count data from 23 cities across 17 countries, and statistics from Eurostat and other sources for annual VKT and EU fleet data.

Input data for the simulations included OpenStreetMap data, EU27-wide traffic volume, vehicle fleet information, weather data from national and European sources, and AD's technical and traffic evaluation outputs

Estimated changes in traffic flow, fossil fuel consumption and CO_2 emissions impacts need to be translated into economic values for the purpose of the overall impact evaluation. Traffic flow, fossil fuel consumption and CO_2 emissions impacts are quantified as either an increase or decrease per VKT. Impact on fossil fuel consumption is measured in liters for petrol, diesel and liquid petroleum gas (LPG), while impacts on CO_2 emissions are measured in tons.

The standard unit costs needed to calculate the economic value of such discrepancies should reflect the same scenario for all individuals. This means that the average cost of travel time needs to be calculated against time cost differences caused by travellers' income, travel purpose, travel duration and other factors which may influence the cost of travel. Standard unit costs for fuel consumption and CO_2 emissions apply to all individuals.

The basis for the standard unit costs which are applied in the economic evaluation of efficiency and environmental impacts are documented in Annex A2.

4.1.3 Survey data

The Hi-Drive Global Survey was conducted using participants from the general public who hold a driver's license in nine European and non-European countries in 2024 (France, Germany, Poland, Spain, Sweden, the UK, China, Japan and the US). A minimum of 1,000 responses were collected in each country. Details about the survey are provided in Hi-Drive Deliverable D6.1 *User acceptance and awareness results* (Lehtonen et al., 2024).

As the focus of the socioeconomic evaluation is on AD's impact in the EU, we utilised data from respondents in the five EU countries participating in the survey. For the evaluation, particular attention was paid to the questions that assess respondents' willingness to pay above the average market price for a manual vehicle to acquire an AD-equipped vehicle, the factors behind their willingness to pay, their willingness to use it, and their expectations of how AD might affect their driving pattern.

When utilising the survey data for the overall economic evaluation of AD, we assume that the respondents constitute a representative sample of all drivers in the EU. This is because there are no statistics available indicating the composition of EU drivers, or indeed for any country, according to their demographic characteristics. To upscale impacts to the European level, answers are interpreted as if each respondent has answered in their capacity as a potential driver of an automated vehicle. Furthermore, it is assumed that each respondent represents one vehicle.

4.1.4 Costs of implementing AD

The ADFs and enablers tested during Hi-Drive require different hardware and software components in the cars, as well as in the infrastructure. Costs required to equip passenger

cars with, e.g., sensors, are referred to as private goods, which will represent a variable cost that increases with the number of vehicles equipped with them. Costs for road infrastructure represent a public good, with fixed costs that are independent of the number of vehicles making use of it.

Regarding cost estimations, only the cost of enablers evaluated as part of at least one of the impact areas on safety, and efficiency and environment, either for simulations or scaling ups, are considered.

Estimation of the costs of equipping passenger cars with EADF represents a challenge. Vehicle manufacturers or so-called Original Equipment Manufacturers (OEMs) are understandably quite reluctant to provide information on such costs. This is due to company policies on business-sensitive information, and also because OEMs need avoid any allegations of market collusion.

Thus, the approach taken for the estimation of costs involved defining the necessary additional vehicle components required for EADF compared with a manually driven vehicle. Industry experts were consulted during this process, with the aim of providing a realistic cost estimate ranging from expected minimum cost to maximum cost. The focus was predominantly on vehicle components in addition to the components required for the mandatory Advanced Driver Assistance Systems (ADAS).

As for public good enablers, the focus has been on defining additional technical components that are required for road infrastructure so it can handle the use cases investigated as part of Hi-Drive. Information from operation owners is used to consider to what extent the required enablers would generate additional annual road infrastructure costs. For instance, use cases with V2I/V2N communication with traffic lights require no additional technical components for road infrastructure since they are part of the Cooperative Intelligent Transport Systems (C-ITS) specifications that are rolled out for its deployment also for use cases beyond AD. Thus, it is not expected that these enablers will incur any additional road infrastructure costs in comparison to the standard deployment of C-ITS. On the contrary, the Hi-Drive use cases expand selected services to incorporate highly automated and connected vehicles. Therefore, by increasing the number of vehicles being able to use C-ITS services, the Hi-Drive use cases provide additional benefits without incurring extra cost. In contrast, collective perception use cases, such as those for complex intersections that cannot be supported solely by V2V communication, require additional infrastructure sensors and computational resources, leading to increased infrastructure costs. Since total costs depend heavily on the roll-out strategy (i.e., which intersections are equipped) and the specific sensor and computation setup (i.e., how each intersection is equipped), these costs are not considered in this analysis.

Similarly, the estimated effects on efficiency and environmental impact for these use cases are also neglected, see Annex A1.5 for details.

Moreover, Hi-Drive use cases that deal with improved positioning aim to overcome the problems of missing information (weak GNSS signals, missing/deteriorated lane markings) by sensor fusion in the vehicles instead of communication with the infrastructure. Hence, the overall assumption is that the relevant Hi-Drive use cases do not result in additional costs regarding the road infrastructure.

All details related to cost estimation for connected and automated driving are presented in Annex A1.

4.1.5 Compatibility of estimated impacts and data sources

The purpose of the socioeconomic analysis is to provide an overall evaluation of all impact following AD implementation. In Hi-Drive, these impacts were assessed for areas such as safety, efficiency, environment and users. Thus, it is essential to ensure that the impact estimates that are included in the socioeconomic impact evaluation are compatible across the different impact areas.

To facilitate the estimates' compatibility, we need to ensure that:

- Effects are estimated with reference to the same technology
- Estimates measure effects that unfold over the same time period
- Estimates are made with comparable penetration of the investigated technology
- The estimated economic value of impacts is based on the same basic guidelines

4.1.6 Ensure compatibility in investigated technology

Impacts relating to safety, efficiency and environment have been estimated for two types of technologies. One is referred to as Baseline ADF (BADF), and the other includes enablers that are realised by more advanced on-board units in the car and roadside units in road infrastructure, which are referred to as Enabler ADF (EADF).

The technology investigated in Hi-Drive Global Survey refers to an automated car, which is described as follows: the car can usually drive in automated mode on motorways, urban roads and when parking. On rural roads, and whenever requested by the AD-system, the car must be driven manually.

The descriptions of AD provided to the survey respondents explaining how an automated vehicle will function were in line with the EADF capabilities, even though this Hi-Drive-specific term was not used in the surveys.

EADF's impacts on safety, efficiency and environment are assessed separately for motorway and urban driving. The impact estimates derived from the survey data on willingness to pay (WTP) do not distinguish between driving on motorways and urban roads. It concerns all driving taking place as part of ADF's operational design domain (ODD). In the overall socioeconomic evaluation, we consider impacts of ADF on driving on motorways and urban roads combined.

This is also sensible from an economic point of view. Even though the ADFs for motorway and urban driving are separate systems, the investigation of these ADFs in Hi-Drive revealed that their components overlap to a considerable extent. For instance, the cost estimate for installing motorways and urban ADFs, including enablers, combined is less than 10% higher than the cost of installing one of these ADFs.

4.1.7 Ensure identical periods of time for effects to spread out

Consistent with the snapshot approach (see Chapter 3.2), the impacts on safety, efficiency and the environment are estimated according to their magnitude over one year, i.e., on an annual basis. Impacts derived from the survey data on WTP are, on the other hand, meant to reflect the magnitude of impacts as they are spread out over the lifetime of the EADF equipment. To be included in the overall evaluation, the economic value of the lifetime benefits must be annualised. Furthermore, the estimated cost of having AD and its enablers produced and installed is an investment that must be annualised.

4.1.8 Ensure compatibility in penetration rates

The focus of the overall evaluation is primarily on impacts estimated by assuming 30% EADF penetration, measured as the AD share of vehicle kilometers traveled (VKT) by passenger cars inside the ODD. This is also how penetration is operationalised when impacts relating to safety, efficiency and environment have been estimated.

When utilising data from the survey, the answers of each respondent are interpreted as representing the expectations of a potential AV driver and each respondent as representing one car. Thus, when applying survey data to estimate AD's economic impacts and the costs of implementing AD, one crucial question is how many cars need to be replaced with AD to achieve 30% AD penetration, measured as a share of total VKT.

For the economic analysis, the calculation of the required share of AD-equipped vehicles focuses on those expected to be the first adopters, as this group demonstrates the greatest willingness to invest in AD technology. This selection aligns closely with the theoretical basis of the snapshot approach.

When calculating the share of AVs that is required to match 30% AD penetration as a share of VKT, it must also be considered that annual driving distance differs between drivers. In addition, it is found to be more realistic to assume that the use of AD is voluntary, meaning that the expressed willingness to use AD must be considered. Details on the selection of cars to be equipped with AD are presented in Chapter 6.2.2.

4.1.9 Ensure common principles to estimate the economic value of impacts

Impacts relating to safety, efficiency and environment are measured in non-monetary units, such as changes in the number of accidents according to severity or changes in travel time, energy consumption and CO_2 emissions relative to the baseline. To assess the socioeconomic value of AD, all estimated impacts must be monetised. To express the monetary value of estimated impacts, we need to ascribe an economic value to each unit of the measurement scale that is applied. For instance, when impacts are measured as reductions in the number of fatal accidents, we need to calculate the costs of one fatal traffic accident. When impacts are measured in hours spent travelling, we need a unit cost for one hour of travel time.

These unit values are referred to as standard unit costs. Costs differ between individuals and countries for various reasons, such as differences in income. For the economic evaluation, standard unit costs are calculated to express costs that can apply to all individuals in the EU. This means that a guiding principle is to calculate standard unit costs based on average values intended to represent the general population. The standard unit costs applied in the economic analysis are described in Annex A2.

Impact estimates based on the WTP survey data are directly expressed in monetary terms. To be compatible with how the economic value of non-monetary impacts is calculated, the economic estimates derived from WTP should be based on average values for all respondents. Ultimately, all economic values should be expressed to reflect the price level of one common year. All values in the economic evaluation are adjusted to reflect 2024 prices.

4.2 Reliability of impact estimates

Efforts have been taken at several stages to endorse the reliability of estimated outcomes. This concerns the design of pilot studies, the way simulations are set up, clarifying baseline for impact detection, how outcomes are detected according to different driving scenarios, and the way results are upscaled to estimates referring to the EU. All details, including limitations, regarding the estimation of safety impacts are described in deliverable D7.3 *Effects* (Sonntag et al., 2025), while deliverable D7.4 *Effects on Mobility, Efficiency and Environment* (Innamaa et al., 2025) presents details relating to the estimation of traffic efficiency and environmental impact.

The explanation of this procedure, along with the accompanying elaborations, ensures that the estimated impacts remain transparent and open to scrutiny, which is fundamental to a scientific approach to impact assessment. With regard to the survey data, we assume that respondents understood how AD will function when asked to indicate their willingness to pay for its installation. The same assumption applies to their responses concerning how AD may help them overcome health-related driving limitations. We also assume that respondents answered honestly.

Given that it is currently difficult to anticipate precisely how AD technology will perform in practice, these assumptions enable us to generate informed estimates of its potential effects on users. Although the survey asks respondents to state their willingness to pay extra for equipping their car with automated driving, it is widely acknowledged that eliciting true preferences is challenging (Carson and Groves, 2007; Boardman et al., 2018). Nonetheless, this approach allows us to gather substantial information on the topic and use it constructively in the analysis.

5 User benefits

The purpose of this chapter is to investigate the extent to which AD is expected to generate benefits for its users. These user benefits are central to determining both the expected market demand for AD and the broader welfare effects for AV adopters. As such, it is important to assess the perceived benefits that users expect to gain from AD, and the associated costs of purchasing.

We start by outlining a theoretical framework, from which we derive the expected user benefits. Based on this framework, we quantify these benefits using data from the Hi-Drive Global Survey, focusing on five EU countries: France, Germany, Poland, Spain and Sweden. Respondents were asked how much extra they would be willing to pay for AD systems to be installed in their next car. Respondents were informed that the cost of a conventional car and a comparable car equipped with AD is the same except for the cost of installing the equipment needed for automated driving.

The stated willingness to pay (WTP) to have AD systems installed is meant to reflect the net present value of the benefits that users expect from using AD. As no additional usage costs are expected (as detailed in Annex A1), the WTP responses provide insight into how individuals differ in their expectations of AD benefits. Comparing the distribution of WTP with the estimated installation cost of AD, we assess the likelihood of users' positive net welfare gains.

Furthermore, we use the stated WTP to estimate a demand curve for AD. We assume that only respondents with a WTP equal to or greater than the estimated cost of having AD installed will choose to adopt AD, which allows us to estimate its potential market demand.

We acknowledge that economists typically prefer to observe individuals' actual valuation of goods and services, rather than eliciting their valuation via surveys. Nevertheless, surveys are widely used in marketing research to explore willingness to pay for new goods or services, and their validity has been extensively debated (Breidert et al., 2015). Some express skepticism towards directly asking customers about their WTP (Nagle and Müller, 2018). On the other hand, the frequent and widespread application of WTP surveys indicates that many find them valuable.

The use of survey-based stated preference when evaluating the utility of new products is also acknowledged by Boardman et al. (2018) in their seminal cost-benefit analysis textbook. They acknowledge, however, that a major concern in designing such surveys "is whether respondents are truly able to understand and place into context the questions they are being asked and, consequently, whether they can accurately value the good in question" (p. 383).

As the general public currently lacks firsthand experience with AD, this factor is particularly relevant when interpreting survey outcomes.

Consequently, we must address the reliability of applying survey data to quantify user benefits for a product that is not yet available. In particular, we expect that respondents may report a lower WTP for AD systems than their true underlying WTP. Although many individuals express positive attitudes toward AD technologies and a desire to use them, they may be reluctant to state a high WTP in survey settings due to hypothetical bias, budget constraints, or uncertainty about future benefits. Consequently, the stated WTP figures may be conservative, implying that the actual user benefits could be higher than reported. However, the degree of underestimation is difficult to determine.

Previous research has noted this tendency for respondents to understate WTP in stated preference surveys, particularly for new or unfamiliar technologies. For example, Hensher (2010) and Louviere et al. (2000) discuss strategic and hypothetical biases in stated choice experiments, while Bansal et al., (2016) found that although many individuals were interested in automated vehicles, their stated WTP was relatively low compared to their expressed interest.

In the following our approach for incorporating user benefits into the overall economic evaluation of AD is outlined.

5.1 Welfare effects for AD users

To understand why people might be willing to pay for AD equipment, we must examine the benefits that users expect to gain from doing so. According to economic theory, individuals are willing to buy a commodity if they expect it to improve their overall welfare, i.e., if the benefits outweigh the costs.

In Annex A3, a theoretical model is presented to formalize how people perceive the welfare benefits of AD, which is decisive for their willingness to pay for equipping their car with AD technology. The basic component of the model is that personal welfare depends on the time available for work and leisure. While work generates income to purchase goods and services, leisure provides opportunities for relaxation and recreation. In addition, the perceived discomfort of driving is assumed to be another factor which influences welfare.

The underlying argument is based on time being a limited resource, making it valuable from a welfare economic perspective. Driving consumes time and will therefore reduce the amount of time available for welfare-generating activities, namely productive work and leisure. We refer to the time available for these activities as *untied time*.

To explore the welfare effects of AD, we introduce the concept of *effective travel time*. Effective travel time is a) the actual time spent travelling; b) additional work time required to cover travel-related costs, such as fuel, tolls and insurance; and c) time needed to regain energy to recover from the physical or mental strain of driving.

Based on this model, AD can be expected to generate welfare gains by reducing effective travel time, thereby increasing the amount of uncommitted time available for welfare-generating activities. This effect arises because AD enables drivers to engage in alternative activities such as work or relaxation during the trip, rather than focusing on active driving. Similarly, welfare gains may occur if travellers in AVs experience fewer or shorter delays as a result of AD. Moreover, beyond reducing effective travel time, AD can further enhance welfare by increasing perceived comfort, specifically by reducing the discomfort typically associated with driving.

Furthermore, it is important to recognize that driving involves uncertainty. In assessing the welfare effects of AD, we must also consider how AD affects risks associated with driving, i.e., the likelihood of accidents or delays. Negative events such as accidents and delays increase costs, as well as effective travel time and discomfort.

As most people are risk-averse, they make efforts to minimize uncertainty, i.e., by reducing both the likelihood and consequences of negative events, such as accidents and delays. These efforts often come with trade-offs, such as driving more cautiously to avoid accidents or adding time buffers to avoid delays and their consequences. These actions increase effective travel time. Similarly, people may spend more money on insurance to reduce the costs if accidents occur, or on safety features in cars. Such costs can be reduced as AD reduces the risk of negative events.

Based on the theoretical model, we have identified five different types of benefits that users may expect to gain from AD. Their willingness to pay for AD depends on how they perceive what they will gain from these benefits.

The design of WTP questions in our survey is inspired by this theoretical approach. After a short description of how an AD equipped car functions, the respondents were asked to state their willingness to pay extra for AD. Then, they were asked to distribute their WTP across different AD-generated benefits. We distinguished between outcomes related to accidents and delays, and outcomes related to the opportunity to engage in non-driving activities and experiencing less stressful driving. Hence, when deciding how much they were willing to pay for AD, respondents considered:

1. WTP for *increased safety*: interpreted as lower risk of accidents, implying feeling safer and lower expected accident costs
2. WTP for *fewer and shorter delays*: interpreted as lower risk of delays and less additional travel time
3. WTP for *spending travel time on work-related activities*
4. WTP for *spending travelling time on relaxing*
5. WTP for *increased comfort (less stressful driving)*: interpreted as reduced discomfort

5.2 Willingness to pay for AD

As mentioned earlier, the descriptions of AD provided to the survey respondents were in line with the EADF capabilities, even though this Hi-Drive-specific term was not used in the surveys.

In the survey, respondents were asked how much extra they would be willing to pay to have an automated driving system installed. The stated willingness to pay for AD equipment varies among respondents, reflecting their expectations of the benefits of AD. Table 5.1 shows the distribution of respondents across five predefined WTP categories. Respondents' answers vary considerably regarding their expectations of AD's benefits, with most indicating a willingness to pay (WTP) in the lower price ranges or expressing no willingness to pay at all.

Table 5.1: Willingness of respondents from five EU countries to pay extra for installation of AD in their next car.

	€0	<€4,000	€4,001-€6,000	€6,001-€8,000	>€8,000	Total
Number of respondents	1,621	1,745	1,110	327	190	4,993
%	32.5%	34.9%	22.2%	6.5%	3.8%	100%

WTP represents the net present value of the benefits that users, on average, expect to gain over the lifetime of AD equipment. Based on the data in Table 5.1, the average WTP – or the economic value of users' expected benefits from AD – is €2,650. In Table 5.2, the average WTP is also calculated for different groups, with respondents classified by their stated WTP, gender, and income. These averages are calculated under the assumption that respondents are linearly distributed within each WTP category.

Table 5.2: User benefits in terms of WTP for AD, by gender and income (€).

	WTP (€)
WTP (from top)	
• Top 10%	8,176
• 10-30%	5,133
• 30-50%	2,373
• Low 50%	352
Gender	
• Male	2,814
• Female	2,488
Income	
• High	3,317
• Medium	2,708
• Low	2,034

The WTP groups are constructed by focusing on the top 10% of respondents with the highest expressed WTP for having AD installed, followed by a group representing the 10-30% range of the highest WTP, the 30-50% group, and finally the 50% with the lowest stated WTP. The table also displays the differences based on gender and income. For income, respondents are classified as high, average, and low-income groups, based on background information from the survey. Categorization of income per country was derived from annual net and gross earnings (income) data for European countries (Eurostat, accessed on 26/01/2025).

As shown in the table, user benefits vary significantly depending on respondents' stated WTP for AD. On average, the WTP for the top 10% group is more than 20 times higher than the WTP for the lowest 50% group, and more than twice the total average.

The results also reveal a slight difference in expected user benefits according to gender. Average WTP is 8% higher for men compared to women. Moreover, WTP tends to increase with income level. WTP for the high-income group is on average more than 60% higher than the low-income group, and more than 20% higher compared to the medium-income group.

5.3 Aggregate welfare effects

When evaluating the welfare benefits of AD for consumers, the user benefits must be considered in relation to the associated costs. The minimum estimated cost for original equipment manufacturers (OEMs) was estimated to €1,570, and the maximum cost to €3,580 (see Chapter 8.2.1 and Annex A1). It is important to note that the cost for users as consumers is not equivalent to producer costs but reflects the market price of having AD installed. Based on the FESTA Handbook (2021, page 167), the market price is estimated to be three times the production cost, which means a minimum market price estimate of €4,710 and a maximum market price estimate of €10,740.

When accounting for the net present value of expected benefits (as shown in Table 5.2), the results suggest that a limited number of individuals are likely to experience net positive welfare effects from AD. One of the respondent groups expressed a WTP that on average matches the maximum market price estimate. When setting an upper WTP limit of €12,000, only 60 of the respondents (1.2%) were expected to gain a net positive welfare effect.

At the minimum market price estimate, the share of respondents expected to have net positive welfare effects due to AD increases. On average, the top 10% and the top 10-30% WTP groups match the minimum market price estimate. However, within the top 10-30% WTP group some individuals report a WTP below the minimum estimated market price. In total, 1,233 respondents (24.7%) are expected to experience net positive welfare effects at the minimum market price.

In conclusion, the survey results indicate that, under the assumptions used in the analysis, the vast majority of consumers would not find it profitable to equip their cars with AD.

5.4 Expected market demand and consumer surplus

Based on the information provided in Table 5.1, a demand for AD in EU 27 can be identified by assuming that each respondent represents one car, that the respondents are representative of all car owners in the EU, and that the respondents are linearly distributed within each WTP category. The demand curve is depicted in Figure 5.1.

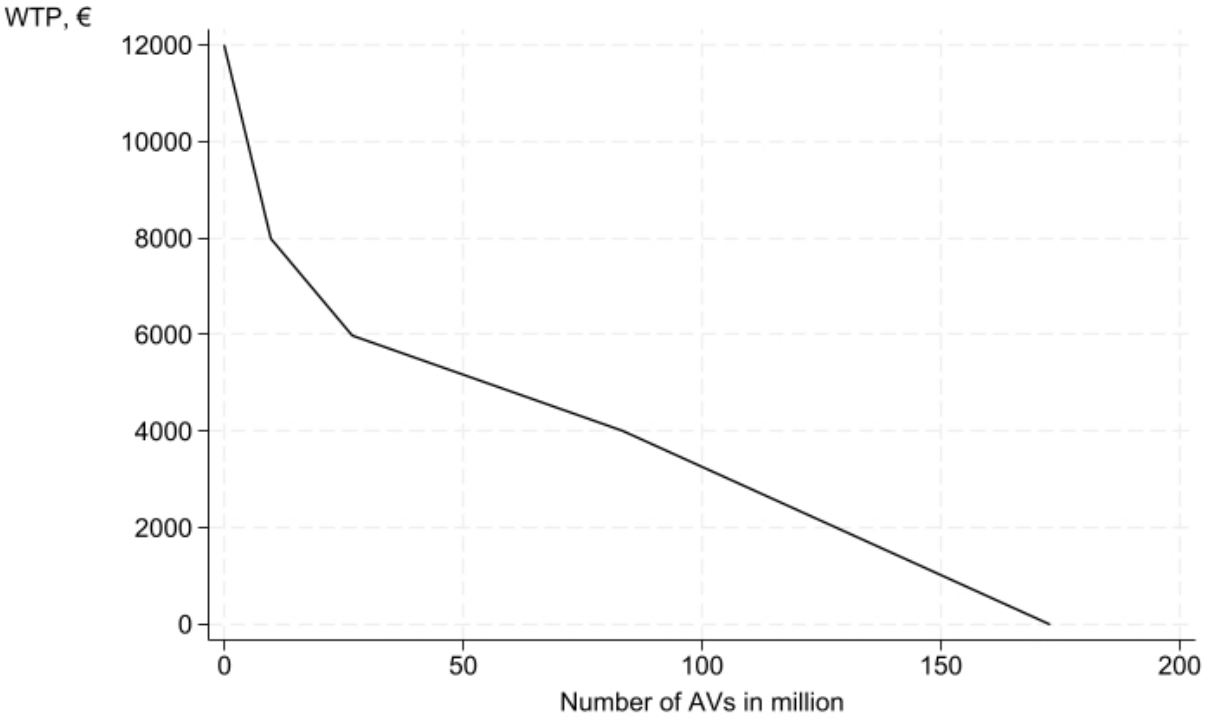

Figure 5.1: Demand curve for AVs derived from WTP.

The demand curve is drawn by assuming that the total of 4,993 respondents in the survey represent the population of car owners in the EU27. When 190 respondents in the survey stated that they are willing to pay more than €8,000 to acquire AD, it is interpreted as 9.7 million drivers across the EU expressing that they are willing to pay for AD at this price (i.e., 3.8% of the EU's 256 million passenger cars (Eurostat, 2024)). At a price of €6,000 in additional cost, demand rises to 26.6 million AD-equipped cars. Accordingly, 83.5 million are expected to be equipped with AD at an additional cost of €4,000. The demand curve reaches zero at a total of 172.8 million cars.

In economics, we expect that the demand for AD is determined by all individuals whose WTP is equal to or greater than the market price for having AD installed. As discussed in the previous section, we expect a minimum market price estimate of €4,710 and a maximum estimate of €10,740. This approach is essentially the same as the share of consumers that can be expected to gain a net positive welfare effect from AD. Based on these price estimates, the estimated market demand, i.e., the endogenous AD penetration, ranges from 1.2% of all cars at the maximum market price estimate to 24.7% at the minimum market price estimate.

The demand curve presented in Figure 5.1 reflects the willingness of private individual consumers to pay extra for AD. It does not represent the demand for company-owned passenger cars equipped with AD. This raises the question whether private consumers' WTP data can fully represent the total demand for AD-equipped passenger cars.

To the extent that company-owned passenger cars can be used in a way that by and large resembles private ownership, the WTP for company-owned passenger cars may differ from the WTP expressed among private consumers. This could be the case if there are cost advantages involved with using a company-owned car, e.g., favorable tax treatment compared to a privately owned car. We have not investigated this issue in this study. It means, however, that the actual AD demand may be higher than what is indicated by private consumer demand alone.

The expected demand for AD can also be used to estimate the consumer surplus that those who acquire AD are expected to gain. Consumer surplus is the aggregate welfare effect of AD for consumers across the EU. At the maximum market price estimate, the net welfare gains for consumers are clearly quite modest. Only 1.2% of consumers are expected to find it profitable to acquire an AV, with an average net welfare benefit of €630. Applying this to 1.2% of the 256 million passenger cars in the EU (Eurostat, 2024), the aggregate net welfare is estimated at €1,935 million over the entire lifetime of the AD-equipment. Assuming a 10-year lifetime for AD equipment and a 5% consumer discount rate, the annual net welfare effect corresponds to €251 million.

If the minimum market price estimate applies instead, 24.7% of consumers would find it profitable to acquire AD. The average net welfare benefit in this case is €1,785. This leads to a consumer surplus, or aggregate welfare benefit of €112,869 million for those who acquire an AV. Hence, the annual welfare benefit is €14,640 million.

5.5 Reliability of stated WTP

There is a general concern surrounding the reliability of survey data in ascertaining people's willingness to pay for private and public goods and services. Standard economic theory assumes that respondents answer in such a way that maximizes their expected welfare. According to Boardman et al. (2018), respondents often overstate their WTP for products under consideration for development in an effort to encourage producers to proceed. By inflating their stated WTP, they can influence the likelihood that the product will be developed and introduced to the market, without incurring any obligation to purchase it.

In other cases, however, the sound strategic response is to understate true WTP preferences. This is likely in the context of AD technology, which was portrayed as imminently entering the market, thereby incentivising respondents to report lower WTP values to avoid signalling a higher acceptable price point. In this context, the purpose of stating a WTP is not to influence whether AD will be developed, but rather to shape how producers might set the market price. Hence, repondents may strategically ***understate*** their true willingness to pay, anticipating that a lower aggregate WTP could result in a lower market price once AD becomes available.

Another factor that may contribute to the underestimation of actual WTP is myopia, or short-sightedness, in decision-making. Respondents may primarily focus on short-term costs and benefits and do not account for the full 10-year expected lifetime of AD. Alternatively, they may implicitly apply a discount rate higher than the 5% used in our analysis, thereby placing less value on the future benefits of AD.

6 Economic impacts for the EU

We investigate the economic impacts of EADF by first examining how EADF is expected to affect the number and severity of traffic accidents, followed by defining standard unit costs for different types of accident severity. Then, we focus on including user benefits in assessing the economic impacts for the EU. This is essentially about how EADF affects different aspects of drivers' travel costs. Finally, we address the economic implications of cumulative effects such as how EADF is estimated to influence traffic flow affecting all travellers, and the environment affecting society at large.

6.1 Safety impacts

We start by presenting an overview of the total number of road traffic accidents in EU in 2023, involving passenger cars by severity type. Thereafter, we present the expected reduction in different types of accidents at EU the level due to 30% AD penetration, as estimated in Deliverable D7.3 *Safety Effects* (Sonntag et al., 2025). To assess the economic value of these safety impacts, we must define standard unit costs applicable to the EU. These costs are used to calculate the magnitude of accident cost savings at the EU level.

6.1.1 The magnitude and severity of traffic accidents

An overview of traffic accidents involving passenger cars according to severity type in 2023 based on the CARE database is presented in Table 6.1. Fatal accidents are classified as accidents with at least one fatality; severe injury accidents refer to accidents with no fatalities, but with at least one severe injury; and slight injury accidents are accidents which involve only slight injuries.

Table 6.1: The number of traffic accidents involving passenger cars by accident severity and road type. EU27, 2023.

	Fatal accidents	Severe injury accidents	Slight injury accidents
Motorway	1,083	6,495	41,793
Urban	4,807	55,667	397,396
Rural	7,420	28,425	133,120
Total	**13,310**	**90,587**	**572,309**

Less than 10% of all accidents occur on motorways. Rural roads account for the majority of fatal accidents (55.8%), whereas urban roads account for the most severe injury accidents (61.5%) and slight injury accidents (69.4%).

6.1.2 AD and traffic accidents

As mentioned in Chapter 3, two configurations of ADFs are defined for the assessment of safety impacts. The first configuration represents the baseline ADF (BADF), which operates without any enablers. The second configuration, referred to as the enabled ADF (EADF), includes the enablers that support or improve the ADF's performance. The difference in safety outcomes between the BADF and the EADF reflects the impacts of the enablers investigated in the Hi-Drive project.

The upscaled safety impact estimates, which form the basis of our economic analysis, are described in detail in Deliverable D7.3 *Effects on Safety* (Sonntag et al., 2025). Table 6.2 presents the estimated reduction in the number of accidents[4], according to severity, for 30% AD penetration for BADF and EADF, compared with the actual traffic situation in 2023, referred to as the *Traffic today baseline*. The estimates include reductions in accidents within ADFs' ODD on motorways and urban roads, as well as effects on rural roads. The latter arise from the advanced in-built ADAS components of ADFs, which are expected to further reduce the number of accidents on rural roads beyond the effects achieved by mandatory ADAS.

Table 6.2: Annual reduction in the number of injury accidents by accident severity (1) ***relative to Traffic today baseline****. 30% BADF and EAD penetration.*

	BADF (ADF without enablers)	EADF (ADF with enablers)
Fatal accidents	1,737	1,960
Severe injury accidents	13,374	15,385
Slight injury accidents	88,286	102,835

As shown in the table, EADF is expected to prevent injury accidents by 13%-17% more than BADF for the different accident severities (13% for fatal accidents, 15% for severe injury accidents, and 17% for slight injury accidents). The total number of prevented accidents at 30% EADF penetration corresponds to about 15% and 17% of all fatal and severe injury accidents in the EU, respectively, where passenger cars have been involved, and about 18% of slight injury accidents involving passenger cars.

As mentioned in Chapter 3.4, several ADAS components have been made mandatory for all new vehicles in the EU as of July 2024, (EU's General Safety Regulation, July 6, 2022). These systems are expected to contribute to a significant reduction in the number of traffic accidents (European Commission, 2024a). The benefits of mandatory ADAS will be realised

[4] The estimates are presented as point estimates and not accompanied by any probability distribution. It is not clear whether each of the point estimates represent the most probable or the expected value of the outcome.

regardless of whether EADF is implemented or not. Therefore, mandatory ADAS should be considered part of the baseline for the socioeconomic evaluation of EADF. The estimated safety impacts relative to an ADAS-adjusted baseline reflect the expected number of accidents resulting from EADF beyond the safety impacts of mandatory ADAS.

Table 6.3 reports the accident reduction estimates for BADF and EADF relative to the *ADAS-adjusted* baseline. Comparing the figures with those presented in Table 6.2, ADAS is estimated to prevent a slightly larger share of accident reductions for BADF compared to EADF. The table presents the impacts estimated at 30% EADF penetration.[5]

Table 6.3: Annual reduction in the number of injury accidents by accident severity (2) ***relative to ADAS-adjusted baseline****. 30% BADF and EADF penetration.*

	BADF (ADF without enablers)	EADF (ADF with enablers)
Fatal accidents	871	1,012
Severe injury accidents	7,412	8,718
Slight injury accidents	47,502	56,783

The difference between the number of expected accident reductions for EADF relative to *Traffic today* baseline (Table 6.2) and EADF relative to the *ADAS-adjusted baseline* (Table 6.3), reflects the expected safety impacts of mandatory ADAS. Based on this comparison, mandatory ADAS is estimated to prevent 48.4% of fatal accidents, 43.3% of the severe injury accidents and 44.8% of the slight injury accidents that EADF is estimated to prevent relative to the *Traffic today baseline*.

These estimates indicate that the decision to make some types of ADAS mandatory in the EU will have significant positive impacts on safety. Other studies have expected that full implementation of ADAS will prevent roughly 15% of all traffic accidents relative to the current number of traffic accidents (Bjorvatn et al., 2021; Costa, 2023; Bjorvatn et al., 2025), while the meta study of Scholliers et al. (2020) indicated reductions in the range of 12.9% to 27.3%. The estimated impacts of ADAS in Hi-Drive are in line with these expectations.

6.1.3 EADF and PDO accidents

EADF is expected to reduce not only the number of injury accidents, but also accidents with property damage only (PDO accidents), particularly those that are labeled low-speed

[5] Deliverable D7.3 *Effects on Safety* (Sonntag et al., 2025) provides further estimates of the impacts for 10% and 50% AD penetration. These estimates are made resembling a linear relationship between penetration and impact size in the range of 0-30% penetration relative to Today's traffic baseline. There is also a linear relationship in the point estimates for 0, 30 and 50% penetration relative to the ADAS-adjusted baseline.

accidents. There are no comprehensive statistics on PDO accidents, which explains why such impacts have not been reported in Deliverable D7.3 *Safety Effects* (Sonntag et al., 2025).

According to the comprehensive overview of traffic accidents at European level for all types of accidents by Wijnen et al. (2017), the magnitude of PDO accidents was roughly nine times the number of all types of injury accidents in total. In the absence of more detailed investigations to derive specific estimates for reductions in PDO accidents due to EADF, we assume that PDO accidents will decrease in the same relative magnitude, i.e. nine times the estimated number of injury accidents. Our estimate of the expected reduction in PDO accidents is presented in Table 6.4.

Table 6.4: Expected reduction in the number of PDO accidents due to EADF relative to Today's traffic and ADAS-adjusted baselines.

	Reduction in injury accidents	PDO injury factor	Expected reduction in PDO accidents
EADF relative to Traffic today baseline	120,180	9	1,081,623
EADF relative to ADAS-adjusted baseline	66,512	9	598,610

6.1.4 Cost of accidents

There are no established unit cost estimates for the different types of accident severity at EU-level. We use the cost estimates for human injuries, on which the *Handbook on the external costs of transport* by the European Commission is based (Essen et al., 2020).

Table 6.5 presents the 2024 values for the different cost components used to calculate the standard unit injury costs of three types of injury severity. All details behind these estimates are presented in Annex 2.

Table 6.5: Standard unit costs for each injury type by main cost components, €$_{2024}$.

Injury type	Human costs	Medical costs	Production loss	Administrative costs	Property damage costs	Other costs	Standard unit injury costs
Fatality	4,190,578	7,216	859,853	8,434	15,160	4,773	5,086,014
Severe injury	669,919	22,220	57,239	5,800	10,000	542	765,720
Slight injury	51,532	1,912	3,502	2,493	6,976	681	67,096

In EU's *Handbook on the external costs of transport* (Essen et al. (2020), all estimates of the different cost components, except for human costs, are based on Wijnen et al. (2017), where great effort was made to harmonize national data across Europe and provide cost estimates at European level. These cost estimates were originally presented at 2015 prices.

We note that the underlying national data in these studies are in several cases older and have been subsequently price adjusted. The human cost estimate is based on even older data (OECD, 2012), in which the value of statistical life was derived from a research meta study from around 2005. Accordingly, the cost figures presented in Table 6.5 reflect older underlying estimates that have been subsequently updated to 2024 price levels. The accuracy of estimates that have only been subject to price adjustment over 10-20 years can obviously be questioned. Ideally these old estimates should have been recalculated utilising more recent data. Such a recalculation is, however, a demanding task and beyond the scope of Hi-Drive.

Since safety impacts are estimated as changes in the number of traffic accidents by accident severity, the standard unit injury costs must be recalculated to show the standard unit accident costs that will be applied in the economic evaluation. To calculate standard unit accident costs, we need to know both the magnitude (number) and severity of human injuries across the different accident types. Wijnen et al. (2017) found reliable information only for Greece and Norway on this matter in Europe. As we are not aware of other relevant studies, we follow the same procedure as Wijnen et al. (2017) to calculate the number of accidents by accident severity for the EU in 2023. This means that one fatal accident on average will cause 1.1 fatalities, 0.22 severe injuries and 0.43 slight injuries, one severe injury accident 1.11 severe injuries and 0.44 slight injuries, and one slight injury accident causes 1.36 slight injuries.

The resulting standard unit accident costs are shown in Table 6.6, where the unit cost estimate of PDO accidents is also based on Wijnen et al. (2017).

Table 6.6: Standard unit accident costs by accident severity, €$_{2024}$.

Accident severity	Standard unit accident cost (€)
Fatal accident	5,791,924
Severe injury accident	879,471
Slight injury accident	91,251
PDO accidents	5,196

All details relating to the estimation of standard unit accident costs are presented in Annex A2. A decisive component for estimated unit costs of fatal accidents, and to some extent for severe injury accidents, is the value of statistical life (VSL). As shown in Table A2.1 in Annex A2, more recent studies than those EU's *Handbook on the external costs of transport* (Essen et al., 2020) are based on, suggest that an updated recalculation of the VSL would imply significantly higher values. This means that the economic value of safety impacts in our calculations, particularly relating to fatal accidents and to some extent also severe injury accidents, is likely conservative estimates.

6.1.5 Accident cost savings

The economic value of reduced number of traffic accidents at the EU level is calculated by multiplying the expected number of accident reductions within each type of accident severity with the relevant standard unit accident cost. The results are presented in Table 6.7 for the expected reductions compared to each of the two baselines: *Traffic Today* and its *ADAS-adjusted* version.

Table 6.7: Accident cost saving at EU level, 30% EADF penetration, Million €$_{2024}$.

	30% EADF penetration	
	Traffic Today baseline	**ADAS-adjusted baseline**
Fatal accidents	11,354	5,862
Severe injury accidents	13,531	7,667
Slight injury accidents	9,384	5,181
PDO accidents	5,620	3,110
Total accident cost savings	**39,889**	**21,821**

When impacts are estimated relative to the *Traffic Today* baseline, the results indicate societal savings of approximately €40 billion due to reduced accident costs. In comparison, relative to the *ADAS-adjusted* baseline, the estimated savings amount to approximately €22 billion.

6.2 Economic evaluation of impacts derived from user benefits

In this section, we focus on cost reduction that will predominantly benefit drivers of AVs. As explained in Chapter 5, WTP reflects how respondents value all types of *benefits* they expect to gain from acquiring an AV compared to a conventional car. To estimate the economic value of the different perceived benefits underlying individuals' WTP, we first clarify the relative importance of these perceived benefits. Next, we assess how these underlying WTP factors can be used to estimate the annual value of user benefits for the EU at 30% EADF

penetration, making it comparable to scaled up impact estimates for safety, efficiency, and environmental effects. This allows us to estimate the economic value of user benefits at the EU level. Finally, we discuss how these benefits contribute to the overall societal value of EADF.

6.2.1 WTP components

WTP reflects the utility that users expect from having AD installed in their next car for the duration of its functionality. It represents the net present value that users anticipate gaining from AD, which is the total valuation of various types of benefits. In Chapter 5.1, we outlined the theoretical framework for deriving the benefits that users are likely to value. This relates to increased safety, the possibility to work and/or relax instead of driving, lower risk of being exposed to unexpected delays and increased comfort as driving may be perceived as less stressful.

These AD attributes were listed in the survey asking the respondents to state the relative importance of these benefits for their stated WTP. The result is presented in Table 6.8.

Table 6.8: Relative importance of different attributes for those with WTP>0, in percent.

	%
Increased safety	40.6
Fewer and shorter delays	11.2
Spending travel time on work-related activities	10.7
Spending travel time on recreation	12.2
Increased comfort (less stressful driving)	22.6
Other	2.7
N	3,372 = 100%

The major impact, from users' point of view is benefits they expect to gain from increased safety. Benefits that users expect to gain from increased comfort (less stressful driving) are also of relatively great importance.

6.2.2 Upscaling benefits to match 30% AD penetration

Impacts relating to safety, efficiency and environment are estimated in scenarios where AD is not fully implemented. The prime focus is on 30% AD penetration, measured as AD's share of vehicle kilometers traveled (VKT) within its ODD.

To utilize and scale survey data on user benefits to the EU27 level, we assume that each respondent represents one vehicle, and that the respondents are representative of all drivers across the EU27. Then, we need to determine how we select vehicles from the baseline to be equipped with AD and how we can estimate the share of AD-equipped vehicles needed to achieve the 30% AD penetration measured as share of VKT.

We find it most reasonable to select vehicles to be equipped with AD from those with the highest WTP, as these are most likely to be the first adopters of AD. In a way, this is also consistent with the steady state assumption, underlying the theory behind the snapshot approach. Furthermore, we assume that using AD is voluntary and that we need to consider that drivers vary in how much they drive in one year and to what extent they are willing to use AD if it is available. Table 6.9 provides the essential information to make this calculation. The annual driving distance and the willingness to use AD differ between drivers. In the table, this information is provided for each WTP category.

Table 6.9: Willingness to use AD and average VKT by WTP categories.. Number of respondents.

		Willingness to pay, €				
		€0	**<€4,000**	**€4,001-€6,000**	**€6,001-€8,000**	**>€8,000**
WTP to use AD	Strongly disagree	564	99	42	13	10
	Disagree	352	202	111	32	18
	Neither agree nor disagree	437	439	177	45	18
	Agree	203	698	490	138	62
	Strongly agree	75	307	290	99	82
No of respondents	N	1,621	1,745	1,110	327	190
Average VKT	km/year	10,335	10,932	13,188	13,374	16,685
Average AD-activated VKT	km/year	3,762	6,613	8,678	8,961	11,646

We also calculated the expected average VKT driven with activated AD for each WTP category by interpreting the five categories of willingness to use as equal quintiles, i.e., 20% intervals ranging from 0% to 100%. Furthermore, we assume that the respondents are linearly distributed within each quintile, which means the average willingness to use is 10% for the

lowest quintile, 90% for the highest, and 30%, 50% and 70% for intermediate categories. Based on this information, we calculate that 2,030 respondents with the highest WTP would be required to achieve a 30% AD penetration in terms of VKT, representing 40.7% of all respondents in the sample.[6]

To upscale user benefits to the EU to match 30% EADF penetration, we assume that 40.7% of EU's 256 million passenger cars, i.e., approximately 104.2 million cars, need to be AVs. It is the same number of AVs that is applied when we calculate the costs of equipping cars with AD in the overall evaluation in Chapter 8.

To comply with the principle of applying economic measures that can reflect all citizens (Section 4.2.4), we use the average WTP for all respondents in the survey. However, we override the predefined WTP response categories by excluding the possibility of a net present value of expected benefits equal to €0. The rationale is straightforward: AD will unambiguously enhance traffic safety. The magnitude of this benefit may be debated, but the positive effect is certain. Since we assume that everyone assigns some positive value to their own life, the net present value must be greater than zero. Accordingly, the 32.5% of respondents who expressed a WTP of €0 have been reclassified into the category WTP less than €4,000. With this adjustment, the average WTP applied in the economic analysis is €3,299, which is 24.5% higher than the average WTP calculated without any reclassification. The average applied reflects the net present value of all expected benefits over the lifetime of the AD equipment.

As impacts regarding safety, efficiency and environment are estimated on an annual basis, WTP also needs to be annualised so that the estimated economic value of user benefits is comparable to the economic value of the other impacts. According to industry experts, the

[6] In the survey, 4,993 respondents report that, on average, they drive 11,642 km annually. For the calculations, we assume that total VKT can be used as a proxy for total VKT within ADF's ODD. Hence, the total VKT is $4{,}993 \times 11{,}642\ \text{km} = 58{,}128{,}506\ \text{km}$. This means that 30% of VKT is 17,438,551.8 km driven with AD.
As 30% of VKT equals 17,438,551.8 km, we need to include all 190 respondents with WTP > €8,000, all 327 respondents with WTP €6,001–8,000, and all 1,110 respondents with WTP €4,001–6,000, plus replace respondents with WTP < €4,000.
The exact number X is estimated using the following equation, which calculates the vehicle kilometers traveled (VKT) driven with AD within each WTP category to reach 30% of total VKT:
$X \times 6{,}613 = 17{,}438{,}552 - (190 \times 11{,}646) - (327 \times 8{,}961) - (1{,}110 \times 8{,}678)$
Thus, $X = 403$. That is, 403 respondents are needed from the WTP < €4,000 category.
This means that the number of cars needed to achieve 30% AD of total VKT is: $190 + 327 + 1{,}110 + 403 = 2{,}030$ cars. Since the total number of respondents (cars) in the survey is 4,993, this means that 40.7% AD-equipped cars are needed to achieve 30% EADF penetration.

expected lifetime of AD is 10 years, and we assume that the secondhand value of AD-equipped cars after 10 years is the same as similar conventional cars. Then, the annual WTP is €427, when we assume that the annual interest rate facing consumers is 5%.[7]

6.2.3 Users' valuation of expected benefits

When calculating the economic value of benefits at the EU level that users expect to gain from AD, we estimate a benefit per car for each type of impact by multiplying the share of expected impacts for respondents' WTP (Table 6.8) with the annual WTP value of €427. Then, the economic value of these benefits at the EU-level for 30% EADF penetration is calculated as the product of these unit benefits and 104.2 million cars.

The different benefits that are addressed are benefits that are achieved when AVs are driving in automated mode.

- ***Increased safety.*** Accidents caused by human error are reduced. As a result, overall safety improves, leading to a greater sense of safety/security for users of AD. A decrease in accident frequency also reduces total accident-related costs.
- ***Possibility to work/Productivity during trip.*** Drivers no longer need to devote time to active driving. Instead, they can engage in work-related activities or other non-driving activities. According to Deliverable D7.4 *Effects on Mobility, Efficiency and Environment* (Innamaa et al., 2025), the Global Survey indicates that around 30% of respondents would always or very often engage in work-related activities in AVs while commuting, whereas fewer than 20% would do so during leisure trips. The share of those who rarely or never plan to work while travelling is considerably higher; 45% when commuting and more than 60% on leisure trips.
- ***Relaxation and Recreation/Possibility to relax.*** Automated driving also allows drivers to use their time for relaxation and/or recreation. The same survey results show that people are more likely to spend time on relaxation or engaging in recreational activities than working, both during commuting and leisure trips.
- ***Fewer and shorter delays.*** With full connectivity AVs can communicate in real time with other AVs, exchanging information about current traffic conditions.[8] If one AV encounters congestion, other AVs will be informed and can reroute accordingly. When the risk of unexpected congestion is reduced, drivers of AVs can experience fewer and shorter delays.

[7] We use 3% discount rate to calculate economic net present values from society's point of view. It is generally accepted that individuals are faced with higher interest rates. Hence, we utilize a discount rate of 5% when calculating net present values for users of AD. This means that the annual benefit will appear as slightly higher than if the lower discount rate of 3% had been applied.
[8] Full connectivity is not addressed in Hi-Drive use cases and impact assessments.

- ***Increased comfort.*** Automated driving reduces drivers' exposure to situations that are experienced as strenuous when driving manually, thereby increasing comfort as driving becomes less stressful.

The estimated economic value of these user benefits is presented in Table 6.10.

Table 6.10: AV users' valuation of expected benefits. EU27. 30% EADF penetration.

Type of benefit	Benefit per car, €	Aggregate economic impact, million €
Increased safety	173.4	18,071
Increased comfort (less stressful driving)	96.5	10,054
Possibility to relax	52.0	5,423
Fewer and shorter delays	47.8	4,982
Possibility to work	45.7	4,761

The perception of increased safety is by far the benefit that is most highly valued. It is ranked well above the possibility for drivers to engage in other activities than driving. The possibility of being able to work instead of driving is valued as less important than all the other attributes.

The perception of increased comfort is also a major factor. Comfort is, however, difficult to assess in relation to AD, as comfort is a concept with many dimensions. When the risk of accidents is reduced, comfort may increase. This is also the case when the risk of experiencing unexpected delays decreases, and when travel time predictability improves. Comfort may also increase when travel time can be used for relaxation and recreation instead of active driving. Hence, users' valuation of increased comfort due to AD is presumably much higher than what we capture by referring only to less stressful driving.

6.2.4 Value of user benefits for the EU

The users' valuation of the different types of benefits they expect to gain from AD does not necessarily add additional value from society's point of view. Among the user benefits, the valuation of increased safety, amounting to €18,071 million, is considered to be an integral part of the safety impacts already estimated as reductions in traffic accidents, where the accident cost savings for society were estimated at approximately €40 billion for *Traffic Today* baseline (Table 6.7). To avoid double counting in the cost-benefit analysis, user benefits from increased safety as perceived by AD users are excluded from the overall evaluation of AD. User benefits from *fewer and shorter delays* are also excluded as these effects are captured in the estimated impact of EADF on total travel time. However, after the survey was conducted,

it became evident that such benefits cannot be achieved unless AVs are fully connected. Since this condition is not met for EADF, the user impacts that must be considered are those not accounted for elsewhere. These include the possibility for drivers to engage in activities other than driving, such as work or relaxation, and the benefit of increased comfort as driving is experienced as less stressful.

As the estimated user benefits are derived from the stated WTP, which encompasses all types of perceived benefits, the economic values of the remaining four WTP attributes (increased safety, possibility to work, possibility to relax, and increased comfort) were recalculated. A 12.6% upward adjustment was applied to the corresponding values reported in the table to ensure consistency with the revised scope, which excludes delay reductions.[9] The results are presented in Table 6.11.

Table 6.11: AV users' valuation of expected benefits. EU27. 30% EADF penetration.

Type of benefit	Adjusted Aggregate economic impact, million €
Increased safety	20,348
Increased comfort (less stressful driving)	11,321
Possibility to relax	6,106
Fewer and shorter delays	0
Possibility to work	5,361

We do not expect mandatory ADAS to affect user benefits such as increased comfort, possibility to relax and possibility to relax, implying that respondents' reference to *Traffic Today* is identical to an *ADAS-adjusted* baseline. Consequently, the estimated economic value of these benefits is consistent with the estimated accident costs savings relative to the ADAS adjusted baseline.

6.3 Economic valuation of cumulative effects

The operation of EADF/AD-equipped vehicles is likely to differ from manual driving in terms of speed control, acceleration, and deceleration. These differences may influence overall traffic flow efficiency across the vehicle fleet, potentially generating cumulative effects. Changes in traffic flow efficiency, in turn, can affect energy consumption and consequently the level of CO_2 emissions from fossil fuels.

[9] Fewer and shorter delays account for 11.2% of the stated WTP. If this effect is excluded and the WTP is redistributed across the remaining four attributes, their average values increase by 12.6% ($100 \div 88.8 = 112.6$).

6.3.1 Traffic flow impacts

Table 6.12 presents the estimated changes in travel time resulting from Efficiency impact assessment, referring to changes in total travel time in the EU over a year within EADF's ODD at 30% penetration rate for the *Traffic Today* and *ADAS-adjusted* baselines. Estimates were made separately for driving on motorways and urban roads. In the economic analysis, it is the sum of the two that counts.

As shown in the table, total travel time is expected to increase with EADF. The difference between the estimated traffic efficiency impact is similar for the two baselines, but slightly higher for the *ADAS-adjusted* baseline compared to the *Traffic Today* baseline. This is to be expected as AVs adhere to all regulatory speed limits.

Table 6.12: Additional travel time within ODD of EADF relative to Traffic today baseline *and ADAS-adjusted baseline. Expressed in million hours, EU27, 30% EADF penetration.*

	Traffic today baseline	ADAS-adjusted baseline
Urban	100	164
Motorway	220	191
Total	**320**	**355**

The increase in total travel time implies that EADF comes as a cost to society. The economic value is calculated by applying a standard unit travel time cost estimate that cuts across all different travellers, their travel purposes, and the length of their trips. In Annex A2, this is estimated based on national unit travel time cost data in the EU, taking into consideration the average number of people travelling in passenger cars and the share of business or commuting trips, leisure trips, and the share of heavy goods transportation on the roads. The standard unit cost of travel time applied is €21.12 per hour.

The economic value of less traffic efficiency is calculated by multiplying the increase in hours spent travelling with the standard unit travel time cost. The estimated cost is presented in Table 6.13.

Table 6.13: Cost of additional travel time due to EADF. Million €. 30% EADF penetration.

	Traffic today baseline	ADAS-adjusted baseline
Cost of additional travel time	6,767	7,503

6.3.2 Energy and environmental impacts

Deliverable D7.4 *Effects on Mobility, Efficiency and Environment* (Innamaa et al., 2025) also provides estimates of how energy consumption and CO_2 emissions are affected by EADF. These impacts are not directly generated by EADF per se, but as a result of how EADF, for instance, affects traffic efficiency. It is, however, not straightforward to determine to what extent such impacts on energy consumption or climate gas emissions should occur, or whether they are likely to increase or decrease. Table 6.14 presents the estimated changes in fossil fuel consumption, as well as CO_2 emissions for *traffic today baseline* and *ADAS-adjusted baseline*.

Table 6.14: Estimated change in fossil fuel consumption and CO_2 emissions. *30% EADF relative to Traffic today baseline and ADAS-adjusted baselines.*

	Traffic today baseline		**ADAS-adjusted baseline**	
	Fossil fuels Million liters	**CO_2 emissions 1000 tons**	**Fossil fuels Million liters**	**CO_2 emissions 1000 tons**
Urban	562	1,362	327	791
Motorways	666	1,329	0	-100
Total	**1,228**	**2,690**	**327**	**690**

Fossil fuels include petrol, diesel and liquid petroleum gas (LPG). Positive number: Reduction; Negative number: Increase

Fossil fuels: The estimated changes in fuel consumption at 30% EADF penetration show a reduction of 1,228 million petrol-equivalent liters in fossil fuels consumption[10] relative to *Traffic today baseline*, and 327 million liters relative to the *ADAS-adjusted* baseline.

For the valuation of these impacts, we apply the standard unit cost of one liter of petrol net of taxes, which has been calculated at €0.75 in Europe. Based on this unit cost, the cost savings from reduced fossil fuel consumption are €921 million relative to *Traffic Today* baseline, while it is €245 million compared to the *ADAS-adjusted* baseline.

CO_2 emissions: The estimated effects on CO_2 emissions are quite small. In the *Traffic Today* baseline scenario, a 30% EADF penetration reduces CO_2 emissions by about 2.69 million tons in total for motorway and urban driving. In the *ADAS-adjusted* baseline scenario, CO_2 emissions are estimated to decrease for urban driving, whereas they are expected to increase on motorways. Overall, the combined effect results in an estimated net reduction of approximately 0.69 million tons of CO_2.

[10] It is assumed that one liter of diesel is equivalent to one liter of petrol, while LPG is considered to be 20% less efficient.

The standard unit cost for CO_2 emissions is €342 per ton, which implies that the economic value of lower CO_2 emissions is €920 million with *Traffic Today* baseline, and €236 million with the *ADAS-adjusted* baseline.

7 Transport Equity

7.1 Introduction

Social equity is a concept used to address the distribution of services, resources, benefits and responsibilities in society. The idea is to take systemic inequalities into account to ensure that everyone has access to the same opportunities and outcomes. When discussing social equity impacts of AD, we focus on access to car use and the benefits of using a car.

The AD investigated in Hi-Drive focusses on driving in automated mode on motorways and urban roads, which means that the environment does not need to be monitored by the driver while the system is activated. At this level of automation, the driver can take their hands off the wheel, eyes off the road, and engage in other activities instead of actively driving. The driver must, however, be prepared to take over manual control of the car whenever it is required by the AD system, and to operate the car manually whenever travelling on rural roads.

These AD features reduce the burden which driving can represent. A key question is whether the introduction of AVs will provide new driving opportunities for drivers who suffer from health-induced hindrances to manual driving.

7.2 AD and transport equity

It is widely accepted that full development of automated driving technology allowing for driverless vehicles, has the potential to improve mobility and transport equity for people who currently are unable to fulfil their transport needs because of various disabilities (Cordts et al., 2021; Petrovic et al., 2022; Vijaygopal et al., 2023).

The AD technology investigated in Hi-Drive does not concern fully automated driving. Even though drivers have the possibility to engage in other activities than monitoring the environment, they should have full driving capabilities in case of takeover requests by the system or for driving on urban roads.

In the following section, we discuss the impacts of AD on transport equity by focusing on individuals who experience health-related conditions that affect their ability to drive. The analysis is based on data from the Hi-Drive Global Survey 2024, as previously discussed in relation to user benefits. The survey data also shed light on the prevalence of health-induced hindrances to driving among people who hold a driver's license, their background characteristics, and their expectations of automated driving. Specifically, we assess whether those with driving disabilities expect that AD will help them restore their driving capacity. In addition, we investigate to what extent these individuals are likely to adopt and use AD once

it becomes available. Finally, we conclude by summarizing what we consider reasonable to expect of AD and its potential impact on improving transport equity.

7.3 Health-induced hindrances to manual driving

As AD is not yet available on the market, we lack real empirical evidence to document how and to what extent it may facilitate driving for those who experience health-induced hindrances to manual driving. Given the lack of empirical evidence, we base our considerations on the data from the Hi-Drive Global survey (see Section 4.1.3).

In the survey, respondents were asked whether and how a health-related condition affects their ability to drive, specifically referring to manual driving of conventional cars. Table 7.1 provides information on the prevalence of health-induced hindrances to manual driving.

Table 7.1: Distribution of respondents by whether a health-related condition has affected driving.

	Number of respondents	%
Yes, not driving anymore	274	5.5
Yes, I have reduced driving	660	13.2
Not affected	4076	81.4
Total	5010	100

Close to 20% of respondents expressed that their driving of manual cars has been affected because of a health-related condition, where 5.5% do not drive anymore, while 13% of respondents have reduced their driving). Table 7.2 presents background information by gender and age for individuals whose driving has been affected and those whose driving has not.

Table 7.2: Distribution of drivers by whether a health-related condition has affected their driving, by gender and age.

	Do not drive anymore	Have reduced driving	Driving not affected	N
Gender				
Male	147 5.9%	301 12.2%	2028 81.9%	2476 100%
Female	124 4.9%	356 14.1%	2038 80.9%	2518 100%

	Do not drive anymore	Have reduced driving	Driving not affected	N
Age				
<30 years	61 8.0%	127 16.6%	575 75.4%	763 100%
30-44 years	102 7.1%	184 12.8%	1149 80.1%	1435 100%
45-59 years	47 3.5%	145 10.7%	1166 85.8%	1353 100%
60-74 years	32 2.9%	133 12.1%	939 85.1%	1104 100%
75-85 years	32 9.0%	71 20.0%	252 71.0%	355 100%

There are no substantial gender differences in how health-related conditions affect driving. When it comes to age, driving-related problems are more apparent among older individuals (75 years and older), which is according to our expectations. Interestingly, the youngest (under 45 years) also report more extensive driving difficulties than the middle-aged group, which is not so easy to explain. However, the extent of driving disabilities does not vary substantially between the other age groups.

7.4 How can AD be expected to affect transport equity?

The existing literature does not provide any clear points of reference for assessing whether and to what extent AD can be expected to overcome health-induced hindrances to car use. It should, however, be noted that AD (SAE level 3) necessitates a driver who can operate the vehicle manually whenever the automated mode is unavailable or upon request by the AD system, even when automated driving is expected to function. In other words, health-related impairments still constrain drivers' capacity to operate AVs in the same way as conventional vehicles. What differs is essentially the amount of time spent driving manually.

AD may substantially reduce the amount of time manual driving is required for, in comparison with that of conventional vehicles. This may imply that some will experience driving an AV as being less burdensome. If the driving threshold is lowered because AD shortens the time that is needed for active manual driving, it may have a positive impact on access to car use. AD also represents a step towards developing Level 4 highly automated driving, or Level 5 fully automated driving, which should be expected to have broader transport equity effects.

7.5 General public's expectations of AD and transport equity

A key question regarding transport equity is whether AD can facilitate driving in a way that helps people overcome barriers associated with manual driving. Survey data on this topic focus on how respondents perceive the technology and the expectations they form based on understanding of the technology involved.

The survey uses the term "automated car," describing its functionality as equivalent to EADF. EADF is generally possible on motorways, urban roads, and during parking, while all driving tasks outside these areas must be performed manually by the driver. The survey asked respondents experiencing health-related driving disabilities whether they anticipated any changes in their driving behaviour if they had access to an automated car. According to Table 7.3, more than three out of four individuals who experience health-related conditions which prevent them from manual driving expect to be able to drive again using an automated car.

Table 7.3: Expected effect of AD on driving among those who do not drive anymore due to a health condition.

	Number of respondents	%
Expect to drive again	211	77.9
No change expected	60	22.1
All who no longer drive a manual car	271	100

As evident in Table 7.4, more than two out of three who have reduced their manual driving due to a health condition expect to drive more if they had access to an automated car.

Table 7.4: Expected effect of AD on driving among those who have reduced driving due to a health condition.

	Number of respondents	%
Expect to drive more	440	67.1
No change expected	216	32.9
All who have reduced driving a manual car	656	100

The vast majority of those who mentioned that a health-related condition affects their ability to drive conventional cars, expect that this could be overcome if they acquired an automated car. This is questionable as equipping a car with AD still implies that the driver has to execute manual driving outside areas where automated mode can function and whenever requested by the system.

The results in Table 7.3 and Table 7.4 indicate that the threshold to driving resumption seems to be lower for those who have completely stopped driving due to their health condition than for those who have merely reduced their driving. Such expectations and the possibility of overcoming driving difficulties can be questioned. Automated vehicle operation may be advantageous for certain physical and mental disabilities as it reduces the amount of active driving required by making the driving process easier and less exhausting. However, AD will still require manual driving skills required for conventional vehicles. Therefore, it is unrealistic to expect that AD will enable anyone who no longer is able to drive a conventional car to drive again. The overwhelmingly positive survey responses indicate that some of the participants perhaps misunderstood the term "automated car" as referring to a fully automated vehicle, assuming there would be no need to reassume control at critical moments during the trip.

On the other hand, the large share of respondents who have merely reduced their manual driving activities due to health conditions and expect to drive more if provided with an automated vehicle, support a more plausible argument. As these individuals are still in a position to perform some manual driving, the supportive function provided by driving in automated mode will hopefully increase how often they can drive.

8 Overall socioeconomic evaluation

The basic idea of cost-benefit analysis is to express all relevant impacts of a project in monetary terms. Then, the overall evaluation consists of comparing the total value of all impacts, i.e. the net benefits, with the total costs of achieving them. When net benefits exceed costs, i.e., the benefit–cost ratio is greater than one, the project is profitable from society's point of view.

The benefit–cost analysis of EADF is conducted by focusing on the impacts that AVs would have if they reached a 30% penetration. To this end, we first recap the main findings from the previous chapters, summarizing the estimated benefits and costs across different impact areas. We then calculate the costs of equipping vehicles with EADF in order to realise these impacts. Finally, we combine all monetary values related to EADF and its implementation into an overview, which forms the basis for calculating the benefit–cost ratio. The chapter concludes with a discussion of the sensitivity of the results to the underlying assumptions.

8.1 The economic value of estimated impacts

The analysis measures the annual difference in estimated impacts between a scenario in which 30% of all vehicles operate using EADF and a scenario without EADF. All monetary values are expressed in euros and reflect 2024 price levels.

As discussed in Chapter 7 on transport equity, AD is not expected to enable individuals with driving disabilities to overcome all limitations that currently prevent them from operating conventional vehicles. Consequently, transport equity impacts in terms of driving disability or limitations are not included in the overall economic evaluation. Individuals with minor driving disabilities, who currently limit their driving of conventional vehicles, may benefit from AD by being able to drive more frequently in automated mode.

In the overall evaluation, the economic impacts for the EU are incorporated from the findings presented in Chapter 6. EADF is expected to reduce the number of accidents across all severity categories, resulting in lower aggregate accident costs. The overall evaluation demonstrates the genuine contribution of EADF by excluding safety impacts already attributable to ADAS functions, which are mandatory for all new vehicles since 2024. The societal value of accident cost savings is estimated by multiplying the relevant unit accident costs by the expected number of accident reductions for each severity level, relative to the *ADAS-adjusted* baseline at 30% EADF penetration.

The economic valuation of traffic efficiency impacts is based on the total travel time within ADF's ODD. At 30% EADF penetration, total travel time is estimated to increase. On the other hand, a modest decrease in fossil fuel consumption and CO_2 emissions is estimated.

The economic value of user benefits from AD (EADF) is estimated from survey data on respondents' willingness to pay for AD-equipped vehicles. WTP reflects the utility users anticipate from AD and represents the net present value of all expected benefits, including safety improvements. To prevent double counting, perceived safety benefits are excluded from the overall cost–benefit analysis.

Table 8.1 summarizes the economic value of all estimated impacts, adding up to economic benefits that are expected based on 30% EADF penetration in the EU. These have been presented previously for the main impact areas in Chapter 6.

Table 8.1: Economic value of EADF generated impacts. EU level, 30% penetration. €$_{2024}$.

Impact	Traffic today baseline, Million €	ADAS-adjusted baseline, Million €
Safety Impacts		
• Less fatal accidents	*11,354*	*5,862*
• Less severe injury accidents	*13,531*	*7,667*
• Less slight injury accidents	*9,384*	*5,181*
• Less PDO accidents	*5,620*	*3,110*
Total accident cost savings	39,889	21,821
Increase in travel time (cost)	-6,767	-7,502
Lower fossil fuel consumption	921	245
Reduction in CO_2 emissions	920	236
Impacts benefiting users only		
• Possibility to work	5,361	5,361
• Possibility to relax	6,106	6,106
• Increased comfort (less stressful driving)	11,321	11,321
Economic value of estimated impacts	**57,751**	**37,588**

In both baseline scenarios, the major components of the economic evaluation are the benefits arising from safety improvements and the benefits users expect from the possibility of working, relaxing, and enjoying increased comfort while travelling. Another significant component is the increase in travel time costs. The estimated benefits related to energy consumption and CO2 emissions are comparatively small. Overall, society is estimated to gain annual benefits of nearly €58 billion under the *Traffic Today* baseline and approximately €40 billion under the *ADAS-adjusted* baseline.

8.2 Additional costs for AVs

The enabling technologies enhancing automated driving require investments in vehicle equipment and road infrastructure. Therefore, in our economic evaluation of EADF, we need to include those additional costs that society will face. This allows us to compare the economic value of the expected impacts with the additional costs.

We need to consider the additional costs of equipping cars with EADF, and the costs related to ensuring that relevant road infrastructure is in place, separately. This is because total costs of equipping cars with EADF will increase with the number of AVs, while additional costs of road infrastructure will not depend on the number of AVs and therefore represent fixed costs. The relevant costs for both are the economic value of resources that society must reserve for the implementation of EADF-equipped vehicles. The valuation should reflect production costs excluding all taxes.

8.2.1 Additional costs to equip cars with EADF

EADF technology is close to market introduction, which means that much of the necessary development has already been completed. From society's perspective, these development costs are considered sunk and therefore are excluded can therefore be excluded from estimates of additional EADF costs in the EU-level economic evaluation Hence, for EADF, production costs are defined as the variable material and labour costs required to equip a vehicle with the technology.[11] Consequently, it is assumed that there is no fixed cost component affecting the unit cost, which remains essentially constant regardless of the number of cars equipped with EADF.[12]

To estimate the variable material and labour costs to equip cars with EADF, we have defined on-board components required for EADF to function compared with a conventional car and assessed costs. Focus has been on on-board components other than components already considered in a manually driven basic vehicle (cf. Annex A1.4). The cost estimates are provided within a range, which defines minimum and maximum costs. The estimated range of variable production costs for each vehicle is presented with minimum and maximum cost estimates in Table 8.2. The table also provides estimates of the expected range of EADF's market price for consumers, derived from estimated producer costs.[11] The estimated additional costs for the EADF are assumed to be identical for both baselines. This is because

[11] Producers will ensure that all sunk costs, including R&D and fixed production costs, are covered in the market price. For consumers, this price also includes value-added tax and other applicable taxes. Following the FESTA Handbook (2021, p.167), we estimate that the consumer price of AD will be roughly three times the variable material and labour costs of production.

[12] This implies that any unexploited economies of scale are assumed not to influence unit costs, and that potential productivity improvements arising from "learning by doing" are not considered.

all new vehicles, whether entering today's traffic (*Traffic today baseline*) or a future scenario with high mandatory ADAS penetration (*ADAS-adjusted baseline*), must be equipped with mandatory ADAS as part of the basic vehicle (standard configuration).

Table 8.2: Minimum and maximum unit cost estimates. Producer's material costs and expected market price for consumers. €2024.

	Minimum, €	Maximum, €
Producers' material costs	1,570	3,580
Market price for consumers	4,710	10,740

8.2.2 Additional costs in road infrastructure

To function, EADF will also utilize infrastructure such as roadside units, sensors and global network satellite system (GNSS) stations. It is, however, not clear whether additional infrastructure costs will be incurred due to EADF. The impact assessments in Hi-Drive Deliverables (D7.3 by Sonntag et al., 2025 and D7.4 by Innamaa et al., 2025) have investigated use cases implying communication between vehicles and infrastructure (V2I) and between vehicles and networks (V2N). Based on information from Hi-Drive Operation owners, none of the use cases investigated, except for the "complex intersections" use case, require additional technical components for road infrastructure purposes according to the specifications of Cooperative Intelligent Transport Systems (C-ITS) that are rolled out for other purposes than automated driving. Thus, AD is not expected to incur any additional road infrastructure costs in comparison with the standard deployment of C-ITS. An exception is the "complex intersection" use case, which was investigated in the Efficiency and Environmental impact assessment. That assessment required perfect knowledge of all objects present at every intersection – a level of situational awareness achievable only through V2I communication and dedicated infrastructure sensors. Because this use case remains highly experimental and its cost estimates are extremely sensitive, its efficiency and environmental impacts are excluded from the benefit–cost analysis. For further details and the full reasoning, see Annex 1.5.

For the other use cases, by increasing the number of vehicles being able to use C-ITS services, EADF provides additional benefits without incurring increased costs. Furthermore, EADF operates using improved positioning to overcome missing information due to weak GNSS signals and deteriorated lane markings. Hence, the overall assumption is that there will be no

additional road infrastructure costs because of EADF. For this reason, these costs have not been incorporated into our economic evaluation.[13]

All details relating to infrastructure costs mentioned above are presented in Annex 1.

8.2.3 EADF-equipment cost estimate for the overall economic evaluation

Based on previous discussion, the variable material and labour production cost can serve as the point of reference for the overall economic evaluation when calculating the aggregate costs of implementing EADF. In the overall economic evaluation, the estimated unit value of these production costs needs to be annualised. Then, the aggregate cost for the EU27 is calculated by multiplying the annual unit cost with the number of AVs that are needed for 30% penetration.

To annualize unit costs, we assume the lifetime of EADF equipment to be 10 years[14], and apply a 3% discount rate as recommended in the FESTA Handbook (2021, page 169). The range for the annual unit cost estimated is presented by a minimum and maximum cost estimate in Table 8.3. As discussed in Chapter 6.2.2, 104.2 million AVs are required to reach 30% AD penetration, measured as the share of AD-equipped vehicles in total traffic. Total annual costs for implementing AD in the EU27 are calculated by multiplying this number by the unit cost per vehicle.

Table 8.3: Minimum and maximum unit cost estimates. 30% EADF penetration. €2024.

	Annual unit cost, €	Million AVs for 30% EADF	Aggregate cost estimate, Million €
Minimum cost estimate	184	104.2	19,173
Maximum cost estimate	420	104.2	43,764

8.3 Cost–benefit analysis

Tables 8.4 and 8.5 present key information for the overall economic evaluation of EADF, based on estimated impacts relative to the *Traffic Today* and *ADAS-Adjusted* baselines. It

[13] There are use cases that may imply additional road infrastructure costs, such as complex intersections. It has not, however, been possible to estimate any upscaled impacts from these use cases. As no benefits from these enablers are included in the evaluations, we have not proceeded to investigate to what extent this might affect annual road infrastructure costs.

[14] The average lifetime of a car in the EU is approximately 20 years. This means that reinvestments would be necessary for AD to remain functional throughout the vehicle's lifetime. We assume that the same type of equipment can be reinstalled at the same cost as the original installation, implying that the estimated annual unit cost remains unchanged.

comprises two main components: the economic benefits and costs resulting from the implementation of EADF. The economic valuation of all estimated impacts is shown for each impact area. Accompanying costs are presented as minimum and maximum cost estimates, in addition to the average cost estimates.

Table 8.4: Costs and benefits of EADF implementation in the EU: ***Traffic today baseline****. 30% penetration.*

Impact	**Million €**		
Total accident cost savings	39,889		
Travel time efficiency	-6,767		
Consumption of fossil fuels	921		
CO_2 emissions	920		
Users' benefit of experiencing increased comfort (less stressful driving)	11,321		
Users' benefit of being able to relax instead of driving	6,106		
Users' benefit of being able to work instead of driving	5,361		
Economic value of all impacts	**57,751**		
	Minimum cost estimate	Maximum cost estimate	Average cost estimate
Cost of EADF implementation	**19,173**	**43,764**	**31,469**
Net benefits	38,578	13,987	26,282
Benefit/cost ratio	**3.0**	**1.3**	**1.8**

For the *Traffic Today* baseline, the main benefit components are safety improvements, estimated at approximately €40 billion, followed by user benefits of about €23 billion. Benefits from reduced energy consumption and CO_2 emissions amount to €1.8 billion, while increased travel time costs due to lower traffic efficiency total €6.8 billion. The total economic value of these impacts amounts to €58 billion at a 30% penetration rate of passenger cars equipped with EADF.

Costs associated with implementing automated driving systems in passenger cars across the EU were estimated at minimum, maximum, and average levels. Comparing these with the societal benefits shows that, under all cost estimates for the *Traffic Today* baseline, the net economic benefits clearly exceed the costs.

*Table 8.5: Costs and benefits of EADF implementation in the EU: **ADAS-adjusted baseline**. 30% penetration.*

Impact	Million €		
Total accident cost savings	21,821		
Travel time efficiency	-7,502		
Consumption of fossil fuels	245		
CO_2 emissions	236		
Users' benefit of experiencing increased comfort (less stressful driving)	11,321		
Users' benefit of being able to relax instead of driving	6,106		
Users' benefit of being able to work instead of driving	5,361		
Economic value of all impacts	**37,588**		
	Minimum cost estimate	Maximum cost estimate	Average cost estimate
Cost of EADF implementation	**19,173**	**43,764**	**31,469**
Net benefits	18,415	-6,176	6,119
Benefit–cost ratio	**2.0**	**0.9**	**1.2**

In the *ADAS-Adjusted* baseline scenario, the main benefit components remain safety improvements, estimated at around €22 billion, followed by gains for AV users who can work, relax, or enjoy greater comfort while the vehicle operates in automated mode (€23 billion). Increased travel time costs due to reduced traffic efficiency constitute another major component (€7.5 billion). In comparison, the benefits from reduced energy consumption and CO_2 emissions are relatively modest (€0.5 billion). Overall, the total economic value of these impacts for society is estimated at €38 billion at a 30% penetration rate of EADF.

Comparing societal benefits with implementation costs of EADF indicates that net benefits exceed costs under the minimum and average estimates, while total costs slightly surpass benefits under the maximum estimate. These results are reflected in the corresponding benefit–cost ratios: the net economic benefits exceed costs under the minimum estimate (benefit–cost ratio = 2) and fall below total costs under the maximum estimate (benefit–cost ratio = 0.9). With the average cost estimate, the benefit–cost ratio is 1.2, suggesting that benefits are expected to outweigh costs for most values within the estimated cost range.

8.4 Sensitivity analyses

The results of the cost–benefit analysis are clearly sensitive to uncertainties in the estimated costs and benefits. A closer examination of Table 8.5 (ADAS-adjusted baseline) indicates that EADF would be socially profitable for approximately 75% of the estimated cost range, from the minimum to the maximum. Costs would need to exceed more than 85% of the maximum estimated value before they outweigh the estimated net economic benefits. Additionally, costs could increase relative to net benefits if EADF, contrary to our assumptions, incurs additional annual road infrastructure expenses.

Regarding expected net economic benefits, uncertainties in the estimation of economic values must also be considered, particularly for the two major impact areas: safety and user benefits. For safety, this includes uncertainty in the point estimates of accident reductions as well as the standard unit accident costs applied. For user benefits, uncertainty arises from the stated willingness to pay.

8.4.1 Uncertainty regarding estimated EADF costs

Our analysis is not based on one specific cost estimate, but on estimated minimum and maximum costs. We expect that actual costs will be within this range. While it is considered unlikely that actual costs will exceed the maximum estimate, this possibility cannot be entirely ruled out.

The estimated costs of EADF implementation are highly sensitive to the assumption that annual infrastructure costs will not increase as a result of EADF. It appears reasonable to assume that Day 1 C-ITS deployment is sufficient to support EADF. However, this deployment alone is not enough to fully exploit all potential benefits of EADF, e.g., those arising from its use in complex intersections. This limitation does not pose a problem for our analysis, as efficiency and environmental impacts of this kind are not included in the upscaled estimates used for the economic evaluation. Safety benefits could also be achieved without additional infrastructure investment.

If the additional infrastructure costs mentioned above were to materialise, a permanent increase of €6 billion per year would cause total costs to exceed benefits, even under the average of the minimum and maximum cost estimates for AD implementation in the ADAS-adjusted baseline scenario. In 2016, total annual road infrastructure costs in the EU27 were around €170 billion (Schroten et al., 2019), equivalent to approximately €220 billion in 2024 prices. If enablers affect road infrastructure costs, they are likely to influence investments rather than annual operational expenditures, which make up over 80% of total costs. ADF enablers are expected to impact investments in traffic signs, signalling, and telecommunications, while the largest infrastructure costs are associated with constructing

roads, bridges, tunnels, overpasses, lighting, and acquiring land for road use. Hence, AD-supporting enablers in roadside units constitute only a small fraction of total annual road infrastructure costs. Nevertheless, if EADF leads to an increase in these costs, the benefit–cost ratio would decline compared to the values presented in Table 8.5.

8.4.2 Uncertainty regarding estimated benefits

We have argued that the WTP stated by survey respondents most likely underestimates their true willingness to pay for AD. This is because respondents are asked to indicate how much they would be willing to pay for a technology that is expected to become available on the market in the near future. As a result, their strategic interest may lead them to understate the benefits they anticipate. It is not possible to determine the exact extent to which respondents understate their valuation of AD. However, we assume that the degree of underestimation is mitigated by the fact that a WTP of €0 was overruled when calculating the average WTP to be applied. Overall, we nevertheless expect that the estimated economic value of benefits that users can expect to gain from AD is more likely to be understated than overstated.

With respect to accident cost savings, uncertainty relates to the point estimates of expected accident reductions due to EADF across different categories of accident severity, as well as to the standard unit accident costs applied in the analysis. Neither source of uncertainty is expected to be of serious concern.

Regarding the estimated reduction in traffic accidents, Deliverable D7.3 *Safety Effects* by Sonntag et al. (2025) notes that the upscaled estimates of injury accidents should be considered conservative. Even if these estimates were somewhat overstated, the number of prevented accidents would need to be reduced by 40% before EADF would appear unprofitable under the average cost estimate in the ADAS-adjusted baseline scenario.

The estimation of the standard unit accident costs applied are based on relatively older studies (cf. Chapter 6). The VSL data used by Essen et al. (2020) is based on recommendations from a meta study of OECD (2012), which in turn relies on studies conducted around 2005. Since then, the values have merely been price-adjusted rather than re-estimated. More recent attempts to estimate VSL is made by Blincoe et al. (2023) for the US, and by Schoeters et al. (2022) for Belgium, France, Germany and the Netherlands. In the US, the estimated VSL is more than twice as high as the VSL applied in our study, while the VSL in the four European countries is almost 60% higher. This suggests that accident cost savings in our analysis have likely been underestimated, and that the economic values for EADF would be even higher if more up to date VSL estimates were applied.

The primary explanation for differences in VSL across countries is the variation in GDP per capita, as VSL largely reflects the income levels of each country. According to World Bank

Group (2025), GDP per capita is measured using Purchasing Power Parity to account for price differences across countries. In 2024, EU27 GDP per capita was 72% of the US level, suggesting that the VSL used in our standard unit accident cost estimates could have been nearly 70% higher. Alternatively, comparing to Schoeters et al. (2022), which covers Belgium, France, Germany, and the Netherlands, GDP per capita in the EU27 is 90% of these higher-income countries, implying a 44% higher VSL.

Illustratively, if the OECD (2012) VSL were adjusted upward by 40%, the estimated accident cost savings would increase to €26,359 million, implying €4,538 million, or 21%, higher than the estimated safety benefits in the *ADAS-adjusted baseline* estimate.

8.5 Summary

The cost-benefit analysis results indicate that 30% EADF penetration should appear to be profitable from society's point of view within 90% of the maximum cost estimate when compared to the *ADAS-adjusted* baseline. Obviously, there are uncertainties regarding the estimated economic values of the different impacts in the analysis. These have been discussed in the previous section, where the main points are summarised in Table 8.6.

Table 8.6: Summary of uncertainties related to key estimates of the overall economic evaluation.

Topic	Consideration
Unit cost of installing EADF	The possibility of exceeding the maximum cost estimate is very low.
Cost of infrastructure enablers	The assumption of no additional costs may be questioned. If additional investments in traffic signs, signalling, and telecommunication lead to higher annual road infrastructure costs, the EADF will appear less profitable.
Economic value of user benefits	A strategic behaviour in WTP surveys is that respondents underreport their true willingness to pay. While this bias is partially corrected by excluding zero WTP responses, it is likely that some underestimation persists.
Estimated reduction in traffic accidents	According to Deliverable D7.3, all assumptions underlying the estimates have been deliberately conservative, implying that the actual impacts may be higher than the estimates provided.
Standard unit accident costs	The applied estimate for the VSL is low compared to recent studies. If a GDP per capita-adjusted VSL based on Schoeters et al. (2022) were applied, the estimated accident cost savings would increase by more than 20%.

In essence, we argue that prevailing uncertainties are more likely to underestimate the economic value of the estimated benefits, while the risk of significantly underestimating costs is considered smaller.

Benefits should also be expected to increase relative to costs if some of the general assumptions made in the cost-benefit analysis were relaxed. For instance, relaxing the assumption of funding neutrality would increase the benefits of EADF without increasing the costs. This is because the marginal cost of tax funding is greater than one as taxes introduce distortions that reduce economic efficiency. Empirical studies have documented that tax funding comes with a cost (Ballard et al., 1985; Jorgenson and Yun, 1991). In Norway, it is recommended to add 20% to costs that are funded by taxation (NOU 2012:16). In the case of EADF, the estimated cost saving from expected reductions in traffic accidents will to a significant extent affect public budgets for police, emergency services, hospitals and medical treatment. If the additional cost of tax funding were considered, cost saving in areas with public funding should be adjusted with a markup. Incorporating this adjustment would increase the economic value of accident cost savings, making it higher than the estimates reported in Table 8.4.

Relaxing the assumption of neglecting distributional aspects of EADF is not likely to affect the overall conclusion either. Most EADF-generated benefits that are accrued directly by AD users are likely to be gained by higher-income individuals, who are expected to be among the first adopters of AD. As we have calculated the economic value of user benefits based on how people on average value AD, and not on the WTP expressed by those who value it most, distributional aspects are in some sense already considered in our economic evaluation.[15] In addition, EADF generates impacts that do not solely apply to its users. Lower accident risk and the prevention of traffic accidents that AD users will benefit from, also generate large positive externalities benefiting all road users, regardless of their socioeconomic background. The estimated economic value of accident cost savings represents a benefit that all participants in traffic and taxpayers in general may expect to gain.

Relaxing the static premises of the analysis, we may consider that EADF is expected to increase both the length and frequency of passenger car driving and may even encourage car use at the expense of public transport (Deliverable D7.4 *Mobility, Efficiency and Environment* by Innamaa et al., 2025)). Higher traffic volumes are in general expected to lead to more accidents, and more fuel consumption resulting in higher CO_2 emissions. Hence, on the margin, there will be impacts that may slightly counteract EADF benefits that are quantified in

[15] If the average WTP had been calculated for the highest WTP group, i.e., for those we have considered to be the first adopters, it would have been €5,537, which is 67% higher than the €3,299 average WTP used in the analysis.

the socioeconomic evaluation. However, this will in no way alter the overall conclusion that EADF by and large can be expected to be beneficial for society.

More dynamic perspectives would also incorporate lessons learned from observing EADF in real-world conditions. If EADF proves beneficial for AV users, public willingness to purchase AD-equipped vehicles may increase. This experience also enables the consideration of effects from R&D and learning-by-doing, which can foster innovations that reduce the costs of producing and implementing higher levels of AD, thereby enhancing profitability for both consumers and society.

9 Main findings and concluding remarks

This Deliverable presents a socioeconomic evaluation of EADF, exploring its potential effects on both consumers and society. The assessment considers impacts on safety, efficiency, and the environment, as well as the benefits of freeing drivers from active driving – allowing them to engage in other activities and enjoy greater comfort while on the move. The analytical approach isolates the impacts directly attributable to EADF, providing a clear view of its specific contributions. While the analysis does not attempt to capture the full potential of EADF technology, it focuses on the outcomes expected at a 30% market penetration rate.

The findings indicate that EADF is broadly advantageous from a societal perspective. However, many consumers may initially feel that the private costs outweigh their individual benefits. This perception is likely to shift if EADF demonstrates tangible real-world advantages or if ongoing innovations reduce adoption costs, allowing more people to experience its benefits as the technology becomes more widespread.

Societal perspective: From an economic perspective, the most significant benefits arise from accident reduction, specifically from fewer human injuries and fatalities. Additional benefits include benefits for users due to reduced driving strain, the opportunity to engage in non-driving related activities, and increased comfort. These gains come with an increase in total travel time, as AVs are expected to affect driving behaviour in traffic and to adhere to speed limits. Although this represents a negative externality that affects all road users, its economic magnitude is minor relative to the safety and user benefits.

Consumer perspective and market deployment: The finding that EADF appears profitable for society but not for most consumers raises the question of whether public intervention is needed to accelerate adoption of automated vehicles. While subsidies or financial incentives could theoretically enhance consumer uptake, we argue that this may not be necessary.

Survey-based willingness to pay estimates are likely to be influenced by respondents' strategic considerations. In our survey, participants were informed that EADF would soon be available on the market. Hence, their strategic response or incentive is to understate how much they were willing to pay. It is therefore reasonable to assume that adoption rates of AD will exceed those implied by the survey data and will be sufficient to stimulate early market demand. As becomes more familiar and if its benefits become observable, WTP is expected to increase, expanding the potential market for AD without the need for government subsidies to promote adoption of AD. Instead, policy efforts may be better directed toward facilitating safe implementation of AD, for example by addressing legal and regulatory issues, liability frameworks, and cybersecurity challenges associated with automated driving.

Legal Responsibility and Liability. A central issue in the deployment of AVs is the clear allocation of responsibility when accidents or malfunctions occur. Unlike conventional vehicles, where liability typically rests with the driver or manufacturer in cases of technical defects, automated systems involve multiple actors including OEMs, software developers, service providers, and drivers. These roles, in the event of an incident, may be difficult to disentangle. Without a clear legal framework, this uncertainty over liability could hinder both consumer adoption and industry investment. Establishing transparent rules, possibly through a combination of strict product liability, shared responsibility models, and insurance involvement, will potentially reduce these uncertainties.

At present, it has been established that the vehicle manufacturer is responsible for incidents occurring during automated driving, provided that the driver has fulfilled their obligations. Compliance is verified through mandatory driver monitoring and vehicle data recording.

Initial steps toward a regulatory framework have already been taken through *UN Regulation No. 157 – Automated Lane Keeping Systems (ALKS)*, which defines technical requirements for Level 3 automation. Future developments toward Level 4 and Level 5 automation will require continued progress in legislation, liability allocation, and standardization. From an insurance perspective, the automated vehicle must hold liability coverage to compensate for any damage to third parties in incidents involving automated vehicles.

Cybersecurity: Cybersecurity represents another critical challenge. Since AVs rely heavily on interconnected sensors, communication networks, and cloud-based systems, they are inherently vulnerable to cyberattacks and external disruptions. Malicious interference could compromise not only individual vehicles, but also the broader transport infrastructure, posing risks to public safety and data privacy. Although cybersecurity impacts were beyond the scope of this socioeconomic analysis, we would like to point out that ensuring robust protection, continuous monitoring, and resilient system design will be essential prerequisites for safe and widespread EADF deployment.

Broader impacts of higher automation levels: This evaluation focuses on impacts expected from SAE Level 3 and 4 automated driving, considering impacts relating to safety, efficiency and the environment, along with impacts on travel time, cost savings and comfort. However, the deployment of fully automated driving, i.e., SAE L5 is likely to generate broader societal impacts. Fully automated driving could transform mobility systems by shifting from privately owned vehicles toward shared, collective, or publicly organised forms of transport. Such developments could improve accessibility for groups currently facing mobility disadvantages, including the elderly, individuals with disabilities or health-related limitations, and those without access to private vehicles.

In conclusion, while connected and automated driving at its current level of maturity indicates net social benefits, its broader transformative potential will unfold gradually as technology, regulation, and social acceptance evolve together.

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Annex 1 Costs of automated driving and its enablers

A1.1 Introduction

The ADFs and enablers tested and evaluated in Hi-Drive require a range of different hardware and software components. For most activities in Hi-Drive, e.g. impact assessment, it is sufficient to deal with the enablers on an abstract or aggregated level. However, to investigate costs related to the implementation of the enablers, it is necessary to break down the enablers into their specific components. The cost of providing the investigated enablers – or more precisely their components – will be variable for some of the enablers and fixed for others.

Costs required to equip cars with e.g. sensors or software programs are referred to as private goods purchases in the following sections. Most of the enablers include private goods components. However, improvements to road infrastructure and telecommunication, which are required for few enablers, represent public goods. It is essential to make a distinction between these two types of enablers/components, as these public goods will represent a fixed cost independent of the number of vehicles making use of it, while the private goods will represent a variable cost, which increases in accordance with the number of vehicles equipped with them (see also Deliverable 4.5, p. 107, *Effects evaluation methods,* Vater et al., 2023).

For the cost-benefit analyses carried out in the socioeconomic impact assessment (SEIA), it is first necessary to identify which use cases – and their respective components – are relevant for the SEIA and which cost category they are made up of: private and/or public goods.

Subsequently, it is important to identify which costs – investment and maintenance – are related to the necessary components for the EADF scenario[16]. For example, some of the components (Sensors, On Board Units, Antennas, …) may already represent standard equipment for new passenger cars and therefore incur no additional cost. Particularly from an infrastructure perspective, the components are mainly deployed for other purposes such as connected traffic lights for public transport purposes or can be used for a variety of different purposes at a time (multi-use), as such it is possible that only a fraction of the cost has to be allocated to the Hi-Drive enabler (if any).

[16] EADF is defined as Enabled ADF or ADF with enablers. In the impact assessment, this refers to a market-ready ADF, which includes the technology enablers investigated in Hi-Drive. The focus is on the extended functionality of the EADF and less on which enablers are needed to realise these functionalities, because multiple enablers can support the same use case (Hi-Drive Deliverable D4.5. p. 42).

A1.2 Overview methodology

The methodology developed to ascertain the costs of private good versus public goods components is divided up into the steps listed below:

Work-steps:

- Definition of relevant enablers
- In-depth analysis of relevant enablers
  - Review of related documents of Hi-Drive operations and enablers
  - Identification of relevant components and/or services
- Desktop research and exchange with Hi-Drive operation owners on relevant components
  - Research on technical implementation, costs, lifetime, current deployment in Europe
  - *Where necessary, supplementary interviews with experts on specific technologies*
- Derivation of input for cost calculation
- Calculation of annual costs for relevant components

A1.3 Definition of relevant enablers

In Hi-Drive, a large number of enabler technologies for highly automated driving are implemented, tested and assessed. The assessment refers to the impacts on the following areas: safety, efficiency, environment and mobility (WP 7.6 – Impact assessment). The socioeconomic analyses are mainly based on the results of these impact areas. Therefore, it makes sense to include on the cost side only those enablers that were evaluated in at least one of the impact areas, either directly in the simulations or through scaled-up results. See Deliverable 4.5 p. 44, *Effects Evaluation Methods,* Vater et al., 2023 for the scope of the use cases.

A1.4 System cost calculation for private goods enablers

The socioeconomic impact assessment requires estimates for the costs of introducing automated driving (AD) systems to the market. This includes the costs incurred due to installation of additional components required (i.e., the AD systems) in conventional manually driven, hereinafter referred to as "basic vehicles". These *basic vehicles* can be purchased in the "reference year" for the evaluation.

It is necessary to define the basic vehicle along with the previously included relevant components first. As part of the second step, the additional required components are installed to transform the basic vehicle into an automated vehicle. The AD-relevant components required in the basic vehicle due to regulations or EuroNCAP consumer testing

standards have been identified. This is necessary to avoid additional cost assignment of components to the ADF, which is already available in the basic vehicle. The regulations and standards define relevant systems, but not the components required to achieve the desired system behaviour. To define the additionally required components, exemplary ADFs have been defined and based on these definitions and the required additional components have been determined. There might be other approaches to achieve the desired ADF behaviour having, e.g., a different sensor setup. The defined components and sensor setups provide a basis for realistic cost estimates.

Basic vehicle

ADFs investigated in Hi-Drive are expected to be introduced in C-segment vehicles and higher. C-segment vehicles are medium-sized vehicles, like the Volkswagen Golf and Toyota Corolla.

The ADFs will be introduced in new car models only. Therefore, it can be assumed that the basic C-segment vehicles are already equipped with all mandatory ADAS and Euro-NCAP-related features. As a result, certain components which are also required for the AD system will be present in the basic vehicle and therefore do not require additional cost. The Euro NCAP-relevant features in the basic vehicles are included because vehicle manufacturers aim to achieve the 5-star rating for their cars.

Mandatory ADAS is defined in the Vehicle General Safety Regulation (2019/2144). Considered systems are intelligent speed assistants (ISA), reversing detection, lane keeping assistance (LKA), driver monitoring, and different advanced emergency braking (AEB) systems.

Consumer testing organisations such as Euro NCAP define additional tests, which require additional and more advanced ADAS to achieve good safety ratings. This includes more advanced AEB, such as crossing, reversing, and turn across path AEB, systems to mitigate dooring, and blind spot monitoring (BSM).

As a result, the basic vehicle will already be equipped with components supporting automated driving. This includes, e.g., general connectivity capabilities to the cloud and to other vehicles as well as some sensors. Thus, it is assumed that the basic vehicle is already equipped with a vehicle-to-everything (V2X) module and connection to the internet.

For ISA and LKA, a long-range front camera is required. The reversing detection and reversing AEB require ultrasonic sensors and a short-range camera at the rear. The BSM can be implemented using corner radars at the rear. The rear end AEB and crossing AEB require a long-range radar at the front and mid-range radars at the front corners. The crossing AEB covering cyclists can be achieved using a short-range camera with high opening angle at the

front. This results in an exemplary sensor setup of a basic vehicle visualised in Figure A1.1. In addition, a driver monitoring camera is included in the basic vehicle.

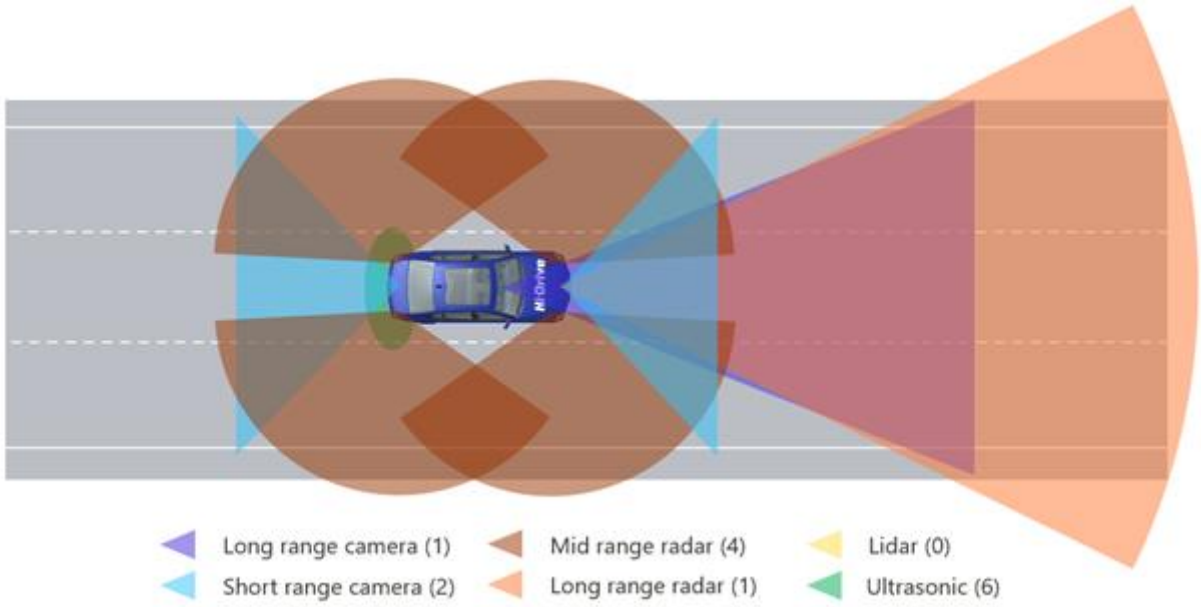

Figure A1.1: Basic vehicle sensor setup, ranges and opening angles are not to scale. The numbers in the brackets indicate the total number of sensors being part of the sensor setup.

Automated driving system

For the definition of the AD system components, a single ADF is defined, which operates in both urban and motorway operational design domains (ODDs), see Table A1.1, and represents the EADF capabilities assumed in the impact assessment analysing the effects of EADF in traffic.

Table A1.1: Summarised ADF ODD considerations.

	Motorway		Urban	
	BADF	**Extension for EADF**	**BADF**	**Extension for EADF**
Speed limit	130	-	50	-
Infra-structure	• Motorways and motorway-like roads • All short tunnels • Long tunnels with separation of the directions inside the tunnel, no intersections inside the tunnel	• Ramps, merging lanes and exit lanes (cooperative merging) • Roadwork sites (positioning support) • Long tunnels without separation of the directions or with intersections inside (positioning support)	• All intersections (unsignalized and signalized) • Streets with bicycle lanes, bus lanes, bus stops and tram tracks • Streets with on-street parking • All short tunnels • Long tunnels with separation of the directions, no intersections in tunnel • Speed bumps	• Roadwork sites (positioning support) • Long tunnels without separation of the directions or with intersections inside (positioning support)
Lane width	3.2 m	-	3.0 m	2.5 m (pos. support)
Lane marking	• Needed on both sides (short gaps OK)	• Incomplete lane-markings OK (positioning support)	• Lane marking or curb needed at least on one side	• No lane-markings or curbs (positioning support)
Weather	• Light and moderate rain • No snowfall (reduced visibility and snow covering sensors)	• Snow on the road, lane-markings not needed (positioning support)	• Light and moderate rain • No snowfall (reduced visibility and snow covering sensors) • Snow on side of the street when lane-markings are (mostly) visible	• Heavy rain (improved sensor setup to overcome visibility issues) • Snow on the street, lane-markings not needed (positioning support)

To fulfil the automated driving capabilities required, an extended global navigation satellite system (GNSS) chip set is added for advanced positioning in combination with HD maps. In addition, redundancies for the electric actuation of the steering, engine, and brakes are added to the basic vehicle. A data storage system for automated driving (DSSAD) is required by the Regulation UN ECE R157 compared to an event data recorder in the basic vehicle. The computing is done by a central computation unit including redundancies.

To fulfil the sensing requirements, several sensors have to be added to the basic vehicle. On the one hand for extended sensor capabilities, e.g., field of view (FOV), but also for the sake of redundancy. As the driver no longer serves as a fallback, the AD system needs to be designed in a fail-operational manner.

Similar to the regulations considered for the basic vehicle, the regulations for automated driving functions do not define which sensors are to be used. Instead, e.g., UN ECE R157 defines requirements for the sensing capabilities and operation conditions of an ADF to be introduced to the market.

This includes, among others, the requirements listed in Table A1.2, leading to sensor implications.

Table A1.2: Collection of requirements for ADFs from UN ECE R157 and derived implications for the vehicle setup.

Requirement from UN ECE R157	Implication for vehicle setup
The AD system needs to be able to perform a Minimum Risk Manoeuvre (MRM) lane change, as it operates with up to 130 km/h.	Also in case of an MRM, a safe lane change still needs to be performed.
It needs to be able to form an access corridor for emergency and enforcement vehicles.	At least one camera at the back is required.
The ALKS shall implement strategies to detect and compensate for environmental conditions that reduce the detection range.	Detection of environmental conditions is required. Night vision camera is required.
The activated system shall detect the risk of collision, particularly with another road user located ahead of or beside the vehicle, due to a decelerating lead vehicle, a cutting in vehicle or an obstacle which appears suddenly.	Full 360° sensing system is required with high resolution.
The activated system shall avoid a collision with an unobstructed crossing pedestrian in front of the vehicle.	High resolution detection to front that allows for object classification and motion prediction.
The vehicle is equipped with a sensing system capable of fulfilling the front, side and rearward detection range requirements as defined in paragraphs 7.1., 7.1.1.1., 7.1.2.1. and 7.1.3.	150 m sensor range to front, as the ADF can drive up to 130 km/h. At least 150m to rear to check for approaching vehicles when performing a lane change. For those ranges, at least 9 m to each side from center of vehicle.
A lane change shall only be initiated when the relevant area of the target lane is expected to remain unoccupied throughout the maneuver.	Precise detection of longitudinal velocities of approaching vehicles required.
Another vehicle's potential for changing into the target lane on a conflicting trajectory shall be assessed.	Lateral movement of surrounding vehicles needs to be detected precisely.
The manufacturer shall declare the area, if any, within the Potential Vehicle Presence Area (PVPA), in which the system is able to assess the status of other vehicle's direction indicators.	Implies that detection of indicators makes sense, 360° in near field, longer distances to front and back à short-range cameras for surround view and long-range cameras to front and back.
A single perception malfunction without failure should not induce hazardous event. The system shall perform self-checks to detect the occurrence of failures and to confirm system performance at all times.	Hints at required redundancy in sensing system.

Discussing these requirements led to the minimum sensor setup depicted in Figure A1.2. The surround view cameras and the long-range cameras ensure the identification of emergency vehicles, activated indicators and the precise classification of surrounding and approaching objects. The corner radars and the front radar are already in the basic vehicle and allow for precise velocity determination of surrounding objects and serve for redundancy. The rear radar covers fast approaching vehicles from behind on motorways. The Lidars allow for precise lateral detection of surrounding objects. Especially for urban use cases, they allow for detection of objects approaching from the side at intersections as well as vulnerable road users (VRUs) approaching and overtaking from left or right. In addition, it serves for redundancy.

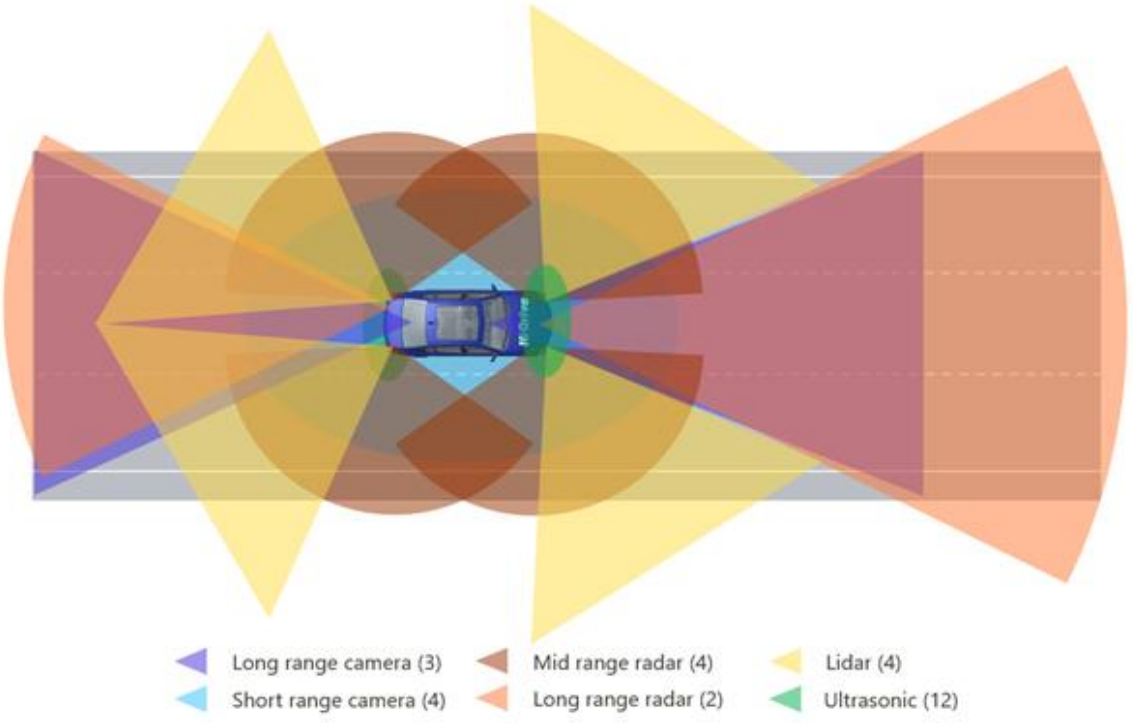

Figure A1.2: Basic vehicle sensor setup, ranges and opening angles are not at scale. The numbers in the brackets indicate the total number of sensors being part of the sensor setup.

While Figure A1.2 is not to scale to make the individual sensors identifiable, Figure A1.3 gives an impression of the sensor coverage to scale.

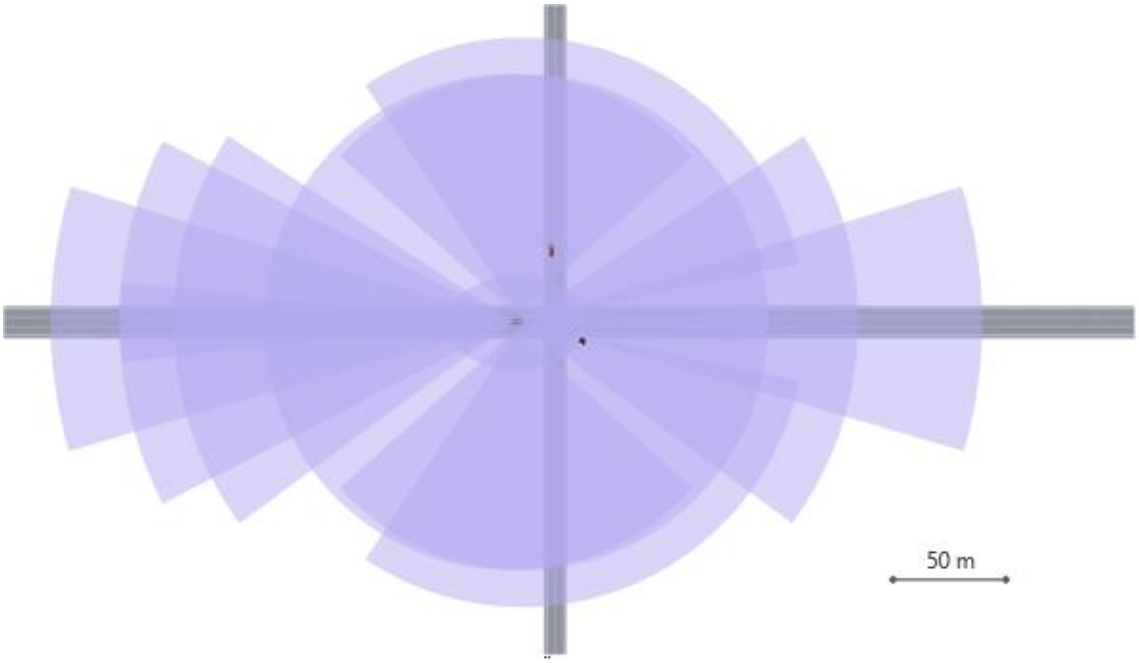

Figure A1.3: Sensor setup visualised to scale.

Based on the additional sensors and other components required for the ADS, apart from those already included in the basic vehicle, the producer costs were estimated based on input from an independent industry expert. Based on the individual components' estimate minimum and maximum costs, the overall producer costs were estimated for a combined package of ADFs including urban, motorway and parking ADFs. This results in minimum estimated producer costs of €1,570 and maximum estimated costs of €3,580. The estimated consumer price is calculated based on these figures applying a factor of three. This leads to a range from €4,710 to €10,740.

A1.5 System cost calculation for public good enablers

After the definition of the relevant enablers/use cases and subsequent identification of the Hi-Drive enablers with public good components, the respective use cases were analysed in-depth with respect to their different components. This was done by performing a thorough review of all related deliverables and internal project reports plus making further enquiries with the operation owners in cases clarification were necessary.

The following paragraphs give a short summary of the identified public goods components across various use cases and to what extent they need to be considered in the cost-benefit-analyses, as their use may incur additional costs in those contexts.

V2I/V2N communication – enhanced perception

Most of the Hi-Drive enablers, that include public goods components, address the bidirectional exchange of information between the Hi-Drive vehicles (connected and highly automated) and infrastructure elements (e.g. traffic lights, road sensors). The aim of this exchange is to enhance or extend the perception of Hi-Drive vehicles beyond the capabilities of the onboard sensors to anticipate other vehicles, road-users, obstacles or lane-closures due to accidents or roadworks at an earlier point than otherwise possible. Ultimately this is expected to improve traffic safety, efficiency and sustainability.

For the deployment of the relevant Hi-Drive use cases on the infrastructure side, the operation owners chose a range of varying setups and components. The use cases include communication via Roadside Units (RSU), direct or via Traffic Management Centres (TMC) or cellular with or without the support of Mobile Edge Computing (MEC). Additionally different types of Roadside Sensors (RSS) are used to collect the necessary data.

The in-depth-analysis showed that most of these components are already an integral part of existing or planned Cooperative Intelligent Transport Systems (C-ITS)[17] within the European Union (EU), the United States of America (USA) and Asia. C-ITS – next generation ITS - is expected to improve road safety, traffic efficiency and driving comfort even more than ITS (European Commission, 2024b). Hence, the European Union[18] foremost but also Member States, industry and public authorities are carrying out a multitude of coordinated activities to support the development and deployment of these innovative transport technologies[19], e.g. by standardisation, coordinated further development and intelligent as well as cost effective upgrade towards Connected Cooperative and Automated Mobility (CCAM). So that CCAM will also be set-up on the technological components deployed for C-ITS services and not on completely new technologies and infrastructures.

The activities resulted, amongst other things, in the inclusion of a list of technologically mature and highly beneficial C-ITS services, that should be deployed quickly, as part of the European C-ITS Strategy (European Commission, 2016b, p.6). These services are called **Day 1 services** (see A1.5.2 for additional information on C-ITS services and the list of Day 1 services). To ensure quick deployment, specific actions were included in the C-ITS Strategy,

[17] Cooperative Intelligent Transport Systems and Services refers to transport systems, where the cooperation between two or more ITS sub-systems (personal, vehicle, roadside and central) enables and provides an ITS service that offers better quality and an enhanced service level, compared to the same ITS service provided by only one of the ITS sub-systems (C-Roads 2024, Glossary).
[18] Important multi-stakeholder initiatives supported by the EU are: C-ITS Platform (C-ITS Platform 2016 & 2017) and C-Roads Platform (C-Roads 2024).
[19] Important Initiatives by industry are: 5G Automotive Association (5GAA), Car 2 Car Communication consortium (C2C-CC), in Standardisation: IEEE (e.g. 802.11 for WLAN communication) and ETSI (e.g. ETSI TC ITS).

e.g. the adoption of the appropriate legal framework at the EU level by 2018 to ensure legal certainty for public and private investors, the EU funding for projects and the continuation of the C-ITS Platform process (European Commission, 2016b). Together with all other undiminished activities by the multitude of stakeholders, it can be assumed that it is very likely that at least these Day 1 C-ITS services will be implemented on a large scale and in an interoperable way across Europe.

The Hi-Drive V2I/V2N use cases can be assigned to these Day 1 services (e.g. roadwork warnings, green light optimal speed advisory/GLOSA), but they refer only to a small number of these services. Meaning that components such as RSU or TMC are used for far more Day 1 services than only the Hi-Drive use cases and therefore the Hi-Drive use cases are not the driving force behind the implementation of these public goods components, and hence their costs.

Furthermore, due to information from the operation owners, these Hi-Drive uses cases have no additional technical requirements compared to the C-ITS specifications, and therefore no additional costs compared to the standard deployment. On the contrary, the Hi-Drive use cases expand selected services to include highly automated and connected vehicles. Therefore, by increasing the number of vehicles able to use these C-ITS services, the Hi-Drive use cases provide additional benefits without additional costs. And as various stakeholders already address the need to align the CCAM development with the C-ITS deployment, it should be safe to assume that there will be no major technological changes when progressing from C-ITS to CCAM, and therefore no major costs for new components, but only minor upgrades or modernizations should be required.

Special use case: Complex intersection

The enabler for addressing complex non-signalised intersections relies on cooperative awareness or collective perception use cases. This enabler is considered a special use case, as it remains at a highly experimental stage. So far, V2I applications require a higher number of sensors than the typical C-ITS use cases. Moreover, these sensors must also be of higher quality to collect the necessary data. Consequently, this use case would involve additional costs compared with the previously discussed use cases, which do not have such requirements. To estimate the costs for complex, non-signalised intersections, an exemplary intersection with four approaches was chosen. This geometry is in line with the intersection-type for the microscopic simulations, as the impacts are provided by these simulations. Two different sensor setups: one with high accuracy (setup 1, including lidar sensors and cameras) and one with lower accuracy (setup 2, camera only) were defined for these intersections. For both setups, three sensitivity analyses were carried out, to determine the effects of different parameters of the calculation/estimation on the overall result. Costs were considered for the

sensors, computation, infrastructure adjustments such as pole installation, and additional hardware for mounting, communication etc. The resulting range of annual costs per equipped intersection is estimated between 8,000€ to 22,000€, depending on the components used, their cost estimates, and their estimated lifetimes. The sensitivity of this range is amplified by significant uncertainties regarding which intersections will ultimately be selected for equipment. While there is likely a small fraction of intersections, where installing traffic lights, which is an alternative measure to increase safety, would not be justified, equipping these intersections with the setup required for this enabler may still be reasonable. Nevertheless, it would not be reasonable to equip every unsignalised intersection, given the substantial installation and operation costs. Due to the high sensitivity of the estimated EU-wide costs, which had to be considered, the project decided to exclude this enabler from the cost-benefit analysis in order to obtain overall more robust and less sensitive results.

As a consequence, in this regard, the impacts derived from the Efficiency and Environmental simulations were not considered in the socioeconomic impact assessment. In those simulations, it was assumed that all information on all objects which were present at the intersections was available. Under such conditions, for some cases, the ADF could approach intersections more quickly, as it was aware when no conflicting objects were present. Instead, the Safety impacts from the corresponding complex intersection simulations were considered in socioeconomic analyses, since the general driving strategy of the ADF did not assume perfect knowledge and therefore remained unchanged. The safety-related use case considered can also be achieved through V2V communication, which does not require additional infrastructure components and therefore associated costs. This is further supported by the fact that many new vehicles already broadcast ETSI Cooperative Awareness Messages, which could be utilised by ADFs for this purpose.

GNSS reference stations - improved positioning

Other use cases deal with the extension of the ODD using improved vehicle positioning. Depending on the setup of the respective Hi-Drive use cases, this could result in the need for more GNSS reference stations. These stations provide the correction signals for the precise RTK positioning (centimetre-level accuracy) needed for automated driving, within the relevant ODD. As this could result in costs for the public good of GNSS reference stations – depending on the business case – these use cases were further analysed. However, the analysis of the Hi-Drive use cases showed additional GNSS reference stations are not necessary and therefore no additional costs will be incurred on the infrastructure side (public goods). The use case with a GNSS-denied environment (tunnel) or the use cases addressing weak GNSS signals (urban canyons etc.) aim to overcome this problem without communication with other vehicles or infrastructure, but merely by using sensor fusion in the

vehicle. Another use case, dealing with improved positioning within the ODD motorway, states, that the GNSS coverage is sufficient and therefore no additional reference stations are necessary. Additional desktop research also showed that there is a multitude of public and commercial providers, which offer extensive coverage across Europe. Therefore, no additional costs for GNSS reference stations need to be considered in the SEIA cost-benefit analysis for these Hi-Drive use cases.

Deteriorated or missing lane markings – improved positioning

Similar to the use cases with GNSS reference stations, the use cases that deal with deteriorated or missing lane markings, aim to overcome the "problem" by improved sensor fusion purely on the vehicle side. This means lane marking improvements, which would be major public investments, are not necessary to be implemented for these Hi-Drive use cases. Hence, improvements to lane markings are not relevant for the costs-benefit analyses in the SEIA.

The Hi-Drive V2I/V2N use cases are not the driving force behind the implementation of the public goods components - e.g., RSU, RSS and TMC - instead, they form the backbone of the Day 1 C-ITS services. On the contrary, the Hi-Drive use cases add additional benefits by expanding the utilization of Day 1 services to a new class of vehicles (highly automated), while there are no extra costs for special or additional requirements of the components needed for the Hi-Drive V2I use cases, compared to the C-ITS specifications of the Day 1 services.

Hence, the assumption for SEIA is that the Hi-Drive V2I use cases do not result in additional costs for their deployment. Therefore, they do not have to be considered in the SEIA.

Moreover, the use cases that deal with improved positioning (weak GNSS signals, missing/deteriorated lane markings) aim to overcome the issues of missing information by allowing for improved sensor fusion in the vehicles, instead of communication with the infrastructure. Therefore, these use cases do not generate any costs on the infrastructure side. Thus, the overall assumption is that the considered Hi-Drive use cases do not result in additional costs on the side of road infrastructure, and for this reason, this category will not be considered in the socioeconomic impact assessment.

A1.5.1 Additional information on Day 1 services of C-ITS-systems

The Hi-Drive V2I-use cases are generally considered to be services within the Cooperative Intelligent Transport Systems (C-ITS), which have already been tested or are even put in place for manually driven connected vehicles and are now being implemented into highly automated cars in Hi-Drive. These are especially services, which are to be deployed based on

their importance from a policy perspective or potential for positive impacts e.g., relating to road safety, as well as technical readiness in the short-term.

In 2016, a "cost and benefit analysis (CBA) of deploying C-ITS services for road transport in the Member States" was commissioned by the C-ITS Platform[20] (European Commission, 2016a). The CBA concluded that Day 1 C-ITS services – when deployed in an interoperable way across Europe – should produce a benefit cost ratio of up to 3 to 1 based on cumulative costs and benefits from 2018 to 2030. A rapid deployment of as many services as possible will also mean they "break even" more quickly and will lead to higher overall benefits, mainly due to the network effect. This means, on the other hand, that slow initial uptake rates would result in relatively long periods with few benefits (European Commission, 2016b, p. 6). The study also states that, the dominant cost item, when deploying C-ITS services, is the new vehicle (due to in-vehicle ITS sub-system) with 86 % of the investment and maintenance costs, followed by 10 % for the aftermarket devices (personal ITS sub-systems as: mobile phones and tablets), the categories of Roadside ITS sub-systems (e.g. traffic monitoring sensors, smart traffic lights allowing V2I communications) and Central ITS sub-systems (e.g. centralised traffic management systems) make up for the remaining 4 % of the costs and therefore contribute only to a relatively small portion (European Commission, 2016a, p. 23ff). However, the study also states that even if the infrastructure costs are low compared to the in-vehicle costs, it might still pose problems for local road authorities to find this budget.

Based on the results of the CBA study, that were included in the recommendations of the final report of the C-ITS Platform, the European commission incorporated Day 1 C-ITS services in the European Strategy on Cooperative Intelligent Transport Systems as technologically-mature and highly beneficial C-ITS services which should be deployed quickly (European Commission, 2016b).

The following table shows the full list of Day 1 C-ITS services.

[20] C-ITS Platform: The Platform was established in November 2014 by the European Commission. It provides an operational instrument for dialogue, exchange of technical knowledge and cooperation amongst the Commission, public stakeholders from Member States, local/regional authorities and private stakeholders, in order to create a shared vision and concrete implementation solutions for the interoperable deployment of C-ITS in the EU.

Table A1.3: List of Day 1 C-ITS services (based on: European Commission, 2016b, p. 6).

Group	Day 1 C-ITS services list
Hazardous location notification	Slow or stationary vehicle(s) & traffic ahead warning
	Road works warning
	Weather conditions
	Emergency brake light
	Emergency vehicle approaching
	Other hazards
Signage applications	In-vehicle signage
	In-vehicle speed limits
	Signal violation / intersection safety
	Traffic signal priority request by designated vehicles
	Green light optimal speed advisory
	Probe vehicle data
	Shockwave damping (falls under European Telecommunication Standards Institute (ETSI) category 'local hazard warning')

The main components to implement these services are Roadside Units, Roadside Sensors and Traffic Management Centres. They can be used for various Day 1 C-ITS services, while the Hi-Drive use cases rely only on a small number of the Day 1 services.

Annex 2 Standard unit costs

To estimate the economic value of impacts quantified in non-monetary terms, standard unit costs must be applied to the respective measures. Annex A2 documents the basis for the standard unit costs which we have applied for the socioeconomic analysis of EADF. This concerns the estimation of economic values regarding

1. Accident cost savings
2. Drivers' cost of travel time
3. Traffic flow impacts
4. Impacts on CO_2 emissions

All standard unit costs are measured according to the price level of 2024.

A2.1 Accident cost savings

Safety impacts of EADF are estimated as the expected reduction in traffic accidents according to different types of severity. Unfortunately, there are no standard unit accident costs available that allow us to calculate the economic value of changes in traffic accidents directly. There are, however, standard unit costs available for calculating the economic value of different types of human injuries, which we will use to derive standard unit accident costs. This method complies with Wijnen et al. (2017).

Injury types are classified according to MAIS (Maximum Abbreviated Injury Scale) and grouped in three categories:

- Fatality (MAIS 6)
- Severe injury (MAIS 3, 4 and 5)
- Slight injury (MAIS 1 and 2)

These three categories comply with the conceptualization of accident severity that are used in the estimation of safety impacts: Fatal accidents, Severe injury accidents and Slight injury accidents. However, we must account for the fact that a single accident may involve more than one injury, and possibly different types of injury.

In the following section, we describe the standard unit injury costs that were applied in the economic analysis, and how these were transcribed to standard unit accident costs.

A2.1.1 Standard unit injury costs

The unit injury costs include all costs for society that are incurred by accident-induced human injuries.[21]

It is generally acknowledged (Wijnen et al., 2017; European Commission, 2019) that the following cost components will capture all relevant costs related to human injuries:

- Human costs, relating to the cost of pain and suffering due to shortened life years and reduced quality of life
- Medical costs, covering the costs of all different types of medical treatment
- Production loss, which measures lost output per casualty, be it permanent or temporary
- Administrative costs, covering all costs related to non-medical emergency services, such as the police force and fire service
- Material and damage costs, for the purpose of repairing and replacing damaged property
- Other costs, mainly comprising the additional costs borne by other travellers as a result of congestion caused by accidents.[22]

A2.1.1.1 Human costs and the value of statistical life

Human costs are by far the largest cost component in total human injury costs. This holds for all injury categories. The critical factor is the estimated value of statistical life (VSL), which is decisive for the human cost estimate for all types of injuries.

The estimated value of statistical life differs between different studies. Table A2.1 illustrates that estimates differ between studies and countries. The studies covered are from the SafetyCube project (Wijnen et al., 2017), EU's Handbook on external costs of transport (Essen et al., 2020), a more recent study covering Belgium, France, Germany and Netherlands (Schoeters et al., 2022), and US data based on National Highway Traffic Administration (Blincoe et al., 2023). All values in the original studies are updated to 2024 prices with nominal GDP growth per capita.

Table A2.1: Estimated values of statistical life (VSL).

Source	VSL estimate, €year	€2024
Wijnen et al. (2017)	VSL Europe €20151,587,001	2,348,763
Essen et al. (2020)	VSL Europe based on OECD (2012) €20163,575,721	5,152,938

[21] Costs are calculated without VAT and public administrative fees.
[22] When estimating the traffic flow impacts of AD, effects on accident-induced congestions are not included. Hence, we avoid double counting by including it when calculating the costs of human injuries.

Source	VSL estimate, €year	€2024
Schoeters et al. (2022)	VSL four European countries €20206,190,000	8,238,589
Blincoe et al. (2023)	VSL US $2021 11,800,000 = €20219,980,000	12,156,708

It is only reasonable that we choose to focus on VSL estimates relating to Europe. We chose to use the VSL estimate applied by the European Commission (Essen et al., 2020) as we consider the EU's Handbook on external costs of transport (Essen et al., 2020) to have a more authoritative status than the other studies.

According to Essen et al. (2020), the human costs of a fatality are calculated as the value of statistical life minus consumption loss to avoid double counting with production loss, which is estimated separately. Consumption loss was estimated to €667,800 in 2016. Adjusted to 2024-prices with the same factor as VSL (nominal GDP growth per capita), this amounts to €962,360, which explains the difference between the VSL estimate in Table A2.1 and human costs of a fatality in Table A2.2.

For severe and slight injuries, human costs are simply calculated as a share of the value of statistical life. As for the human costs related to severe injuries, Essen et al. (2020) building on Wijnen et al. (2017), recommends that it is set at 13% of VSL. Schoeters et al. (2022) estimate it to be somewhat higher (15-16%), while it is above 20% in the US (Blincoe et al., 2023). Consistent with Essen et al. (2020), we apply 13% of VSL when calculating the economic value of human costs related to severe injuries.

For slight injuries, we apply 1% of VSL to calculate human costs. This is also consistent with Essen et al. (2020) and Wijnen et al. (2017), and in line with the US estimate of 0.8% (Blincoe et al., 2023). Slight injuries were not addressed by Schoeters et al. (2022).

A2.1.1.2 Other components of total human injury costs

We use the unit costs that the EU's Handbook on external costs of transport (Essen et al. (2020) is based on for the remaining cost components required to calculate the total costs of a human injury. This includes medical costs, production loss, administrative costs, material damage costs and other costs as they are estimated in Wijnen et al. (2017).

The estimates are updated to the price level of 2024 in the following way:

- Medical costs and administrative costs are labour-intensive services, which means that we expect prices to follow the nominal wage increase.
- Production loss, property damage costs and other costs are price-adjusted using the GDP-deflator.

A2.1.1.3 Standard unit costs for injury severity

Table A2.2 presents 2024 values for the different cost components that add up to the standard unit injury cost for different types of injuries.

Table A2.2: Standard unit costs for each injury type by main cost components, €2024.

Injury type	Human costs	Medical costs	Production loss	Administrative costs	Property damage Costs	Other costs	Standard unit injury cost
Fatality	4,190,578	7,216	859,853	8,434	15,160	4,773	5,086,014
Severe injury	669,919	22,220	57,239	5,800	10,000	542	765,720
Slight injury	51,532	1,912	3,502	2,493	6,976	681	67,096

As previously mentioned, the standard unit injury costs are meant to capture all costs that are incurred by traffic accidents, as seen from society's point of view. For each type of injury severity, all costs, from the pain and suffering incurred for those injured to time that other travellers must spend in traffic due to congestion following an accident, are included in the unit cost estimate.

A2.1.2 Deriving standard unit accident costs from human injury cost estimates

To calculate the economic value of safety impacts of EADF, measured as changes in the number of different types of accidents, we need to know the magnitude and severity of human injuries which occur as a result of different types of accidents. There is a general lack of reliable information on this matter. For assessing accident injury costs at EU-level, Wijnen et al. (2017) only found reliable information for Greece and Norway. As we are not aware of any other relevant studies, we apply the same procedure as Wijnen et al. (2017) assuming that the average for Greece and Norway is representative for the whole of EU.

The average implied that

- One fatal accident caused 1.1 fatalities, 0.22 severe injuries and 0.43 slight injuries
- One severe injury accident caused 1.11 severe injuries and 0.44 slight injuries
- One slight injury accident caused 1.36 slight injuries

In Table A2.3 these values are applied to calculate the standard unit accident cost for the different types of accident severity.

Table A2.3: Standard unit costs for each injury type by main cost components, €2024.

Accident severity	Transforming unit injury cost to unit accident cost	Standard unit accident cost
Fatal accident	5,086,014 x 1.1 + 765,720 x 0.22 + 67,096 x 0.43	5,791,924
Severe injury accident	765,720 x 1.11 + 67,096 x 0.44	879,471
Slight injury accident	67,096 x 1.36	91,251

In the economic analysis, we also use information from Wijnen et al. (2017) to make our own estimate of EADF-induced reductions in traffic accidents with property damage only and their economic value. The GDP-deflator is applied to adjust the unit cost estimate for accidents with property damage only (PDO-accidents) to the price level of 2024. This unit cost estimate amount to €5,196 in 2024 prices.

A2.2 Drivers' cost of travel time

EADF is expected to reduce the unit cost of travel time for drivers of AVs, since they can engage in activities other than driving, either productive work or relaxation. This impact is measured as an expected percentage reduction in the unit cost for drivers' travel time. To calculate the economic value of a percentage reduction in the unit cost of travel time, it is essential to know the economic value of the unit cost that is reduced.

There are no well-established unit travel time costs to build on for studies at the European level. Furthermore, the cost of travel time differs between travel purpose, drivers' income and the length of the travel, which presents a challenge.

For our analysis, we have to settle for one unit cost of time which can be regarded as reflecting the average of all drivers and for all different travel purposes. We have used information on the unit cost of travel time for travels >32km for all EU27-countries (Table 87 in Essen et al, 2020). In the calculations, we have assumed that 35% of the travel time relates to business or commuting and that 65% is for personal purposes. In Table A2.4 values are used to calculate the average travel cost per driver for each country. The resulting national averages are then aggregated to an EU-wide average travel time cost by weighting each country's value according to its share of the EU's GDP.The GDP-weighted travel time cost estimate for passenger car drivers in the EU27 is expressed 2016 price level.

Table A2.4: Unit travel time cost for drivers of passenger cars, >32 km inter-urban by country. GDP-weighted EU average, €$_{2016}$/hour.

	Business Commuting	Personal (leisure)	Drivers' average travel time cost	% of EU GDP	EU weighted average
Austria	19.8	7.8	12.00	2.83	0.340
Belgium	21.2	7.2	12.1	3.49	0.442
Bulgaria	8.5	3.0	4.38	0.53	0.026
Cyprus	12.5	5.1	7.69	0.17	0.013
Croatia	9.6	3.7	5.77	0.43	0.025
Czechia	14.0	5.4	8.41	1.75	0.147
Denmark	20.7	7.6	12.19	2.37	0.289
Estonia	12.1	4.6	7.23	0.23	0.017
Finland	20.6	6.7	11.57	1.69	0.195
France	15.7	6.4	9.66	16.72	1.614
Germany	20.0	7.6	11.94	24.46	2.921
Greece	11.4	4.1	6.66	1.32	0.088
Hungary	11.7	4.1	6.76	1.07	0.072
Ireland	28.3	11.2	17.19	3.18	0.546
Italy	16.7	5.9	8.60	12.08	1.039
Latvia	10.6	4.0	6.31	0.25	0.016
Lithuania	12.1	4.6	7.23	0.42	0.030
Luxembourg	38.9	15.8	23.89	0.49	0.117
Malta	15.3	5.8	9.13	0.11	0.010
Netherlands	22.2	7.8	12.84	5.96	0.765
Poland	10.4	4,2	6.37	4.14	0.264
Portugal	12.4	4.8	7.46	1.51	0.113
Romania	8.8	3.6	5.42	1.81	0.098
Slovakia	13.4	4.7	7.75	0.68	0.053
Slovenia	13.2	5.1	7.94	0.37	0.029
Spain	15.0	5.6	8.89	8.41	0.748
Sweden	19.6	7.6	11.80	3.53	0.417
EU AVERAGE					10.434

The countries' weighted travel time cost for drivers adds up to the standard unit travel time cost for drivers in EU27. According to Table A2.4 it was €10.43 in 2016. This is updated with the consumer price to reflect the price level of 2024, which means that the standard unit cost for drivers that will be used in the economic analysis equals €13.57.

A2.3 Traffic flow impacts

Traffic flow impacts are measured as the change in the amount of time travelled, in comparison with the baseline figures. To estimate the economic value of travel time changes, a unit cost of time is required that resembles the average for all types of travellers that are affected. Then, we also need to include vehicles other than passenger cars.

For the calculation, we have for simplicity's sake only included cargo traffic in addition to passenger cars. The traffic composition is assumed to consist of 10% heavy-duty vehicles, 31.5% of passenger cars used for business or commuting, and 58.5% of passenger cars for personal purposes.[23] Travel time costs are estimated based on national unit costs of travel time based on travel over 32 km (Tables 87 and 88 in Essen et al, 2020).

Travel time impacts concern all people in the vehicles affected, either as drivers or passengers. We consider that there will only be drivers in cargo traffic, while it is assumed that each passenger car on average, regardless of travel purpose, transports 1.5 people. The unit cost for each country and how it is used to estimate a unit travel time cost for the EU is shown in Table A2.5.

Table A2.5: Cost of travel time when all traffic is affected, >32 km inter-urban. GDP-weighted average, €$_{2016}$/hour.

	Business + personal, 1.5 person/passenger car	Freight (cargo)	Average travel time cost all vehicles	% of EU GDP	EU weighted average
Austria	18.00	22.5	18.45	2.83	0.522
Belgium	18.15	33.4	19.68	3.49	0.687
Bulgaria	6.57	8.0	6.71	0.53	0.036
Cyprus	11.54	13.2	11.71	0.17	0.020
Croatia	8.66	10.6	9.03	0.43	0.039
Czechia	12.62	10.2	12.38	1.75	0.217

[23] The values 31.5% and 58.5% are derived from the assumption that 90% of total traffic consists of passenger cars, with travel purposes distributed as in the previous section: 35% for business and commuting, and 65% for personal travel.

	Business + personal, 1.5 person/passenger car	Freight (cargo)	Average travel time cost all vehicles	% of EU GDP	EU weighted average
Denmark	18.29	21.9	18.65	2.37	0.441
Estonia	10.85	13.3	11.10	0.23	0.026
Finland	17.36	19.3	17.55	1.69	0.297
France	14.49	29.8	16.02	16.72	2.679
Germany	17.91	20.9	18.21	24.46	4.454
Greece	9.99	11.9	10.18	1,32	0.134
Hungary	10.14	9.6	10.09	1.07	0.108
Ireland	25.79	32.3	26.44	3.18	0.841
Italy	12.90	28.1	13.71	12.08	1.656
Latvia	9.47	11.4	9.66	0.25	0.024
Lithuania	10.85	8.9	10.66	0.42	0.045
Luxembourg	35.84	28.2	35.08	0.49	0.172
Malta	13.70	19.5	14.28	0.11	0.016
Netherlands	19.26	22.5	19.58	5.96	1.167
Poland	9.56	10.0	9.60	4.14	0.397
Portugal	11.19	13.2	11.39	1.51	0.172
Romania	8.13	9.0	8.22	1.81	0.148
Slovakia	11.63	11.3	11.60	0.68	0.079
Slovenia	11.91	13.1	12.03	0.37	0.045
Spain	13.34	19.5	13.96	8.41	1.174
Sweden	17.70	21.8	18.11	3.53	0.639
EU AVERAGE					16.235

The unit travel time cost to be applied when providing economic values to the estimated changes in traffic flows measured in hours, will be the estimated EU average, calculated to be €16.24 in 2016. This standard unit cost will be applied in the economic evaluation of traffic flow impacts generated by EADF. The consumer price is applied to adjust the estimate to the price level of 2024. The 2024-value of the unit travel time cost, that will be applied when all traffic is affected, is €21.12.

A2.4 Impacts on CO_2 emissions

CO_2 emissions arising from human activities impose costs that society must bear. For that reason, the EU has introduced a quota system to monetize the cost of CO_2 emissions. This is based on the principle that polluters must pay for their emissions by buying quotas (permits) that allow them to emit a certain volume of CO_2. The system has established a market price for the emission of one ton of CO_2, which varies over time. Permits reached an all-time high in February 2023, when one ton was traded at €105.73. As of late 2024, permits are traded in the range of €65-70. The price on traded carbon permits does not, however, reflect the full cost of CO_2 emissions to society.

The Handbook on external costs of transport (Essen et al., 2020) summarizes research on the costs that are required to reduce CO_2 emissions according to the targets that are set. These targets have been set to be more ambitious over time. Hence the costs also increase so as to reach the targets set for 2040-2060, compared with the targets for 2030. The studies providing estimates typically present them in three versions, as a low-, a medium- and a high-cost estimate. In Table A2.6, the cost estimates in the Handbook (Essen et al., 2020) are adjusted to 2024 prices with the GDP-deflator.

Table A2.6: Standard unit costs for greenhouse gas emissions per ton CO_2-equivalent, $€_{2024}$. Low, medium and high-cost estimates.

	Low	Medium	High
Short and medium-term run	76	128	241
Long-term run	199	342	633

For the socioeconomic evaluation of EADF, it seems most relevant to consider costs estimated to reach targets set for a long-term perspective. We choose to apply the medium-cost estimate, i.e., €342 per ton of CO_2 that is emitted.

The estimate of €342 per ton of emitted CO_2 is higher than recommended by Rennert et al. (2022), who made a comprehensive evaluation of social costs of CO_2 emissions, which they found to be higher than generally acknowledged. Their recommendation was that analysis of current projects should set the cost of one ton CO_2 emittance to $185 (2020 US dollars). Based on the exchange rate of that year, this implies $€_{2020}176.37$, which equals €216.60 in 2024 prices. This is close to the high estimate for the short- and medium-term in Table A2.6. It is also in line with the unit cost which the Ministry of Finance recommend for economic

analyses in Norway where emittance costs of one ton CO_2 in 2030 are set at €214 in 2024 prices[24].

Germany's Federal Environment Agency (UBA) has made cost estimates based on a damage cost approach, and its recommended cost estimates are much higher. In 2030, they are set at €335 in 2024 prices, increasing to €435 in 2050, as current welfare is weighted slightly higher than future welfare. If no time preference for welfare is assumed, the recommended climate cost estimate becomes higher – €940 in 2030, increasing to €1,080 in 2050.

In accordance with the view expressed in the Handbook on external costs of transport (Essen et al., 2020), it is easier to reach a mutual understanding as to what is needed to reach the targets for avoiding CO_2 emissions, than to agree on the types and magnitude of damage that should be included for the calculation of damage costs. Thus, we acknowledge that the unit cost for CO_2 emissions could be higher than the estimate we apply. The cost estimate of €342 per ton CO_2 is, however, well anchored in the recommendations found in the EU's Handbook on the external costs of transport (Essen et al., 2020).

A2.5 Impacts on energy consumption

To estimate the standard unit cost of fossil fuels for the economic analysis, we base our calculation on the market price of petrol. We assume that the standard unit cost equals the market price of petrol minus all taxes. This net-of-tax price represents the amount charged by producers, which is expected to cover production costs and a normal profit margin. Under competitive market conditions, this price (excluding taxes) should be approximately uniform across Europe.

For the calculation, we use the 2024 consumer price of petrol in Germany, set at €1.65 per liter. This price includes a 19% value-added tax (VAT) of €0.26 and other local taxes. Although these local taxes vary by fuel type, they are assumed to be €0.59 for this calculation. Subtracting these tax amounts yields a standard unit cost for petrol of €0.75 per liter.

[24]According to the Norwegian Ministry of Finance (2023), the unit cost is estimated at NOK 2,000 (2020 prices) for 2030. This corresponds to NOK 2,456 in 2024 prices, equivalent to €214.

Annex 3 Theoretical approach: Drivers' willingness to pay for AD - A microeconomic perspective

A3.1 Introduction

In this annex, we present a theoretical model explaining how travellers may gain benefits by acquiring an AD-equipped car. The focus is on drivers and the net benefits they can expect to gain from AD. We expect that the net benefits, or the increase in drivers' expected utility because of AD, will determine their willingness to pay to have it installed in the car.

Our point of departure is that people travel for a particular purpose. When deciding to travel, they expect that the utility they derive from fulfilling the travel purpose exceeds the costs of driving.

When considering benefits that users may gain from AD, there is no reason to expect that AD will, in any way, affect what they can gain from fulfilling the purpose of their travels. Hence, to capture the types of benefits that users can expect from AD, we can concentrate on how AD may affect the costs of driving. The valuation of expected AD generated cost reductions, or user benefits of AD, will, in turn, determine the willingness to pay to acquire AD.

The key valuable resource in the model is time, or rather *untied time*, defined as the time people have disposable for welfare generating activities such as work and leisure. Being committed to driving, the time spent travelling will, by definition, reduce drivers' untied time.

The model sketches how AD in many ways may be expected to increase the amount of untied time for the driver. There are direct impacts as drivers of AVs can work and recreate instead of driving. Also, more indirect impacts can be expected, derived from measures that drivers (and car holders) take to reduce the probability and consequences of unwanted traffic incidents. is expected to reduce the risk and severity of traffic accidents, as well as to reduce the risks of unexpected delays due to traffic congestion.

The theoretical model that follows, is formalised to document these effects in detail, step by step. In addition, the model includes a welfare component associated with people's perceived driving discomfort. People who experience driving as strenuous in certain situations can also expect a direct reduction in the perceived discomfort of driving, as AV will handle such situations in automated mode.

A3.2 A microeconomic model of time, travelling and welfare

In economic theory, time is considered as an important resource. Let T present untied time available for activities that directly contribute to utility, welfare, or happiness – namely, *work* to earn money for the consumption of goods and services and *leisure* for activities necessary for rest and recreation.

Let *V(T)* denote the traveler's utility from consumption and recreation, where it is assumed that the traveler always chooses the optimal allocation of time *T* between work and leisure. *V(T)* is concave in *T* (positive first and negative second derivative), meaning that the marginal utility of untied time is decreasing.

Travelling is time-consuming, reducing the amount of time available for work and leisure. This means that *T* and consequently utility would have been higher if travelling were not necessary. Let *TOT* represent the total amount of time, and *TE* the effective travel time. Then, the untied time available for work (consumption) and leisure (recreation) is:

$$T = TOT - TE$$

Untied time can alternatively be interpreted as purchasing power in terms of consumption and recreation. Since time has a price (opportunity cost) in the labour market, denoted by the wage rate *w*, the monetary value of travel time, referred to as the travel time cost, is *wTE*. Similarly, the monetary equivalent of untied time, *wT*, is here referred to as full income.

Effective travel time consists of direct travel time on the road, *TT*, including time buffers and careful driving to avoid the risk of accidents and consequences of delays. In addition, *TE* includes other travel costs, *C*. These costs are mainly monetary costs/expenses, for example vehicle operation costs. Uncertainty during travel adds further to the monetary costs, for instance through formal insurance premiums.

Since monetary costs must be covered by labour income, they add to the effective travel time with the amount of time that has to be spent working to pay for them. There may also be benefits B, measured in time, if travel time can be used for productive or recreational purposes.

$$TE = TT + C - B$$

Discomfort

In addition to being time-consuming, travelling can also be stressful and burdensome, leading to/causing discomfort, denoted by *D*. Let *U(D)* represent the negative effect of discomfort on the traveler's utility. The function *U(D)* is assumed to be convex in D (positive first and positive second derivative), meaning that the marginal disutility of discomfort/stress is increasing.

We express the traveler's aggregate utility function as a function of untied time and discomfort in the following way:

$$W(T,D) = V(T) - U(D)$$

Risk

Travelling is also risky. Events with negative consequences can happen such as accidents or delays (even without directly being involved in accidents). Accidents and delays impose costs on the traveler – here taken into account as increased effective travel time *TE* and/or increased discomfort *D*.

We are now going to focus primarily on costs *internalised* by the traveler, from now on explicitly assumed to be a car driver.

Let subscript *n* represent a normal situation, e.g., a day without accidents or delays, and subscript *e* represents a negative event, with higher effective travel time *TE* and/or higher discomfort *D* than a normal situation.

Untied time in a normal situation is then:

$$T_n = TOT - TE_n$$

where

$$TE_n = TT_n + C_n - B_n$$

Untied time in case event e occurs:

$$T_e = TOT - TE_e$$
$$= TOT - (TE_n + TL_e)$$

where

$$TL_e = TT_e + C_e - B_e$$

is the **loss** of untied time in case of a negative event: direct travel time will most likely increase (TT_e is positive), there will be extra monetary costs (C_e is positive), and travel-related benefits will be reduced (B_e is negative).

The driver's discomfort can be distinguished between normal conditions and exceptional events. Under normal conditions, the discomfort is denoted as D_n. In the case of an event *e*, the total discomfort is:

$$D_e = D_n + DL_e$$

where DL_e represents the **loss** in terms of additional discomfort or stress incurred due to the event.

Let q_e represent the probability of event *e*. $(1-\sum_e q_e)$ is then the probability of a normal situation.

Expected utility

The uncertainty involved in driving represents a cost for the driver; he is risk averse. That is why he finds it beneficial to buy insurance and invest in (costly) self-insurance and preventative actions.

Insurance amounts to sacrificing untied time (representing purchasing power in terms of consumption and recreation) in a normal situation for benefits (loss reduction) in situations where a negative event has occurred (ex-post). Preventative activities are meant to reduce the likelihood that negative events take place (ex-ante).

The driver wants his expected utility to be as high as possible. Expected utility may be expressed as

$$E(W(T,D)) = (1-\sum_e q_e)x(V(T_n) - U(D_n)) + \sum_e q_e x(V(T_e) - U(D_e))$$

$$=(1-\sum_e q_e)x(V(TOT - TE_n) - U(D_n)) + \sum_e q_e x(V(TOT - TE_n - TL_e) - U(D_n + DL_e))$$

where

$$TE_n = TT_n + C_n - B_n$$

A3.3 Willingness to pay for improvements

Given the theoretical approach above, the driver's welfare depends on

- untied time in a normal situation, T_n, determined by effective travel time on a normal day
- untied time in case event e occurs, $T_e = T_n - TL_e$, determined by the loss caused by increased effective travel time
- discomfort in a normal situation, D_n
- discomfort in case event e occurs, $D_e=D_n+DL_e$
- the probability of events *e*, q_e

The determinants of these factors are partly exogenous to the driver (physical infrastructure, traffic volume, …) and partly endogenous (speed, car type, …).

It is evident that activities or efforts that reduce effective travel time or discomfort under normal conditions, minimize losses in the event of disruptions, and/or lower the probability of such negative events are valuable to drivers. This explains their willingness to pay for these improvements.

To determine the driver's WTP, we examine his expected utility and assess how much he would *be willing to pay in terms of untied time under normal conditions* to obtain a specific exogenous improvement. In other words, when such an improvement increases his expected

utility, we determine the amount of untied time (encompassing both full income/consumption and leisure) that could be taken from him to restore his utility to its original level.

We consider relatively small improvements. If the improvements are substantial, our approach may overestimate the benefits and, accordingly, the WTP. This follows on from the concavity of $V(T)$ and the convexity of $U(D)$.

Formally we differentiate $E(W(T,D))$ with respect to untied time on a normal day and the relevant parameter, set the sum to zero, and solve the equation for the amount of untied time the driver is willing to give up in order to obtain the relevant parameter change.

A3.3.1 Exogenous improvements (in driver's environment)

To illustrate the driver's willingness to pay for improvements we must first look at exogenous changes in his environment.

More untied time on a normal day

Assume that a new tunnel shortens the driving distance and changes the direct travel time by ΔTT_n hours (a negative number). How much untied time would he be willing to give up? Let WTP_{Tn} represent the willingness to pay for a *marginal* increase in untied time on a normal day, his or her aggregate WTP for the total time saved is:

$$WTP_{Tn} \times (-\Delta TT_n) = 1 \times (-\Delta TT_n)$$
$$= -\Delta TT_n$$

I.e., the driver is willing to give up (maximum) the entire benefit – hour by hour – bringing him back to the original expected utility level.

Formally, WTP_{Tn} is found as the partial derivative of $E(W(T,D))$ with respect to TT_n divided by the partial derivative with respect to T_n, multiplied by -1. The first must equal the second multiplied by -1.

Less discomfort on a normal day

Assume that an old dark tunnel is equipped with lighting, making driving more comfortable. The change in discomfort is ΔD_n, a negative number. Let $-WTP_{Dn}$ represent the willingness to pay for a marginal reduction in discomfort, the aggregate WTP is

$$(-WTP_{Dn}) \times (-\Delta D_n)$$

Formally, we find WTP_{Dn} by dividing the partial derivative of $E(W(T,D))$ with respect to D_n by the partial derivative with respect to T_n multiplied by -1. The higher the discomfort at the outset, the higher this WTP will be.

More untied time in case event e occurs

Assume that a dangerous bend on the road, where drivers sometimes drive off the road, is equipped with some installation that reduces the damage in case an accident happens. The damage change is ΔTL_e (a negative number). His WTP is:

$$WTP_{Te} \times (-\Delta TL_e)$$

where WTP_{Te} represents the willingness to pay in terms of untied time in a normal situation for a marginal increase in untied time in case event *e* occurs.

Formally, we find WTP_{Te} by dividing the partial derivative of $E(W(T,D))$ with respect to T_e by the partial derivative with respect to T_n multipled by -1.

It depends critically on what we might call the driver's *environment*; the higher the loss at the outset and the higher the probability, the higher WTP will be.

Reduced discomfort in case event *e* occurs

Let us assume that a system is introduced that provides drivers, who are caught in an unexpected queue, with information on the anticipated duration of the delay. This may reduce the stress level by ΔDL_e (a negative number).

$$(-WTP_{De}) \times (-\Delta DL_e)$$

The higher discomfort at the outset, the higher this WTP will be.

Lower probability of event *e*

Let us assume now that a bend on the road is straightened out, changing the probability of an accident by Δq_e (a negative number). How much untied time in a normal situation would he be willing to give up? His WTP is

$$(-WTP_{qe}) \times (-\Delta q_e)$$

Where $(-WTP_{qe})$ represents willingness to pay in terms of untied time in a normal situation for a marginal reduction in the probability of event *e*. This WTP will be high if the probability at the outset is high and the loss (in terms of reduced effective travel time and increased discomfort) is high.

The last three WTPs reflect the same environment: The seriousness of the negative event *e*. However, they are conceptually different from each other and their numerical values will not be the same. The willingness to pay here reflects the *gross* benefit of the positive exogenous changes to the driver's environment. If there is a "price" to be paid, it must be deducted to find the *net* benefit (surplus). This net benefit reflects the increased benefit (surplus) of travelling.

A3.3.2 Endogenous improvements: Insurance and prevention

Given the specific environment, the driver is to some extent able to influence his own effective travel time and discomfort in a normal situation, in addition to probabilities and losses in case a negative event occurs.

Losses and probabilities are influenced by insurance against losses (ex post) and prevention/self-protection (ex-ante) to keep the probability low. The gross benefits of exogenous effects, working as insurance and prevention are presented above. However, the driver may also "buy" insurance and prevention on his own initiative. Such insurance and prevention come with a *cost in terms of untied time in a normal situation*.

A normal situation: The driver may increase his untied time by purchasing a high-performance car, which allows him to save time through faster acceleration and maintaining higher speeds. The cost of such a vehicle is included in C_n. Alternatively, the driver may attempt to drive faster in his current car, thereby increasing the probability and/or severity of an accident. The cost is reflected in increased C_e and/or q_e. The driver may also incur additional costs to reduce driving discomfort, for example by choosing automated transmission instead of manual gear.

Insurance: Insurance is often understood as coverage purchased from an insurance company. While certain types of insurance are mandatory, most car drivers also opt for additional voluntary coverage in the insurance market. Such formal insurance represents a monetary cost and is included in C_n. Beyond formal insurance, drivers face other types of monetary risk management: for example, they can choose between safer and less safe vehicles. A safer vehicle reduces potential losses in the event of an accident, but entails additional monetary costs, which are also included in C_n. In addition, drivers engage in non-monetary risk mitigation strategies, such as adding time buffers to expected travel time, to reduce the costs associated with delays. This is included in TT_n.

Prevention: The more expensive, safer, car not only contributes to reduced losses in case of an accident; it may also reduce the probability of an accident. In addition, low speed and careful driving – time-consuming – tend to reduce the probability. Again, the costs are added to C_n and/or TT_n.

The extent to which the driver invests in insurance and preventive measures depends on the balance between benefits and costs. The driver will choose to do so as long as the marginal benefit – reflected in the marginal benefit (marginal WTP) – exceeds the additional costs, both expressed in terms of untied time under normal conditions. In other words, the driver will continue to "buy" insurance or prevention as long as the expected utility increases.

The amounts of untied time spent on different types of insurance and preventive measures must be determined simultaneously – since the benefit of each one of them depends on the levels of the others.

The benefits of each type of insurance and preventive measures also depend on many exogenous factors influencing the driver's environment. Exogenous improvements (related to traffic infrastructure) such as those described above will reduce the benefits that the driver derives from his own activities/efforts. As a result, he will cut down on them, thereby reaping benefits from those exogeneous changes in excess of the direct benefits (his WTP as described above). We use the word *secondary* benefits to describe these extra benefits. Such secondary benefits may be important if the exogenous improvements are substantial.

A3.4 Willingness to pay for AD-equipment

In this section, we assume that the AV has only positive effects for its owners. Whether that is true or not is an empirical question. Automated vehicles can reduce effective travel time on a normal day (TE_n is reduced) as well as lower discomfort (D_n is reduced). In addition, it provides both insurance (TL_e and DL_e go down) and a means of prevention (q_e is reduced). What determines the willingness to pay for the "package" of benefits, *ceteris paribus*, should be clear from the discussion above – at least as long as we stick to the direct and disregard the secondary benefits:

$$WTP_{AD} = (-\boldsymbol{\Delta TE_n}) + (-WTP_{Dn}) \times (-\boldsymbol{\Delta D_n}) + \sum_e (WTP_{Te}) \times (-\boldsymbol{\Delta TL_e}) + \sum_e (-WTP_{De}) \times (-\boldsymbol{\Delta DL_e}) + \sum_e (-WTP_{qe}) \times (-\boldsymbol{\Delta q_e})$$

$$= (-\boldsymbol{\Delta TT_n - \Delta C_n + \Delta B_n}) + (-WTP_{Dn}) \times (-\boldsymbol{\Delta D_n}) + \sum_e (WTP_{Te}) \times (\boldsymbol{-\Delta TT_e - \Delta C_e + \Delta B_e}) + \sum_e (-WTP_{De}) \times (-\boldsymbol{\Delta DL_e}) + \sum_e (-WTP_{qe}) \times (-\boldsymbol{\Delta q_e})$$

The terms in bold could be described as **the effectivity of the new technology**. The WTPs reflect what has been called the drivers' environment, reflecting among other things road infrastructure and, terefore, also the levels of the driver's own insurance and preventative measures at the outset.

- The welfare gain on a normal day is determined by the reduction of effective travel time (disregarding for the moment the extra monetary cost) as well as reduced driving discomfort. The reduction of effective travel time is again determined by the effect on the direct travel time and the productive and recreational value of the time in the car – in excess of a car without ADF.
- The actual loss reductions in case of event *e* reflect shorter delays, less severe accidents, as well as reduced discomfort. The welfare gain of a marginal reduction of the loss in case of event e depends critically on the gravity of the loss and the probability of the loss. The

higher the probability and the higher the loss, the higher the welfare gain of a loss reduction will be.

- The actual reduction of the probability of event *e* depends critically on how well the AD technology works. The welfare gain of a marginal reduction of the probability of event *e* depends critically on the seriousness of the event. The higher the welfare loss, the higher the gain from a marginal reduction of the probability.

However, the rational potential buyer knows that the resources spent on insurance and prevention (both mandatory and optional), provided a safer and better car is available, can be reduced. These secondary benefits will manifest themselves in reduced C_n and TT_n. This will add to his WTP as calculated in the formula. For the sake of simplicity, we can assume that the secondary benefits are included in ΔTT_n and ΔC_n in the equation above.

Driver's cost–benefit analysis

Would a car driver choose to invest in an AV? The answer depends on whether the gross benefits – including willingness to pay for automated driving functions (WTP_{AD}) and any secondary benefits – exceed the associated costs (AD), with both expressed in terms of untied time under normal conditions. The difference between these two quantities, representing the driver's expected net benefit or welfare gain, is commonly referred to as the surplus obtained from switching car types. This surplus adds to the driver's expected travel surplus in the baseline situation, i.e., with the original car:

$$\Delta E(W(T,D)) = WTP_{AD} - AD$$

The model presented is meant to form a theoretical foundation for the investigation of welfare effects caused by a technological change related to travelling. As time is the essential resource for welfare generating activities, focus has been on how a technological change may affect the amount of time that is at each traveler's disposal to engage in such activities. We refer to this as the traveler's untied time. By applying microeconomic theory, we have considered different types of impacts that can be expected to affect travellers' untied time, and, hence, their welfare. This provides a theoretical explanation of people's willingness to pay for AD, which we also have utilised to decompose different types of user benefits that constitute the stated WTP for AD.